HISTORY

OF THE

CAUVERY-METTUR PROJECT

C. G. BARBER

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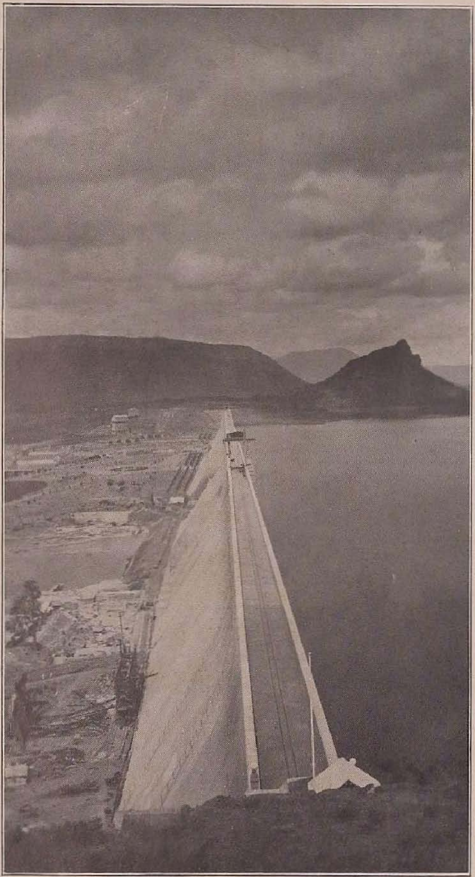

BIRD'S EYE-VIEW OF METTUR DAM AFTER COMPLETION.

HISTORY OF THE CAUVERY-METTUR PROJECT

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MADRAS

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PREFACE

THIS History of the Cauvery-Mettur Project attempts to place before the reader a true account of the events from its inception up to the time of its completion, of the many events which led to the change, both of design and location of the Dam and of portions of the Canal System, and of the methods of construction employed.

As far as possible events are described in chronological order, though it has frequently been necessary to interrupt the narrative in order to describe one or other of the many processes by means of which the work was eventually brought to a satisfactory conclusion. Since there was no connexion between the works carried out at Headworks and in the Canal Zone, it has been thought advisable first to deal with the Headworks and then with the Canals in order to avoid confusion between these two entirely separate works.

For the benefit of the non-technical reader, the book has been divided into two parts. Part I confines itself to a general outline of events as far as possible though, where a detailed description may be of interest to the general reader, it has been furnished. Detailed reports and technicalities generally have been relegated to Part II.

To the average reader, the perusal of a mass of statistics can be intensely tedious and detailed estimates and tables of costs have therefore been omitted since these may be found in the Completion Report of the Project which is to be published separately. Such brief statistics as are considered necessary to support the matter contained in certain chapters in Parts I and II will be found in the Appendix at the end of the book.

In attempting to describe a work of this magnitude and complexity it is feared that some repetition is inevitable, while matters which deserve a place in this history have perhaps been overlooked. The main difficulty has been to condense into the pages of a single volume a very large mass of matter which might perhaps have been expanded into two or three volumes.

Methods of construction and the choice of materials have been freely discussed and criticized in the earnest hope that the lessons learned on this great work may be of assistance and guidance to those whose duty it may be to design and construct similar works elsewhere (in South India in particular) in the near future. It is only by experience in the actual construction of works of this nature that one is able to compare the advantages and disadvantages of the various methods and processes of construction, to study the limitations of Indian labour and to decide upon the extent to which it is profitable to employ machinery. Conditions in India differ so widely from those obtaining in other countries that it is not safe to assume, at the outset, that what is best elsewhere is in any way suitable for the execution of large works in this country. Few could have conceived, prior to the construction of the Mettur Dam, for instance, that, despite the employment of modern machinery, some four-fifths of the Dam would actually be built by hand! In no other country, perhaps, could such methods have been employed economically or such a high rate of outturn maintained.

It is realized that a good illustration can often convey to the reader a clearer impression than can be given in several pages of letterpress and it is hoped, therefore, that the photographs and diagrams contained in this book will be of interest and guidance.

We gratefully acknowledge contributions from officers of the Revenue department, the Audit department and the Medical and Health departments whose work contributed in no small measure to the rapid and successful completion of this great Irrigation Scheme.

To the Chief Engineer for Electricity we are indebted for the particulars of the development of the great Hydro-Electric Scheme, in connexion with which one of the large generating stations is now in course of construction at Mettur. The Director of Fisheries has also contributed an interesting little note on the development of fisheries on a large scale in the Mettur reservoir.

Lastly, our thanks are due to the many officers of the Public Works department engaged on these works and from whose notes this history is mainly compiled.

C. G. BARBER.

MADRAS,
31*st July* 1936.

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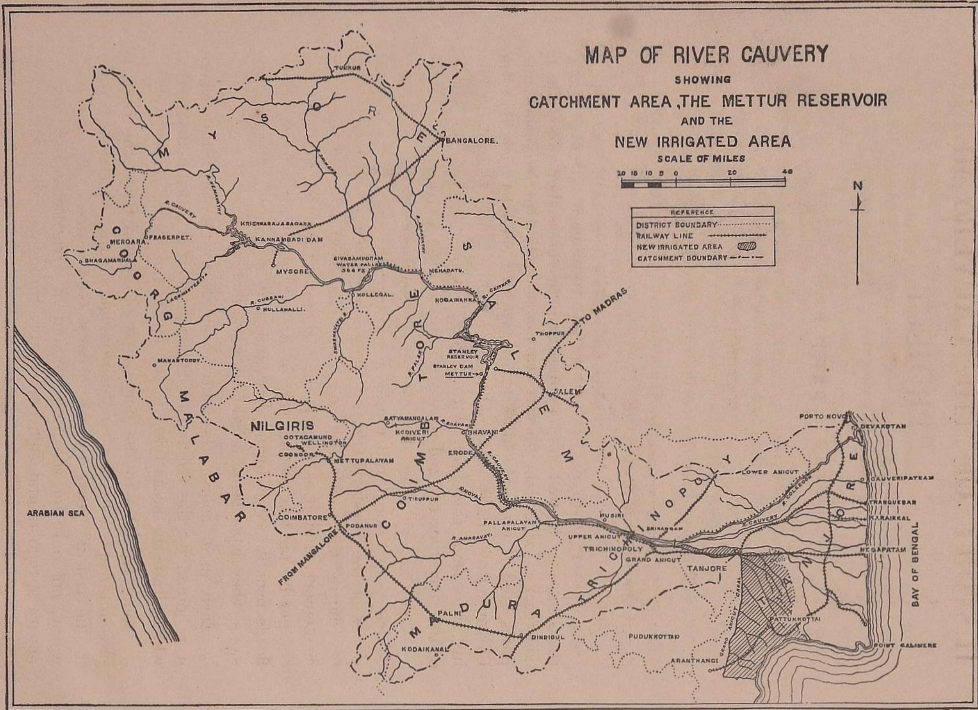
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HISTORY OF THE CAUVERY-METTUR PROJECT

PART I

CHAPTER I

THE CAUVERY RIVER, ITS COURSE AND CATCHMENT.

IT MAY be advantageous to the reader if, before proceeding to digest the early history of the Cauvery-Mettur Project, he is made acquainted with the course and the geographical relations of the river Cauvery with its more important tributaries. One of these, the Bhavani, figured very prominently in the earlier proposals to construct a large dam for the storage of water for irrigation purposes, and it was only after many years of consideration that the Cauvery was finally selected as being the more suitable. This history opens, therefore, with a brief chapter tracing the course of the river Cauvery and its more important tributaries.

The Cauvery river, the largest in Southern India, rises near Mercara, in Coorg, and drains a considerable area of the eastern slopes of the Western Ghats. This area is subject to heavy rainfall during the south-west monsoon which extends from June to September, and it is during these months that the Cauvery discharges by far the greater part of its annual supply. The highest floods usually occur during July and August though, on rare occasions, they have been as late as November.

Early in its course, the Cauvery enters the Mysore State where it is joined by the tributaries Hemavathi and Lakshmanathirtha, which drain the areas lying to the north and south, respectively.

Some 12 miles to the north-west of Mysore City, the river is now intercepted by the Krishnarajasagara dam, constructed within the last 20 years by the Mysore Government. It impounds water, not only for the improvement of irrigation, but also to ensure a regular and sufficient supply throughout the year to the important Hydro-Electric generating station at Sivasamudram situated lower down the river on the Madras-Mysore border Before reaching Sivasamudram, it is joined from the south by another important tributary, the Kabbini river which drains a large tract of country above Manantoddy where the rainfall during the south-west monsoon is heavy. Several less important streams, which contribute their quota during the north-east monsoon rains, join the main stream which now takes a sharp turn from east to south at the Hogainakal falls. These falls now form the northern limit of the Mettur reservoir. The river runs in a gorge for some 15 miles below the falls before reaching more open country. Three minor tributaries, the Palar on the west, and the Chinnar and the Thoppiar on the east, enter the reservoir above Mettur where the dam, presently to be described, has been constructed.

From Mettur, the Cauvery takes a southerly course as far as Bhavani town, where it is joined by the important tributary of that name. The Bhavani and its northern branch, the Moyar, drain the mountainous Nilgiri district and the north-west corner of the Coimbatore district.

Taking a more easterly course from Bhavani, the Cauvery enters the plains and is joined by two more tributaries, the Noyyel and the Amaravathi, before reaching the Trichinopoly district. Here the river becomes wide, with a sandy bed, and flows in an easterly direction. At the upper anicut, the function of which will be described in a later chapter, the river divides, the northern branch being called the Coleroon while the southern branch retains the name of the parent river. Some 10 miles below Trichinopoly the two rivers again join to form the Srirangam island. At their junction, the Grand Anicut, also to be described later, forms the head of the great irrigation system in the Tanjore district. Here, the Cauvery becomes one of three regulated streams, and ultimately discharges into the Bay of Bengal some eight miles north of Tranquebar as an insignificant stream, the whole of its waters having been utilized for irrigation.

At the Upper anicut and Grand anicut water not required in the Tanjore delta is diverted into the Coleroon by means of regulators and that river continues in a north-easterly direction until it discharges into the sea a little south of Porto Novo, not, however, before satisfying the requirements of three more canals taking off at the lower anicut.

From its source to the head of the delta at the upper anicut, the catchment area of the Cauvery is 26,172 sq. miles. Of this, the area within the influence of the south west monsoon is roughly 15,700 sq. miles, while that influenced by the north-east monsoon is 10,500 sq. miles.

CHAPTER II

Early History of the Project.

The question of improving the conditions of irrigation in the Tanjore delta by storage of Cauvery water was first considered well over a century ago for it was in 1834 that the first recorded proposal for damming the Cauvery was made by Sir Arthur Cotton. No attempt, however, appears to have been made to ascertain the practicability of his proposal and, unfortunately, no particulars of his scheme are now available.

Twenty-two years later, in 1856, Major Lawford submitted proposals for the construction of a reservoir on the Cauvery near Nerinjipet (a site only about 11 miles below the site of the dam now constructed), but he withdrew his proposal after inspecting the valley of the Bhavani river and its tributaries where Mr. W. Fraser, a Civil Engineer, was already investigating suitable sites for reservoirs. He concluded that the Cauvery valley was less well suited to the construction of a reservoir than the Bhavani valley.

Though Major Lawford's reason for abandoning his first proposal is not recorded, it is probable that the Nerinjipet site was regarded as unsuitable for the construction of a high earthen dam. This may now be readily understood since the difficulties of providing for the surplus of high floods in the Cauvery in those days would at that site have appeared almost insuperable, and the risk of a dam, being washed away, would have been very great.

The idea of constructing a storage reservoir on the Cauvery thus appears to have been dropped in favour of a series of schemes on the Upper Bhavani.

In 1869, Capt. C. J. Smith, R.E., under orders of Government, undertook the further investigation of Mr. Fraser's proposed reservoir sites. In 1880 Major Montgomerie elaborated the scheme taken up by Capt. Smith, and three years later, in 1883 Capt Romilly continued the investigations and the scheme now reached the stage of preparing rough estimates for reservoirs of various capacities on the Bhavani. His proposals were reviewed by Col. Hasted who submitted alternative proposals, but Government did not then require further investigation to be made, neither did they say what was to be done.

It was not until 1892 that the subject was revived when Mr. J. C. Larminie, the then Executive Engineer at Coimbatore, was instructed to resume investigations.

It is, perhaps, unnecessry in this report to trace the course of events, consisting of a series of arguments for and against the various Bhavani proposals, for the more detailed particulars of which the reader is referred to Volume I of the Cauvery Reservoir Project Papers of 1910. The difficulty, it seems, was to devise any project for the regulation of supply of water to the Tanjore delta which had any prospect of proving to be a paying proposition. The Cauvery-Vennar regulators at the present site of the Grand Anicut, had already been constructed in 1887, and Mr. Larminie objected to the use of Bhavani water there solely for the use of Tanjore, considering that the Coimbatore district had a better claim to it. He further pointed out the injury that would be done to Tanjore irrigation by drawing upon the early freshes to fill a reservoir situated on the Bhavani.

Mr. Hughes proposed to overcome this difficulty by fixing a gauge level on what was known as the Cauvery dam (at the Upper Anicut, and not to be confused with the Mettur Dam) and impounding Bhavani water only when the combined flow at that point exceeded that level and, as the river fell, water would be returned to keep it up to that level.

Colonel Smart who took up the question very vigorously, insisted that Mr. Hughes' allowance for early supply was far from sufficient and that the water, instead of finding its way to the seed beds, would nearly all be absorbed in the dry sandy beds of the delta canals. He therefore made a new proposal for the construction of a large reservoir on the Cauvery and showed that such a reservoir would, while giving more efficient protection to Tanjore without reducing the full supply level at the Cauvery Dam, allow a very large extension of wet cultivation. Mr. Hughes raised various objections to this new scheme, believing for one thing, that the Cauvery reservoir would trap a great deal more silt than the one on the Bhavani, and would not only become useless for want of capacity very much sooner, but would deprive the water that reached the delta of much of its fertilizing value. The data on which his conclusions were based proved, on further investigation, to be erroneous.

Mr. Hughes, however, completed his Bhavani Project investigation and issued his final report on it, while Colonel Smart proceeded with his Cauvery Project investigation.

In 1901, the two schemes were placed before Mr. (later, Sir Thomas) Higham, the then Inspector-General of Irrigation. Having gone into the whole question very thoroughly, he came to the conclusion that "A reservoir on the Cauvery would be likely to prove more effective and remunerative than one on the Bhavani, provided the abstraction of silt from the upper Cauvery water by deposition in the reservoir did not so materially affect the irrigation area by diminution of fertilising material deposited on the fields as to constitute a bar to carrying out the proposals."

On receipt of his note, some tests were made to ascertain the manurial value of the silt in samples taken from the Cauvery, Bhavani and Amaravathi rivers. These showed that the fertilising value of the silt from the Amaravathi and Bhavani was materially greater than that of the Upper Cauvery and thus confirmed the general opinion of the ryots. The silt carried by the Amaravathi, in particular, has always been specially prized by them.

The abstraction of silt from the Cauvery, therefore, by the construction of a reservoir above the confluence of these other streams, was shown to be the least objectionable.

Accordingly, a detailed project for a reservoir on the Cauvery was drawn up by Mr. H. A. Moss, whose report is fully described in Appendix I of G.O. No. 971 I., dated 2nd September 1904.

Mr. Moss's project provided for a reservoir of 40,000 million cubic feet capacity, with a masonry dam 130 feet in height to be constructed at a site three miles above Nerinjipet—at or near the site originally selected by Major Lawford as far back as 1856. His scheme was designed (*a*) to protect all existing irrigation in the Cauvery delta and to extend the double crop area in this area to a total of 160,000 acres; (*b*) to extend irrigation to a new area to the extent of 216,000 acres in Tanjore district and (*c*) to irrigate, by channels taking off direct from the reservoir, 46,000 acres in the Salem and Coimbatore districts. The estimated cost of Mr. Moss's project amounted to Rs. 292·3 lakhs with an estimated net revenue of 13 lakhs. It was forwarded to the Government of India for sanction with letter No. 597-I. of 13th June 1906.

The Government of India, however, returned it with a note by the Inspector-General of Irrigation, dated 17th September 1906, recommending the abandonment of the channels taking off direct from the reservoir, and endeavouring, instead, to find an area to the south of Pattukkottai taluk, in the Tanjore district, which was more suitable for irrigation than the undulating land on either bank of the Cauvery near the reservoir, which involved the crossing of numerous jungle streams.

These proposals led to further investigation, and the question was raised as to whether the required canal should take off the Cauvery at the Grand Anicut or at a point higher up the river. The latter proposal contemplated the construction of a canal taking off the Cauvery at Kattalai, just below the confluence of the Cauvery and the Amaravathi. Preliminary estimates showed that for such a scheme to be remunerative, a new irrigated area of about 490,000 acres would be required, as against 330,000 acres of paying area under the lower or Grand Anicut Canal Scheme.

Despite this, the Kattalai Canal Scheme was considered preferable on the grounds that a canal on this alignment gave scope for extension of irrigation far in excess of the above figure, while the Grand Anicut alignment afforded little scope for future extension.

But such a large extension, as the Kattalai scheme was considered capable of affording, called for more detailed investigation as to the availability of water. Available information of flow in the contributing rivers was not at that time sufficiently complete or accurate to settle the question and, consequently, special flow observations were taken during the year 1909 to determine more accurately the calibration of the existing river gauges, and the supplies which could be relied upon. The results were collected and submitted for consideration, in January 1910, to Mr. (later, Sir) John Benton, the Inspector-General of Irrigation. These are recorded in G.O. No. 72 I., dated 11th March 1910. Mr. Benton accepted the recommendations of the Chief Engineer for Irrigation, Mr. H. E. Clerk, that the Grand Anicut Canal Scheme should be prosecuted, since, though it involved a smaller area of new irrigation, it provided a more assured supply to the existing cultivated area.

Though some later attempts were made to revert to the Kattalai scheme, the Grand Anicut scheme, as finally adopted, adheres fairly closely to that approved by Sir John Benton.

The recommendations for a Cauvery scheme with a new canal system for the extension of irrigation in the Tanjore district with its head at the Grand Anicut, having now been generally accepted, the proposals for the Bhavani Reservoir Project were held in abeyance, and the Cauvery scheme investigation was now pushed on vigorously.

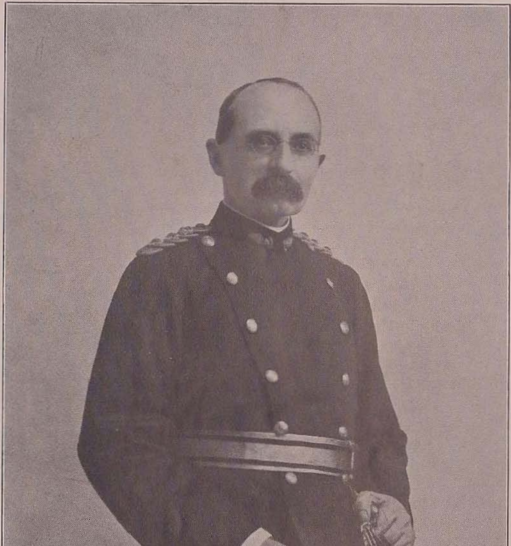
Col. W. M. Ellis, R.E., appointed Special Superintending Engineer to draw up a detailed working scheme, submitted his report in 1910. The report published in "Papers regarding the Cauvery Reservoir Project" presents a very complete estimate for the entire work as then contemplated, and furnishes a mass of detailed data with working tables to show the effect on the irrigated area and reservoir assuming that the proposed dam had been in existence during the years for which measured discharges in the river Cauvery were available. These tables give figures for each day of the year for the years 1889 to 1910 and have since proved of great value.

For fixing the reservoir capacity by means of these tables, two scales of duty were provided.

The scope of the project submitted by Colonel Ellis provided for the following :—

(a) Construction of a masonry dam across the Cauvery at Mettur, a small village on the right bank of the river some

PLATE No. II.



COL. W. M. ELLIS, C.I.E., R.E.

11 miles above Nerinjipet, the site previously considered by Mr. Moss. This reservoir was to have an effective capacity of 80,000 million cubic feet.

(*b*) The construction of a canal and distribution system taking off from the right bank of the Cauvery just above the Grand Anicut to supply Cauvery water to a new area of 285,304 acres, to be called the " Grand Anicut Canal System ".

(*c*) The remodelling and extension of an existing irrigation canal called the Vadavar, and constructing a distributary system to supply with Cauvery water a new area of 43,091 acres. This system was to be called the " Vadăvar System " (now known as the Vadavar Extension System).

(*d*) Improving, through the benefits to be obtained by the storage of flood water in the reservoir, the water distribution and supply to the existing ' wet ' area in the Cauvery delta, a gross area of roughly one million acres, and for extending in this area extent of double-cropped lands by 70,000 acres.

The gross area referred to above included existing irrigation under the Lower Anicut (Coleroon) System, amounting to about 100,000 acres.

Colonel Ellis's note on the " Effect of the reservoir on cultivation seasons " may here be quoted verbatim :

" The whole project hinges on the questions of seasonal supplies of river water, seasonal rainfall, and seasonal requirements of irrigated crops, and the function of the reservoir is to store and distribute the water available to the crops so as to benefit and secure these to the greatest extent possible.

" The existing cultivation customs and seasons of cultivation (as described elsewhere) are those which experience has shown to be more suitable for the raising of wet crops with the existing seasonal distribution of river flow and rainfall."

" The effect of the reservoir on these seasonal supplies will be—

(*a*) to secure an adequate supply at an earlier average date than before, both for double and single crop lands, and to guarantee that once such supply is issued it will not, as at present, be subject to fluctuations of a nature whicl cannot be foreseen; and

(*b*) to ensure, from the time of transplantation (of paddy), a steady and adequate flow for irrigated area by impounding excess flow for issue when the natural flow is deficient."

"The general effect of this alteration on the cultivation practices will be to make transplantation of both double and single-cropped lands earlier, and this specially applies to the single-cropped lands in the eastern part of the delta (i.e., tail-end lands) where transplantation is now delayed on account of the frequent failure, in September and October, of the flow supply which is generally available in July and August (the south-west monsoon flood period), thus leaving early transplantation to wither for lack of water before the north-east monsoon rainfall on those lands is available to supplement the flow supply."

The few sentences, quoted above, are perhaps sufficient to convey to the reader, be he Engineer or layman, the benefits which the construction of a dam and the storage and regulation of flow of flood water, much of which would otherwise run to the sea as waste, will bestow on those lands which, due to the ever-varying conditions of floods and rainfall from year to year, have, in the past, too frequently suffered through drought or excessive floods.

In fixing the scale of 'duties' of water, or the number of acres to be irrigated for each cubic foot per second of flow in the canals, Colonel Ellis was careful to make liberal allowances for the old irrigated area, and based them, for the purpose of full supply, on actuals for the combined Cauvery and Vennar areas for several years prior to the drawing up of his scheme.

Colonel Ellis's Dam Site—The Mettur Site selected.

Let us now examine the very important matter of selecting a suitable site for a dam of the magnitude contemplated. First, the nature of the country should be such that the greatest possible storage capacity is obtained for every foot of height of the dam. The Engineer has therefore to search for a site where the river, after passing through a stretch of open flat country enters a gorge where the geological conditions are such that sound foundations are obtainable and materials suitable for the construction of the dam are readily available. Without these conditions, the cost may run so high that the whole scheme becomes impracticable. Where the dam must, of necessity, be of great height, and the floods to be surplused are of considerable magnitude it is not desirable to pass surplus water over the dam but, if the natural features admit, to pass it through surplus works at a flank, preferably away from the dam altogether.

Colonel Ellis was able to secure these conditions when he selected the Mettur site for his dam. The sites proposed by earlier investigators all lacked one or more of these essentials. Before proceeding, it may here be as well to review the conditions which led to the consideration and rejection of those sites.

CHAPTER III

INVESTIGATION OF SITES FOR THE DAM AND COLONEL ELLIS'S ORIGINAL SCHEME.

AS PREVIOUSLY noted, the Cauvery runs in a narrow gorge for the first fifteen miles of its course below the Hogainakal Falls, and no reservoir of any considerable capacity could be constructed in that reach. Between Cauveripuram and Samballi * there is more open country, while immediately below the latter village the hills again close in and another valley only a mile and a half or so in average width and about 12 miles in length extends down to Nerinjipet. Here, the valley again opens out but the river continues to run between high banks as far as the lowest possible dam site, Urachikottai, 3 miles north of Bhavani town.

Thus, the site for a dam had to be looked for between a point just south of Samballi and Urachikottai, the practical up-stream and down-stream limits.

Outstanding among the several sites examined before 1910 were—

(i) The Urachi site,
(ii) Nerinjipet site,
(iii) Navapet site, and
(iv) Samballi sites, A, B, C and D.

(i) *Urachi site.*—The site had certain advantages from a topographical point of view. The relatively open country above provided great capacity for a relatively small effective height of dam, offered facilities for surplusing large floods and was easily accessible by road from Bhavani. It was, however, condemned mainly on the geologist's report that its foundation rocks were of inferior quality as well as uncertain in depth. The prospects of having to carry the dam foundation down to a great depth (which could be actually revealed only on the opening out of foundation trenches) led to the abandonment of this site in favour of one of the sites higher up the river where the rock foundations were of a better class.

(ii) *The Nerinjipet site (or Seccanur site).*—This was the site proposed by Mr. Moss in 1901 for a reservoir of 40,000 million cubic feet, providing also for local irrigation. Subsequently, on the decision of the Inspector-General of Irrigation to drop this proposal for local irrigation, the site lost its value as, higher up the valley,

* Two important villages, both of which are now submerged in the Mettur reservoir. (Ed.)

there were better dam sites suitable for the same reservoir capacity when local irrigation was left out of consideration. The site was considered unfit for a large reservoir as it was roughly estimated to involve 14 per cent more masonry than would be needed for a similar dam at Col. Ellis's site; secondly, as there were no natural surplusing facilities, the floods would have to be passed only through or over the dam, both of which methods were impracticable from a constructional standpoint.

(iii) *Navapet site.*—This is 1½ miles above Mr. Moss's site. The site might have been favourable for a small scheme but was unsuitable for the formation of a large reservoir.

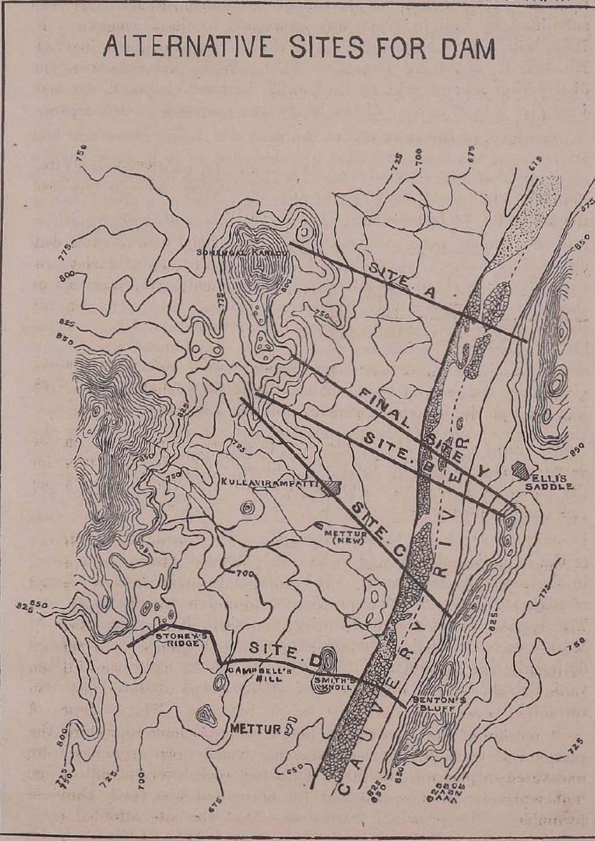
(iv) *Samballi sites, A, B, C and D.*—*Site A* was discarded even at the outset because the site contained such a variety of rocks with numerous faults and junctions, while trap-rock intrusions intersected the dam line and were considered a source of danger to any structure on that site.

Site B contains bands of schistosegneisses, inferior in quality to those at sites C and D, and it was not known what class of rock underlay the thick belt of alluvium on the left bank.

Sites C and D.—There was practically nothing to choose between sites C and D, but the rough estimates of quantities for the dams at these points showed that site C would involve 5 per cent more masonry and hence site D was finally selected.

Site D.—This site is immediately to the north of Mettur village and passed through what is now the Mettur township, with its left flank abutting the prominent mass of rock called "Benton's Bluff." The proposed alignment for the dam was not straight, but followed the rocky out-crops, known as, Smith's Knoll, Stoney's Ridge, Campbell's Hill, and thence to a terrace of rock at the right flank. This line appears to have been chosen more on the visible evidence of rock out-crops at intervals than on actual observations of what lay in between. The evidence of rock out-crops was apparently taken as sufficient to assure the economical feasibility of the scheme. Some open trenches were excavated in places to ascertain the actual rock level but did not go sufficiently far to show whether the alignment was really the best available. The principal feature was that the site afforded command over the saddle on the left (known as, "Ellis Saddle") which could be made to serve as a natural surplus escape. As no other site combined in itself these two unique features, the pre-eminent superiority of the site was undoubted and this was, perhaps, one of the reasons why a more thorough and systematic survey of this site was never launched throughout the 15 long years, from 1910

PLATE No. III



to 1925, during which the scheme was kept in abeyance. Plate III illustrates the alternative sites for the dam referred to as A, B, C and D. The final site Y is also indicated on the map.

Colonel Ellis's Dam (1910) *briefly described.*—We have thus reached the point in the history at which the site of Col. Ellis's

Dam was definitely located at Mettur. He made a detailed investigation of the scheme and an estimate amounting to Rs. 385 lakhs submitted by him in 1910, was forwarded to the Government of India with the recommendations of the local Government in G.O. No. 386 I., dated 3rd December 1910. While the details of the distribution scheme will be dealt with in later chapters, we may here give a brief outline of the headworks proposed in this scheme.

The level of the river bed at the dam site, being about 620 feet above mean sea level, the dam was designed to give a net storage capacity of 80,000 million cubic feet, with a full reservoir level of +785·00, the maximum water level being taken as + 788·0, while the level of a 14 feet roadway over the dam was at + 794 and the tops of parapets were to be at +798. The height of the roadway above river bed was thus about 174 feet. The length of the proposed dam was about 6,000 feet. It was pierced by three groups of sluices, called respectively, the deep, central and right supply sluices, designed to supply irrigation requirements and to be capable of operations at full reservoir level to supplement the surplus sluices at times of extraordinary floods. The surplus was provided over the natural saddle called the "Ellis Saddle" near the left bank of the Cauvery about $1\frac{1}{4}$ mile up-stream of the dam site, the surplus course following the bed of an existing vari in the valley to the east of the Chetamalais, which joined the river about $1\frac{1}{2}$ miles below the site of the dam. The surplus works were to consist of 19 vents each of 40 feet width, with sill level at + 771 and designed to discharge 120,080 cusecs at F.R.L. (+785), that is, with a depth of 14 feet over sill. The combined discharge of the irrigation sluices was to be nearly 130,000 cusecs with water in the reservoir standing at +785, so that the combined discharge of both surplus and irrigation sluices would be 250,000 cusecs. The highest floods recorded during a period of 28 years prior to 1910 were only a little over 200,000 cusecs. These occurred on the 30th July and 1st August 1896, when the gauge readings at Bhavani Bridge showed discharges of 207,000 and 201,000 cusecs, respectively.

A section of the dam as designed by him is here reproduced as plate IV, showing the stresses in the masonry at various points, and the resultant lines of thrust with the reservoir full and empty. The stresses were worked out by both Bouvier's and Unwin's formulæ.

PLATE IV

NOTE:- AVERAGE QUANTITY OF MASONRY IN THE BRIDGE PER FOOT RUN OF DAM = 107 CUBIC FT.

COL. ELLIS'S PROFILE OF DAM

WITH COMPUTED STRESSES

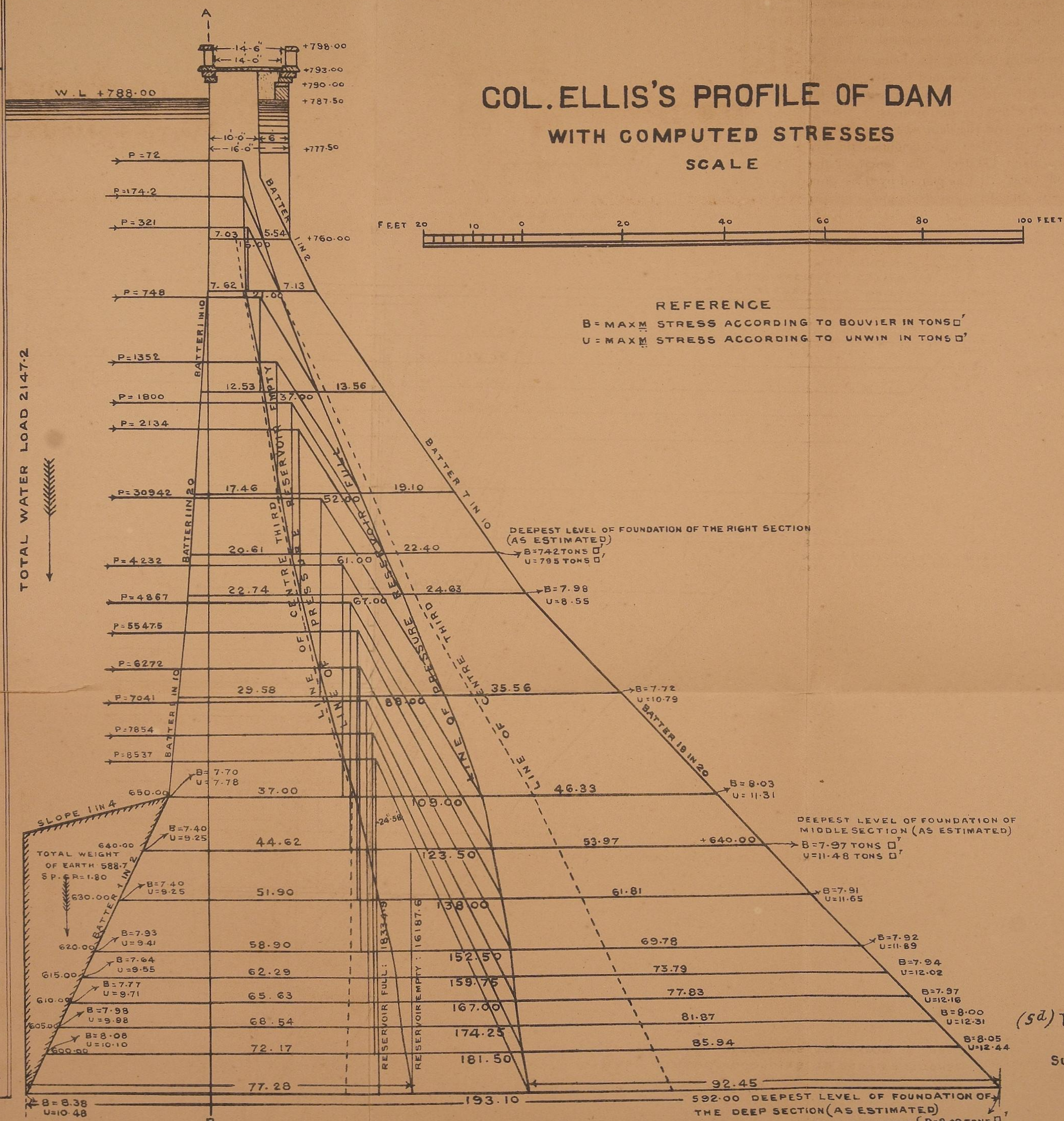
SCALE

REFERENCE

B = MAXM. STRESS ACCORDING TO BOUVIER IN TONS □'

U = MAXM. STRESS ACCORDING TO UNWIN IN TONS □'

LEVELS	QUANTITY OF MASONRY CUBIC FT. PER FOOT RUN OF DAM EXCLUSIVE OF BRIDGE, PARAPETS, &c.
+788.00	50
785.00	80
780.00	130
775.00	180
770.00	231
765.00	292
760.00	366
755.00	452
750.00	551
745.00	665
740.00	801
735.00	956
730.00	1131
725.00	1325
720.00	1539
715.00	1770
710.00	2021
705.00	2290
700.00	2579
695.00	2885
690.00	3211
685.00	3559
680.00	3934
675.00	4334
670.00	4761
665.00	5214
660.00	5694
655.00	6199
650.00	6731
645.00	7294
640.00	7894
635.00	8529
630.00	9201
625.00	9909
620.00	10654
615.00	11433
610.00	12250
605.00	13103
600.00	13992
595.00	14918
592.00	15492



(Sd) W. M. Ellis

COL. R.E.

SUPG. ENGINEER

13.9.10

Reg. No. 58/1 Copies 631

NOTE.—Reproduced from the original received from the Chief Engineer, for Irrigation Madras.

Helio-Zinco., Survey Office, Madras, 1939.

CHAPTER IV

The Madras-Mysore Dispute and Krishnarajasagara Scheme.

While the 1910 scheme was still under consideration by the Government of India, it received an unexpected set back through a dispute which arose between the Madras and Mysore Governments.

The Mysore Government had already decided to construct a dam for the storage of water at Kannambadi, on the Cauvery, some 12 miles above Mysore city. Their object was to develop irrigation locally to the extent of 125,000 acres, and to use the controlled water also for the further development of power at their hydro-electric power station at Sivasamudram, which had been constructed in 1905. The summer flow at that place normally fell to below 500 cusecs while the proposals for development of power called for a minimum flow of about 900 cusecs, involving the storage of some 10,000 million cubic feet of water for issue during the four dry months in the year from February to May. The claims of the two Governments regarding the rights to this water were warmly contested, but in 1913 a Court of Arbitration was constituted to settle the dispute and it gave its award in 1914. The award, however, was of a nature which the Government of Madras were unable to accept and they therefore appealed to the Government of India and later to the Secretary of State who thereupon reopened the question. The principal objection of the Government of Madras to the award of 1914 lay in the fact that, it did not provide for what were contended by Madras to be their established rights in regard to existing irrigation in the Cauvery delta. Negotiations between the Governments of Madras and Mysore were then commenced with a view to an equitable and friendly settlement of the points at issue. Joint gaugings of the supplies available in the river in each month of the irrigation season, at the Cauvery Dam (Upper Anicut), were continually maintained and registered. The more exact data thus obtained, which showed that the previous flows had been much underestimated, marked the first step in the final settlement of the dispute, and, in July 1921, rules of regulation for the Krishnarajasagara, which also fixed the limit gauge readings at the Cauvery Dam, were agreed to by the Chief Engineers of the two Governments. A covering agreement for making these rules of regulation operative and for fixing the rights of the parties on other points at issue had to be entered into.

Further negotiations took place in 1922 and numerous meetings were held during 1922 and 1923 in which the late Hon'ble Sir

K. Srinivasa Ayyangar and the Hon'ble Mr. (later Sir) C. P. Ramaswami Ayyar took a prominent part in championing the cause of the Madras Government. It was not until February 1924, at a final meeting held in Bangalore when Mr. Gebbie, the Consulting Engineer to the Government of India, was present, that a final and amicable agreement was reached. Under this agreement, executed on the 18th February 1924, the rules for the regulation of the Krishnarajasagara agreed to by the Chief Engineers of Mysore and Madras, in July 1921, were confirmed and the limit of effective capacity of the proposed Madras reservoir was fixed at 93,500 million cubic feet.

The Krishnarajasagara scheme.—While this long-drawn-out dispute was taking place, the Mysore Government were proceeding with their reservoir scheme and the construction of the Krishnarajasagara Dam was started in 1911. It is a work of very considerable magnitude and took 16 years to complete. With a catchment area of 4,100 square miles, the dam forms a reservoir of 49·9 square miles, having a gross capacity of 48,335 million cubic feet and an effective capacity above the irrigation sluices of 44,827 million cubic feet. The dam is 8,600 feet in length, including the weir portion, while its maximum height above deepest foundations is 140 feet, the maximum depth of water being 124 feet. One of the chief objects of the Mysore scheme was to ensure a steady supply of water for generation of power at Sivasamudram, where the power generated has, through the construction of the dam, increased from 10,000 h.p. to 46,000 h.p., guaranteeing supplies of power to the Kolar Gold Fields and other important industrial concerns, amongst which we may refer, particularly, to the Mettur dam construction which received its power from Sivasamudram for a period of six years. (This will be referred to in detail in a later Chapter.) The estimated final cost of the Krishnarajasagara dam was 2½ crores, while the entire scheme, including the hydro-electric scheme, cost about 6¾ crores.

CHAPTER V

Colonel Ellis's Scheme revised.

In view of the unfavourable award of 1914, necessitating a reduction in the new area to be irrigated under the Mettur Reservoir Project, Col. Ellis undertook the revision of his 1910 estimates, credit being taken only for such water as could not be intercepted by the Krishnarajasagara Dam operating under the rules of regulation as awarded by the arbitrator in 1914. The principal engineering features of the scheme were retained without alterations, but the new area of 329,396 acres originally proposed for irrigation was reduced by 32,396 acres and the probable area to be double-cropped was also reduced from 75,000 acres to 10,000 acres. The extension of second crop in the existing area was also reduced from 70,000 acres to 65,000 acres. The time necessary for making these revisions afforded an opportunity at the same time to examine certain proposals which had been made by Sir John Benton regarding the design of the dam. Sir M. Nethersole also inspected the site of the dam in August 1916, and made further suggested modifications. It is to be recollected that the Great War, which broke out in 1914, had by this time caused a general rise in rates both for material and labour, while the price of machinery and even land had risen considerably since 1910. The estimate as revised in 1916, therefore, made provision for these increases in rates, and the estimated cost of the scheme rose to 409·5 lakhs. The anticipated return on the outlay was estimated at 5·97 per cent. This 1916 estimate was submitted to the Government of India with Madras Government's letter No. 614 I., dated 28th December 1916. There the matter rested, pending the passing of final orders of the Secretary of State on the Madras-Mysore arbitration case.

The revised rules prepared and provisionally approved by the two Governments in 1921 now necessitated further revision of the Mettur-Project estimate and Mr. Morgan, Executive Engineer, was placed on special duty for this work and completed his work early in that year. By this time the cost of everything had further risen, and the 1921 estimate, as now revised, jumped to Rs. 558·9 lakhs, as compared with the Rs. 385 lakhs estimate of 1910. By the beginning of 1924, when the Madras-Mysore arbitration case was finally settled, rates had risen again, and the project estimate was once more revised and now amounted to Rs. 612 lakhs. As we shall see later, even this was by no means final for it eventually rose to no less than Rs. 737 lakhs, due mainly to radical changes both in design and materials, the dam alon(finally costing about Rs. 100 lakhs more than Col. Ellis's entire 1910 scheme.

The 1924 estimate amounting to Rs. 612 lakhs as mentioned above was forwarded to the Government of India for the Secretary of State's sanction in G.O. No. 94 I., dated 31st March 1924, and was received back sanctioned by the Secretary of State for India on the 3rd March 1925.

This estimate, based on the conditions set forth in the Madras–Mysore Agreement of 1924, provided for the construction of the dam on Col. Ellis's site. 'Cyclopean' masonry with 25 per cent of 'plums' was substituted for 'rubble' masonry, 'crushed stone' was substituted for 'natural sand' in the concrete required for the cyclopean masonry, as it was at that time presumed that little natural sand could be obtained from the river bed which is mainly of rocky nature. Coursed rubble was to replace random rubble for the upstream face of the dam while the downstream con crete face was merely to be 'treated' to remove unsightly marks left by the forms. Col. Ellis, in the original project report, had proposed constructing the dam of small rubble in surki mortar, but anticipating that it might be impossible to make satisfactory progress owing to the difficulty of obtaining sufficient masons, he provided for plant for building two-thirds of the dam in concrete, if such a course should be found desirable. Mr. (later Sir Hugh) Keeling, who had been to America to study dam-construction there, strongly favoured the use of 'cyclopean' masonry, consisting of large stones set in concrete for the hearting of the dam, a method of construction then popular in America and in Australia, where the Olive Bridge and Barren Jack dams were under construction. It is interesting to note that in the latter dam the use of large 'plums,' as the height of the dam increased, was abandoned as the cost of handling large stones at great heights became uneconomical. The same difficulty was experienced at once during the construction of the Mettur Dam and the use of really large 'plums,' originally contemplated, was not attempted even in the foundations. This matter however will be dealt with in its appropriate place.

PLATE No. V.

OBELISK COMMEMORATING THE 1925 INAUGURATION OF THE PROJECT.

CHAPTER VI

INAUGURATION OF THE PROJECT (1925).

IMMEDIATELY the Secretary of State's sanction of the Project estimate was received, the Madras Government took steps to put the work in hand, and, to signal the commencement of so large a work, an Inauguration Ceremony was performed at the site of the Dam by His Excellency the Right Honourable Viscount Goschen, Governor of Madras, on the 20th of July 1925. The ceremony took place on the high rocky ridge at the right flank of the proposed Dam line, where a cutstone obelisk, to mark the occasion, was under erection. Owing to a mishap, the large and heavy needle which was to surmount the base was not erected in time. The ceremony was attended by a number of distinguished persons. To mark the actual 'Opening,' His Excellency unveiled a marble tablet on the plinth of the obelisk and the first blast of rock was simultaneously fired. Plate V presents a photo of the Obelisk which, when the site of the dam was shifted later, was dismantled and re-erected near the right flank of the dam at the new site.

The address presented to His Excellency Lord Goschen is reprinted below :—

Address to His Excellency The Right Honourable Viscount Goschen, G.C.I.E., C.B.E., Governor of Madras, on the occasion of the Inauguration of the Cauvery-Mettur Irrigation Project, 20th July 1925.

We thank Your Excellency for the honour you have conferred upon the department by consenting to come here at great personal inconvenience to perform the ceremony and we also thank our guests for attending it.

This great irrigation project, the commencement of which Your Excellency will be asked in a few minutes to inaugurate, has had, since its first inception by the late Sir Arthur Cotton in 1834, a most chequered history. In view of that history, of the vicissitudes which the several proposals for storage on the Cauvery have passed through, of the magnitude of this project, and of the vital necessity of storage works for the future prosperity of the Madras Presidency, the ceremony which is about to be performed may be described as one of exceptional interest and importance.

It is of interest to note that the Secretary of State for India has recently referred to the supreme necessity to develop agriculture in India. Agriculture in India connotes irrigation and it is hardly necessary to emphasize the supreme importance of storage works in this Presidency. Our principal available irrigation supplies may be classed under two heads : the normal flow in the rivers—practically the minimum flow in the irrigation season—on which alone we can depend for irrigation by direct flow without storage, and the much greater flood discharges which can be utilized only by means of storage. In this Presidency there is no possibility of any more cheap schemes of any magnitude such as the Godavari and Kistna systems, depending upon direct flow. Our resources of that nature have practically been exhausted. Yet we have large areas of valuable land as yet unirrigated, and we have enormous volumes of water, in the flood discharges of our rivers, passing to waste into the sea. We can utilize these supplies only by means of storage projects of which the Cauvery-Mettur Project is a great example. We hope that it may fall to Your Excellency to inaugurate also another storage project, on the river Bhavani, to irrigate a large area in the Coimbatore district, the estimates for which are now ready and being submitted to Government, and that these will be followed by storage works on the other great rivers of this Presidency.

The first proposal for storage on the Cauvery was put forward by the late Sir Arthur Cotton in 1834 but that great and enthusiastic Irrigation Engineer, who left such a mark on this Presidency, brought to fruition as much work as could possibly be compressed into the too short period of his strenuous career. Since that date one after another of four Engineers have proposed storage works on the Cauvery, Bhavani and other rivers. In this connexion it is of interest to refer to the competition between the various sites proposed for a reservoir on the Cauvery and between a Cauvery reservoir and one on the Bhavani. In 1856 Major Lawford submitted proposals for an earthen dam on the Cauvery at Nerinjipet, about nine miles below the place where we now stand. Major Fraser was at this time examining the Bhavani for a suitable site, and after consultation the Nerinjipet scheme was withdrawn for the time. To pass over the intermediate period during which storage on these rivers was persistently advocated by the Engineers, in 1901 alternative proposals for storage on the Cauvery and the Bhavani were placed before the Inspector-General of Irrigation, and in accordance with his advice the Government of Madras decided in the first instance to prepare a detailed project for a reservoir on the Cauvery.

Mr. Moss who was placed on special duty submitted in 1904 estimates amounting to Rs. 292 lakhs, for a reservoir of 40,000 million cubic feet capacity, having a masonry dam 130 feet high, to be situated three miles above Nerinjipet. This project provided for 216,000 acres of new irrigation in Tanjore and 46,000 acres in

Salem and Coimbatore, the latter area to be supplied by channels from Nerinjipet. The project also provided for an increase of second crop irrigation in the Tanjore delta and for the protection of the existing irrigated area. The proposal to irrigate land in Salem and Coimbatore was subsequently abandoned in consultation with the Inspector-General of Irrigation, owing to the very high cost of the necessary channels in comparison with the area that could be irrigated. This question has recently been taken up again and re-examined with some care and with much sympathy for the desires of these districts for a share in the benefits; but we have to admit with regret that the prospects are not very promising. We find that a water-rate of nearly Rs. 30 per acre would have to be levied in these districts as compared with Rs. 15 in the Tanjore area.

Colonel Ellis, who was afterwards Chief Engineer for Irrigation, was then deputed to prepare the detailed project in accordance with the final conclusions, and in 1910 estimates amounting to Rs. 385 lakhs were submitted to the Government of India. These estimates provided for: constructing a masonry dam at Mettur and forming a reservoir of capacity 80,000 million cubic feet; excavating canals and a distributary system taking off from the right bank of the Cauvery just above the Grand Anicut for a new irrigation of 285,300 acres; remodelling and extending the Vadavar for irrigating 43,094 acres of new area; and for extending double cropped area under existing channels by 70,000 acres.

At this stage the unfortunate dispute with the Mysore Government arose which led to the postponement of the Madras project for some fifteen years. The history of the dispute is well known and need not be recapitulated. It is sufficient to say that the Mysore Government having, with the concurrence of Madras, sanctioned a storage project on the Cauvery at Kannambadi in Mysore with a dam 80 feet high to store 11,000 million cubic feet, applied for permission to increase the storage to 41,500 million cubic feet with a dam 124 feet high. The issues which arose from this were most complicated and the Government of India were unable to pass the Madras project until the matter was settled. The matter went to arbitration, but the Government of Madras were unable to accept the award which was made in 1914 and confirmed by the Government of India in 1916, and appealed under the terms of the arbitration agreement to the Secretary of State, who admitted the appeal. Negotiations were then started between the Chief Engineers of Madras and Mysore in an endeavour to arrive at a friendly settlement.

In 1921 a partial agreement dealing with certain technical details of regulation and supply as between the Mysore and Madras reservoirs was arrived at. The question of the division of the surplus waters of the Cauvery between Mysore and Madras was then taken up and the negotiations proceeded. The importance of this issue may be gauged by the fact that at the end of the year 1923 the Government of Mysore still adhered to their claim that Madras should surrender all right to any further extensions of irrigated area under the Cauvery or under its tributaries rising and flowing in Madras territory whether by improvement of duty or otherwise, and should refrain from constructing any reservoirs on these rivers other than the Mettur reservoir.

During this stage of the negotiations a number of personal discussions took place in addition to the prolonged correspondence. In June and July 1922 the late Sir K. Srinivasa Ayyangar, then in charge of the Irrigation portfolio, discussed the issues with the Diwan of Mysore in Mysore and Ootacamund. There was an informal discussion at Bangalore in January 1923 between Sir Charles Todhunter and the Diwan and in April 1923 the matter was taken up by the present Hon'ble Member for Irrigation who, with Sir Charles Todhunter, met the Diwan of Mysore and the First Councillor in Bangalore. In the following June the Honourable Member proceeded to Simla and discussed the case with the Government of India. In September 1923 Sir F. St. J. Gebbie, the Consulting Engineer to the Government of India, was deputed to be present at a discussion between the Chief Engineers at Bangalore, but the Conference failed to arrive at a settlement. An agreement was finally arrived at after a five days' discussion in Bangalore in February 1924 at which the Consulting Engineer was again present. The agreement was ratified by both Governments on the 18th February 1924. Under this agreement Madras secured the right to extend irrigation under the Cauvery and its branches and to construct additional reservoirs in Madras territory and the capacity of the Mettur reservoir was increased from 80,000 million cubic feet to 93,500 million cubic feet. A noteworthy and pleasing feature of these prolonged negotiations was the cordial and friendly atmosphere in which they proceeded, culminating in a settlement fair to both sides.

From the moment that Sir C. P. Ramaswami Ayyar assumed charge of his office he took a close personal interest in getting this longstanding dispute settled and a beginning made with this project and it must be a great source of satisfaction to Your Excellency's Government and the public that we are able to meet here on this occasion to inaugurate the project.

The estimates, revised to cover the increased cost of labour and materials, and amounting to Rs. 612 lakhs, were submitted to the Government of India on the 31st March 1924 and the sanction of the Secretary of State was received in March 1925.

The organization and preliminary arrangements had already been taken up. A circle has since been formed in charge of Mr. Stoney, Superintending Engineer, Mr. Mackay and Mr. Narasimha Ayyangar have been appointed to the Mettur and canal divisions, respectively, and roads and other subsidiary works are in progress.

The project as finally sanctioned provides for a masonry dam 200 feet high at the deepest section and 6,352 feet long extending from the point at which we now stand to the hills on the opposite side of the Cauvery. The monument has been constructed approximately on the centre line of the top of the dam. There will be 14 low level sluices 6 feet × 12 feet, 16 supply sluices 6 feet × 25 feet and 8 supply sluices 16 feet × 16 feet. The surplus works will be on a saddle half a mile above the dam. As sanctioned they consist in 19 sluices 40 feet long by 15 feet high.

The lake formed by the dam will be about 100 miles round, extending 34 miles up the river to the Hogenkal Falls and submerging an area of 55 square miles with a capacity above the sluices of 93,500 million cubic feet. The dam alone will contain 38½ million cubic feet of masonry and the dam and incidental works are estimated to cost Rs. 375 lakhs. The main canal, taking off from the right bank of the Cauvery above the Grand Anicut, will be about 80 miles long. The main canal and distributaries are estimated to cost Rs. 157 lakhs, and the Vadavar will be extended and remodelled. The project provides for 301,000 acres of newly irrigated first crop and 90,000 acres of second crop, and will in addition effectively protect the existing irrigation from the fluctuations of supply which have proved so troublesome in the past. The net annual revenue will be Rs. 46½ lakhs—about 7½ per cent on the capital expenditure, while the annual value of crops irrigated will be about 3½ crores of rupees.

An interesting feature of this dam will be the methods and organization adopted for construction. The time for construction allowed in the estimates is ten years. It is hoped by the adoption of modern methods and modern plant and machinery considerably to reduce this period, and thus by reducing the period during which borrowed capital will be lying idle, to improve on the financial forecast. It is proposed to construct the mass work of the dam of Cyclopean masonry, consisting in large blocks of stone dumped into concrete. By the organization which has been worked out, the stone will be brought from the quarries up to the foot of the dam by rail and lifted and dumped into the work by travelling derricks which will run on ledges left for the purpose on the face of the dam and will work their way up as the dam progresses. As no suitable natural sand is available the sand for the mortar will be composed of crushed rock. The stone crushers and the stone breakers to break metal for concrete will be installed in batteries. These materials together with the surki and lime for the mortar will pass direct to concrete mixers, and from these the concrete will be carried to the work, distributed and dumped *in situ* by a system of ropeways. By these means the materials will be delivered direct on to the work and placed in position with the minimum of handling and the maximum of speed. The whole of the plant will be electrically driven from a central station. It is estimated that about 6,000 labourers will be required. In view of the local conditions the sanitation of the works area is receiving very careful attention, with the valuable assistance of the Director of Public Health. Arrangements are being made for the installation of a filtered water-supply, not only for the labour camps and the drinking water-supply, but also for water to be used in the work as it is impossible to prevent coolies from drinking water supplied for the latter purpose. A suitable sewerage system is also being installed. Anti-malarial operations are already in progress under the direction of the Director of Public Health, to whom the Public Works Department staff are greatly indebted for his assistance. It is hoped by these means not only to prevent the outbreak of epidemics which would seriously retard the work and increase its cost, but also to convert what is unfortunately at present a very malarious area into a healthy one. The well-being of our labourers is also being carefully considered in other respects and we hope to produce very satisfactory organization and labour camps. It is also proposed to make arrangements to employ a number of labourers from certain of the criminal settlements. It will be realized that the successful organization of a work of this magnitude involves an immense amount of thought and attention to details, but we hope that the results will justify the work of the staff.

CHAPTER VII

COMMUNICATIONS—ROADS.

METTUR, geographically situated in the Coimbatore district on the right bank of the Cauvery, is actually nearer Salem than Erode, both important junctions on the South Indian Railway, but in 1925 direct communication with the former place was practically impossible. The Cauvery, some 1,200 feet in width and subject to heavy floods, was at that time unbridged, the nearest bridge across the river being at Bhavani, 26 miles from Mettur, and there was no road of any description on the left bank within several miles of the Dam site, Nangavalli and Mechcheri being the nearest villages possessing roads. The country lying between these villages and the river was rough and difficult and even country carts were rarely to be seen in any of the smaller villages and hamlets in that area, for the villagers could not use them.

The country lying between Bhavani and Mettur, however, was served by a cart-track running almost parallel to the river. There is evidence that this track was at one time a road of some importance for it formed a fairly direct route to Kollegal on the Mysore border via Cauveripuram, though from the latter place it passed through mountainous and thickly wooded country. There is, here and there, evidence of this track having been metalled, but in recent years it had received very little attention. The old mud fort at Samballi, two miles north of Mettur, lends colour to the suggestion that Tippu Sultan used this route when he came down from Mysore on his raiding expeditions into British territory through Trichinopoly and the South. At all events, the existence of this track through comparatively easy country, bordering the river between Bhavani and Mettur, influenced the decision of the Public Works Department to make Erode the point at which materials for the construction of the dam should be unloaded from the railway. The reconstruction of this road, to render it fit to carry the very heavy traffic between the railway and the Dam Site, thus became a matter of urgent necessity, and was put in hand immediately in December 1924 in anticipation of sanction to the Project estimate. The old track was devoid of bridges or culverts, and abounded in water splashes at the crossings of streams, the approaches generally being at very steep gradients. The new road, in many places re-aligned, was designed with a 14-foot soled and metalled roadway with wide berms on either side, and well drained. Every cross drainage was bridged, the most important bridge being at the crossing of the Chittar, a stream joining the Cauvery from the west, some 17 miles south of Mettur. This road, on which work was started about the middle of 1925, was completed early in 1927 at a cost of nearly Rs. 9 lakhs.

Very shortly after the work was put in hand the preliminary plant required for the dam began to arrive, and to avoid congestion at Erode Junction had, of necessity, to be conveyed to the work site, or at least as far as Bhavani.

Prior to the completion of the new road, communication between Bhavani and Mettur was often extremely difficult and the writer has recollections of occasions in 1925–26, during the rains, when his conveyance got stuck in the mud or he was prevented from making the journey beyond Bhavani at all on account of the depth of water in the varis into which the water backed up when the Cauvery was in flood. So, it was no uncommon thing in those early days for Mettur to be cut off entirely from the outside world sometimes for 2 or 3 days at a time. Under such road conditions the transportation of heavy machinery was very slow, the steam lorries and their trailers used at that time for heavy haulage often taking several days to cover the distance of 36 miles from the Railway Siding at Erode to the site of the Dam. Credit is due to Mr. T. I. S. Mackay, the Executive Engineer entrusted with the construction of the new road and preliminary work at Mettur, for its early completion despite the difficulties of having to deal with the heavy traffic which was passing along it, necessitating the construction of many difficult diversions at places where bridges and culverts were under construction. The old track beyond Nerinjipet was densely overgrown with prickly-pear and much time and labour was required to uproot and burn this pest. Had the cochineal insect, which later cleared the whole district of prickly-pear, been available and made use of a few years before the work was commenced, the pioneer work of opening up communications would have been greatly simplified.

CHAPTER VIII

Preliminary Operations at the Dam Site.

The acquisition of lands required for any scheme is a matter for earliest consideration if the work is not to be delayed. Under the rules of the Land Acquisition Act, the many formalities that have to be gone through usually take considerable time before possession of the land is obtainable. Accordingly, the Revenue Department were early on the scene at Mettur and lost no time in effecting the acquisition of the land required for the head works, thus enabling the Engineering Department to commence their preliminary operations without delay. For the temporary housing of the small staff that was then beginning to arrive, the villages of Mettur and Thukanampatti, comprising in all some 200 thatched mud huts and 3 or 4 tiled buildings in more or less dilapidated condition, were first made available. Of these, the most substantial buildings were the old Roman Catholic Church and the adjacent Priest's house. In November 1925, the first Headworks division, known as the Stores and Tests division, was created and the two buildings mentioned above were utilized for the Executive Engineer's office and quarters, respectively. Most of the old huts were unfit for occupation and were pulled down, the remainder being improved and re-thatched for occupation until such time as permanent quarters could be constructed. A standing camp of tents was maintained for the use of inspecting officers, and many a time the occupants must have wished themselves elsewhere, for Mettur is subject to violent storms and more than once this camp was razed to the ground. It is interesting for one connected with the Project to look back to those days of discomfort and compare them with the present when the inspecting officer has the advantage of staying in a well built furnished house, equipped with electric light and fans, good water and almost every other home comfort, including ice! For this digression we crave the readers' indulgence. Let us now return to our main subject and examine what was being done at the site of the dam.

Even before the Inauguration Ceremony took place in August 1925, some work had already been done in opening out trial pits along the alignment of the Dam at Col. Ellis's Site "D." By the end of that year this investigation had been considerably extended, and further trial pits were excavated to greater depths to ascertain the levels to which the foundations of the dam would have to be taken, the removal of jungle growth and the blasting away of boulders on the hillocks on the alignment of the dam being proceeded with at the same time. These early investigations at once made it apparent that the site was not nearly so favourable as had originally been supposed. The trial excavations revealed the fact that between the rocky hillocks known as Smith's Knoll, Stoney's Ridge, Campbell's hill and the rocky ledge at the right flank which had been selected for the dam line, there existed deep pockets of schist of a very friable and porous nature, whilst the removal of boulders from the tops of these hillocks showed that they consisted of deep masses of badly fissured rock. Where anything in the nature of sheet rock was encountered it was found to contain large faults. It was clear therefore that if this line was to be adopted, the depth of foundations would have to be very much greater than the estimate contemplated, while the use of the valleys between these hillocks as supply channels from the sluices in the dam would necessitate heavy expenditure to render them fit to withstand the effects of heavy discharges and to protect the rear toe of the dam at these places against erosion.

At this time it happened that two geologists, Dr. Smeeth of the Mysore Geological Survey and Mr. Vinayaka Rao of the Geological Survey of India, were on a tour of inspection in the District examining the lime stone deposits in connexion with the supplies of lime required for the Project works and they were called in to inspect the excavations at the dam site. Prior to their arrival Mr. Barber, the Executive Engineer, Stores and Tests division, under the direction of the then Superintending Engineer, Mr. R. F. Stoney, had been examining possible sites further up the valley and had found a site called site " Y " a short distance above the old site " B ", which appeared to have many advantages over the site already under examination, though, until further trial excavations and borings were made, it was not possible to determine whether those advantages were real.

The geologists, after examining the excavations on Col. Ellis's site, agreed that the bands of schist and other decayed rock which lay up and down the valley almost at right angles to the dam alignment might be expected to run to great depths. The rock strata dipped at an angle of 70° to 80° to the horizontal, and it was evident that these wide bands would present many difficulties. They then examined the new site and considered it far superior from the geological aspect. At that site several of the bands of schists, which, from a point below the old site spread out rather like the fingers of one's hand, the wrist representing the wide belt along the right bank of the river, had petered out and left only one or two fairly well defined faults in the otherwise sound rock. The geologists were of the opinion that the foundations towards the right flank for a dam constructed at the new site would have to be taken down to a depth of about 12 feet only, but subsequently excavations proved that they were unduly optimistic in their estimate, though excellent foundations were encountered at somewhat greater depths.* In view of their favourable report on the new site, further examination of Col. Ellis's dam site was stopped, and work was concentrated on the examination of the new site.

* For details of Geologist's report see Appendix A.

CHAPTER IX

The 1924 Flood and its Influence on the site.

The Project estimate of 1924 had already been completed and submitted for sanction when there occurred in the Cauvery the greatest flood in living memory. During a period of 42 years prior to that occurrence the highest recorded flood, as has already been observed, was in 1896 when 207,000 cubic feet per second passed the site of the dam. Col. Ellis had allowed for a flood of 250,000 cusecs when designing his surplussing arrangements, but this great flood of the 26th July 1924 was computed to amount to no less than 456,000 cusecs, nearly two and a half times as great as the highest flood previously recorded, and over 200,000 cusecs more than the discharge which the present scheme was capable of passing! But for the long dispute between the Mysore and Madras Governments, it is probable that the dam would have been constructed and completed several years before the occurrence of the great flood, and one shudders to contemplate what its effect would have been on that work. Apart from its effect on the surplus works the dam would most likely have been overtopped to a depth of about 5 feet, and the extent of destruction caused by this mass of water passing over the top of the dam and falling down the rear face from such a great height is difficult to conceive. We have since experienced the effect of a mass of water falling 100 feet over a specially prepared spillway into a water cushion in rear of the present dam during its construction in 1933, which leaves but little doubt that portions of the dam would, under the circumstances have been undermined, and that the greater part of the structure would have collapsed with appalling consequences. That dispute, therefore, must be regarded as providential.

As soon as the effects of such a flood on the scheme had been carefully analysed, it was evident that the arrangements for surplussing flood waters would have to be entirely revised. It was not entirely practicable to extend the surplus works on the Ellis Saddle without cutting far into the hills on either flank, though the effective discharge was capable of being greatly increased by providing larger surplus sluices and discharging at a greater depth over their cills. The natural facilities for surplussing flood water over the other saddle to the West of 'Tiger Hill', near the right flank, were now examined, and a detailed survey of the site showed that it would be possible to lower the crest of that saddle to the required level at no very great expense, and provide a by-wash of suitable dimensions to dispose of a super flood even 25 per cent greater than the 1924 flood, an event which the Meteorological experts now declared was not beyond the bounds of possibility, since the rains which caused the 1924 flood, though very heavy, were not as widespread as they might conceivably have been. Here, then, we have the curious coincidence of finding the original scheme unsuitable, firstly from the point of view of foundations for the dam and secondly because, as designed, it could not cope with a flood such as had just been experienced, and at the same time discovering a new site, hitherto not even considered, which, while having the prospects of affording good foundations, presented an unique opportunity to provide supplementary surplus works near the right flank. The new site (site " Y "), being about a mile upstream of site " D " (see plate VI), had the additional advantage of being at a higher level so that, while the height of the dam did not have to be increased materially to obtain the requisite depth of discharge to pass a high flood through the Ellis Saddle Surplus, it was at the same time unnecessary to lower the cills of the surplus sluices to any great extent. Under the old scheme the cutting down of the ' F ' Saddle at the right flank was of no value as it discharged at a point above the old site of the dam.

This strong combination of circumstances naturally led to the complete abandonment of the old site, and preliminary work at the new site was taken up in earnest. Trial trenches were opened up all along the new dam line and power drills were put to work making deep borings to locate and examine the nature of the rock underlying the hard alluvial deposits on either bank of the river and the wide band of gneisso-schist near the right bank which later became popularly known as the " Deep Hole." With regard to the river crossing, that most important part of any dam, the new site was seen to have distinct advantages over the old one. The latter had a deep rift towards the left bank, the closing of which for constructional purposes would have presented some difficulty. The presence of this rift in the river bed pointed to a weakness in the rock structure at that place, and so was not, in any event, a desirable feature. The river bed at the new site, on the contrary, was comparatively flat and uniform, showing no particularly weak formation though later, when the foundations were actually excavated, it was found necessary to remove much of the rock to a depth of some 30 feet in order to secure really sound foundations for a structure of this great size, particularly as it was necessary to surplus the annual floods over the dam at that site during construction, and no risk of scour at the downstream toe of the dam could under any circumstances be tolerated.

THE NEW DAM SITE (FEBRUARY 1926).

CHAPTER X

Camps and Buildings at Mettur Headworks.

Leaving the work on the dam line for a while, let us now consider other preliminary works on which the whole construction work, where many thousands of persons are to be employed at one spot, must depend.

A preliminary scheme had been sketched out for the location of the camps, offices, workshops and all those essentials for a work of this nature, assuming, of course, that the dam was to be constructed on Colonel Ellis's Site. The preparation of plans for such a scheme had of necessity to be held in abeyance until the new site, a mile further up the valley, had been finally selected, when all previous proposals had to be scrapped. In 1926, while the preliminary investigation of the new dam site was being made, labour was beginning to pour in and several temporary coolie camps had sprung up. On account of the delay necessitated by the shifting of the dam site, it had not as yet been possible to make adequate provision for a protected water supply to these temporary camps, and the coolies, as was their custom, had recourse to the river. As a result, that dread scourge cholera made its appearance, and the small and somewhat ill-equipped medical staff, working heroically, had the greatest difficulty in keeping the epidemic in check.

Immediately the new dam site had been selected, working plans and estimates for the lay-out of a regular Township at Mettur were prepared and put into execution as rapidly as possible. In planning the housing scheme for the very large number of work people to be employed here, many basic principles had to be considered. One school of thought considered that buildings of a cheap and temporary nature would suffice, and that quarters might be constructed with mud walls and thatched or tiled roofs, that there was no necessity to provide elaborate drainage arrangements, and that sanitation, generally, could be left to look after itself, a very dangerous policy when one recollects the appalling death-rate that resulted from lack of attention to such details on many other large projects in the past, notably the early attempts of the French to construct the Panama canal.

In 1925, Mettur and other villages in this part of the Cauvery valley suffered severely from malaria, and the Health Department very rightly stressed the necessity to eradicate and prevent the recurrence of this wasting disease, the prevalence of which would very seriously undermine the health and efficiency of the people to be employed at the headworks. Very strict measures were taken in this direction and the subsequent anti-malarial campaign produced results of which the Health Officers and their staffs could rightly be proud.* Without a really efficient drainage scheme, the work of the Health Department would have been in vain. Wiser counsels therefore prevailed, and it was decided to adopt a more liberal policy and provide for all measures which would ensure the health and comfort of all. At the commencement of the work a few coolie lines had been constructed with mud walls, but these suffered such damage during the frequent and violent storms to which Mettur is subject that it was soon evident that this class of construction was entirely unsuitable, and that the cost of frequent and heavy repairs, besides causing much discomfort to the occupants, would ultimately far exceed the cost of structures built in burnt brick or stone, in the case of outer walls the former being protected with lime plaster, and the latter being pointed with lime or cement.

Though mud mortar was used almost exclusively for the construction in the superstructure of buildings it was found that the protection afforded made them entirely weatherproof and very little was spent in maintenance during the whole period of the work.

All roofs were tiled, some with locally manufactured pan tiles while the better classes of buildings were roofed with Mangalore tiles, received by rail at Erode from the West Coast and then transported by lorry to Mettur via the new road. Various cheap forms of flooring were used, the public buildings being floored with locally made pressed clay tiles. Officers' quarters were floored with third class 9 inch flooring tiles, obtained from the West Coast, laid on a prepared mud floor and cement pointed. This was a very cheap and excellent type of flooring and proved most satisfactory. No timber of suitable quality was available locally for roofing, so all the smaller types of quarters were provided with bamboo rafters obtained from the reserve forest in the hills within a few miles of Mettur. For the larger buildings, requiring timber for trusses and joists, country wood was obtained from the Forest Department who adopted special kiln-drying processes for the rapid seasoning of the timber supplied. Some jungle woods did not respond very readily to this rapid seasoning process and were found to be considerably warped or buckled when received. The doors and windows for the coolie lines were mostly constructed with reinforced concrete frames and braced corrugated iron shutters. All other buildings had doors and windows made of one or other of the various kinds of country wood, pillamarudu being the most widely employed.

* For a more detailed account of the work of the Health Department, see Part II—Chapter II.

PLATE VII

LAYOUT OF
METTUR HEADWORKS.

PLATE No. VII

Camp roads.—All the more important roads in the camp were well constructed from the start, being soled and metalled and these, with proper maintenance stood up to the heavy traffic excellently, proving that it pays, on a work of this magnitude, to provide really well-constructed roads in the first instance. Roadside drains of ample capacity were provided to deal with the heavy run-off from rapidly falling ground, so that flooding, even during the heaviest storms, was of short duration. Suitable masonry road culverts were constructed at all the more important stream crossings, notably at the Kullavirampatti and Thukkanampatti varis.

A glance at the layout-plan of the headworks (see plate VII) will convey to the reader the general arrangement of the roads, workshops, hospital, officers and residential area. In planning this scheme every endeavour was made to group and locate the various classes of buildings in suitable relation to the work. The power house, workshops and machinery stores were located as near the site of the dam as possible, but allowing ample space in rear of the dam for the laying out of an adequate tramway system, on the efficient working of which satisfactory progress of the work would depend. Space also had to be provided for the construction of a large supply channel by means of which the discharge from the irrigation sluices could be conducted with safety to the river below the dam. The Hospital and Health Laboratories, next in importance from a works point of view, were located between the workshop area and the residential area so that accident cases could be treated promptly at the hospital without the necessity of conveying the patients long distances, while it was also within easy reach of the most thickly populated portion of the residential area. Next, working southward from the dam, the main offices, Magistrate's Court, Treasury and Police station were located, the police lines being constructed near the police station. To the West of these buildings the coolie lines were constructed facing the West main road. These were in blocks of 20 quarters each, quarters being designed for two or three persons. Ample space was provided between the blocks, which it may here be noted, were given an ample piped pure water supply, with flush latrines connected to the main underground drainage system, and later, the streets and many of the quarters in these lines were lit by electricity. South of the coolie lines, to the west of the main road, were constructed blocks of peons' and menials' quarters, and quarters for mechanics. Between the East and West main roads were located mechanics' and clerks' quarters, appropriately graded and classified. East of the East main road the post office and school and a few blocks of clerks' quarters were located so as to be within easy reach of those who would frequent those places most. A market square, containing numerous shops and stalls, occupied the centre of the township, while, to the south of this main area, quarters for Government officers and subordinates were located. The quarters of the senior officers, enclosed in conveniently arranged compounds, occupied the southernmost end of the town furthest from the dam, as such officers would generally possess motor cars or other conveyances and could get to and from the works and offices without inconvenience. The distance of a mile and a half or so from the work site to their quarters therefore presented no difficulty. Rest-houses for both European and Indian Visitors were provided near the officers' quarters. This, briefly, is an outline of the layout scheme for the works and residential area on the Mettur side of the river. For detailed descriptions of the various types of building and quarters the reader is referred to Chapter III in Part II.

With the exception of the senior officers' quarters, which lay outside the drainage area of the township, all houses and quarters, including the hospital, were connected to the underground drainage system, while all were provided with piped water supply. The sewage disposal works consisted of a pumping station equipped with the necessary screening chambers and suction well, with storm-water overflow to the river, the sewers all operating on the gravitation system with the exception of the hospital system for which an air ejector was found necessary on account of the presence of a rocky ridge between the hospital buildings and the head of the Town Sewer System. The raw sewage was pumped to a farm located between the West main road and the foot of the hills which form the valley, which, while sufficiently far from the nearest residential area also possessed excellent light soil, well suited for the purpose (for detailed description, see Part II, Chapter V).

The construction of the Mettur township was commenced in March 1926 and completed about the end of the following year. During the construction of the camp a temporary water supply was provided on a small scale from a reservoir situated on the top of Smith's Knoll, one of the hillocks nearest the river at the old dam site. The water pumped from the river was treated in a portable type of Paterson Filter and chlorinated before discharge to the works. Prior to the construction of this temporary plant, water was pumped from the best of several old wells which were in existence in the Mettur village when it was acquired. The water from these wells was somewhat saline and being unprotected, was liable to contamination. The well from which water was pumped was, however, protected and the public had no access to it after the pumping plant was installed. The permanent water works situated on the left bank of the river were designed and constructed only after the bridge across the Cauvery at Mettur had been built and made that side of the river accessible.

CHAPTER XI

CONSTRUCTION OF THE CAUVERY BRIDGE AT METTUR.

UNTIL 1927 communication between Mettur and the left side of the river could be effected only by means of coracles, light circular basket boats covered with raw hide. This is the only type of craft employed in the lower reaches of the Cauvery both for ferry purposes and for fishing. The men who operate these craft show considerable skill in navigation of the most difficult water and accidents are of very rare occurrence. Owing to the very high velocity of the stream during the flood season, however, it was no uncommon experience to find that by the time one reached the opposite bank, the coracle had travelled perhaps a mile downstream and one then had the pleasure of walking back to the starting point and wasting much time in the process.

The transport of anything in the shape of heavy machinery or materials by means of coracles during the flood season was thus out of the question though, by constructing a large raft consisting of four coracles, lashed together with bamboos surmounted by a timber platform, some of the smaller plant required urgently on the left bank was actually transported safely across the river before the bridge was constructed.

In the original sanctioned estimate, provision was made for the construction of a bridge across the Cauvery at a cost of Rs. 1·5 lakhs. This was to be situated at mile 25/2 on the Bhavani-Cauveripuram road. This bridge was quite necessary for conveyance of large quantities of materials during construction from one side of the river to the other. Later on, when a through-road was completed, the bridge would establish communication between the districts of Salem and Coimbatore. It was seen that the construction of a new road from Thoppur in Salem district to Bhavani *via* Mettur over this bridge would reduce the distance between Madras and Coimbatore by fourteen miles. The District Boards of Salem and Coimbatore were invited to contribute towards the cost of this bridge, but they refused contribution on the ground that the locality in which this bridge was to be constructed would never be of any importance commercially; that the trunk road, if diverted as proposed, would be far away from the important town of Salem, and that the route was mostly through hilly and malarial country of very little economic or commercial importance. The bridge had therefore to be constructed entirely at the cost of the project.

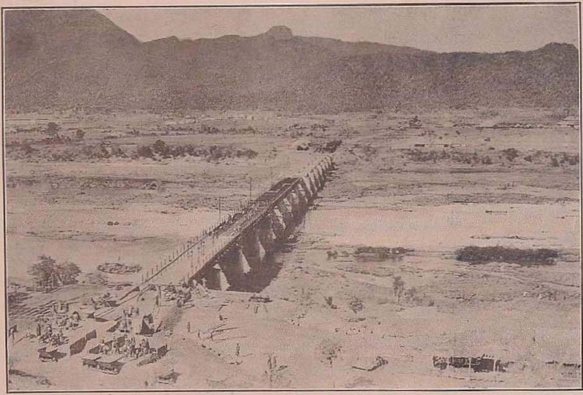
The girder bridge originally proposed was to be of 15 spans of 64 feet clear, constructed opposite mile 25/2 on the Bhavani road across the Cauvery river. It was proposed to purchase and utilize the main girders of the old Cauvery Railway bridge near Erode for Rs. 85,000, as these were available then and were in excellent condition. These were to be placed at 15 feet centres on stone-masonry piers built in surki mortar. The main girders were to carry cross girders at 7 feet centres over which it was proposed to construct a reinforced concrete decking. The load on the bridge was taken to be equivalent to that due to a 10-ton tractor pulling 2 wagons of 10 tons each and a crowd load of 100 lb. per square foot. The width of the roadway was to be 18 feet between kerbs.

The preliminary survey of the bridge site was made in January and February 1926, and the work was about to be started in March 1926, when it was stopped owing to the change of the site of dam to its present position. A site survey at the new site, about $1\frac{1}{4}$ miles higher up the river, was then made and found to be satisfactory, and the excavation of the right abutment was commenced in March 1926. The bank at that place was of 'kankar' of so hard a nature that the vertical excavation for the abutment stood one year's flood without any tendency to scour. The section of the abutments and wings was consequently designed light, assuming an angle of repose of 50° for the soil in rear. Masonry work was commenced with the aid of petty piece-workers, but, later on, the work was entrusted to a single contractor on piece-work agreement.

A detailed estimate for Rs. 2,68,000 was prepared and submitted for sanction in July 1926. This was sanctioned in Chief Engineer for Irrigation's Memo. No. 2832/B.E.P., dated 23rd March 1927, the work meanwhile being carried on in anticipation of sanction. The contractor to whom the work was entrusted in April 1926 completed the masonry work of piers and abutments by August 1927. However, as his progress in assembling the steel work for the bridge was slow and unsatisfactory, his agreement was cancelled in August 1927 and the erection of girders was taken up departmentally under the supervision of the Superintending Engineer, Machinery.

The design, as finally sanctioned, was a reinforced concrete decked bridge with 7″ slab thickness laid over steel cross-girders of section 15″ × 6″ × 59 lb. at 8 feet centres on the main girders. The main girders were set on the masonry piers at + 666 level (bottom level of the girder) at the 15′ 10″ centres. The level was fixed with reference to the flood of 1924. The width of the bridge

PLATE No. VIII.



THE CAUVERY BRIDGE UNDER CONSTRUCTION.

between hand rails was 20 feet, and 18 feet clear between kerbs. Over the reinforced concrete decking there was to be 3″ of Ferrocrete Concrete to serve as a wearing surface. But in actual construction 11 inches of cement concrete was laid in one operation with ½″ reinforcing rods at 3″ centres and ¼″ rods at 6″ centres in the bottom of the slab. A double tram-track was fixed with rails flush with the concrete road surface for tramway traffic, guard rails being provided.

There was some difficulty in obtaining the required cross-girders as the whole quantity was not then available with any one firm in India. The girders were finally ordered from Europe by the contractor and this caused some delay in construction. This purchase of foreign imported stores through a contractor was open to audit objection, and the special sanction of the Government had to be obtained for their purchase.

There was some difficulty in the construction of one of the piers, the seventh from the left abutment, as a bed of shingle overlay the rock and rendered the excavations difficult owing to heavy flow of water at this point even during the dry season. The other piers were all founded on good rock which was available 2 or 3 feet below the river bed. The foundations of the seventh pier, however, had to be taken down 6 to 7 feet below river bed. Naturally, this necessitated the construction of ring bunds and a coffer dam and heavy pumping was found necessary. The lower portion of all the piers was built with squared ashlar in cement mortar up to about 628·5 (levels varying from 626·5 to 630·5), the pockets in the rocks being carefully filled with cement concrete. The piers had a bottom width of 9 to 10 feet, while the top width was 6 feet. The top level of the piers was 655·5. The sides were vertical and the 6″ off sets at 10-foot intervals were all chamfered to prevent lodging of debris on them during floods. A description of the method of launching the girders may be of interest. A temporary suspension bridge of heavy steel wire ropes was first slung by anchoring 2 ropes securely at either bank and passing them over the piers, to which timber saddles had been bolted. Bamboos, placed close together, were lashed across these ropes to form a foot path. This rope way bridge was found very useful for communication between the banks. It was 9 feet wide, was provided with hand rails and was laid on the middle portion of the piers, leaving space at either side for the longitudinal girders to be launched without interference with the rope bridge.

The longitudinal or main girders were assembled in their 140′ lengths on the right bank in pairs, so that one pair would cover a double span. Each pair was braced with the old available short cross braces. The main girders were temporarily fitted with 90 lb. rails clamped to the bottom flanges, and cast iron rollers mounted on suitable brackets were fixed on the abutments and piers.

The braced pair of girders was attached to wire rope tackle passing over a fixed pulley block on the left bank returning to a steam winch on the right bank.

They were then jacked up to the proper level so that the heads of the rails below the girders just rested on the rollers at the abutment. The pair of girders was then pulled forward by means of the winch. As the piers were at 70 ft. centres, and as each girder was 140 feet in length, the rear portion of the girders balanced the front portion when the leading ends reached the rollers on the second pier and thus received support. The rear ends were, however, loaded to prevent any risk of the leading ends dropping before the final points of support were reached. The girders were thus successively launched and the process continued till the first pair reached the abutment on the other bank. When the girders reached their final position they were jacked up for the removal of the remaining rollers and rails and then lowered and traversed into their final positions. In this way all the girders were conveyed from the right abutment towards the left and fixed in position. The first pair of girders was launched on 20th October 1927, and the last girder was in position by the middle of March 1928. Expansion joints were provided at alternate piers, i.e., on even piers at intervals of 140 feet, the other ends being anchored to the bed plates on the piers. The bridge was completed and opened for traffic in June 1928, with certain restrictions as to the class of traffic.

In July 1930, on account of very heavy tramway traffic on the bridge, improvements were made by adding a side-walk on the upstream side for the use of pedestrians. This consisted of cantilever girders fished on to the cross girders of the bridge over which reinforced concrete slabs were laid. This side-walk was provided with handrails on the outer side.

The whole bridge in its original form was completed at a cost of Rs. 2,57,368. The additional cost of the side-walk was Rs. 5,761, thus making up a total of Rs. 2,63,129.

CHAPTER XII

Protected Water Supply for Headworks.

It was only on the completion of the Cauvery bridge in June 1928 that it became possible to start works on the left bank on any appreciable scale. The most urgent need was for a sufficiently large and permanent protected water supply. For reasons explained in detail in Part II, Chapter IV of this history, it was found inconvenient to instal permanent filter plant and service reservoirs on the right bank. An almost ideal site for the raw water intake was found at a point on the left bank, a little below the Cauvery bridge, where a natural deep pool existed. By constructing the filter plant and reservoirs on the high hill on the left bank near the left flank of the dam, command was given not only to the camps, but even to the top of the dam itself when completed. During the construction of the dam and before a pipe line could be laid at that site, the main distribution pipes for the Mettur camp and all works connected with the dam construction, workshops and power-house on the right bank had of necessity to be carried over the bridge across the river, and this continued to be the main supply line, though a subsidiary 6″ steel pipe line supplied the dam-works direct at a later stage, the supply being drawn direct from the High Level Reservoir.

It was originally proposed to use raw water for the masonry works on the dam, but the danger of this water being used by the labour for drinking purposes, with the consequent risk of cholera in epidemic form, led to the decision to use only filtered and chlorinated water for all purposes. The installation of two separate pumping and storage plants was thus avoided, and it is estimated that nothing was lost thereby, the pure water supply plant being equal to all demands both for domestic consumption and works throughout the duration of the construction, while the cost of the entire pumping and purification of the water was unusually low, despite the high lift involved.

The installation of the pure water supply to both works and camps had immediate and very beneficial results, and water-borne diseases practically disappeared at once. From the time the pure water supply came into general use, cholera ceased. Once again the patient reader is referred to Part II, Chapter I, wherein statistics relating to this subject will be found.

CHAPTER XIII

THE SALEM CAMP.

WITH THE opening of the new bridge the construction of the second camp on the left side of the river, at a high elevation and within reasonable distance of the surplus works and the left flank of the dam, was put in hand. This camp, known as the Salem camp (being on the Salem side of the river) was located on open sloping ground which had not previously been built upon, but was mainly waste or was under dry cultivation. The land had been acquired for the project along with the other headworks land very shortly after the scheme was sanctioned in 1925 so that, as soon as the layout had been planned and the estimates prepared, the work of construction on this camp went on very rapidly. It consisted of blocks of coolie lines, each block consisting of 20 huts, for the accommodation of 2,000 coolies. The quarters of the permanent staff, which would remain for the maintenance and control of the works at the dam after its completion, were also constructed in this camp, on the presumption that the main duties of the staff would be connected with the operation of the surplus works. Besides quarters for an Assistant Engineer, quarters were constructed for supervisors, maistries, mechanics and peons, while a rest-house, suitable for the accommodation of either Indian or European visitors was also provided. For the Salem camp the installation of an underground drainage system was not considered necessary, as the camp was situated on steeply falling ground. Surface drainage was accordingly provided, the open cement-plastered masonry drains of ovoid section proving entirely adequate. The sullage carried by this drainage system was gravitated to a small sewage farm some distance to the south-east of the camp, which was leased out to contractors annually and proved profitable.

A filtered water supply was obtained direct from the high level reservoir on the top of the hill immediately to the west of the camp, and a piped supply was given to every block of quarters. During the period of its occupation this camp was quite a model village, being compact yet with plenty of space between the blocks of buildings.

A dispensary and police outpost completed the requirements of this camp. To the north of the camp, blocks were reserved for the construction of shops which later did a fair amount of business, but it was noticed that the inhabitants of this camp generally preferred to do their shopping in the Mettur market and invariably attended the weekly 'Shandy' or market which was held every Sunday at the Government-controlled Shandy, situated some distance to the south of the Mettur camp at the headworks boundary.

The buildings constructed at the Salem camp were of the same types as provided in the Mettur camp for the different classes of labour.

For a more detailed account of the camp the reader is referred to Part II, Chapter III, wherein the cost of the different types of buildings will be found.

Communication between the Mettur and Salem camps is via the Cauvery bridge. Immediately after crossing the bridge to the left bank, the road climbs the steep face of the Chettamalais and has a gradient of about 1 in 17. It is 18 feet wide and nearly three-fourths of a mile in length, and contains six hair-pin bends. It rises from +660 level at the Cauvery bridge to +860 at its highest point where it crosses the saddle through a small cutting, falling again towards the Salem camp. Super-elevation is provided at all curves and hair-pin bends which are thus easily negotiated.

CHAPTER XIV

Temporary Coolie Camps.

In the foregoing chapter the reader will have gathered that while the preliminary investigation of the new dam line was being attended to there was great activity in the construction of the camps, with their water and drainage schemes and the bridge connecting with the left bank. It was only when these had reached a stage of completion in 1928 that really intensive work on the dam line could be started, and labour could be introduced on a large scale. While the permanent camps were under construction, several coolie camps of a temporary nature had sprung up for the housing of the labour employed by pieceworkers and contractors, the permanent camps being occupied almost exclusively by departmental employees. Two of these temporary coolie camps were situated to the north of the dam line, mainly for the accommodation of voddas or quarry men whose work lay upstream of the dam line at the right flank and they continued to be occupied till the time when the rising of the water in the reservoir necessitated their removal. Another large camp, which grew steadily as the construction work proceeded, was situated near Kullavirampatti, to the south of the dam line and west of the workshops. This camp was maintained right up to the completion of the work in 1934. The Health Officer was responsible for the proper layout of the huts in these camps and for their maintenance in thoroughly sanitary condition. A piped filtered water supply was given in each case, and ' dry ' latrines were provided departmentally and properly maintained by the Sanitary department under the directions of the Health Officer. The camps which had sprung up in the Mettur camp area in the earlier days of the work were demolished when the permanent camp was built. Another coolie camp for pieceworkers' coolies was constructed on a piece of open ground immediately to the south of the Salem camp, and remained there almost till the completion of the work.

The necessity for these camps may be realized when it is stated that at one time the population at headworks exceeded 18,000, of which perhaps one-third were actually employed on the works.

The customs prevailing in India differ considerably from those of the West. In Europe, and more especially in America, labour on a large project is usually accommodated in bunk-houses, with common dining-halls. This is possible where only male labour is employed, but in India, when a man seeks work, he takes his entire family with him. In the case of the labourer his wife is also a worker and his children follow in his footsteps at a very early age. A very large number of female coolies were employed at the headworks, and it may be said, did invaluable work, while, for the lighter jobs, boys and girls were generally employed. The older women, who were too old to work, remained at home to look after their houses and cook the families meals.

In the case of the superior employees, such as, clerks and mechanics, of a family of four or five, perhaps only one member would be actually employed, and it is this class which is mainly responsible for the large difference between the actual population and the number of persons engaged on the works or in the offices. To these, of course, must be added the many shop-keepers and their families, and the inevitable hangers-on to be found every where in India.

CHAPTER XV

Boring and Grouting of Foundations.

Let us now return to our main subject, the preliminary work on the dam line. In Chapter VIII, we left it in its earliest stages of exploration, when trial excavations and borings were being started to ascertain the nature of the rock on which the dam was to be founded. A brief description of the methods adopted for testing the foundations is here given.

In the original sanctioned estimate for the project a provision of one lakh of rupees was made for ' boring ' in foundations and " grouting. "

When Dr. Smeeth, the geologist, inspected the site in March 1926, one calyx drill boring had been put down near the western margin of the river bed to a depth of 25 feet in charnockite rock. He was informed then that it was under contemplation to put down a number of bore holes to a depth of 40 feet at ten feet intervals along the line of the proposed dam with a view to test the character of rocks at deeper levels. He was of the opinion that deep test holes were unnecessary in the case of deep-seated charnockite and gneiss which dip steeply and more or less uniformly towards the east and that such test results were not likely to afford much more satisfactory information than could be gathered from an examination of foundations down to hard rock level only.

Mr. D. G. Harris, C.I.E., Officiating Consulting Engineer to the Government of India, when he inspected the dam site in October 1926, discussed the desirability of making further borings. After referring to the opinion of Dr. Smeeth on the subject, he preferred to continue the borings so as to ensure that the fundamental rock had been reached; he considered that the work was too large and important to admit of the slightest risk being taken. Subsequent events showed his fears to be well-founded.

The Government, in November 1926, when communicating the support given by the Inspector-General of Irrigation in favour of the new site " Y " gave instructions to the Chief Engineer for Irrigation to pursue the work of making exploratory excavations and borings along the new line selected for the dam.

Accordingly, it was decided to test the whole rock foundations by a series of rapid test drill holes in all suspected seams in the downstream area as well as by extra deep holes along the line of the front foundation trench to prove solid rock to a depth of

40 ft. The strike of the strata at Mettur being approximately upstream and downstream, a series of minor fissures and faults were in evidence which might cause seepage of water underneath the foundation of the dam and thereby create a certain amount of uplift in some sections. As one of the precautions taken to eliminate this, the bore holes were utilized for injecting cement under pressure into the crevices of the rock foundations.

The foundation cut-off trench under the upstream face was taken sufficiently deep until the over-burden of all the decomposed and disintegrated rock was removed and all loose boulders and layers of soft rock had been blasted out and cleared till sheet rock exposed throughout. To prove the quality of this rock further, two sets of holes were drilled in the upstream area. The first set consisted of a series of bore holes 40 ft. deep and 40 ft. apart drilled along the entire length of the dam line with calyx drills producing a hole 3½″ diameter and yielding a 2½″ cylindrical core. The line of these holes was just in rear of the " impervious face ", or that portion between the front face of the dam and a line 5′ 9″ upstream of the centre line of the dam. The cores from these holes were carefully examined and the excavation, by blasting, was continued until it was made sure beyond all possibility of doubt that the foundation rock was absolutely sound.

Upstream of the calyx holes and staggered with them, a series of holes 20 ft. deep and at 40 ft. centres were made by means of tripod drills operated by compressed air. With this drilling no core was obtained. The evidence of the nature of the strata passed through would be mainly gauged from the behaviour of the drill and from a careful examination of the washings from the bore holes blown up from the bottom by the water and compressed air. By comparison with similar washings obtained from known samples of hard rock and with experience gained as to the nature, effort and speed of penetration, a fair knowledge of the composition of the rock could be obtained. These holes were made about 3 ft. inside of the upstream toe of dam. Originally, it was proposed to drill these also with the calyx machines but this was later given up as it was found that the latter method was very much slower and more expensive. The core-drilling, therefore, was restricted to the line of 40 ft. holes just in rear of the " impervious " face of the dam.

Between the calyx holes, and in line with them, another set of ripod holes 20 ft. deep was drilled at suitable intervals, and at all suspected joints and depressions in the foundation trench. It was possible for a calyx hole to have penetrated absolute solid rock, while within a few feet of that spot there might be a boulder resting on it or a faulty seam running across, and the hole would give unreliable information as to the true rock level. The tripod test holes would bring to light such unreliable information.

In rear of the impervious face, as many holes were drilled as were found necessary to make sure that the foundations were solid. All doubtful places wherever located, were proved by calyx drilling. Thus a net-work of holes was formed with the holes spaced at approximately 20 ft. intervals and sometimes closer all over the foundation area and at places where additional treatment of foundations was indicated by the nature of the rock excavated. These borings were made with the tripod drill, which is well suited for rapid operation and is easily transported.

After the foundations were tested by the bore holes, the whole of the impervious area was subjected to pressure grouting. The chief object of grouting was to prevent uplift under the base of dam by providing a water tight cut-off in the foundations under the front toe to which was to be cemented the water-tight masonry founded on it. In nature, all rocks more or less contain fissures, cracks and crevices, sometimes with weaker material sealing the joints. The cement grout, injected through the bore holes under pressure, was depended upon to fill these crevices and after setting, to arrest effectively the seepage of water through them when the reservoir was full and so guard against any possibility of uplift. For grouting the impervious face, the pressures adopted were 85 lb. to 90 lb. per square inch, being somewhat greater than that due to the head of water to which it would be subjected when the reservoir is full. For grouting the downstream area the pressure of grouting was somewhat reduced.

If, by chance, after grouting, any seepage were still found to occur past the water-tight cut-off, provision was made for future grouting of the foundations by extending, during the construction of the dam, the calyx bore holes by means of suitable G.I. piping up into the floor of the drainage gallery in the dam, whence the future grouting of these holes could be carried out.

The excavations along the dam line showed the hard rock to be in the form of a series of alternating ridges and depressions. Between the ridges there were layers of soft rock intercollated between the harder layers with fractured seams. The extent and depth of these layers was proved by means of calyx borings, the cores from which showed exactly where the soft rock ended and solid reliable foundations could be obtained. When penetrating a seam of disintegrated or fractured rock, the calyx frequently jammed, and would not proceed. In such cases the sides of the bore holes would cave in, the loose material obstructing further drilling. When this happened, either a casing pipe or liner was inserted, or the hole was cement-grouted sufficiently to consolidate the sides and the hole was then re-drilled. Occasionally, what appeared at first to be solid rock would later turn out to be merely a boulder overlying soft decomposed material. Such cases were detected by the calyx. Sometimes there would be a complete gap in the length of core indicating the existence of crevices. Natural breaks in the cores would bear evidence of fracture in the solid rock and indicate the bedding planes of formation. These, if not extensive, were consolidated by effective pressure-grouting, as described above. It was only when a continuous or nearly continuous core of hard granite was obtained that it was decided to proceed with the foundation work. Generally, it was found easier and more rapid in Shot-drilling to drill through hard solid rock where a uniform speed of cutting could be maintained. It was when loose material was met with that the calyx drills gave trouble.

A detailed description of the principle of the calyx drill and its operations will be found in Part II, Chapter XIII.

More detailed reports of the operations of the various types of drills employed, with some data regarding the speed and cost of drilling, will also be found there.

The method of grouting and the plant used for that important operation is described in Part II, Chapter XIV.

CHAPTER XVI

PROFILE OF THE DAM.

WE MAY now proceed to describe the revised design of the dam prepared to satisfy the conditions required at the new site. Some indication as to the depth to which the foundations would have to be taken had already been obtained from the earlier boring operations, while consideration of the disposal of high floods, necessitating the increased depth of surplus over the Ellis Saddle, and the loss of capacity resulting by moving the site a mile or so higher up the valley called for a somewhat higher dam than that already designed by Col. Ellis.

The revised design assumed the use of rubble masonry in ' surki '' mortar, having a safe intensity of pressure of 8 tons per square foot. The specific gravity of the masonry was assumed to be 2·30, as compared with 2·25 adopted for Col. Ellis's design. The stresses in the masonry were calculated by Bouvier's method. The top width of the dam was to be 18 feet while Col. Ellis's design allowed for a width of 10 feet only, exclusive of the piers and arches on the rear side which he provided for obtaining the necessary road width on the top.

Generally speaking, it will be seen that the profile followed fairly closely the form of Col. Ellis's design, but in view of the adoption of a higher specific gravity for masonry and the increase of the top width to 18 feet, the width at foundation was decreased, and the batters both in front and rear were modified.

The later decision to employ cement (an important change which we shall deal with elsewhere) in place of surki mortar for the construction of the dam, however, enabled the designers to further modify the profile of the dam. The section finally adopted is illustrated in Plate IX.

The provision of a drainage gallery with drainage shafts, the very complete survey of the rock underlying the dam and the provision for the connection of the bore holes to the gallery justified the modification of provision in the design for uplift. Referring to the model section finally adopted, the calculations as worked out in the office of the Engineer-in-Chief are given in Appendix B. A model test for stresses in the practical profile is also appended.

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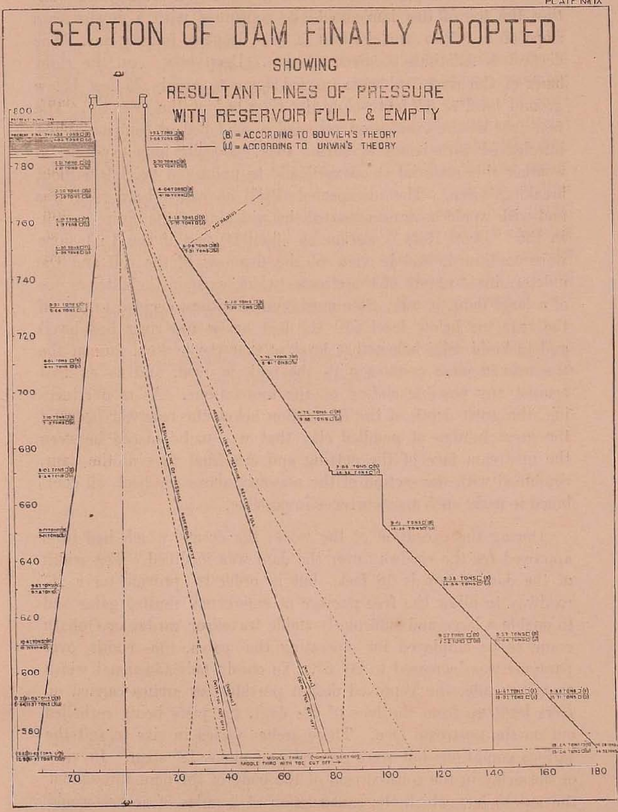
1 ' Surki ' is powdered burnt clay, the addition of which to lime mortar, when fresh, imparts certain hydraulic properties to the mortar. Surki mortar is in general use in many parts of India for irrigation works. (Ed.).

PLATE Nº IX



CROSS SECTION OF DAM AS CONSTRUCTED.

The calculations assume that, at some future date, the height of the dam may be raised by 10 feet to compensate for loss of capacity of the reservoir through silting. The section adopted, therefore, more than satisfies present requirements and may be considered very safe.

In actual execution of the work the question arose as to whether the toe of the dam should be continued with a downstream slope of 1 : 1 to the bottom of the deepest foundations. The deepest foundations occurred in the "Deep hole" on the right bank of the river and were carried down to nearly 75 feet below ground level or 45 feet below the river-bed at the crossing. The rear face of the excavation revealed a solid bed of compact schist interleaved with bands of harder rock. Despite long exposure to weather this material stood vertically to unlimited heights without breaking down. The unexpected depth at which hard rock was met with would have necessitated the widening of the entire trench in the "Deep Hole" section by about 20 feet if the 1 : 1 slope were continued, and in view of the firmness of the soil and the indeterminate nature of the stresses which exist in the extreme toe of a large dam, it was, after much consideration, decided to cut off the rear toe below level 610 (15 feet below the river bed level) and to build solid below that level so that the vertical face at the toe was in close contact with the rock in rear, and so ensured against any possible sliding on the foundations. As to overturning, the great depth of the foundation below the reservoir bed and the great burden of puddled clay that was to be placed between the upstream face of the cutting and the front face of the dam, combined with the section of the masonry above the heel, all combined to make such an occurrence impossible.

During the execution of the work, the design which had been approved for the roadway over the dam was modified. The width of the dam at top is 18 feet, but in order to provide for a 16′ roadway to allow the free passage of emergency shutter gates and to enable a large and sufficiently stable travelling gantry or Goliath crane to be employed for operating the gates, the width over parapets was increased to 20′ 6″. To obtain this additional width on either side, the approved design provides for arches carried on piers built up from the face of the dam, the piers being corbelled out on the upstream face. These arches varied in size to suit the various conditions but were generally of about 18′ span. In view of the delay in the construction of the body of the dam throughout the top 15 feet which the construction of 2 miles of arches would have involved, together with the comparatively high cost of such arch work it was finally decided to adopt a uniform section throughout the length of the dam. This was effected by corbelling the masonry 15″ on the upstream face, by giving a reverse batter from level +786·5 to +794·0, and by building the rear face vertically from the level at which the rear curve met a line 9 feet in rear of the centre line.

All unnecessary ornamentation was thus cut out and the upper masonry work, being straightforward, proceeded almost as rapidly as in the lower stages. The upstream corbelled face incidentally serves as a wave-breaker at F.R.L. or above. This change in design for the top of the dam undoubtedly enabled the dam to be completed many months earlier than would have been possible had the arched design been adopted, while the saving in cost, directly and indirectly, was very great. Had the arched design been adopted, it would not have been possible to complete the dam before the 1934 flood season commenced. This would have necessitated keeping open the spillway section in the dam for another year and in view of the extraordinarily weak monsoon of 1934, the effects on irrigation in the delta, which was already counting upon improved supply, would have been disastrous, and had the dam not been completed and the reservoir filled to the greatest extent possible during that flood season, the crops would have failed completely.

The final appearance of the dam due to the above modifications in design is not unpleasing, and its plain and solid stateliness is impressive.

CHAPTER XVII

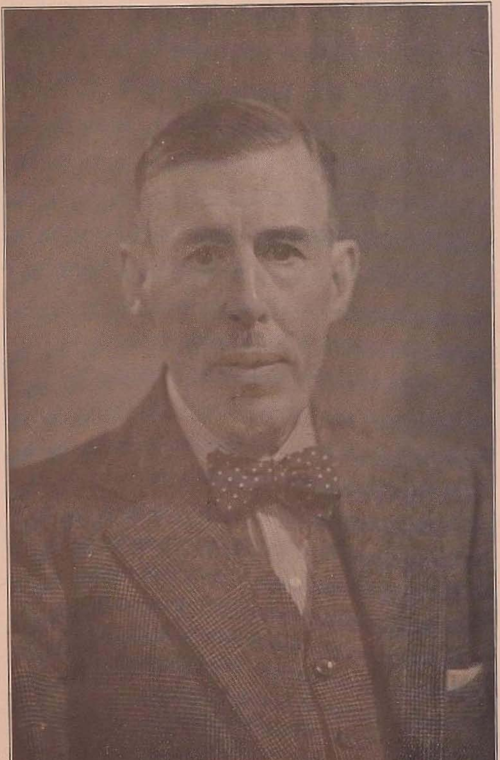
Materials for construction of the Dam.

In giving a very brief description of the profile of the dam as first revised and then as finally adopted, we have lightly referred to one very important feature which had an enormous influence on both the time and methods of construction and on the selection of machinery for the construction of the dam. This was the substitution of cement for lime, and it will here be appropriate to relate the sequence of events which finally led to the adoption of cement.

Cement replaces Lime.

As we have already seen, the earlier proposals and estimates for the construction of the dam all provided for the use of lime or surki mortar, the latter being lime mortar with a proportion of surki added at the time of grinding. Now, the 1910 preliminary investigations and surveys were of a somewhat general and superficial nature as they had, of necessity, to cover a great deal of ground. In consequence, the survey of the surrounding country for the determination of the extent of suitable lime deposits proved, on more detailed investigation during 1925 and 1926, to be of but little value. Many exploratory excavations were made over a very wide area in the places where large deposits of lime had been reported, but the results were disappointing. With the exception of the lime stone deposits near Sankari, between Bhavani and Salem and some 38 miles by road from Mettur, the deposits examined consisted mainly of kankur nodules widely scattered and nowhere in large quantities so that it was early realized that the collection of the millions of cubic feet of lime required for this vast work would entail very special arrangements. Another difficulty was that, on analysis, the samples of lime from the different deposits showed considerable variations in quality so that much difficulty would have been experienced in maintaining a proper standard of quality of the mortar had lime been employed for the construction of the dam. Nevertheless, there were certain officers in the department, who, on the strength of their experience on much smaller works on which lime surki mortar had been used, strongly urged the use of lime for the construction of the dam, considering that what was good enough for one work was good enough for another; that speed of construction was a minor matter, and that the use of special machinery was entirely unnecessary.

PLATE No. X.



SIR CLEMENT MULLINGS, *Kt.*, C.S.I.

Mr. (later Sir C. T.) Mullings, at this time Chief Engineer for Irrigation, the only officer of the Madras Public Works Department who had previously had experience of large masonry dam construction (in Hyderabad in 1913–15), strongly advocated the use of portland cement in place of lime, showing amongst other things, that the use of cement would enable the dam, then estimated to contain 45 million cubic feet to be constructed in about seven years, as against 15 years that would probably be required if lime were used. That the speeding up of construction by the use of cement would result in a corresponding acceleration in the development of irrigation and that the greater height and dimensions of the dam at the new site made the use of cement desirable to ensure its structural safety were some of the considerations favouring the choice of cement. But the substitution of cement concrete in place of surki masonry involved an extra 50 per cent in the cost and the use of special and expensive plant and it was contended in some quarters that as the new area was not likely to develop within the 5-year period assumed, the project would loose more money by way of interest on the capital if the agricultural development did not actually materialize. Rubble masonry, it was argued, had some inherent superiority over concrete because it required less mortar, was more imprevious and could be turned out at any desired rate provided sufficient manual labour were forthcoming. In view of the peculiar circumstances in India, where manual labour is cheaper than machinery, it was further held that the use of machinery should be limited to the extent required to supplement manual labour, which should be preferred to machinery for work, wherever possible. A reversion to the original proposal for a dam of surki masonry with a 15-year construction period was now suggested but it was turned down on the general ground that, whatever the rate of development in new irrigation might be, a saving of eight years in construction would admit of eight years earlier development and hence would yield eight more years of full revenue (estimated to amount to the enormous figure of Rs. $3\frac{1}{2}$ crores) which would repay—eight times over—the extra outlay on cement and plant involved in the shorter programme.

The Government, before finally deciding on the use of cement and on the use of the special plant proposed, referred the matter to the Central Board of Irrigation, inviting technical remarks on the issues (1) whether cement concrete in the proportion suggested was superior to rubble in surki mortar, (2) whether stresses of 10 tons a square foot might safely be allowed in such a concrete, (3) whether the programme of machinery and methods as proposed was generally acceptable and (4) whether, with the arrangements proposed, the dam could reasonably be expected to be completed within the time scheduled. The consensus of opinion received was in favour of the first two and, while a doubt was expressed that the maximum outturn possible by the machines was not sufficient to ensure the average outturn corresponding to the rate of construction proposed, it was also opined that the use of a larger number of smaller units would minimise the stoppage of work in the event of breakdowns, by localising their effect without affecting the greater part of the work. On receipt of these opinions, the Government generally approved the proposal to construct the dam of cement concrete, by means of the machinery proposed, subject to any modifications the Engineer-in-Chief might make on the suggestions made by the Engineers consulted. (The reader who may be really interested in this argument is advised to peruse G.O. No. 1815, I., dated the 22nd August 1927, in which the case has been dealt with in great detail. Space does not admit of its reproduction in this report).

With the approval of the use of cement in place of lime, the design of the dam was again somewhat modified, and the many changes which the use of this new material necessitated led to the preparation of yet another revised estimate, but this will be dealt with in a later chapter after we have seen the results of investigation of the other essential constituents of the Dam, sand and stone.

CHAPTER XVIII

SAND.

IN CHAPTER V, it will have been noted that it was proposed at one time to employ crushed stone in place of natural sand, it having been assumed that nothing like the twenty-two million cubic feet or so of sand required for the work would be available in the vicinity. Examination of the river bed for several miles above and below the dam site, during the dry weather of 1926 and in subsequent years, revealed the existence of a number of large shoals and enabled an estimate of the quantity of sand of suitable quality in these shoals to be prepared. The extent of the shoals was measured and the depth of sand overlying the rocky bed of the river was ascertained by means of steel probes. Between Samballi and the Dam site considerable deposits of sand of excellent quality for building purposes were found, and as it was realized that, with the construction of the dam and the impounding of water, any sand above the dam would rapidly be rendered inaccessible, steps were taken to commence the collection and haulage of the sand up to the high river banks as soon as the first tramway plant was received. Sand collection could, of course, only be made during the dry season when the river was at its lowest, so that during a period of 4½ to 5 months annually, sufficient sand would have to be collected and stored above flood level to supply the construction work for the whole twelve months.

In view of the very high speed of construction contemplated, this necessitated very intensive work on sand collection each year during this brief period, and no time was lost in collecting as much sand as possible above the dam site, the shoals below the dam being reserved for tapping after the upstream shoals had been worked out or had become inaccessible on account of the rise in water level in the reservoir. There was at first considerable speculation as to whether shoals once removed would be re-formed during subsequent flood seasons, some holding that they would not do so to any appreciable extent. There was also the fear that the shoals lying below the dam site would be washed away during the earlier years of construction and would not be replaced during floods as the dam would trap any sand carried down the river. Fortunately, these fears were only partially realized, and it was gratifying to find that a very appreciable replacement of the shoals occurred at the end of each flood season, so that annual collection was actully found possible right up to 1934.

In 1910, Col. Ellis was of the opinion that sand would have to be dredged from the river bed some 10 or 12 miles above the site of the dam near Cholapadi, and made provision in his estimate for such dredging operations. Under such conditions, however, the rate of sand collection would have been slow, while the cost per unit would have been comparatively high. It may seem strange now that his report does not mention the existence of any appreciable sand shoals at or near the site of the dam, though, in fact, the quantity available from 1925 onward was more than sufficient to construct a dam nearly 50 per cent larger than the one for which his 1910 estimate provided, without touching the shoals to which he refers! This peculiar change in the sand situation appears to have been brought about entirely by the extraordinarily high 1924 flood which carried down sand in such quantities that shoals were deposited where they had not previously existed—Hence Col. Ellis's proposal to convey sand from Cholapadi. In 1926, labour for sand collection was fortunately available in sufficient numbers. Tramways, with ramps down the banks were laid in the river bed as soon as river conditions each season permitted, and large reserve stacks of sand were formed on the banks at safe levels as near the site of work as possible so that, as the work proceeded, train-loads could be conveyed to the concrete and mortar mixers as and when required. In the earlier days, winches were used to haul the trucks up the ramps from the river bed, but later as the number of locomotives was increased, trains of sand were hauled direct from the river bed and the rate of collection was much accelerated. When conditions were favourable, the tramways were supplemented with large coracles, by means of which sand was collected from shoals as far as 5½ miles above the dam site. The loaded coracles, floating down with the stream, delivered sand directly to the work in the river bed during the building of the construction-sluices while the masonry in that section was still low.

As the reserve stacks of sand collected on the river bank up-stream of the dam were used up, others were being formed below the site, and, when the quantity of rolling stock had been considerably augmented and more locos became available, the conveyance of sand from these stacks to two large sand-dumps on the right bank just in rear of the Dam and East of the Cauvery bridge proceeded day and night for months at a time. In order to avoid double handling, sand trains, as often as possible, delivered sand collected in the river, direct to the sand bins at the work spot, and by this means considerable saving in cost of handling was effected and a large reserve stock was maintained.

As the shoals nearer Mettur became exhausted, it was found necessary to extend the tramline along the Bhavani road, and eventually the length of that line was about 10½ miles, exclusive of the numerous sidings connecting the sand dumps on the river bank with that line.

The total quantity of sand collected amounted to no less than 28·717 million cubic feet, after allowing for a bulkage of 17·9* per cent, while nearly 904,000 cubic feet of stone dust delivered from crushers was also supplied in lieu of sand, making a total of 29·621 million cubic feet. For the accurate measurement of this vast quantity of sand it was necessary to make due allowance for wastage in the various processes of stacking and loading and for bulkage. The latter proved to be a great problem for the bulk of sand changes according to the amount of moisture it contains. As this was ever changing, a more liberal allowance was made than finally proved to be necessary, with the result that some 457,520 cubic feet of sand was still in reserve when the works were completed. This was as well, however, for had there been a shortage instead, the completion of the work (which happened to occur after the flood season of 1934 has commenced) might have been seriously delayed. Further, it has since proved very beneficial to the Hydro-Electric Department who are drawing their requirements of sand for the construction of the power house at Mettur from this reserve.

It is also likely that in the near future additional protective works will be required in the great spillway below the Ellis Saddle surplus works, when what remains of this reserve stock of sand may prove invaluable.

The actual issues of sand during the construction were as follows :—

	C.FT.
Issued for work on the main dam	26,651,286
Issued for subsidiary works	1,608,628
Balance found surplus	457,520
Issue of crusher dust to main dam	903,837
Total ..	29,621,271

Of the above 2,239,000 cubic feet of sand were delivered at the site of the dam by coracles, of which no less than eighty were in use at one time. These coracles varied in size and carried between 35 and 60 cubic feet of sand per trip which averaged about 3 miles. After delivering their sand it was usual for the coracles, which are very light, to be taken from the water and conveyed back by land, as that involved less work than paddling them back against the stream. On the Cauvery one rarely sees a coracle being paddled upstream, but it is no uncommon sight to see a procession of gigantic mushrooms with human legs proceeding up the road! One man

* Including 10 per cent for deduction in stack measurement. Actual bulkage was only 7·9 per cent.

is capable of carrying the largest coracle long distances on his head, the coracle being inverted to render this process more simple. Incidentally it may be remarked that a coracle makes a splendid umbrella, or, propped up on the ground, affords shelter for a crowd of people during a storm. Is it to be wondered at, therefore, that this primitive form of craft has survived throughout the ages? It draws but a few inches of water even when loaded, and is so flexible that it can safely be squeezed through a gap of considerably less width than its own normal diameter, but its ability—in the right hands—to ride the roughest water and shoot rapids is perhaps its greatest asset in a river studded with rocks and abounding in rapids.

Sand collection was done through piece-workers who were paid on the measured stacks, or, where the sand was despatched direct to the work spot, on the contents of each wagon, the sand being loaded to a fixed level in each truck. As a check on the measurement, log books were maintained on the concrete and mortar mixers in which the quantities of sand actually consumed was regularly noted.

To give the reader some conception of the rate at which sand was consumed on the work it may be recorded that in one month, March 1932, the quantity issued was as much as 880,000 cubic feet, while the maximum quantity hauled to the headworks from the shoals in any one month was 647,000 cubic feet. Even at the busiest times, when the train crews worked in double shifts, it is noteworthy that there was never an instance of delay in the despatch of trains due to the rakes of trucks not being filled in time, either by day or by night, and the time table was strictly adhered to.

Of the subsidiary works, on which large quantities of sand were consumed, the principal ones were the Ellis Saddle Surplus Escape, with its massive masonry piers and apron, and the combined High and Low Level Channel which contain a number of large masonry drops and a considerable length of high retaining walls.

After adjusting all debits against sand collection, the cost worked out to Rs. 27–7–1 per unit of 1,000 cubic feet, while the estimate provision was Rs. 50 per unit. The saving in cost of sand collection amounted to Rs. 6 lakhs and was effected partly through the rapid fall in tendered rates and partly through the untiring efforts of the officers in charge of that section to maintain a high standard of efficiency in the organization and handling of such a large quantity of material.

CHAPTER XIX

Stone and Quarries.

The methods of obtaining the vast quantity of stone required for the work were varied and underwent many changes. In the earliest days of the work stone required for preliminary works, both for the coffer dam construction in the river bed and for the construction of numerous buildings in the Camp, was obtained mainly by blasting the huge boulders which lay at or near the foot of the hills at either flank, and pieceworkers were engaged to collect and stack reserve stocks, but they lacked method and the contractors seemed to have little control over their quarry men, woddas, local stone workers who are very independent and often difficult to manage. They are tremendous workers while they are at work, but commonly stay away two or three days in the week and drink heavily whenever an opportunity offers. Their women, who are almost as tough, are equally good workers and can wield a sledge hammer with the best of them. Usually, a man and his wife take turns, one holding the drill while the other operates the hammer when boring rock for blasting. Their knowledge of blasting is wonderful, and it is surprising what a large outturn of blasted rock they can produce with the minimum amount of black powder, the only explosive they ever use and which they are capable of manufacturing themselves. But they take dreadful risks when blasting and, while having some respect for their own skins, seem to care nothing for their neighbours' safety! In stacking blasted stone for measurement they are expert cheats, and the officer who measures up their stacks has to be very wide awake, for they are capable of forming a stack which to all appearances seems quite solid but which, on careful examination, will be found to be hollow inside. Despite their many shortcomings, it is mainly to these people that we must hand the palm for having produced the greater part of the many millions of cubic feet of stone required for the construction of this great Dam, and at a cost which could not be attained by any other means. To those with quarrying experience in other parts of the world, the low rate at which these people can produce stone particularly where large quantities are required, comes as a great surprise, and few who see this great work completed can believe that so much of the stone was actually produced by the most primitive methods and at such small cost.

But we are proceeding too fast, for, when the work was started, even those most closely connected with the work never imagined that more than a small proportion of the 54½ million cubic feet of blasted granite required could be obtained through such agency at the required speed, so the adoption of modern quarrying methods on a very large scale appeared essential. Accordingly, arrangements were made to operate on large quarry faces with batteries of power drills and high explosives. The quarry sites were located on the west side of "Tiger Hill" at the right flank of the Dam and on the east side of the Chettamalais, just to the north of the Ellis Saddle and intensive quarrying was started at those places. Stone of good quality was obtained but, as the opening out of the quarry faces proceeded, large faults were encountered, necessitating the removal of large quantities of useless material.

Now, it was estimated that the average daily requirements for the construction would be about 1,400 cubic yards or nearly 37,800 cubic feet of stone per day for a period of about 5 years, and, to produce this quantity, in accordance with modern quarry practice, some 70,000 to 80,000 square feet of quarry face would be required, assuming that intensive quarrying would be done. Half this area was to be found at the right flank quarry and half at the left flank at the sites already referred to but, as the quarry operations proceeded, it was soon found that the required areas would take considerable time to develop if, in fact, they could be obtained at all. The quarrying operations with pneumatic tools on this large scale proved costly, and since the rock was extremely hard and of close texture, the footage obtained with each drill was small, while the charges for replacements and spare parts for the machines were very heavy. It may be remarked, in passing, that the manufacturer of pneumatic tools seems to depend mainly on the sale of spare parts at high prices for his profits, knowing that, having purchased his machines, one is compelled to go to him for replacements and spare parts. This, however, seems common to many trades as the owner of a motor car is aware! The cost of a machine constructed of new spare parts bears no relation to that of a complete machine comprising identical parts purchased in the first instance, but there is always a satisfactory answer available when one protests about the exorbitant prices often charged for spare parts.

For the actual quarrying which was carried out departmentally, pneumatic tripod drills or drifters and jack-hammers were mainly employed for drilling. The quarry faces were developed in ledges. Generally, vertical tripod holes were drilled 12 to 14 feet deep some 6 feet back from the face, while jack-hammer holes were put in 3 feet deep and 3 feet from the face. The lines of holes were staggered, the holes in each row being 8 to 10 feet apart. Often, some 16 to 20 holes would be fired simultaneously by electricity. 'Delayed' firing was not practised. Without the front row of shallow holes it was found that while the quantity of rock brought down was very good for the charge of explosive employed, the individual masses of rock produced were of such size, and in such high proportion to the whole, that a great deal of secondary blasting was necessary, and, in view of the limited area available for these operations, the rate at which the material could be cleared was slow. The use of the shallower charges helped much to reduce the amount of secondary blasting, but, even then, a great deal of handbreaking by the "plug-and-feather" method was necessary before the stones could be handled and despatched to the work spot or crushers, as the case might be.

It was originally intended to construct the Dam entirely of concrete and, with this end in view, three batteries of heavy crushers had been obtained from Messrs. Hadfields, Ltd., in England. The primary crushers in each unit were of unusual size and were capable of taking stones up to 2½ tons in weight each, but there were many things which militated against the handling of stones of such size, which would necessitate the use of a fleet of steam or electric cranes or Navvies and special bottom-discharge trucks for delivering them at the crushers. The sites of the quarries did not admit of the use of such plant economically, and in view of the heavy capital cost which their purchase would involve, it was found better from every point of view to break down the stone to such a size that it could be handled by coolies. This became more and more evident as the price of labour fell.

Since the required outturn of stone could not be maintained at these main quarries, subsidiary quarries were opened and operated by power drills or manual labour, and it was soon found that the cost of stone obtained by the latter method was considerably lower than the former. As quarry labour became more plentiful, new quarry pits were opened up in places which were far more convenient for the delivery of stone to the work spot. It must be explained that the quarry at Tiger Hill which was intended to feed the crushers at a considerable elevation was rather far from the Dam and for masonry works stone had to be conveyed down a steep ghaut railway some mile and a half in length. The number of wagons that could be hauled on this line was strictly limited so that even with a large fleet of locos, the rate of supply was insufficient to meet demands. By opening up quarries at or slightly above the level of the work in a wide area upstream of the Dam on the right bank of the river, it was found that locos could handle four or five times as many trucks in less time. During this process of quarry development the cost of stone obtained by manual labour steadily fell and it was found that it was no longer economical to continue with mechanical methods, and long before the work was completed power drilling was given up. The lesson learnt, therefore, is that where sufficient and cheap labour is available, and where it can be spread over a large area in which numerous quarry pits can be opened, it is more economical to employ such labour entirely even for a very large work of this kind. When intensive quarrying was first decided upon, it was, of course, not realized that the requisite number of men for hand quarrying would ever be available.

CHAPTER XX

CHOICE OF EXPLOSIVES.

THE QUESTION as to the type of explosive to be used for quarrying and for excavating the foundations at Mettur was carefully examined. As already explained, the local quarry men and well-excavators in these districts are accustomed to use black powder only, and they are most proficient in its use. Through long practice they know exactly the charge required to produce a particular result, a result, be it noted, that cannot easily be obtained by the use of any other type of explosive where square stones or slabs are required. However, it was realized that for the bulk of the work for which rough stone was needed, we should require a more powerful type of explosive, and in the earlier days of the work gelignite was employed in large quantities. The Great War, however, had been instrumental in producing an entirely new form of explosive, liquid oxygen, and a Company in India was already attempting to market this product when operations were started at Mettur, and their claims regarding it were duly considered. Tests were carried out with this material at Mettur early in 1927, with impressive results. In consequence, it was generally adopted for this work. Here we cannot do better than reproduce the note by Mr. F. M. Dowley, Officiating Engineer-in-Chief, Cauvery Mettur Project, written on the 22nd July 1929, in which he describes this new explosive and its uses in some detail.

Note by Mr. F. M. Dowley, Officiating Engineer-in-Chief, Cauvery-Mettur Project, dated 22nd July 1929.

[LIQUID OXYGEN EXPLOSIVES.]

The first blast with liquid oxygen in India was set off at Mettur on 3rd May 1927, in the presence of the Engineers of the Cauvery-Mettur Project, and Doctor Sheldon, Chief Inspector of Explosives, India.

Several demonstrations, proving its efficiency and safety in handling followed, and upon the Lightfoot Refrigeration Company, Limited, who own the rights of these explosives in India, undertaking to guarantee a definite rate per ton of rock broken to a given size the contract for the supply of explosives for the project was given to them. The required tonnage will at times reach as high a figure as 3,000 tons of rock daily.

History.—During the Great War (1914–18) Germany required large quantities of nitrated compounds for military purpose, and, as supplies were running short, the Government issued restrictive orders to all mining companies and other users of explosive regulating the supplies of explosive mixtures. Accordingly these companies were forced to seek another form of explosive and liquid oxygen was adopted in the form of a cartridge. The Weber (Patent) Cartridge is now being used at Mettur.

Its progressive use in Europe can be judged from the following figures :—

In 1919 the cartridges used were 631,412, in 1928 the number was 9,818,995. The tonnage broken in 1919 was 1,000,000, and in 1928 it was 17,000,000.

In 1927 the Lightfoot Refrigeration Company, Limited, purchased the rights for India, Burma, Ceylon and the Straits Settlements and it is interesting to note that greater progress has been made in India than in any other part of the British Empire. The company's connexion with the manufacture of oxygen dates back to the time when Mr. T. B. Lightfoot and Professor Linde were closely associated in the experimental stages of preparing oxygen gas.

Liquid oxygen.—Liquid oxygen is a pale steel-blue liquid having a specific gravity of 1·1315. It is not inflammable and therefore can be stored anywhere with perfect safety.

Manufacture.—There are two main principles involved in the manufacture of liquid oxygen from air; first, when a gas is subjected to a certain pressure and temperature it will liquefy; the second principle is in the separation of the nitrogen from the oxygen and this is effected by taking advantage of the difference in the boiling points of these two liquids. Oxygen boils or evaporates at $-182°$C. and nitrogen at $-195°$C. Therefore by allowing liquid oxygen to fall through perforated plates the nitrogen will evaporate first leaving liquid oxygen which is collected at the bottom of the column.

Applying these principles to modern practice, the air is first purified, compressed to 3,000 lb. pressure, cooled and allowed to expand, when it liquefies. The nitrogen is separated in a column as explained above.

Two plants are in operation at the Mettur Project. Each of these plants is capable of producing 20 litres of liquid oxygen per hour. One plant is sufficient to meet the full demands of the project but the Lightfoot Refrigeration Company decided to erect two complete units, one being standby. These plants are managed by the company.

Transport of liquid oxygen.—Liquid oxygen is transported in metal-walled vacuum containers built to stand the roughest handling. The liquid can be easily poured from these containers into vessels in which the cartridges are soaked.

The rate of evaporation as determined when liquid oxygen was first transported from Bombay to the Mettur Project (a distance of 983 miles) is 7½ per cent in 24 hours. When standing, the rate is about 5 per cent in 24 hours.

The Weber Patent Cartridges.—Weber Patent Cartridges are composed of inert materials with high absorbent properties. They are therefore harmless and can be stored anywhere with perfect safety.

A cartridge only acquires explosive properties when it is saturated with liquid oxygen and strongly confined. If a naked light is deliberately applied to a saturated cartridge in the open air it will merely burn rapidly. Cartridges are made to any size from 1 inch diameter upwards.

Evaporation of the liquid oxygen in the cartridge starts immediately the cartridge is withdrawn from the soaking vessel. Therefore after a limited time the cartridge is again inert and there is no danger whatever of drilling into it. Cartridges can be drilled or blown out with absolute safety leaving the hole as before.

Force.—The force of a Weber (Patent) Liquid Oxygen Cartridge can be varied by merely changing the composition of the cartridge. Thus cartridges can be made to suit practically every condition. The force ranges from below black powder to the strongest high explosive made.

Weber Patent Cartridges are made in India and their ingredients are composed mainly of materials found in India.

Application of liquid oxygen explosives.—Liquid oxygen is poured from a container into a soaking vessel until the vessel is about half full. Cartridges are then inserted and allowed to soak for three or four minutes when liquid oxygen is again added, filling the soaking vessel. Directly the cartridges sink to the bottom of the vessel they are saturated and ready for use.

After the holes to be blasted have been cleaned in the usual way, an ordinary fuse-length knotted at the end is inserted into each hole. Cartridges are then dropped into the holes which are later tamped with sand, earth or clay. Directly the fuse spits, it ignites the cartridges which, being closely confined, explode. If two or three cartridges are required for one hole, the knotted end of the fuse may be placed between the cartridges. Liquid oxygen cartridges can be set off by electric detonators but in the ordinary way detonators are not required.

Action of explosion.—The action of liquid oxygen explosives is similar to that of all other commercial explosives, instantaneous combustion of the ingredients of the cartridges is set up upon ignition or detonation. In the majority of explosives, oxygen is supplied in the form of the salts such as nitrates, chlorates or perchlorates containing a large proportion of oxygen which readily gives up when mixed with combustible materials and detonated. The oxygen passes almost instantaneously from the salts to the carbon, hydrogen, etc., of the combustible materials with the formation of water vapour and gases.

In the case of liquid oxygen explosives the oxygen is supplied in liquid form, and the combustible materials are cellulosic, rich in carbon and containing about 40 per cent of oxygen in the molecule and quite harmless.

This explosive has not only been applied to blasting the hard and highly fissured (gneiss) rock at the quarries but also to decomposed rock and earth in the dam line excavations. The last of these is particularly interesting as from records it appears that blasting clay or earth is seldom if ever done in India. It has been extensively adopted in Germany mainly on account of the speed of removing the broken earth.

The blasting of boulders has been fairly extensive during the past year. In one case of a boulder obstructing the construction of a roadway, this blast was interesting because 17 small holes were blasted simultaneously with L.O.X. using an electric exploder.

Advantages of L.O.X.—Some of the advantages of liquid oxygen explosives have been noted already, e.g., it is not an explosive until the inert cartridges and the liquid oxygen are brought together and closely confined, that neither the liquid oxygen nor the cartridges themselves are in any way dangerous. They cannot be stolen and used for purposes other than that for which they are intended. Detonators are not essential, specially constructed magazines are not necessary and, what is perhaps of the greatest importance, there can be no danger from a misfire. Directly the oxygen has evaporated there is no explosive left, simply a harmless mixture of cellulosic materials.

Other advantages may be grouped under the heading 'Efficiency.'

Liquid oxygen is considered cheaper per ton of rock broken than any other high explosive, apart from the fact that detonators are not necessary and the cost of constructing and policing magazines is avoided.

Decomposed rock presents a difficulty in that it is generally too hard to pick by hand and too soft or elastic to blast successfully.

The efficiency of liquid oxygen has been proved but its greatest value is in its safety which cannot be measured in terms of money.

CHAPTER XXI

Supply of Cement and Construction of Railway.

The reader may reasonably ask why he has been expected to wade through so many pages relating to subsidiary matters before coming to the actual construction of the dam. It is felt that unless the various materials and their sources and means of supply are first described he may be unable to appreciate the means by which the construction was actually carried out. For this reason only it has seemed expedient to describe those items first.

There are yet many important items which had to be provided for before the final revised estimate for the project, submitted in 1928, could be prepared. Let us first return to the question of the supply of cement. As soon as it had been agreed that cement should be used in place of lime for the construction of the dam the means of supply had to be considered. Hitherto, all materials which had to be imported to the work site were conveyed by road from Erode junction, though, early in 1926, various proposals for the construction of a tramway or a road from the nearest station on the South Indian Railway in the Salem district were under consideration. The question of collecting lime and the fuel for burning it first led to the proposal to construct a road from Thinnapatti, a station on the main line to the north of Salem which was to run via Mechcheri and Cholapadi where many of the lime deposits were situated, and an estimate amounting to Rs. 3 lakhs was prepared for this road. The Chief Engineer, however, considered that a tramway from Thinnapatti to Mettur would be preferable to a road since it would prove more convenient for the transport of heavy machinery direct to the works. Messrs. Martin Co. of Calcutta in June 1926 offered to construct a line and work it at their own cost, charging the project a flat rate of so much per ton of goods conveyed between these two stations, and actually made surveys for this and alternative routes. At the same time they offered to supply English cement for the works if it was later decided to use that material. Unfortunately for them, neither of these offers was found acceptable.

At about this time the residents of Mechcheri and other villages in the Omalur taluk, seeing that survey operations were being carried out, petitioned the Agent of the South Indian Railway to construct a line to connect their villages with Salem and this probably led to the Railway authorities asking the Superintending Engineer at Mettur for further particulars of the proposed line to Mettur.

In August 1926, the Agent asked what the extent of goods traffic was likely to be and the final route that was proposed. In reply, the Chief Engineer for Irrigation left the choice of the junction station and the question of the gauge to the railway authorities, suggesting at the same time that a light broad gauge line would be preferable to the 2-foot gauge line originally contemplated. He also gave a rough idea of the tonnage to be conveyed 9,000 tons in 1927, 17,000 tons in 1928 and 35,000 tons, 48,000 tons and 32,000 tons in 1929, 1930 and 1931, respectively. In October 1926 it was settled that the South Indian Railway should take up this construction as a broad gauge line and the company applied to their Home Board for sanction to survey the line. The survey of the line was sanctioned by the Board on 18th October 1926 as a broad gauge line from Salem junction and was to be known as Salem-Mettur Dam Railway.

The Executive Engineer, Stores and Tests Division, had recommended an alignment with the junction at Kadiambatti as it afforded easy grades for the line, a reduction of distance from Madras, easy accessibility to the Salem fuel reserves while its passage through the limestone area would reduce the leads from the quarries to the railway line. This line from Salem junction increased the leads from the fuel reserves by 50 to 100 per cent and the leads from the already investigated limestone quarries from 2 to 6 miles. But these objections were of no consequence as a little later the use of cement was decided upon for the construction of the dam.

The selection of the route was finally left to the Railway Company who desired that the line should form part of a permanent line to Dharmapuri, keeping the alignment as far north as possible.

Estimates amounting to Rs. 18 lakhs were then prepared by the South Indian Railway and sent to their Home Board for approval. The Railway Board asked the Madras Government to guarantee the income to be derived from this line on one of the following terms—either to take the whole line from Salem to Mettur Dam as a permanent line and guarantee an annual income of Rs. 65,000 or, making the Salem to Mechcheri line a permanent section and from Mechcheri to Mettur Dam a temporary assisted siding, in which case the Madras Government would be required to contribute 3½ lakhs of rupees (representing the cost of land and earthwork, culverts, etc., in the line) and to guarantee an annual income of Rs. 4,700 till the completion of the project or for a fixed period.

As such a guarantee was not originally contemplated, the Government asked the Chief Engineer to consider other means of transport such as the construction of a light railway as suggested by Messrs. Martin & Co., and the use of Erode-Mettur road only. The Chief Engineer was, however, in favour of a broad gauge line from Salem to Mettur, being of the opinion that we would have to handle 160,000 tons of cement, food-stuffs and machinery in 4 years and that if we decided on road transport we would require about 32 lorries of 5-ton capacity each, costing about 8 lakhs, 7 lakhs for running costs and 5 lakhs for road maintenance, thereby involving a total expenditure of about 20 lakhs. In addition, there was the risk of damaging heavy machinery and of cement being spoilt by rain while in transit from Erode. Considering these risks and the heavy labour and handling charges at Erode, it would, he contended, justify the payment of the cost of the whole line from Salem to Mettur. The siding from Mechcheri to Mettur could be removed after the completion of the project if no longer required, in which case the question of the permanent guarantee for this branch would not arise. The guarantee required for the branch from Salem to Mechcheri was of no concern to the project after the completion of the works at Mettur. He thought, therefore, that it was best to accept the offer of the South Indian Railway. It was finally agreed by the Government of Madras and the South Indian Railway Company to construct the Salem-Mechcheri portion as a permanent branch, with the guarantee from Madras Government for the line from Mechcheri to Mettur Dam as an assisted siding. The guarantee for the assisted siding was Rs. 41,000 annually, the contribution towards capital cost being Rs. 5·9 lakhs. It was also agreed that any excess earnings during the dam construction should be set off, after meeting the interest charges against subsequent deficit which would ordinarily have to be met by the guarantee. (G.O. No. 1422, Rly., dated 7th May 1929, gives the full correspondence on the subject.)

The construction of the line was put in hand by the South Indian Railway Company in February 1928, and would have been completed by the end of 1928, but for a strike on the railway. The line was opened for the conveyance of project goods on 14th February 1929 and for passenger traffic in April 1929. Public goods were carried only from July of that year.

It must be said that the Railway Company carried out this construction with great rapidity. The line, 26 miles in length, over rugged country with heavy cuttings and embankments, was completed within one year of its commencement, though a good deal of time had been lost in preliminary negotiations.

The advantages that this line afforded over road transport were very considerable. By the time the work on the dam was in full swing, trainloads of cement and machinery were arriving from Shahabad and Madras almost daily. The cement wagons arrived just as they had been loaded at the factory, no transhipment being required, and were unloaded with the greatest ease and despatch. A very large cement receiving shed was constructed and was designed so that the broad gauge wagons could be run straight into the shed and unloaded without risk during rains. Wide platforms for the unloading and storage of the cement were constructed on either side of the track at appropriate levels. On the outer sides of these platforms were laid the permanent 2-foot gauge tracks connecting the shed with all points on the works, so that cement could be re-loaded direct into 10-ton bogie wagons with the minimum of trouble. Outside the shed suitable cranes were provided for unloading heavy machinery from the broad gauge trucks and delivering it to trucks on the 2-foot gauge track in one operation, though it must be admitted that there were times when they could not cope with the volume of traffic, especially when the parts of the concreting towers and heavy crushers arrived in large consignments. At such times it became necessary to unload goods along the side of the track in order to release the wagons on which heavy demurrage charges would otherwise be incurred.

With the opening of the railway direct to Mettur Dam station, the transport of goods by carts and lorries from Erode junction was greatly reduced and the siding and goods sheds erected there, which had been of great service for 3 years or more, were eventually closed.

Train service.—When the passenger service between Salem and Mettur Dam was opened in February 1929, mixed trains were generally run, several wagons of cement being attached to the passenger trains. Two trains were run daily in each direction. Towards the end of the work the passenger service increased and three trains were run daily. During festivals, particularly the Adi festival, when large numbers of pilgrim bathe in the 'Sacred Cauvery,' special trains were run from Salem. Hitherto these pilgrims went mainly by road to Bhavani, but the attraction of the lake at Mettur and its easy approach by both rail and road led to this place becoming more popular each year, and its reputation as a bathing place is by now well established.

CHAPTER XXII.

THE TRAMWAY SYSTEM AT HEADWORKS

WHILE THE railway from Salem was under construction, the tramway system at Mettur was being steadily developed. For the handling of the large quantities of materials of all descriptions at headworks it will be realized that a vast tramway system was required, and, as the work advanced, it was frequently necessary to change or extend the temporary feeder line to the various parts of the work to suit the changing conditions. The system was therefore divided into two parts, one, in which the lines remained permanent and undisturbed throughout the period of construction, and the other which was subject to changes of alignment and extension. The well-designed permanent tramways ensured efficient running of trains at all times and the original layout underwent but few minor changes and improvements, generally in the shape of additional loops or sidings to facilitate the handling of trains as the traffic became heavier. With the extension of quarry operations over a large area, numerous extensions and sidings of a temporary nature became necessary. Twenty-four pound rails were used throughout the system. Jungle wood sleepers, much used in the earlier years of the project later gave place to steel-trough sleepers of heavy pattern as it was found that the ravages of white-ants and rot did not justify their continuance, particularly in those sections where the shifting of the lines was necessarily frequent. Creosote, while delaying the deterioration, did not entirely prevent rot, some of the softer species of timber having but a short life under any conditions.

It is scarcely within the scope of this work to describe the tramway layout in detail. Briefly, we may say that with the workshops, loco sheds and wagon repair sheds just in rear of the dam as the centre, the lines radiated in all directions; to the quarries, where innumerable sidings enabled trucks to be taken right up to the workings, thus reducing the lead by head-loads to a minimum and admitting of several rakes of trucks being loaded at one time; to the sand dumps, and to the railway station. The double track laid over the Cauvery bridge continued up a gradient on the steep side of the Chettamalai hills which necessitated the provision of a reversing station about half way up, thence through a cutting at the top of the hill and over the surplus escape bridge at Ellis Saddle to the railway station. Before the construction of the bridge over the escape the line ran up the valley at the left flank of the dam, but as this alignment eventually interfered with the construction of the dam at that flank it had, of course, to be diverted to the new alignment up the hill already described.

All lines were inter-connected so that materials of whatever kind and from whatever source could be conveyed by rail to all parts of the dam from the river banks to the extreme flanks. As the height of the dam increased, many diversions and extensions became necessary. Where the methods of construction admitted, particularly on the right side of the river, trains drawn by locos could actually run along the ledges on the dam itself, delivering the materials where the work was actually in progress and so saving much hoisting by other means. In all, above 60 miles of tramways at one time existed at the headworks.

Locos and Rolling Stock employed.

For the conveyance of materials at a speed necessary to maintain a high output the earlier estimates of the number of locos and trucks required proved quite insufficient. It may be taken that, for every loco employed, about three complete rakes of trucks were needed, with a margin of trucks on the sick list undergoing repairs or general overhaul. If this proportion were not maintained it meant that some locos at least would be standing idle while trains were being loaded or unloaded. It was always arranged. therefore, that while one loaded rake was being hauled from, for instance, a quarry to the dam, another rake would be loading so that by the time the train returned empty the next rake was ready for despatch. By this means—and it may be stated that it needed a lot of organization—the rate of supply was very steadily maintained.

Particulars of the locos and various types of trucks employed on the work will be found in Appendix C.

The first two locos to be brought to the project were old and of the usual horizontal type, but these were not found particularly suitable for this class of work where pretty stiff gradients had to be negotiated. A few new Sentinel locomotives with vertical high pressure boilers and chain driven by vertical high speed engines were received from England shortly after the work started and these proved so efficient, both from haulage and fuel consumption points of view, that several repeat orders for this type of loco were placed. Ultimately some 38 Super-Sentinel locos were at work. Being all of one pattern, parts were inter-changeable and their maintenance in perfect running order was thus rendered comparatively simple, while the stock of spare parts was not heavy. When sufficient numbers of these locos became available, the old horizontal type were sold and were for sometime used by a contractor on the canal construction works where conditions were more favourable for their use.

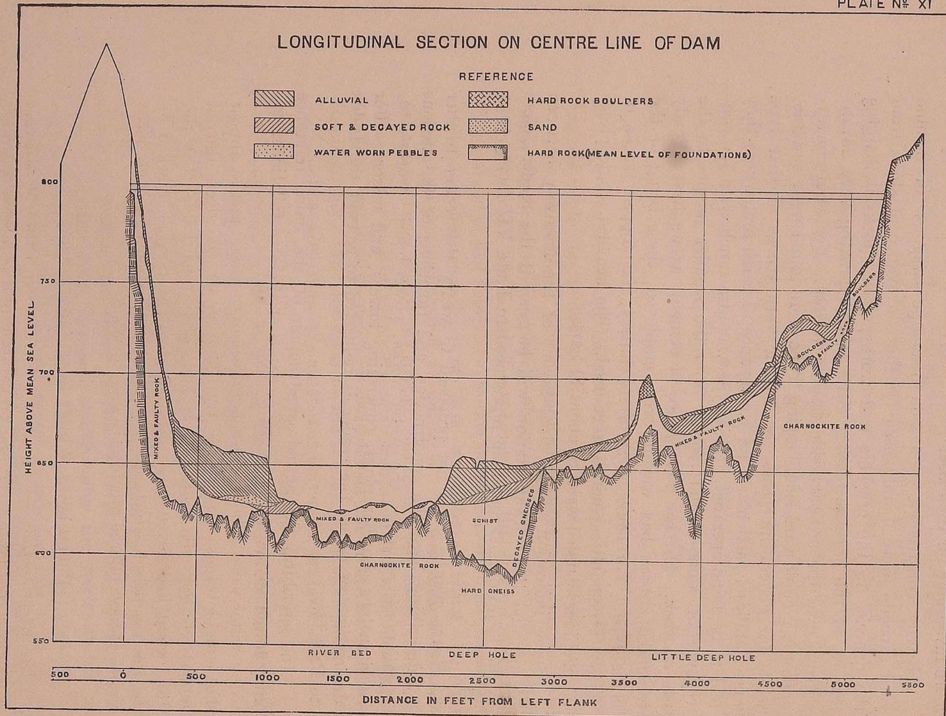
Heavily constructed steel side discharge wagons of 3-cubic yard capacity were mainly used for the conveyance of stone from the quarries to the crushers and works, their quick discharging feature, at the expense of very little labour, proving very advantageous over the ordinary side tipping variety. For sand conveyance the 2 cubic yard side Tipping Type were found most suitable, while for general purposes the 1 cubic yard trucks of that type were handiest, particularly for conveyance of earth and where they had to be hand-operated. This type was also much used for conveyance of concrete and mortar from the smaller mixers to the site of work. For the conveyance of cement, as we have already remarked, 10-ton box wagons were employed, these being of the bogie type. For conveyance of machinery, flat topped trucks of various types and capacities were used. The heaviest single pieces of machinery carried weighed about 14 tons.

Some indication of the final layout of the tramway between Mettur and the railway station will be seen if the reader refers to the headworks layout map reproduced in Plate VII facing page 31.

Heavy plant.—It is not proposed to weary the reader further by describing here the construction and functions of the various installations, such as, the water-works, power-house, workshops, surki factory, crusher plant, concreting towers, and mixers. For descriptions of these, the reader is requested to consult the Index to Part II.

In describing the actual construction of the dam, reference may frequently be made to one or other of these installations.

PLATE No. XI



LONGITUDINAL SECTION OF DAM LINE FOUNDATIONS.

CHAPTER XXIII

Foundations of Dam described.

In Chapter VIII, we had reached the preliminary stage of the examination and opening up of the foundations on the dam line. Let us now proceed to describe the further progress of this work.

The physical features of the dam line are clearly indicated in Plate XI, where the reader can see for himself the classes and depths of sand, soil and rock of different kinds discovered both by boring and actual excavation. The most noticeable features are, starting from the left flank; (1) the steepness of the hill at the left flank, (2) the great depth of hard alluvial soil overlying the rock between 300′ and 1,000′, (3) the depth of faulty rocks overlying the charnockite in the river bed between 1,000′ and 2,200′ (4) the 'Deep Hole' between 2,300′ and 2,800′ with its mass of alluvium overlying a very deep band of schist, all of which had to be removed before the hard gneiss was encountered some 50 to 60 feet below the original ground level, (5) the hillock, popularly known as "Hill 60" at 3,600 ft. from the top of which a large quantity of fissured or otherwise faulty rock had to be removed, (6) the "Little Deep Hole" at 4,000 ft., the existence of which was never suspected by the geologists, but which involved heavy excavation to a depth of nearly 70 feet, (7) a somewhat smaller depression at 4,300 ft. and (8) the boulders and faulty rock overlying the excellent charnockite rock between about 4,600′ and the right flank at 5,300 ft. The hard rock shown in the section is at the mean level of the actual foundations at any cross-section.

It is interesting to observe that in the dim past the river must have flowed nearer the left flank than it does at present, for a bed of water-worn pebbles extends for a length of 600 feet at almost the same level as the present river-bed, under the deep alluvial deposit on the left bank. It is somewhat remarkable that the ancient bed never apparently occupied the position marked by the deep band of schist on the right bank which, for ages past, could not have offered much resistance to scour.

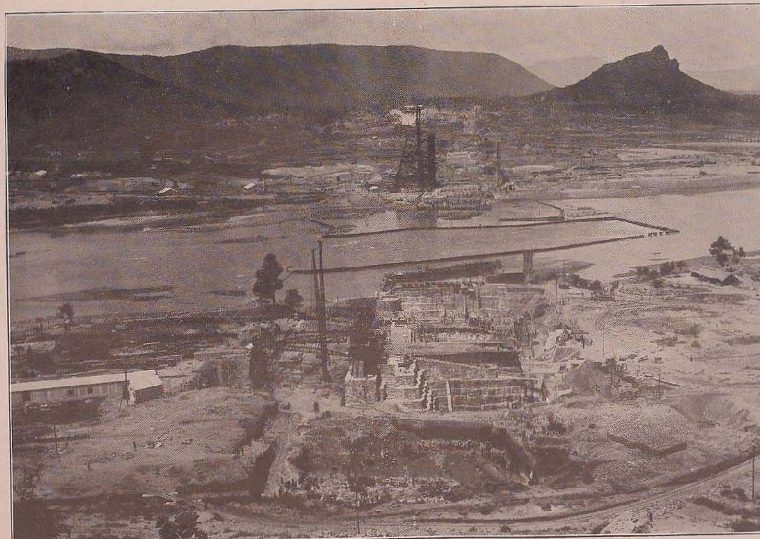
Preliminary Works in the river-bed.

The River section.—As is always the case with the construction of a dam across large river, the preparation of a careful programme of work in the river-bed section was a matter for first consideration, the annual working season in that section being limited to the low water period when the occurrence of freshes is least likely to interfere with the work.

Though there is always the element of uncertainty as to the date by which monsoon floods will subside sufficiently to admit of work in the river-bed, it was estimated that lowest water level would occur about the middle of February and would continue low till at least the middle of May. The programme of work in the river-bed was accordingly prepared on that assumption.

River diversion.—The river-bed at the dam site is approximately 1,200 ft. in width and in order that work should proceed in the river-bed as rapidly as possible during the brief low water period, concrete coffer-dams were to be constructed so as to divide the river-bed into three main sections, the summer flow being diverted to flow through any one of these sections while excavation for foundations of the dam proceeded in the other two.

A detailed survey of the river-bed extending above and below the actual site of the dam was accordingly made, and the alignment of the coffer-dam walls was selected so as to utilize as far as possible the highest rocky outcrops, avoiding deep faults and depressions which might involve heavy bunding and pumping in order to reach safe foundations for the coffer-dam walls, and so delay their construction. Plate XII gives some idea of the actual layout adopted. Sand and shingle available on the spot was selected and hand-mixed with cement to constitute a cheap and very suitable concrete for the purpose, and the coffer-dam walls, both transverse and longitudinal, were constructed from both flanks with the use of simple wooden-box forms. Vents from 6′ to 10′ in width, provided with grooves into which steel shutters could be fitted, were located at all places in the upstream and downstream walls where the rock level was lowest so that the normal dry weather flow of 1,000 cusecs or so could be passed through any one of the three sections without risk of endangering work in those where excavation of the foundations for the main dam would be in progress. The construction of the coffer-dams commenced during the low water season in 1926 and in 1927, with the aid of a few small petrol engine-driven pumps to keep down the water in successive small sections, the work made rapid progress and was sufficiently far advanced by the time the floods arrived to enable work to be started on excavation of the foundations of the main dam in the right and left flank coffer-dams early in the following dry season. It was essential that the work during that season should be concentrated at the flanks in order that the masonry should rise sufficiently high to exclude flood water from the excavations on the banks. The main feature of the work during 1928, the first construction season, was therefore the building of two masses of masonry to form bulk heads, earthwork ring bunds with stone pitched outer faces being formed in extension to prevent the out-flanking of the excavations on either bank,



ARRANGEMENT OF COFFER-DAMS.

where suitable sites for the erection of the two large concreting towers required the very early construction of short sections of the dam up to tower track level.

On the right flank, the comparatively high level of the rock from L.S. 1,900 to 2,300 simplified the work, but on the left bank the rock was lower and an erection site further from the river had to be selected where work could proceed without risk of the excavation being flooded, the construction of the bulk head on that flank having been delayed by the necessity of taking the foundations much deeper than was originally contemplated.

On the right bank, immediately to the west of the tower site, borings and excavations revealed a very deep and extensive fault extending from about L.S. 2,300 as far as L.S. 2,850′ where the rock level again rose sharply. It was evident that the excavation of foundations in this reach would be a long and arduous business and, while the foundation work in the river-bed continued apace during the dry season, work was concentrated in this heavy excavation, popularly known as the ' Deep hole ' during the flood season of 1927 and throughout the two following years. In portions of this reach excavation of decayed rock and boulders continued down as far as 75 feet below ground level before sound rock was reached, 40′ to 50′ below river-bed level. The work in this reach was seriously delayed when on the night of April 24th, 1929, there occurred a very severe storm with 7·63″ of rain, recorded at the Mettur Observatory in about 2¾ hours. This storm occasioned a sudden rise in the river and the water overtopped and breached the ring bund on the upstream side of the right bank bulk-head and flooded the excavation in the deep hole to a depth of nearly 50 ft. All the electric pumps in this excavation were submerged and put out of action. Every available pump was requisitioned from other parts of the work but it was about two months before work could be resumed there. Here, indeed, was an illustration of the grave uncertainty of flow in the river even at a season when all previous records showed that no sudden rise might be expected. The coffer-dams referred to above, provided with shuttered vents were originally intended to divide the river-bed into two sections, diverting the dry weather flow through one while excavation proceeded in the other, but, since it was necessary that the walls should follow the line of the higher rocks in the river-bed, an equal division was not practicable and the right hand portion was found to be incapable of carrying the whole flow without the risk of the walls being frequently overtopped. A third section was therefore opened on the left side, the bed thus being divided into three compartments, referred to hereafter as the right, central and left coffer-dams (as viewed when looking downstream). In view of the various alterations which took place in successive years from 1926 to 1929 the history of these coffer-dams is described in Part II, Chapter XVI, with a brief description of the construction, operation and closure of the construction sluices which played an important part during the earlier years of construction in the river-bed section.

Since the greatest section of a dam usually occurs in or near the bed of the river which it crosses, it is essential that work of excavation followed by rapid construction should take place there. Only about half the year is available for that work, while the whole year is available for work in other parts of the dam. Thus, on the construction of the Mettur Dam the river section received the greatest attention, and many were the difficulties which had to be met and overcome, the greatest being due to the occurrence of untimely floods. The sudden flood of April 1929, for instance, completely filled one of the coffer-dams and excavations for the dam foundations with sand, some four million cubic feet of sand having to be removed before work could be resumed. This sand, however, came as an unexpected gift, for it was all used up on the construction shortly after and saved us the trouble and expense of bringing it in from more distant places. Thus do troubles have their compensations !

PLATE No. XIII.

PROGRESS IN EXCAVATION OF FOUNDATIONS.

CHAPTER XXIV

Excavation of Foundations.

Let us now follow the work of excavating the foundations for the dam. We have seen from the sectional diagram of the site (Plate XI) that there were several places on the line where vast quantities of material had to be removed before sound rock was reached. Early in 1928, apart from the urgent work in the river-bed, excavation was started on the ' deep hole ' on the right bank and at several other points nearer the right flank. The left bank, being more or less inaccessible at that time had barely been touched. Labour had by now begun to pour in and rapid progress was made. Between January 1928 and April 1929 the rate of excavation was greater than during any other period. During November 1928 alone, nearly two million cubic feet of earth and rock were removed from the foundations.

Where the sound rock occurred at a high level and the excavations were comparatively shallow no special means were provided for lifting the spoil and it was done entirely by manual labour, the coolies carrying the spoil up ramps by head loads and depositing it direct either upstream or downstream of the dam line or dumping it into trucks for conveyance to more distant places where material was required for preparing embankments for tramways or filling up depressions. In the case of the deep excavations, such as, the ' Deep Hole ' and ' Little Deep Hole ' to which we have already referred, every conceivable means was employed to excavate and dispose of the spoil rapidly. Trains were run down ramps which circled around the ' deep hole ' and every available crane, perched on the brink of the vertical cutting was commissioned to lift truck loads of earth bodily and deliver them on rails at ground level, with a lift of perhaps 60 to 70 feet. When the rock to be removed was hard, blasting operations took place regularly every day often in the early morning before the labour arrived on the work, at midday when the coolies left for their meals, and always in the evening after labour had knocked off. In cleaning foundations preparatory to receiving concrete or masonry, work was sometimes carried on through the night with the aid of flood lights suspended above the excavations on wires stretched across at ground level, but night work was avoided as far as possible.

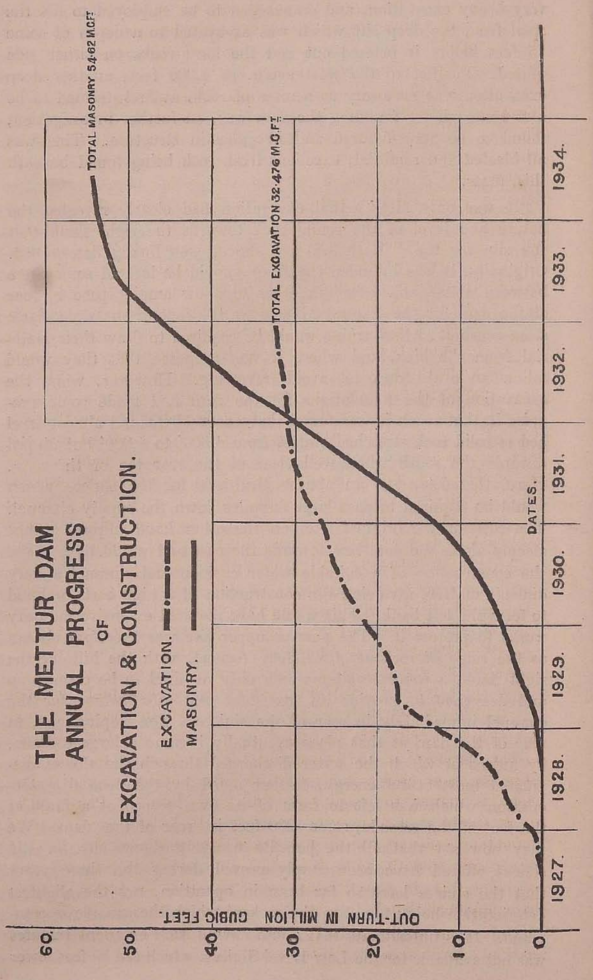
During 1928, work was concentrated at those places where the two great concreting towers, which had already been ordered, were to be erected, and where they would start concreting operations.

It was decided to erect one of these near the right bank 2,200 feet from the left flank. At that place fairly sound rock had been located almost at ground level. So the site was cleared and prepared for constructing the masonry required for the support of the tower during erection. Similar foundations were prepared for the second concreting tower on the left bank of the river early in 1929, so that by the time the component parts of those machines had arrived at site the masonry was ready to enable erection to be put in hand without delay.

Rock occurred near the surface at another point on the dam line which came to be known as 'Vellore Station'—presumably because the arched construction of the rear ledge which formed the track for the concreting tower somewhat resembled that station—and as the old road to Samballi and villages further north crossed the dam line near that place the foundations were excavated and replaced by masonry up to ground level so that traffic could be maintained over it without interruption while the exacavation on either side proceeded. This crossing soon became one of the main tramway tracks by which sand, collected from the shoals higher up the river, was conveyed by train to the dumps on the south side of the dam, and was retained as a 'pass' through the dam for the conveyance of stone from the quarries when the masonry had reached a much higher level (see Plate XXIII). The road, meanwhile, was diverted towards the right flank and crossed the dam line at a point where no intensive excavation had yet been started. Next in importance and urgency was the site for the low level sluices which were to pierce the dam between 3,720′ and 3,860′ on the longitudinal section. The level at which the cills of these sluices were to be constructed was still somewhat uncertain, for it appeared that the level of + 665 originally proposed would involve very heavy cutting in solid rock, besides the lowering of the ground in front to form a suitable approach channel. Then, the site for the four great hydro-electric pipes which, during the earlier part of the construction were to serve as additional construction sluices, received attention and excavation of foundations at both these sites was pushed forward. When the excavation work in all the coffer-dams in the river-bed was at last completed and masonry works there had been started, labour was released for work elsewhere and the other less important sections of the dam line in point of urgency were opened up. Some heavy excavation was found necessary on the left bank of the river where the rock was very defective for some depth and, as in the river section, required to be taken down much deeper than had originally been indicated by borings. The work here was difficult and slow so that there was some delay in bringing the masonry up to the desired level before the 1929 floods arrived. Again, to the west of the low-level sluice site, the "Little Deep Hole" involved very heavy excavation, and cranes had to be employed to lift the spoil from the deep rift which was excavated to a depth of some 75 feet before it petered out and the hard rocks on either side united. Further to the west again, at 4,300 feet, another deep excavation was necessary as a mass of rock, at first deemed to be sound enough for founding the dam was, on further investigation, found to be very fissured and irregular in structure. This was all blasted and removed, excellent fresh rock being found beneath this mass.

It was only after actual excavation had clearly revealed the nature and level of the sound rock towards the right flank that the site for the "High Level" sluices was finally determined. Originally, it was intended that they should be located somewhere between 4,400′ and 4,600′ in order to allow ample space in rear of the dam for the tramway layout at the foot of the right flank stone-crushers, where trains would be required to draw their material from the bins, and where it was proposed that they would follow an oval track to avoid reversing. However, when the excavation of the foundations for the dam had made some progress in that reach it was found that an excellent and almost level bed of solid rock stretched almost from 4,600′ to 4,900′ but dipped towards the south when well clear of the rear toe of the dam. Here, therefore, was an almost ideal site for the sluices which would be required to pass large supplies down the supply channel. The rock at the original site, on the other hand, dipped rather steeply along the dam line towards the east and would have made the construction of a suitable water cushion and channel a very difficult matter, involving the construction of a high earthen bund to form the left bank. This would have required extensive masonry works to protect it. The new or upper site was therefore chosen as the ridge of rock at 4,600 feet formed, with the hill at the right flank, a natural valley which only required to be opened up and deepened to provide an excellent and safe course for the channel immediately in rear of the sluices. The sloping rock in rear of the dam at that place eventually became a large cascade, by means of which the water discharged through the sluices dissipated most of its energy, further aided by the natural water-cushion which was left to form of its own accord at a fault at the foot of the cascade, some 200 feet in rear of the dam. We may now say that all the benefits which the new site for the sluices offered have been amply proved during the three years that the sluices have so far been in operation, not the slightest deterioration being found in the rock of which the cascade is composed. It is unfortunate that a site having such excellent features was not available for the Low Level Sluices, which are 50 feet lower

PLATE No. XIV.


THE METTUR DAM
ANNUAL PROGRESS
OF
EXCAVATION & CONSTRUCTION.
EXCAVATION.
MASONRY.
TOTAL MASONRY 54·62 M.C.FT.
TOTAL EXCAVATION 32·476 M.C.FT.
DATES.
1927.
1928.
1929.
1930.
1931.
1932.
1933.
1934.
OUT-TURN IN MILLION CUBIC FEET.
0
10
20
30
40
50
60

than the high level sluices. There, the enormous energy stored in the water issuing from the sluices has to be dissipated by other means, involving very considerable expense. But this matter will be discussed in its appropriate place.

Thus the excavation of foundations went on side by side with the more urgent portions of the construction from 1928 to 1932. The last portion of the excavation was at the extreme left flank where the work had been postponed to admit of tramway communications being maintained as long as possible between the left flank quarries and the railway station and the concreting tower on the left bank. This tramway cut across the flank of the dam and prevented much progress in the preparation of foundations there. It was only when a very deep rock cutting had been completed through the Chettamalais for the diversion of the tramway that the site could be entirely released for excavation. In consequence, the rest of the dam had reached a considerable height before the foundations at the extreme left flank were even started. The rock there was of an unsatisfactory nature and a great deal more excavation was found necessary than had originally been contemplated. It was stratified and dipped steeply into the side of the hill, so that when the cutting had to be extended into the flank to reach sufficiently sound rock, enormous quantities of overburden had to be removed, necessitating an almost vertical cutting, with but one ledge, nearly 160 feet in height. Had it been realized that this work was going to prove so heavy, there is no doubt that it would have been taken up and completed much earlier for, in actual fact, it caused a great deal of anxiety and, at the beginning of the 1932 flood season which commenced rather earlier than usual, the position was such that the construction was very nearly out-flanked by the rising water and only by the most strenuous efforts of the entire headworks staff with all their resources was this prevented. Thereafter, the work of excavations at this flank was pushed through, working day and night without ceasing, till the foundations were secured and the masonry raised to a safe level above the highest flood to be expected that year.

The progress in the excavation of foundations for the dam cannot be more clearly indicated than in a progress diagram. The reader is invited to inspect the diagram given in Plate XIV, which shows at a glance the progress both in the excavation of foundations and in the masonry and concrete construction. It will be seen that the total excavation amounted to nearly 32½ million cubic feet, or considerably more than half the entire bulk of the completed dam!

Only from about December 1927 was any real progress made, but from then till April 1929 progress was very rapid. Thereafter it continued steadily but at a lower rate till about the middle of 1931, after which only the work at the left flank remained. All excavation was completed by the end of 1932. The actual monthly outturn figures will be found in the table given in Appendix D. The reader may be somewhat surprised to observe that the excavation of the foundation actually occupied about 5 years while the entire construction took only six years, but it is to be remembered that the dam is a mile in length and that, in the deeper portions, the excavation of a trench nearly 200 feet in width and 50 to 75 feet in depth was required, only the top soil was earth of a soft nature, the whole of the remainder being of rock in various stages of decomposition, often containing large boulders. Thus the bulk of the excavation had to be done with the aid of pneumatic picks, where the rock admitted of their use, and by drilling and blasting elsewhere. It is further to be realized that in a dam of this length the earlier work has to be concentrated in those reaches where the section of the dam will be greatest, the shallow portions and the flanks being left till their excavation becomes necessary. Had the excavation proceeded throughout the entire length at one time, the amount of labour and tools required would have been several times greater than was really necessary and would have added enormously to the cost. By judicious distribution of the labour and machines progress was made in the different reaches exactly as required to enable the masonry work to proceed at a uniform rate. Each season's programme was completely worked out in advance and it is extraordinary how very nearly the progress of work adhered to that programme.

CHAPTER XXV

The Construction of the Dam—Early Methods compared.

Before proceeding to attempt to describe the actual construction of the dam it is necessary to acquaint the reader with the more salient features of the dam as redesigned. The revised estimate of 1928 not only provided for the use of cement in place of lime, thereby admitting of a considerably accelerated programme of construction, but also provided for the many modifications in design which the 1924 floods had shewn to be necessary, involving the entire redesign of the irrigation and surplus sluices and the use of machinery on a large scale. The design of the dam itself underwent some modification in view of the adoption of a higher specific gravity for the masonry and concrete than had previously been allowed, and the top of the dam was entirely redesigned to admit of the use of Goliath cranes for the operation of emergency gates at the sluices without obstructing the roadway. The arched projections to produce the required clear width of roadway were retained, but were provided on both the upstream and downstream sides, though later in actual construction, these arches gave way to another form of construction. Making provision for all these changes, the revised 1928 Project Estimate amounted to Rs. 737·08 lakhs. It provided also for certain modifications in the Canal System including the realignment of a portion of the Main Canal. The estimated net revenue from the Project became Rs. 55,53,967 or 6·31 per cent on the sum at charge.

The dam, as redesigned to satisfy all the conditions enumerated, has the following main features :—

The 16-feet roadway over the top of the dam is at +801·0, the tops of the parapets being 3½ feet higher, at +804·5. The dam is designed for a full reservoir level of +790·0 and a maximum water level of +796·0, which may, however, be exceeded by another 2½ feet, since the later provision of the emergency surplus escape at the right flank safeguards the dam even with water standing at that level. The design provides for a further raising of the masonry by ten feet at some distant date to compensate for the loss of capacity of the reservoir through silting, so is of more than ample strength and stability to meet the worst possible conditions that may ever be encountered.

The cills of the main surplus sluices at Ellis Saddle are at +770·0, allowing a depth of no less than 26 feet over their cills with water in the reservoir standing at " Maximum

Water level," while the surplus gates, being 20 feet in height, retain water up to "full reservoir level." A separate chapter will be devoted to a description of this work. (See Chapter XXXII.)

The dam is pierced by two sets of irrigation sluices and a set of large pipes for the generation of power. The high level sluices, eight in number and each 16 feet in height and 10½ feet in width have their cill levels at 720 or 50 feet below the surplus sluices. The low level sluices, five in number, each measuring 14 feet by 7 feet, have their cills at +670·0 or 50 feet below the high level sluices. The Hydro-electric pipes have a front cill level of +640, 15 feet only above the original river bed.

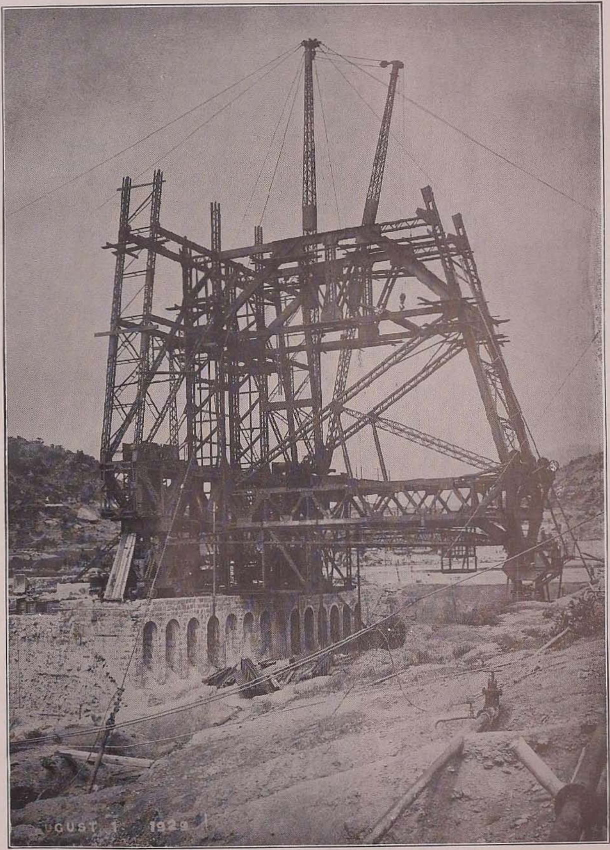
These sluices will all be described, as the construction work proceeds, since their erection is intimately connected with the masonry work.

The normal section of the dam adopted is clearly shewn in Plate No. IX and it is not necessary here to describe the section further. The rear toe of the dam below level +670 has a battar of 1 : 1, but in actual construction, for reasons explained in Chapter XVI, the toe in the deep foundations below +610 was cut off. The upstream toe was retained as indicated in the normal section throughout the length of the dam, except at the sluice sections where the section is modified to withstand the higher stresses caused by the introduction of the vents. The sections of the dam taken through the centres of the vents are illustrated in Plates XVIII, XIX and XX.

The first batch of concrete was laid over the rock at the right bank of the river, at about 2,100 feet from the left bank, in April 1928. At that time it may be remembered, it was intended that the entire dam, with the exception of the extreme flanks should be constructed of cement concrete, and with a view to speedy construction, steel shuttering was to be employed, the forms being designed in such a manner that the shuttering climbed as the pouring of concrete proceeded.

Before any of the steel shuttering was ready, however, about 200 feet of the rear portion of the dam had to be constructed to accommodate the first of the large concreting towers, so the concrete was retained between masonry retaining walls, the ledge, on which the front of the tower was to be supported, being constructed of masonry in the form of 6-feet semi-circular arches supported on 3-foot piers. These are clearly illustrated in Plate XV.

PLATE No. XV.



CONCRETING TOWER IN COURSE OF ERECTION.

The masonry face work was of roughly coursed rubble in cement mortar.

Prior to the completion of the tower erection when the number of concrete mixers intended for the preliminary works was limited, it was found expedient to do a considerable amount of construction in masonry. Various methods of combining concrete and masonry were tried in an endeavour to speed up construction using only the preliminary plant then available. In much of the early work in the foundations, therefore, we find such methods adopted. One method was to construct hexagonal masonry cells with walls built in random rubble, so that, seen in plan, the work resembled a gigantic honey-comb. Tramways were laid over the walls forming these cells and truck loads of concrete were run along these lines from the mixers and dumped in the cells. The concrete was rodded and consolidated by small gangs of coolies stationed in the cells. The walls were usually built in 6-foot stages. Hydraulic tests carried out on the concrete in these cells, however, indicated that the mixture was not sufficiently impervious, and it was suspected that surplus water in the concrete, released when it was consolidated, crept along the faces of the walls and created voids. This method was then discontinued in favour of parallel zigzag walls between which concrete was poured. Besides giving more working space for the men, this system admitted of more rapid progress and was generally adopted, but the hydraulic pressure tests on the concrete, as in all cases where 1 : 4 : 8 concrete was employed, were not entirely satisfactory. However, since the design of the dam provided only for impervious concrete in the front portion of the dam from a line 6 feet in front of the centre line, and the concrete in rear of that line was properly designed for strength only and was not intended to be water-tight, the results of these tests were more or less to be expected. It was only when solid random masonry was tested that a vast improvement in the hydraulic test results was apparent. Owing to the shortage of concrete mixers in the early stages of the work solid masonry construction was started in one reach near the Vellore station. Since masonry requires considerably less than 50 per cent of its volume of mortar, a concrete mixer employed for mixing mortar only could, in a given time, produce material for twice as much masonry as it could for concrete. So, where sufficient masons were available, the concrete mixers were far more profitably employed mixing mortar only. When the block of masonry had been allowed a few days to set hard, holes 16 to 20 feet deep were drilled in it at intervals, 'capped' with steel pipes and subjected to hydraulic tests to ascertain the rate of percolation in the masonry. Despite the fact that the stones were set in 'weak' mortar it was soon proved beyond all doubt that this class of masonry was highly resistant to water pressure, while concrete of an equivalent mix was, by the same tests, proved to be extremely porous, despite all efforts of certain officers who put their faith in concrete to improve its qualities in this respect. For purposes of comparing their densities, large test blocks of masonry and concrete were built in identical steel boxes. These were cured and dried out. On weighing them it was found that the random masonry was definitely denser than the concrete, being no less than 2 to 3 pounds per cubic foot heavier. Other things being equal, therefore, it is seen that masonry is definitely superior to concrete, using angular stone such as was produced by the crushers at Mettur as the matrix. It stands to reason that where stones of suitable shapes are selected and fitted together by hand so as to displace surplus mortar coming between them, the density must be higher than that of a mass of stones coming together at random as is the case with concrete, particulary where stone of unusually high density is employed. Thus, the dam was still in its early stages of construction when the substitution of masonry for concrete first received serious attention, and this method of construction came to be generally adopted in all those reaches where the concrete-placing plant could not be expected to work. A small concreting tower, fitted with chutes, was erected and employed for some time in placing concrete in the area where the 'Red' tower was to start operations, but later this small tower, known as the 'Mulshi' tower, was dismantled and re-erected elsewhere after conversion for use simply as a lift or elevator. In that capacity it did much useful work raising truck loads of mortar from a battery of mixers at ground level to a considerable height on the dam, a movable steel bridge being constructed to connect the top of the tower with the rear face of the dam, whence the mortar was delivered on rails at any desired spot and at any level.

The bulk of the material used for filling the "Deep Hole" was concrete, delivered by the 'Red Tower,' and it may here be appropriate to describe briefly the erection of this outstanding piece of machinery.

CHAPTER XXVI

Concreting Towers.

In April 1926, Mr. W. P. Roberts, then officer in charge of workshops and machinery, was deputed to England to ascertain from manufacturers in Europe and America the methods of concrete-placing in large dams and the various types of plant employed for such works. His investigations led to the consideration of the following alternative methods of dam construction :—

(1) Ropeways, with a continuous series of comparatively small tipping buckets for conveying both raw materials and mixed concrete to any point on the dam from the flanks.

(2) Cableways or cable-cranes each with a single travelling carriage to lift a large skip of concrete or block of stone.

These were to run from the flanks to the desired distance, dump their contents and return with the empty skip.

Both these methods were found unsuitable since the rate at which they could carry materials was far too low to ensure the required outturn. Further, the length of the dam prohibited the mixing of concrete at the flanks on account of the time required for the skips to reach their destination which was the centre of the dam some one mile away from the flanks. Also these methods involved the construction of a series of very high intermediate steel towers along the alignment which would have interfered with construction. It was calculated that with eight towers placed at about 800 feet intervals their height would have been as much as 450 feet, while if fewer towers were used the height would have been considerably greater. To obtain the required rate of feed of material for construction as programmed it was found that no less than 8 sets of cableways would have been needed, and their cost and maintenance would have been excessive. The only alternative therefor was to employ either travelling transporter cranes or travelling hoist towers with chutes, the concrete being mixed on the cranes themselves in the case of the latter.

After numerous designs had been submitted by firms, it was finally decided that the travelling hoist tower with chutes was the most suitable for the peculiar conditions obtaining at Mettur, and two such towers were ordered.

The two towers, designed and constructed by Messrs. Stothert and Pitt of Bath, England, are identical, so the description of one will suffice.

One of these, the " Black " tower was partially erected at the works at Bath, and while this was being dismantled the parts of the other, known as the "Red" tower, had already been despatched. By the beginning of 1929 the Red Tower parts had arrived at site, having been shipped by steamer to Madras and from there despatched direct by rail to Mettur Dam Station. Construction of this tower was immediately put in hand on the masonry which had already been prepared at L.S. 2,200 feet. A special party of European erectors was sent out from England by the firm, and these, aided by a gang of Mappillas who are skilled in heavy erection work, carried out the entire erection of the towers. By May 1929, the front and rear chasis of the Red tower had been erected. Plate No. XV shows the stage of erection on the 1st August 1929. By December of that year the tower had reached a height of 180 feet, and by March 1930 the erection was completed. Plate No. XVI shows the tower completed and with its chutes in working position on 3rd April 1930.

The erection and operation of these stupendous machines excited tremendous interest, not only amongst those connected with the work but also of the thousands of visitors who came long distances to see them. They were 306 feet in height above the rear rails, weighed some 1,800 tons each in working order, were operated entirely by electricity, and travelled under their own power at a speed of 10 to 12 feet per minute up and down gradients as steep as 1 in 36. When working or travelling on a gradient, the tower was kept truly vertical by an ingenious system of powerful jacks mounted on the two front bogies which, controlled by a single operator, could be operated while the tower was in motion.

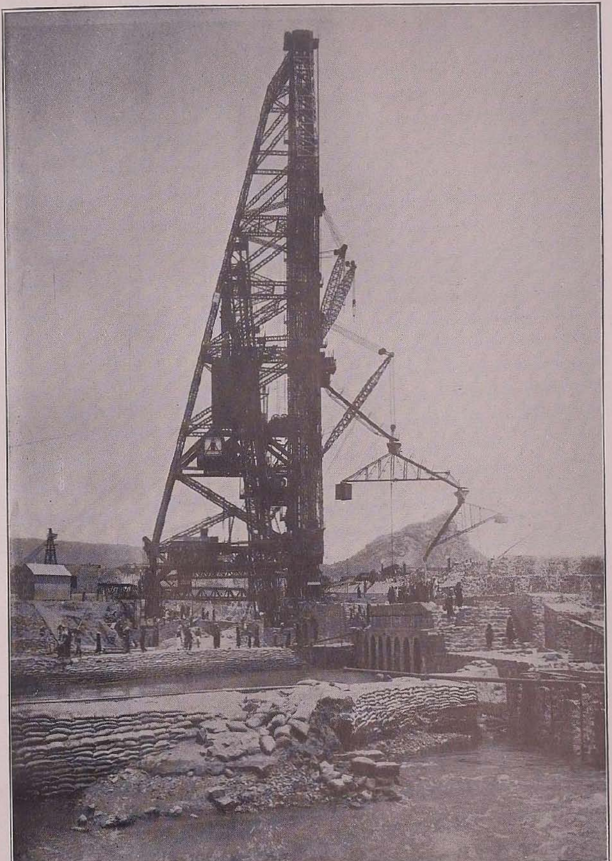
The amount of thought and ingenuity put into its design can scarcely be realized by anyone who did not actually see it in operation, and it is greatly to the credit of Messrs. Stothert and Pitt that both of these towers fulfilled their duties without the slightest trouble. One or two minor breakdowns did occur during the course of the work, but these had nothing to do with either their design or workmanship, being occasioned by other causes. On the night of the 22nd May 1931, a terrific storm caused the chutes of the Red tower to break away from their anchorages and they were partially wrecked. They were, however, quickly reconstructed in the local workshops.

On another occasion rats were responsible for a burnt out armature in the rotary converter on one of the machines.

For a more detailed description of these towers, the reader is referred to Part II, Chapter X.

Power Supply.

The power required for the entire plant at Mettur amounted to 3,400 K.W. and the towers and crushers alone accounted for over two-thirds of this quantity. To generate this electricity by



CONCRETING TOWER COMPLETED.

means of a local thermal station called for installation of special plant. Proposals were drawn up for the purchase and installation of machinery costing Rs. 15 lakhs. Two small Diesel electric sets each with an output of 125 K.V.A. were installed as an initial step and details for the larger plant were still under scrutiny, when, in November 1927, the Mysore Government offered to undertake the bulk supply of electricity from their Sivasamudram Power station.

In December of that year, Mr. L. Henshaw, then Executive Engineer in charge of workshops and machinery division, was deputed by the Engineer-in-Chief (Mr. Mullings) to visit Mysore, to discuss the question with the Diwan and the Chief Engineer (Electricity) Mysore, and to submit his definite recommendations on their proposal. The report of that officer when received showed that by arranging for the power supply from Sivasamudram, an outlay of over Rs. 14 lakhs on the plant could be saved which meant an annual saving of Rs. 84.000 on interest charges. As regards the rate at which power was to be supplied by the Mysore Government, it was evident that the rates proposed were less than half of that which would be possible by the generation of electric power at a local thermal station. The offer was therefore accepted and a preliminary agreement on 14th January 1928 between the Engineer-in-Chief and the Chief Engineer (Electricity) Mysore was followed by a formal final agreement in July 1928. The provisions of this agreement may be of interest and are reproduced below.

Agreement.

1. *Agreement.*—Agreement made this day of 1928, between the Government of Mysore of the one part and the Government of Madras of the other part whereby it is agreed as follows.

2. *Conditions of supply.*—The Government of Mysore shall supply at the receiving station situated in the Mettur dam works electrical energy in the form of a three-phase alternating current at a pressure of (3,300) three thousand three hundred volts across phases and a frequency of fifty cycles per second and the supply shall be available continuously throughout the whole period of the agreement. The power will be transmitted to Mettur over a duplicate circuit transmission line and there stepped down by means of three 22,000 K.V.A. three-phase transformers with a fourth transformer as a spare. The power will be converted from 25 cycles to 50 cycles by means of three motor generator sets each of not less than 1,500 K.V.A. output.

3. *Receiving station at Mettur and its equipment.*—The Government of Madras shall permit the Government of Mysore to occupy free of charge four 20 feet bays for the full width of the building in the existing Power House at Mettur or such other accommodation in and adjacent to the Power House as may be found necessary and agreed upon between the parties together with necessary space outside of the building for the dead-end structure and lightning arrester installation.

4. *Responsibility for Mysore Government's apparatus at Mettur.*—The Government of Madras shall be responsible to the Government of Mysore for the safe custody of all the Mysore Government's apparatus at Mettur and in the event of loss by theft or damage by fire (except fire originating in the property of the Government of Mysore) shall replace or repair the apparatus lost or damaged.

5. *Accommodation for operating establishment at Mettur.*—The Government of Madras shall provide at Mettur and to the standard provided for Madras Government servants of similar status free unfurnished housing, water, sanitation and electric lighting for the Mysore Government operating establishment for the duration of supply and during the construction period.

6. *Compensation or royalty for works on Government land.*—The Mysore Government is not to be charged by Madras Government compensation or royalty in any shape or form on account of their works on Government land within the Madras Territory.

7. *Maximum demand.*—The average demand of 2,040 K.W. approximately at or above 0·75 power factor shall be available normally for 12 hours per day but after 12 hours telephone notice this power shall be available for 24 hours per day. The normal night power requirements will be available without notice. The telephone line necessary for this purpose shall be put up and maintained by the Mysore Government.

The normal peak load shall not exeed 3,500 K.W. at or above 0·8 power factor.

8. *Commencement of supply.*—A partial supply of 750 K.W. shall be available by 14th November 1928, i.e., $9\frac{1}{2}$ months from the 30th January 1928, i.e., the date of preliminary acceptance of the agreement; full supply shall be available within four months from the commencement of the above partial supply. No penalty shall be incurred if the supply is not ready on these dates by reason of causes beyond the control of Mysore Government.

9. *Transmission line.*—The factor of safety of all portions of the transmission line shall be at least two under all conditions, the maximum wind pressure being 10 lb. per square foot with

an addition of 10 per cent for every 1,000 feet of elevation above sea level and shall be according to Mysore Government standard practice.

10. *Meters.*—The energy supplied shall be measured by means of three similar three-phase meters which shall be supplied and maintained by the Mysore Government; the Madras Government shall pay the full cost of supplying and maintaining two of these meters; each three-phase meter shall be complete with a separate set of current and potential transformers. The meters shall be read monthly and the consumption shall be taken to be the average of the reading of the three meters but in the event of one of the said meters varying more than 2·5 per cent from the average of the other two meters the mean between these two shall be taken; if only one meter shall be considered accurate then the reading of that one shall be acted upon; and if all three meters are manifestly inaccurate then the charges for the period of time in question shall be a just charge having regard to the average of prior periods and the circumstances of the case.

11. *Accuracy and testing of meters.*—Should any dispute arise between the parties to this agreement as to the accuracy of the readings obtained under the preceding clause either party may upon giving notice to the other have one or all the meters tested by the Professor of Electrical Technology of the Indian Institute of Science and if upon these tests being made the inaccuracy is found to be more than two and a half per cent the Mysore Government's accounts shall be adjusted as may be required. Should the inaccuracy prove to be less than two and a half per cent no adjustment shall be made. The expenses of such testing shall be borne by the Mysore Government in the event of the account requiring adjustment but if no adjustment follows then the expenses shall be borne by the party at whose instance the test is made.

12. *Tariff.*—The Government of Madras shall take the energy and the charges for the energy supplied shall be according to the following sliding scale :—

(*a*) *Quantity of energy supplied in the month (Board of Trade units) supplied as per the next following clause:*—

	Rate per Board of Trade unit.	
	ANNA.	
Up to 374,999 units	0·750	per unit.
375,000 to 399,999 units	0·725	
400,000 to 424,999 ,, ...	0·700	
425,000 to 449,999 ,, ...	0·675	
450,000 to 474,999 ,, ...	0 650	
475,000 to 499,999 ,, ...	0·625	
500,000 to 524,999 ,, ...	0 600	
525,000 to 549,999 ,, ...	0·575	
550,000 and above	0·550	

(*b*) The rates in (*a*) above shall be daylight rates for 12 hours, namely, 6 a.m. to 6 p.m. or any other period of 12 hours to be agreed upon from time to time to suit the Madras Government's work at Mettur and also the above rates shall apply for all night consumption except as provided for in the next following clause.

(*c*) For all power consumption after the period referred to in (*b*) above the rates per unit shall be 0·40 anna per unit for the power consumed during any period of not less than three hours in which the average load is not less than 750 K.W. The consumption under this clause shall not be used to determine the rate at which the power supplied under (*b*) above will be billed.

(*d*) When the heavy motor driven construction plant is erected and ready for service the Government of Madras shall notify the fact to the Government of Mysore and from that date the charges for energy shall be subject to a minimum charge of 300,000 units per mensem at 0·75 anna per unit, and for this purpose the period from when the full supply is available under clause 8 of this agreement to the date when the abovementioned notification is given shall be limited to six months.

(*e*) When, owing to natural deceleration of construction, the normal power requirements diminish the minimum charge specified in 12 (*d*) above shall be reduced proportionately with the reduced power requirements subject to an absolute minimum charge for 100,000 units, but no reduction in the minimum charge will take place before the expiry of 60 months under the terms of full supply.

13. *Monthly accounts*.—The Mysore Government shall send to the Madras Government a statement of accounts of the electrical consumption during each calendar month and the Madras Government shall pay the amount due within thirty days of the receipt of that account.

14. *Liquidated damages for power supply stoppages*.—(1) The liquidated damages for power supply stoppages shall be—

(*a*) Rs. 1,000 per hour or part of an hour after one hour during the working period of the construction plant.

(*b*) Rs. 100 per hour or part of an hour after one hour when the construction plant is not working.

(2) Provided, however, that no penalty by way of liquidated damages is payable under the above clause (1) (*a*) and (*b*) if the stoppage is due to causes beyond the Mysore Government's control such as vis major, war, riots, storms, fire and floods.

15. *Period of agreement*.—This agreement shall continue for not less than 60 months from the date of notice referred to in clause 12 (*d*) and for so long thereafter as power is required for the construction of the Mettur Dam works. The Madras Government

shall give not less than three months notice of the expected date of completion of the construction. The Mysore Government shall remove all plant and line belonging to them and situated within Madras territory within a period of six months of this said date.

16. *Arbitration.*—The Madras Government and the Mysore Government hereby agree that, if at any time, there should arise any dispute between the Madras Government and the Mysore Government touching the interpretation or operation or carrying out of this agreement, such dispute shall be referred for settlement to arbitration or if the parties so agree shall be submitted to the Government of India.

Action was at once taken by the Mysore Government and the power-line 63 miles long from Sivasamudram was erected and completed by November 1928. Current was actually made available by 27th November and on 18th December 1928, the Mysore Government informed the authorities at Mettur of their readiness to supply the full load provided for in the agreement. The tenure of 60 months began six months from this date (i.e.), on 18th June 1929, and it may here be recorded that throughout the period of supply there was no serious breakdown worth mentioning.

The power-house itself is described in Chapter VI, Part II, where a more detailed reference is also made to the use of the power from Sivasamudram.

Considerable criticism was levelled, in the early stages, at the wisdom of accepting an agreement on the basis of a guaranteed minimum consumption for such a long period as 60 months. It was argued that at least during part of the time the consumption was likely to fall below the minimum limit fixed when it might have been advantageous to develop the power at site. Without entering into the merits of the case we would point out at the outset that the critics had not considered the savings in interest charges on the outlay amounting to Rs. 7,000 a month and, further, that the actual consumption did never fall so low as to justify the assumption in the criticism that it would have been more profitable to generate the power locally. Without further argument we may conclude that the arrangement was profitable and undoubtedly the best in the circumstances which then prevailed.

By 18th June 1934, the contract period came to a close and the demand at headworks had considerably decreased owing to the shut-down of most of the heavy plant, the Electricity Department of the Madras Government was in a position to undertake the supply of the power now required from their Pykara Power station. The Sivasamudram supply was therefore stopped from that date. (For a more detailed reference to the Pykara works and the vast electrification programme in which the future Mettur is to play an important part the reader is referred to Chapter XIX, Part II.)

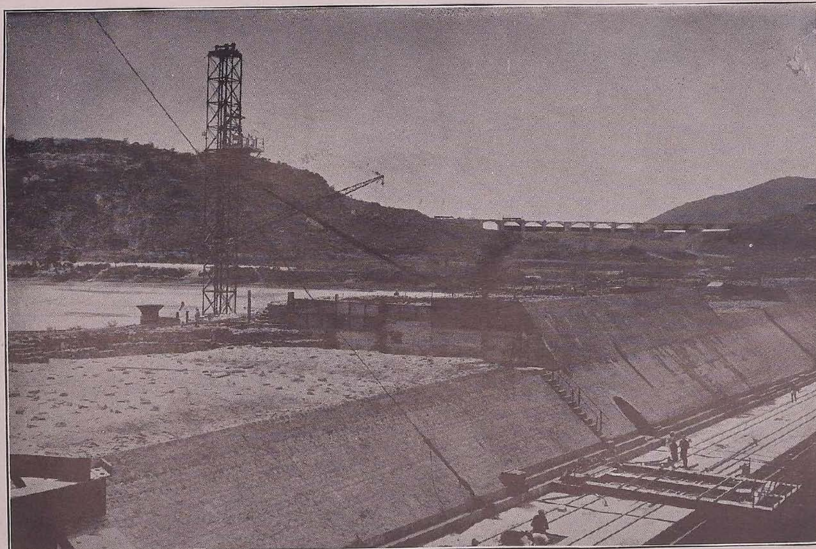
CHAPTER XXVII

Contraction Joints in the Dam.

In a dam of this length and height, the question of expansion and contraction required very early and careful consideration.

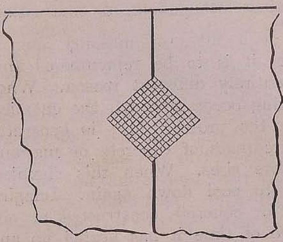
The effect of temperature changes on existing dams in other parts of the world was accordingly studied. Nearly all straight gravity dams (such as was now being constructed at Mettur) develop temperature cracks which, unless controlled, may lead to much trouble and danger. The Assouan Dam, constructed without special provision having been made to counteract its contraction in length during the winter season, presented cracks in the masonry aggregating over 9 inches, and must have been a source of great anxiety to those responsible for its maintenance.

Though the seasonal range of temperature at Mettur is less than that usually experienced in other countries, it was determined that the Mettur Dam was too big and important an undertaking to admit of any risks being taken. Accordingly, all known ways and means of counteracting the tendency for the masonry to crack were studied. Even in his 1910 design, Col. Ellis had suggested means by which cracks due to contraction could be minimized. His scheme was to leave " construction joints " between adjacent blocks of masonry at the close intervals and to fill these with masonry at the appropriate time. While such a method may be simple and convenient for dams of no great height it was now considered hardly suitable for the rapid method of construction with concrete placed by the concreting towers. It was decided, therefore, to arrange for through joints in the dam at intervals of 126 feet throughout its length, the Tower chutes having been designed with a working radius of this length, so that an entire section could be concreted in one operation without moving the tower. So, whether masonry or concrete was employed, alternate sections of the dam, each 126 feet in length, were constructed, steel shuttering being erected at the ends of each of these alternate sections so that the masonry built against it presented a smooth surface. The shuttering was staggered at about 10-foot intervals so as to produce a key which, while preventing lateral movement between adjacent sections, allowed freedom for each section to contract independently of its neighbour. The intermediate sections were then built up in close contact with the ends of those already constructed. Since the bond between two smooth faces is far less than that of any part of the masonry or concrete in each block it is to be assumed that when contraction takes place a " crack " will occur at the smooth unbonded



SHUTTERING ARRANGEMENT AT CONSTRUCTION JOINTS.

junction. Now, when this 'crack' occurs, water under high pressure on the upstream side of the dam will find its way through the junction. How is this prevented? Two independent means of staunching have been employed on the Mettur dam. Near the upstream face of the dam a reinforced concrete diamond-shaped column is precast in position with corners facing up and down stream, i.e., along the joint between two adjacent blocks of masonry. The face of this diamond staunching-bar is given a liberal coat of marine-glue, applied hot to the smooth concrete surface, and the masonry on either side is built up against it. The sketches given below will perhaps make this clearer.



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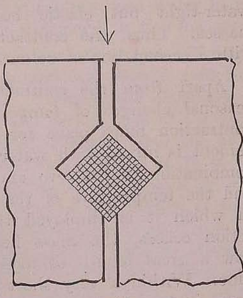


II

The left hand sketch (I), indicating the staunching-bar in plan, shows how it fits between the adjacent blocks of masonry in the dam at the time of construction. The right hand sketch (II), in which conditions are shewn much exaggerated, indicates what happens when the blocks of masonry contract and separate at their joint. The water pressure on the two upstream faces of the bar forces it back against the rear face of the masonry, thus sealing the open joint in rear. Now, in theory, this will appear a very simple and excellent means of preventing leakage through the joint when it opens, but, in practice, we can conceive that, for one reason or another, the bar might not always move as desired. If, for instance, it sticks to one side, the water will leak past the other side, and since, after construction, we have no means of observing the movement of this staunching bar which is lost to sight in the mass of the dam, we have no means of knowing whether it is actually carrying out the functions for which it was designed. To admit of the desired movement, heavy non-ferrous plates have been provided at the foot of each staunching-bar, allowing the bar to slide bodily backwards or forwards. To make quite certain, therefore, that we shall always have a water-tight joint throughout the height of every contraction joint, continuous copper bellows or expansion strips have been constructed at the joints immediately in rear of the diamond staunching-bars. These strips, made of specially annealed copper plate, are bent so that, in section, they somewhat resemble a hair-pin, the ends being bent out at right angles and flanged so that they are held securely in the adjacent blocks of masonry. When the blocks separate, the hair-pin expands, and as it is of sufficient strength to resist the highest water pressure to which it will be exposed, it maintains a perfectly water-tight but elastic bond between the adjacent masonry masses. Thus, the contraction joints in the dam are provided with a second line of defence against leakages due to contraction.

Apart from the contraction of a mass of masonry due to seasonal changes of temperature, it is to be remembered that contraction takes place for an entirely different reason. When cement is mixed with water setting occurs through the chemical combination of the two and, in the process, heat is generated and the temperature of the entire mass of concrete or masonry in which it is employed therefore rises. When this chemical action ceases, the mass begins to cool down again. Imagine now a great length of masonry or concrete constructed at one time. Within a very short space of time it has heated up and since it has no means of expansion longitudinally it becomes compressed. If, as there always must be, there are any voids in the mass when it is laid, some part of that compression will be 'permanent,' so that when it finally returns to its original temperature through the radiation of its heat, the mass will have contracted slightly and cracks will occur. Concrete and masonry possess some degree of elasticity, so the extent of such cracks is not so great as one might otherwise suppose. Nevertheless, such cracks do occur. Here, therefore, we have another very good reason for providing means whereby such cracks may be minimized. No two theorists entirely agree as to the lengths into which sections of a dam should be divided, some maintaining that they should be but a few feet apart whilst others would space them as much as 200 feet apart. Much, of course, depends upon the range of temperature to which the dam will be subjected, and the qualities of the cement employed.

At all events, the Mettur Engineers who had to solve the problem fixed the contraction joints at intervals of 126 feet and, so far, there is nothing to indicate that they have not entirely succeeded in localizing the cracks in the dam at those joints. Where seepage occurs to a noticeable extent it occurs, as might be expected, at those places where the rate of construction was most rapid and where the succeeding layers of masonry or concrete have prevented the rapid loss of heat in the mass lying beneath them. * To minimize the cracking of masonry in a large dam, without the introduction of special means to accelerate cooling process, it would be necessary to carry out the construction in thin layers, allowing ample time for each layer to give up its heat by radiation before the next is applied. Under such conditions the time of construction would be very protracted. In the great American Boulder City Dam, very elaborate measures were taken to accelerate cooling, iced water being circulated through a network of pipes embedded in the masonry.

At Mettur, no such elaborate precautions were taken, it being considered that the raising of alternate sections allowed sufficient time for the intermediate ones to cool. Temperature observations made in the heart of the dam during the earlier days of the construction in the "Deep Hole" indicated, however, that the temperature continued to rise in the mass over a period of 14 to 15 weeks after which a fairly rapid drop occurred; though it was evident that the rate of fall of temperature became slower as time went on and that several years would elapse before the dam entirely gave up its stored heat. It is unfortunate that temperature observations in the dam were not systematically made and recorded throughout the period of construction. The somewhat rough and ready tests referred to above were sufficient to indicate that very valuable data might have been obtained, but it was not till the dam was practically completed that some continuous tests were made in the masonry near the top of the dam. The small mass of masonry and the variable external conditions rendered these tests valueless, the duration of the tests being far too short.

During the years of construction the writer made frequent superficial observations at the contraction joints in the dam and noted with interest the behaviour of these joints at different seasons. During the hot weather the joints at the rear face of the dam, which is exposed to the sun's rays throughout the day, are practically invisible and reveal only the smallest hair cracks even during the cold weather. On the upstream face, however, in the portion of the dam above water-level, the joints generally show a distinct hair crack during the summer months and open up sufficiently in the winter to admit of a visiting card being thrust into the joints. So far, no cracks are discernible anywhere

* An interesting technical paper relating to this subject entitled "Correlation between laboratory tests and observed temperature in large dams" by N. Davey, PH.D., A.M.I.C.E., was published by His Majesty's Stationery Office in 1935.

in the face except at the contraction joints and we may thus feel satisfied that these joints are successfully fulfilling the purpose for which they were designed.

The nature of stresses set up in the masonry in large dams due to temperature changes is very complex, and though numerous theories have been evolved regarding the intensity and distribution of such stresses, we really know very little about the matter and there is room for much further research to be made. One can visualize enormous torsional stresses occurring in the Mettur Dam. While the upstream face is maintained at a comparatively uniform temperature where it is in contact with the water, and the portion above water-level is never exposed to direct sunshine, the top and rear face is subject to very considerable temperature changes, both seasonal and diurnal. Thus, for a thickness of a few feet at least, the skin on the top and rear face of the dam is continually expanding and contracting while the upstream face undergoes but slight changes. At the same time the mean temperature of the former must be considerably higher than that of the latter. In some American designs provision has been made to permit the rear laminæ to expand independently of the main mass of the dam, but by some engineers this is considered doubtful practice, the remedy being possibly worse than the disease, so to speak. In the case of the Mettur Dam no such provision has been made and it is believed that the material employed in its construction is quite capable of adapting itself to meet the various temperature changes to which it may be subjected.

At all events, the dam is found to be extremely water-tight and, in that respect, compares very favourably with many other large dams in other parts of the world.

CHAPTER XXVIII

Drainage Shafts and Inspection Gallery in Dam.

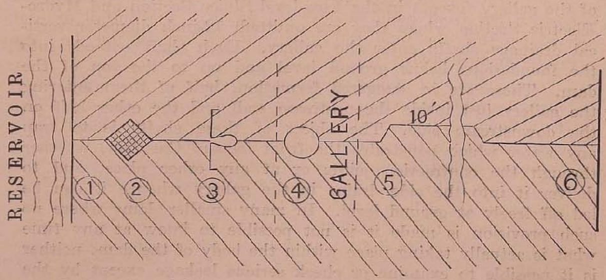
We have remarked on the unusually small leakage which is apparent in this dam. Let us now see what provision was made in its design to guard against and observe such leakage—for nothing which could materially contribute to its safety has wilfully been omitted. In the Chapter relating to borings and the exploration of the rock on which the dam is founded, we referred to the 40-foot ' Calyx ' holes drilled through that rock, at frequent intervals on a line a little in front of the centre line of the dam. Any of these holes which, when subjected to high pressure tests, showed signs of fissures or other faults were extended by means of 3 inches or 4 inches pipes up through the masonry into the inspection gallery. The gallery which is 7 feet wide and 7½ feet high extends at approximately ground level from the extreme left flank for a length of about 4,000 feet through the heart of the dam, being situated slightly upstream of the centre line. It terminates a little to the east of the high-level sluices where the section of the dam, on account of the height of the ground, is relatively small, the top being but 81 feet above the cills of these sluices.

The gallery is everywhere constructed on a gradient and is connected at its lowest points with the rear of the dam at ground level by means of cross-galleries. There are five outlets of this nature, two on the left flank and three on the right bank of the river, and these are so situated that any leakage water entering the gallery is easily led off and drained away in rear of the dam at ground level. At intervals of 15 feet throughout the length of the gallery (except in the Low-level Sluice Section and Hydro-Electric Section where they are omitted) 12-inch diameter vertical drainage shafts enter the gallery. Each shaft extends into the foundations below ground level and up to the top of the dam. These are in staggered formation, half of them entering the gallery just inside the upstream wall and the other half on the downstream side. The object of these shafts is to trap any water which penetrates the front face of the dam, whether through the contraction joints or at any other place, and to deliver it into the side drains in the gallery whence it can be led off freely at ground level. In many smaller dams where no such provision is made it is not possible to know at any time what is actually taking place within the body of the dam, neither is it possible to examine or check serious leakage except by the laborious and somewhat doubtful process of boring and grouting. The Periyar Dam in South India is an example where this process had recently to be carried out since the leakage, which was fairly heavy even from the time of its construction, was steadily increasing as time went by, its age now being over 40 years.

Almost throughout its length the upstream toe of the Mettur Dam is protected by a deep wedge of puddled clay or red earth rammed into the space between the front of the foundation trench and the front face of the dam. In the river-bed section, additional earth of this class was dumped against the face of the dam above bed level to assist staunching. Since the masonry below ground level is not subject to temperature changes, and any conceivable leakage under the toe is provided for by the calyx holes and the regular curtain of 20-foot holes which were all grouted to refusal with cement pumped in under high pressure, it was not deemed necessary to carry the drainage shafts down more than a few feet below natural ground level, neither did the contraction joints in the dam extend below that level. The gallery itself, however, being slightly above ground level is intersected by the contraction joints and therefore affords an excellent means of examining the extent of leakage, if any, through those joints, since any leakage must pass the gallery before it can penetrate the joints in rear of it.

It has been so arranged that a drainage shaft comes exactly at each contraction joint a little in rear of the copper strip, already described. In the event of a fracture in the strip, water escaping past it will be discharged harmlessly down the shaft into the gallery. Most of the percolation through the face of the dam does actually occur at such places, but though the head of water held up by the dam is enormous, this percolation is slight and tends to become less each year as the masonry "Takes up."

The sketch below shows in plan the general arrangement of a contraction joint :—



(1) Upstream face of dam.
(2) Reinforced concrete diamond staunching pillar 12″ × 12″.
(3) Copper strip ' hair-pin '.
(4) 12″ diameter drainage shaft to inspection gallery.
(5) 12″ offset.
(6) Rear face of the dam.

For the construction of the drainage gallery, which has a semi-circular arched roof, collapsible steel centering was used. Rails were laid on the floor of the gallery and the centering, mounted on suitably designed trolleys, was advanced as each section was constructed. In some reaches concrete was used for the arch, the vertical walls all being constructed of coursed rubble masonry, but where the general construction was all of masonry the arch rings were built of stone in mortar. The latter method actually admitted of more rapid construction of the gallery since the arch could be turned in advance of the surrounding masonry.

The drainage shafts were formed as the work proceeded, collapsible steel cylindrical moulds being used. Since the mortar set in the course of a few hours, it was not necessary to use long moulds as they could be withdrawn a couple of feet at a time the lower end remaining in the shaft and acting as a guide. The positions of moulds were carefully checked with reference to the centre line at frequent intervals so that the drainage shafts continued straight from the gallery to the top of the dam, any deviation from the vertical being easily corrected. The pipes connecting the calyx holes beneath the foundations with the gallery were generally brought up above the floor level of the gallery and terminated in small niches thus rendering them accessible without causing any obstruction. The pipes were capped to prevent any foreign matter getting into them, reducing sockets being provided for easy connexion to the pressure-grouting machine should this at any time be found necessary.

The cross-galleries were constructed in exactly the same manner as the main drainage gallery. The side drains which run along both sides of the gallery are of semi-ovoid section, their widths being 4 inches, 6 inches or 9 inches according to the length of gallery to be drained, the larger size, of course, being at the outlet. For the measurement of leakage into the gallery, vee notches, cut from metal plates, are fitted at the outfall of each drain, so that the total leakage in any section of the dam can readily be measured.

In the light of recent observations, however, it would now appear desirable to extend the tops of the drainage shafts which extend downwards from the floor of the gallery to a height of a few inches above the side drains in the gallery. By this means any water collecting in the lower shafts would be free to rise and overflow into the side drains, while the leakage down the shafts above the gallery would not be admitted to the lower shafts. Many of the latter are actually found to be performing the function of drains, so that the total leakage is not actually measurable.

CHAPTER XXIX

Selection of Sites for the Irrigation Sluices.

The irrigation sluices which pierce the dam differ very considerably in size, number and location from those originally proposed, and the circumstances which led to these changes may be of interest.

At Col. Ellis's original site for the dam the configuration of the ground naturally suggested the location and levels of the sluices. These were to be in three sets known as the "Deep Supply," "Central Supply" and "Right Supply" sluices. With the shifting of the site of the dam and the considerable modifications rendered necessary on account of the extraordinarily high flood experienced in 1924, the sluicing arrangements had to be entirely reconsidered. The position of the sluices now depended upon the finding of suitable new sites for the approach and outlet channels, the maximum head which could be permitted at any set of sluices, the capacity of the reservoir at those levels which would admit of the required discharge for irrigation purposes, and the ability of the high-level sluices to assist in the discharging of high floods.

After the new dam site had been fixed, a detailed survey of the water-spread area of the reservoir was carried out by the Survey of India and excellent contoured maps were prepared. From these, the capacity of the reservoir at all levels was calculated and proved of great value in determining the size and capacity of the sluices.

One of the matters requiring careful consideration was with regard to the maximum velocity which could be permitted through the sluices. Many opinions had been expressed on this subject and they differed very considerably.

Bearing this in mind and considering the discharges required at different seasons for irrigation, reference was made to the working tables which had been prepared by Col. Ellis. Originally the gates for the sluices were to be more or less square but on the advice of the sluice gate manufacturers, high and narrow gates were shown to have advantages by reducing the stresses on the gates, the thrust on the piers between the sluices, and overcoming the risk of the gates jamming when being raised or lowered.

As a guide to the design of the sluices let us consider the conditions of supply required for the original scheme.

Between full reservoir level and plus 769 at which the reservoir capacity is about 65,000 million cubic feet a discharge of 25,000 cusecs was required. The greater part of this could be discharged through the surplus sluices. A 10 per cent reduction to 22,500 cusecs was to be allowed till the reservoir capacity fell to 30,000 million cubic feet at about +734·5.

Below this level the supply was to be reduced by a further 10 per cent for the irrigation of the old delta and 40 per cent for the new delta, bringing the total discharges to 21,117 cusecs. During the month of September the discharge was to be 19,915 cusecs for the combined delta. When the capacity of the reservoir fell below 22,000 million cubic feet the supply was to be reduced by 25 per cent and 50 per cent, respectively, for the old and new deltas, or a total of 14,076 cusecs.

The earliest proposals, based on the Manufacturers' recommendations were for four sets of sluices in the dam. This was in March 1927, before very much was known about the rock levels at the new dam site. The arrangements consisted of—

(1) six "Deep Supply" and "Construction" sluices (combined), each 6 feet × 12 feet with sill levels at + 625. They were to be located in the river-bed between L.S. 1,600′ "and 1,800′."

(2) "Eleven" "Central Supply" sluices, each 7½ feet × 15 feet, with sills at + 665 and situated at 4,100 feet—4,300 feet.

(3) "Right Supply" lower sluices, six in number of the same size as above, with sills at + 695 and situated at 4,600 feet – 4,700; and

(4) "Right Supply" upper sluices, six in number and 7½ feet × 15 feet at + 725 level, the sill of the Ellis Saddle surplus being assumed as + 770.

It will be seen that the differences of level between the Central and Right Supply Sluices were each 30 feet only, while the Right Supply upper sluices were 45 feet below the surplus escape.

On further investigation, the then Engineer-in-Chief for the Project, Mr. Mullings, found that the lower sets of sluices would be of little or no use for irrigation purposes as those in the river-bed would soon be liable to become silted up. The capacity of the reservoir below level +678 was small, being only 3,760 million cubic feet. He proposed instead the insertion of suitable pipes which, while serving as construction sluices, could later serve for the generation of electricity. The level of these and the lowest irrigation sluices was not definitely fixed pending the opening up of the dam foundations on which both the location of the sluices and their levels would depend.

Meanwhile, the question of velocities to be admitted through sluices was carefully studied. At the Krishnarajasagara dam it was seen that, with the sluices operating under a head of water as great as 95 feet, the cut stone linings of the sluices did not appear to show any signs of wear, the stone used being very similar to that available at Mettur.

Considering, therefore, that much greater heads and velocities might be permitted than had originally been assumed, it was now possible to reduce the number of sets of sluices to two, terming them " High level " and " Low level," providing the pipes through the dam as already suggested, and employing temporary construction sluices which would be closed permanently as soon as the dam reached the requisite height to enable these pipes to discharge the dry weather flow. This proved to be the ultimate arrangement, after the possibilities of an hydro-electric scheme had been discussed with the officer in charge of Hydro-Electric developments in the Presidency. The details of that important scheme will be discussed later.

It was not until 1930, that the sites for the high and low level sluices were fixed. For some time there was a discussion as to whether the low-level sluices could not be situated in the river section where no supply channel below the dam would be required. If this could be done there was a possibility of forming an independent supply channel for the high-level sluices by making a cutting through a rocky spur near the right flank, a quarter of a mile or so below the dam, and discharging the water into the Kullavirampatti vari, a well-defined water-course which enters the river a little below the Cauvery bridge. It was thought that the cutting through the spur would serve as a very convenient quarry for stone, but it was soon found that the spur consisted of inferior material unsuitable for building purposes. This spur, it may be remarked, was to have formed the right flank of the dams located at sites ' B ' and ' C ', so it is as well that those sites were abandoned as they would have proved most unsatisfactory, necessitating the removal of most of the spur and thereby adding enormously to the bulk and length of the dam.

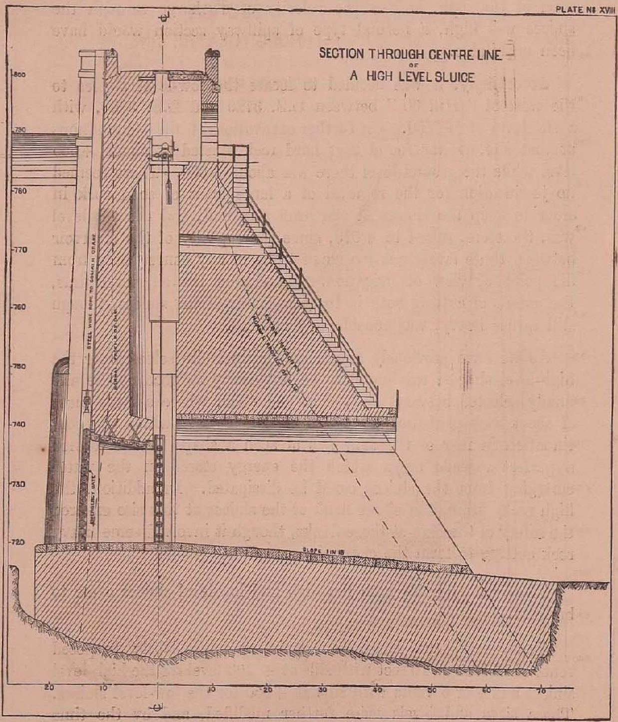
For various reasons, Mr. Mullings, the Engineer-in-Chief, could not see his way to approve of the low-level sluices being situated in the river-bed section. In the first place, this would seriously interfere with the operation of the concreting towers which would not be able to cross the sluice site (and, as a matter of fact, it may be observed, that neither of the towers ever did cross the river). Secondly, the protection of the rear toe of the dam at that site would have presented difficulties, since the water discharging from the sluices would have to fall 45 feet over the back of the dam, and as the velocity of discharge through the sluices was high, a normal type of spillway section would have been unsuitable.

Accordingly, it was decided to locate the low-level sluices to the west of " Hill 60 " between L.S. 3720 and L.S. 3860, with a sill level of + 660. On further excavation of the foundations at that site, it was found that hard rock existed at about +665 level while the ground level there was about +680. There seemed no justification for the removal of a large mass of solid rock in order to keep the sluices at the level proposed, and the sill level was, therefore, raised to +670, since the capacity of the reservoir between those levels was too small to be of any consequence from the point of view of irrigation. By raising the sill level thus, the extent of cutting both in front and rear of the sluices, though still rather heavy, was considerably reduced.

As we have previously noted, the original site selected for the high-level sluices, was found to be not nearly as good as the site finally selected between L.S. 4680 and 4880, where a large mass of sheet rock presented almost ideal foundations, whilst its continuation in rear of the dam was of such a shape that it formed a perfect cascade down which the energy stored in the water emerging from the sluices could be dissipated. In addition, the high rocky ground on either flank of the sluices at this site ensured the safety of the dam at those flanks, though it involved some heavy rock cutting to form the channel.

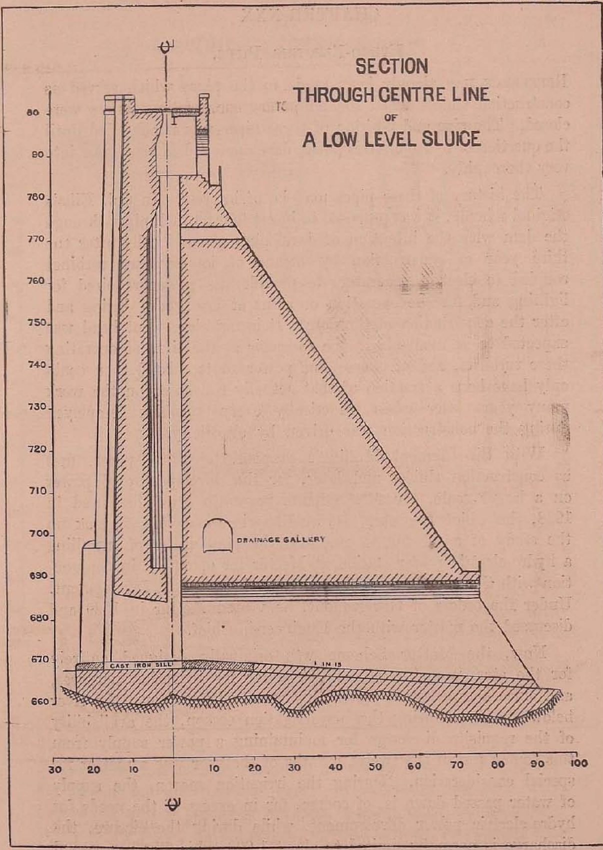
Thus, the sites for both the high and low-level sluices came to be fixed.

Tentatively, the Engineer-in-Chief had previously proposed vents of 16 feet × 16 feet with sills at + 700 level for the high-level sluices and 4 or 5 vents with sills at +660 for the low-level sluices. These sizes and levels were further modified, and by the time the sluice manufacturers, Messrs. Glenfield & Kennedy had been consulted, the proposal had boiled down to having all vents 6 feet wide only, on the score that one emergency shutter and one type of motor-driven gearing would serve for all sluices and the parts would be interchangeable, thus reducing the cost of spares and replacements when required. However, the matter at this stage was left to the manufacturers to decide in view of their world-wide experience with this class of work.



Ultimately, therefore, the manufacturers' plans and proposals were accepted. Their proposals were that the high-level sluices should consist of 8 gates with clear opening $10\frac{1}{2}$ feet × 16 feet, and the low-level sluices should comprise 5 gates, each with 7 feet × 14 feet clear opening. The sill levels were fixed at + 720 and +670, respectively.

PLATE No. XIX



The design of these sluices is described in detail in Part II, Chapter XVIII.

Plates XVIII and XIX show cross-sections of the dam at the high-level and low-level sluices, respectively.

CHAPTER XXX

Hydro-Electric Pipes.

Reference has already been made to the pipes which served as construction sluices when the temporary construction sluices were closed. The size and position of these pipes was not decided until the question of hydro-electric power development had been gone into very thoroughly.

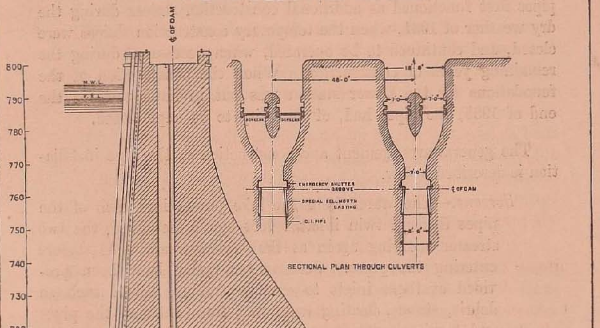
The history of these pipes may be of interest. In Col. Ellis's original scheme, it was proposed to insert four 24-inch pipes through the dam with the intention of developing power locally after the third year of construction by means of low-pressure turbines coupled to electric generators to provide the power required for lighting and for the operation of plant at headworks during and after the construction of the dam. It is not clear what head was expected to be available in the reservoir at the time of operating these turbines, and of course, the power contemplated then could only have been a fraction of that actually consumed on the work many years later when practically every machine employed during the construction was driven by electricity.

With Sir Clement Mulling's proposal to utilize pipes, first as construction sluices and later, for the development of power on a larger scale, the final scheme began to crystallize, and in 1928, the Chief Engineer, Hydro-Electric Development, took up the study of a scheme to ascertain the possibilities of installing a hydro-electric power station at Mettur for operation in conjunction with the great Pykara System then in course of development. Under the orders of Government, he visited Mettur in 1929 and discussed the matter with the Engineer-in-Chief.

Now, the Mettur Scheme was originally designed entirely for the storage and regulation of water for irrigation purposes, and since compensation water only was to be let down the river below the dam during the non-irrigation season, the availability of the requisite discharge for maintaining a power supply from this source for all the twelve months of the year was a matter for special consideration. During the irrigation season, the supply of water passed down is, of course, far in excess of the needs for hydro-electric power development, while during the closure, the discharge is normally limited to about 1,000 cubic feet per second discharged from the reservoir when it is at a comparatively low level. A power station erected at Mettur, therefore, would have to have its power output based either on the minimum dry weather flow during the period, February-June, or else on a higher

PLATE No XX

SECTION THROUGH CENTRE LINE OF A HYDRO-ELECTRIC SLUICE



discharge for part of the year with assistance from another source during the remainder of the year. This matter has been duly considered and a complete scheme worked out. A pamphlet prepared by Major Howard, the Chief Engineer for Electricity, is reprinted in Part II, Chapter XIX of this book. It may be mentioned that Major Howard's scheme is now (1936) in hand and the preparation of foundations for the power-house and erection of power transmission lines have already made considerable progress.

The four sets of 102-inch pipes were supplied complete with needle-valves, screens and dispersers in 1930 and were laid in the dam at L.S. 965, 1,013, 1,061 and 1,109 feet, respectively, being set at 48-foot centres. The sill level at the inlets is + 640. These pipes first functioned as additional construction sluices during the dry weather of 1931, when the temporary construction sluices were closed, and continued to be operated, when necessary, during the remaining years of construction. When the construction of the foundations for the power station was put in hand towards the end of 1935, the pipes had, of necessity to be kept closed.

The general arrangement and construction of the pipe installation is described below.

Screens.—The water from the lake passes into each of the pipes through twin inlets 7 feet by 25 feet deep, the two streams merging again at the down-stream side before entering the pipes. Screens (or racks) have been provided at these inlets to exclude foreign matter such as debris, stones, floating logs, etc., from entering the pipes and turbines. These screens are 7 feet by 25 feet, built up of 3 inches by $\frac{3}{8}$ inch thick plates spaced at $2\frac{1}{16}$ inches centres and contained in a steel frame complete with guide-rollers and hoisting chains extending to the top of the dam. The freeway area of each screen is 150 square feet and the velocity is 3·3 feet per second when the culverts are each discharging 1,000 cusecs.

Should the screens get choked with debris, there would be an appreciable difference of level between the water in the reservoir and in the wet well in rear. This difference would represent the velocity head through the culvert plus the loss through the choked screens. This head is shown by a mercurial differential manometer, to be located later in a suitable place in the power-house but, for the present, fixed in the needle-valve chamber. When this difference of head reaches the allowable maximum it would give a warning that the screens are getting choked, thus restricting the flow of water into the pipes. It is then necessary to remove the screens for cleaning. Before removing them, the two spare screens are lowered into position in the up-stream grooves. These latter screens are intended to function while the main screens are being repaired or cleaned. The lifting and the lowering of the screens is done by 50-ton electrically operated travelling Goliath crane, which is also used for lowering and withdrawing the emergency free roller gate.

The spare screens are also 7 feet by 25 feet deep exactly similar to the main screens, but fitted with a hinged flap at the top to screen the horizontal gap when the regular screen is raised and the spare screen is lowered in the up-stream groove.

The screens roll along C.I. double grooves for the bottom 36 feet above sill. These are in lengths of 9 feet and anchored to the concrete with binding bolts. The roller faces are unmachined, while above 36 feet the grooves are formed in the masonry itself.

The culvert from the bell-mouth up to the wet well is built of masonry, the sides are built with ashlar facing, the flooring is of cutstone slabs, and the roofing is of reinforced concrete. The nose of the pier where the twin inlets merge into one, is provided with cast iron lining to safeguard the walls against any possible erosion.

The Roller Emergency Gate.—Passing the screens the water enters the wet well just in front of the centre line of the dam. Here the flow into the pipe entrance is controlled by a roller emergency gate 7 feet by 14 feet high. This gate is intended to shut off the water when repairing or renewing the seats of the needle-valves (the main regulating valves in rear). The pressure of the water keeps the gate tight in place. It is hauled up by the Goliath crane at top and drops into place under its own weight. The gate seatings are of special Low Moor Iron plate to withstand wear and ensure a durable and satisfactory seal face for the gate bottom. The gate consists of a series of anti-friction rollers moving against a cast iron machine facing with a gun-metal seal on either side to prevent leakage of water. It is claimed by the makers that these gates effectively stop the flow under pressure. The gate is guided throughout its travel by mild steel angle guides extending from the top of the frame casting to top of dam.

Sluice well.—This well is intended to serve the double function of a surge tank and a well for the insertion of the roller emergency gate. The sides of this well are protected with cast iron and steel linings up to level 680·875 as this area will be subjected to a static head of nearly 150 feet and considerable agitation on account of the rush of water past the entrance, or surging when the valve is operated to increase or diminish the flow into the turbines. Behind the wet wells the dam for a width of 12 feet is built of reinforced concrete from the top of pipes to counteract any tension that may be created on account of the reduced width of dam.

Bell-mouth special entrance.—The velocity through the 102″ Dr. pipes for the full capacity is about 17 feet per second, i.e., (about the maximum that good practice allows). To cut down this velocity through the screens and to ensure a steady smooth flow through the pipes a bell-mouth special entrance has been provided. This is a special taper casting having a rectangular front opening 7 feet by 10 feet, the down-stream side being shaped circular to connect with the 8 feet 6 inches diameter pipes. A photo of one of the bell-mouth sections taken in the manufacturer's workshops at Kilmarnock is reproduced in Plate XXI.

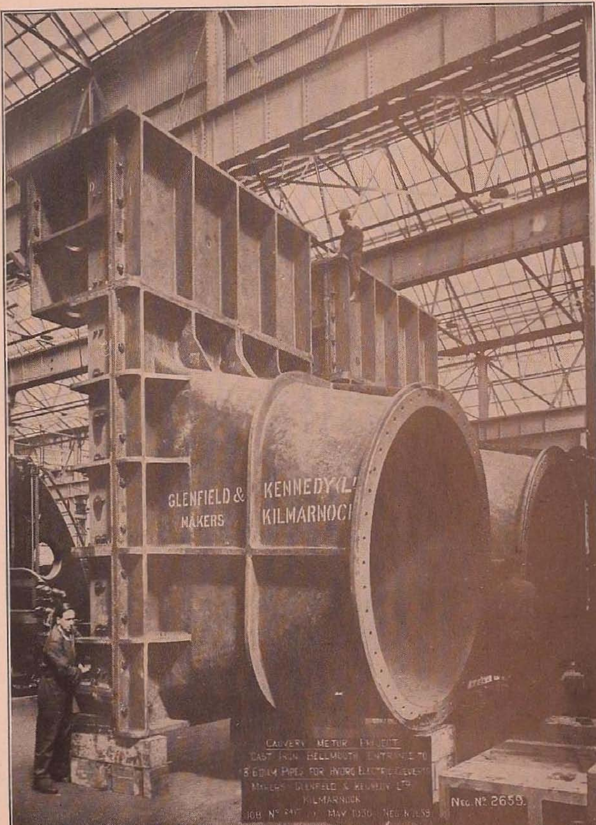
102″ *diameter C.I. pipes*.—Leaving the entrance, the water passes through 102″ diameter C.I. pipes 1½ inches thick discharging 1,000 cusecs under heads varying from 60 feet to 160 feet with a velocity of about 17 feet. The first 4 lengths were received from Messrs. Glenfield & Kennedy, Limited, Kilmarnock (Scotland) and the other 4 lengths from the Bengal Iron Works, Howrah. The latter are 2 inches thick and the flanges are cast with ribs.

The pipes as well as the floor of the culverts in front are laid at an inclination of 1 in 20 to minimise the loss of head through the culverts and pipes. The rearmost pipe is a special casting with a man-hole for inspection of the pipes, and is provided with a 24″ flanged circular opening from which a future connexion for supply of water to Salem may be taken off. At the bottom of this pipe is also a drain 18″ diameter which, by means of a valve, can drain off any leakage past the roller emergency gate and keep the pipes sufficiently dry for inspection purposes.

Needle valve, 102″ *inlet and* 72″ *outlet*.—Immediately in rear of the man-hole casting is the needle valve having an inlet 102″ diameter and outlet 72″ diameter. This is the main valve designed for regulating the flow of water into the turbine. Under a minimum head of 60 feet this valve will be kept fully open to discharge 1,000 cusecs into the turbines. But when the head of water increases, this valve will be throttled suitably to keep the outflow restricted to 1,000 cusecs. The valve is hand-operated and is accommodated in a chamber 14 feet by 28 feet. The valve body is of cast iron and is in two parts securely bolted together. The internal needle is also of cast iron and is fitted with a gun-metal sleeve.

The valve seat consists of a gun-metal face securely fixed to the valve body and, when closed, a similar face on the needle makes contact with the face on the body, thus ensuring a water-tight joint.

The actuation of the valve is through a rack incorporated with the needle and this rack is engaged by a spur pinion which in turn is connected by a vertical steel shaft passing through a gland in the top of the body to a spur reduction gear and then through a second vertical shaft to the head-stock. The second



CAST-IRON BELL-MOUTH TO HYDRO-ELECTRIC PIPE.

vertical shaft passes into the head-stock and carries a worm wheel of manganese bronze which is engaged by a worm cast steel forged from the solid, all gears being machine-cut throughout. The worm shaft is fitted with ball end-thrust washers and the whole is totally enclosed to run in an oil bath. The worm shaft is extended through an end-bearing and carries the spur wheel of the second spur reduction. The pinion wheel is connected through the head-stock to the operating fly-wheel which is provided with a handle. The second spur reduction is totally enclosed by a sheet steel guard. It takes ordinarily about 20 minutes for 2 to 4 men to close or open the valve. The outlet of the valves is connected to 2 lengths of 72 inches diameter C.I. pipes each 9 feet long. The valves were used as free discharging valves during construction of the dam and, if retained, will operate as main regulating valves for the future hydro-electric installation.

The design of the turbines as well as the construction of the power-house is described in the Chief Engineer for Electricity's pamphlet (Part II, Chapter XIX).

Dispersers.—The energy of the discharge through the pipes during the dam construction was dissipated by rotatable jet-dispersers fitted up to the 6-foot diameter pipes. The dispersers are not part of the hydro-electric installation, but were provided only to prevent scouring of the foundations and the river bed in rear of the dam, when the pipes were discharging freely. The outlet nozzle pieces are 5 feet in diameter and are angled to give the nozzle a rotation of 10° in either direction horizontally, so that the jet might not foul the rear bogie of the concreting tower when in its working station in the hydro-electric section. The dispersers have all-steel outlet nozzles tapering from 6 feet to 5 feet, fitted with internal disperser vanes and are a Glenfield and Kennedy's Patent.

Steel platforms with hinged covers, locking bars, and hand railings were also provided to span the screen openings at dam parapet level. These platforms are used when it is desired to clean or inspect any screen when raised by the Goliath crane.

Goliath crane.—50-ton—Electrically operated travelling.—The crane is capable of lifting a maximum working load of 50 tons on the main hoisting gear and 10 tons working load on the auxiliary hoisting gear. The crane is capable of hoisting, traversing and travelling with the heaviest emergency roller gate, 20 tons in weight. The main hoisting, auxiliary hoisting and cross-traversing motions are done by independent electro-motors, while the travelling of the crane is done by hand power.

The crane consists of a steel structure carried by four double flanged rail wheels on each of the dam parapet walls running on 90 lb. rails fixed to the parapet walls at 18 feet centres.

The main hoist gearing arrangements and the auxiliary hoist gearing arrangements, with automatic brakes, are fitted in the crab frame on the cross-tray. The motors provided in the crane are as follows :—

Main hoisting motor	10 b.h.p. at 575 R.P.M.
Secondary hoisting motor ..	5 b.h.p. at 570 ,,
Cross travelling motor	$2\frac{1}{2}$ b.h.p. at 570 ,,

The following are the speeds :—

Main hoist	50 tons at 1′ 6″ per minute 20 tons at 3′ 6″ ,,
Auxiliary hoist	10 tons at 3′ 6″ ,,
Cross traversing	20 tons at 30′ 0″ ,,
Long traversing	20 tons at 15/20 feet per minute 4 men exerting 15/20 lb.

The approximate weight of the crane is 40 tons. Its cost was £2,560 f.o.b. Glasgow.

Erection.—The erection of the hydro-electric pipes was started in November 1930, after isolating the freshes in the river by erecting a temporary coffer dam in front with steel shutters bolted on to girders, closing the inlet openings of the culverts. An earthen ring-bund was raised in rear to prevent the rear water from encroaching into this area.

Temporary tram lines were laid from the place where the materials were stored on to the rear of the dam, with suitable branches along the centre and between the pipe lines at level +636·0.

The masonry of the dam where the pipes were to be fixed was laid out in terraces having a drop of 1 in 20 to correspond with the inclination of the pipes; and rectangular blocks of masonry about 20 feet long, and 1 foot thick were built and finished off to within ½ inch of the bottom of the pipes, being suitably spaced and leaving enough room to admit of the pipe flanges being bolted together.

The heaviest parts of this plant were the bodies of the needle-valves (about 12 tons 5 cwts. each) and the two halves of the bell-mouth special entrances which weighed about 8 tons each.

The erection was started from the needle valves and continued towards the upstream end. Masonry stools for the feet of the needle-valves were first built to the proper level and on these the sole plates were fixed with batt bolts carefully levelled to receive the feet of the valves.

For handling these heavy pipes and valves a gantry was built up by erecting a 12 inch lattice derrick post on one side of the valve and a masonry pier on the other with their tops connected

VIEW OF A NEEDLE VALVE.

by two 12 inches by 6 inches R.S. girders tied together by means of four 9 inches by 3½ inches back-to-back channels. Two 10-ton Morris worm-gear blocks suspended from this girder lifted the body of the valve off the bogie which was then hauled back, and placed it in position on the sole plates. The final adjustments such as raising and lateral shifting were carried out by means of three 12-ton traversing screw jacks suitably placed and operated underneath the body of the valve.

The tram line between the 2 lines of pipes was used to convey the bell-mouth specials and pipes. The same gantry arrangement was adopted to put the two halves of the bell-mouth casting in position on the piers just behind the centre line of the dam. The 102″ diameter pipes were brought to site in bogies, rolled over the masonry blocks into position, packed with broad gauge sleepers and wedges and fitted up tight one by one from the valve and aligned to the correct inclination by means of iron packing pieces underneath. Finally, the two halves of the bell-mouth were joined together and bolted to the pipe-line and the entrance thus completed in front.

The fitting of the 6 feet diameter pipes in rear of the valves was similarly carried out. Two lengths of these pipes were added and lastly the jet dispersers were fixed.

The pipe flanges were all grooved and the joints were made up by means of half inch diameter India rubber card packing inserted in the grooves, thus ensuring an absolutely water-tight joint.

The four pipe lines were completed by March 1931 and the screen frames, screens and linings for the wet wells were fixed by June 1931. On the whole, the work comprised about 900 tons of heavy iron work.

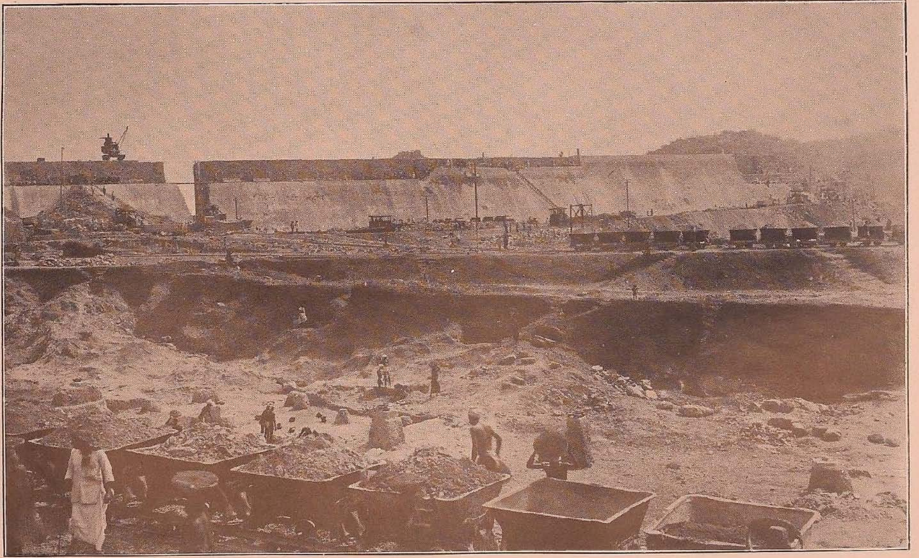
After the pipes line was completed, it was completely cased in concrete of 1 : 2 : 4 mix, two feet thick all round. Over this the normal masonry of the dam was continued.

The cost of this pipe installation alone, exclusive of construction of the power-house, the turbines and the electrical machinery was approximately 8 lakhs of rupees.

CHAPTER XXXI

Irrigation Supply Channels.

Until the sites and levels of the two sets of irrigation sluices had been settled, it was not possible to design the supply channel required to connect these sluices with the river, and even then, it was not possible to determine the position of the falls or drops required in the channel to lower the water from the high-level sluices, with their cills at +720 to the river-bed at +625—a fall of 95 feet in a distance of 4,000 feet only. The bed-fall of the channel had to be kept within limits to prevent undue scour and this necessitated the provision of a number of masonry drops across the channel. Until the channel was actually excavated, the nature of the bed could not be determined and since it was desirable to locate the drops only at those places where good rocky foundation could be found, very little designing could be done in advance. However, a maximum discharge of 25,000 cubic feet per second was the basis of calculations for determining the bed width and depth of the channel. Even this gave the designers something to think about as never before had an artificial channel been constructed by the department for such extraordinary conditions of discharge. The designers, with all their experience in the design of canals and irrigation channels having velocities up to about 3 feet per second, had no data to assist them in designing a channel of this nature. The width of the channel had of necessity to be kept to a minimum in order that the cost of the many masonry works might be kept within reasonable limits, as also the extent of excavation. Accordingly, a bed width of 142 feet was selected for the normal channel section, and it was estimated that a discharge of 25,000 cusecs would produce a velocity of about 13½ feet per second with water flowing at a depth of 12 feet, assuming the banks to be sloped at 1 : 1. It was considered that a free-board of 3 feet would suffice, and the tops of the banks were, therefore, to be 15 feet above channel bed. Mr. Dowley, the Officiating Engineer-in-Chief at that time, at first suggested that the channel might be left to cut its own course, providing only a narrow leading channel to induce it to follow the desired route to the river. But with such high velocities, the dangers of retrogression had to be carefully considered while the danger to which certain buildings near the course of the channel would be subjected could not be overlooked. A large cement-shed stood near the right bank of the channel about half-way down its course while the general stores and power-house stood a little further away on rather low ground. Again, it is probable that, left to its own devices, the stream would have out-flanked the Cauvery bridge near the right abutment, where the natural ground lay in



EXCAVATION OF HIGH LEVEL CHANNEL.

a depression. This proposal could not, therefore, be seriously considered and it was eventually decided to cut the channel to a proper section, with revetted banks throughout its entire length. Trial excavations revealed a variety of soils along the alignment of the channel, but a rocky bed was found throughout the greater part of its course. Whether the softer rocks would be able to stand up to a velocity of 13½ feet per second without undue scour was problematical, but this was a matter which could only be proved by actual experience. Prior to the excavation of the channel, numerous feed lines for supplying materials to the dam crossed its alignment, so the work was delayed as long as possible in order that there should be as little interference as possible with the dam construction. It was realized that eventually a bridge would have to be constructed across the channel for the conveyance of materials to the Red Tower and for the removal of machinery and materials on completion of the work. Accordingly, a bridge of four spans of 31 feet each was designed and later constructed at a point a little below the junction of the high-level and low-level channels. Excavation on the line of the channel revealed several broad bands of hard rock at suitable intervals between the junction of the channels and the high-level sluices, and at such places the masonry drops were constructed. The highest of these drops was 12 feet and, to dissipate the enormous amount of energy stored in the water when 25,000 cubic feet per second passed over these drops, very effective water cushions had to be designed and constructed. In construction, the rock was cut back roughly to the shape of the finished drop and first class coursed rubble masonry was built in close contact with the rock not only for the drop walls but also for the wings and side walls. This ensured the maximum strength and stability of the masonry, and it may here be stated that all the drops have stood up to the buffeting without so far incurring any damage whatsoever.

High-level channel.—The high-level channel, as we have already remarked, starts at the foot of the rocky cascade some 240 feet in rear of the high-level sluices, or 335 feet from the centre line of the dam. At 700 feet from the head a drop of 10 feet is provided. The bed fall of the channel is 1 in 480 throughout. At 1,066 feet a second 10-foot drop is provided, while at 1,450 there is a 12-foot drop. At 2,100 the high and low-level channels meet and continue as a combined channel to join the river about 4,000 feet from the high-level sluices—at 2,158 feet from these sluices the channel is crossed by a bridge of 4 spans of 31 feet each. The high-level channel is entirely in cutting, the tops of banks being generally about 18 feet above bed level. The sides were revetted throughout with rough stone, dry packed, 18 inches thick, but the heavy wave action on the banks has since necessitated the grouting and cement pointing of the greater part of the revetment. Below the second drop where the channel takes a somewhat sharp bend, the revetment is replaced for some length on the right or outer side by a masonry retaining wall, constructed in continuation of the down stream wing wall.

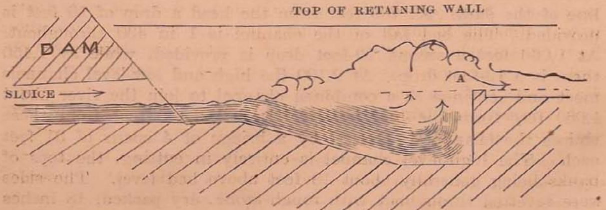
Below the bridge, the channel takes a fairly straight course. The fall of the land is here less and between the bridge and river there are only two drops of 6 feet and 4 feet height.

Some 500 feet from the point where the channel joins the river, a masonry bed-regulator has been constructed. Good rock extends from that point down into the river bed with a fall of 13 feet. Below the bed-regulator no protection is provided for the banks, the stream being permitted to open out. The banks are, however, of extremely hard kankur soil and have so far shown very little tendency to cut back.

The cascade at the foot of the high-level sluices serves effectively to lower the water from +716 at the rear end of the vents to +686·5, at which level the true channel starts, thus accounting for nearly 30 feet of the total drop of 95 feet. The excavation of the high-level channel was commenced in July 1932 and completed in September 1933. The entire cost of the channel together with its large masonry works is Rs. 4,43,704.

Low-level channel.—The low-level channel which starts from the low-level sluices is nearly 1,030 feet long down to its confluence with the high-level channel. This channel is also designed to carry 25,000 cusecs. But its normal discharge will only be 20,000 cusecs, or less, as it is intended to operate only at low reservoir levels when the demand for irrigation is small.

Immediately in rear of the low-level sluices, where the bed level of the channel is practically the same as the level of the sill of vents in rear of the dam a "Hydraulic Jump" has been constructed as a means of dissipating the enormous amount of energy stored in the water emerging from the sluices at a velocity of between 50 and 60 feet per second. The form of this "Jump" is indicated in the sketch below :—



The jets from the sluices dive below the standing wave which forms near the baffle wall in the hydraulic jump and piles it up when they meet the cushion wall at A, thus losing much of their former energy. This water then overflows into the stilling chamber, the bed of which is $1\frac{1}{2}$ feet below the top of the cushion wall. Here the vertical wave action is almost entirely suppressed. The bed of the hydraulic jump is all solid rock. The side walls and the jump wall are built in solid masonry. They have a batter of 1 in 6. The floor of the stilling chamber is paved with masonry in cement mortar. After leaving the stilling chamber, water flows over the natural bed of the channel and then to the river through a succession of drops.

There are two 6-feet drops in this channel between the stilling chamber and the junction with the high-level channel. For the drops in the combined channel below the bridge no masonry aprons are provided as the bed consists entirely of rock at these places. This channel is also 142 feet wide with side slopes 1 : 1.

The excavation of the low-level channel was started in May 1931 and completed in August 1932 including all the masonry works. The total cost of excavation of the low-level channel and masonry works was Rs. 3,83,160.

In excavating the channel the problem of disposal of the spoil was a matter of some importance. A good portion of the spoil was utilized in filling up hollows and in forming high embankments for laying tram lines for feeding of materials to the dam. In fact, the ground in rear of the dam has in places been raised on an average by 10 feet with the aid of the spoil from the channel excavations. The spoil at the tail end was dumped into the river just below the confluence of the channel with the river. Most of the stuff deposited in the river was washed away during the floods of 1932 and 1933.

Good building stones removed from the excavation was partly used on the dam and partly on the masonry works in the channel. Three locos and about 250 trucks were engaged in the disposal of spoil from the excavation of the channel.

In some parts of the channel the rocky soil was found to be very hard. Some of the piece-workers employed on the work found it very difficult to make satisfactory progress with the excavation by hand methods; so certain reaches were taken over departmentally and the excavation was done with the aid of pneumatic tools. Pneumatic picks or busters were used for the decayed rock while jack hammers and tripod drills were used where blasting was necessary, and large masses of hard rock were removed by this means.

General.—Since the channels were constructed and brought into operation, it has been found necessary to carry out numerous improvements. The original free-board allowed, particularly in the low-level channel has been found inadequate. The wave action with the channels running at anything like full discharge is very heavy and the banks were overtopped during 1935, with consequent damage to the revetment. Slips occurred in several places and the stones were torn out of the banks by receding waves. The surface of the water at the bends assumes a considerable super-elevation, the water level on the outer side of the bend being as much as 3 to 4 feet higher than at the inside. In consequence, it has been found necessary to replace the revetted portion of the right bank of the low-level channel between the " hydraulic jump " and the junction with the high-level channel with masonry retaining walls, the height also being considerably increased. Even in the straighter portions of the channel below the bridge the banks have been raised another 3 feet and may still require further raising. In the weaker places the original dry-stone revetment has been replaced with masonry, particularly immediately in rear of the bridge. The afflux at the bridge is very considerable and the water has been up to the bottom of the girders. To protect the girders, the piers of the bridge have recently been extended 12 feet upstream but it is probable that the channel will ultimately have to be widened at the site and an extra span inserted on the right side as the restriction of waterway is excessive.

There is a tendency for the softer rock in the channel bed to scour, and for pot holes to be formed. Above the drops and both upstream and downstream of the bridge apron the deeper scours have been filled with rough-stone masonry set in 1 : 5 cement mortar.

In the course of a few years one may expect to see the entire channel bed lined with masonry, for nothing but the hardest varieties of rock can withstand the high velocity for any great length of time. As the softer rock is eroded the channel had become increasingly rough, the harder rocks projecting well above the scoured bed. These at times become detached and are carried down the stream and deposited in shoals on the inner side of the bends and at the junction of the two channels. It is anticipated that the channel bed will require attention and repairs every year.

The layout of the channels, the cascade below the high-level sluices and the bridge across the channel are clearly illustrated in the general view of the dam given in Plate No. XXIX.

The spray thrown up at the hydraulic jump immediately in rear of the low-level sluices makes it difficult to obtain a good photo of the jump in operation, but to the spectator, it is an impressive display of a fight between man and nature, a fight in which nature always tends to get the upper hand.

CHAPTER XXXII

THE ELLIS SADDLE SURPLUS WORKS.

FREQUENT REFERENCES have already been made to the Ellis Saddle surplus and a more detailed description of the site, the design and construction of the surplus works here follows:

The surplus sluices are located on the left side of the river Cauvery at the original site proposed by Col. Ellis, R.E., when Superintending Engineer in charge of the Investigation of the project and are not adversely affected by the dam itself being about a mile higher up the valley than the site selected by him. The site is fairly ideal being a saddle with natural hilly abutments for the sluices while a natural valley below (Thottilpatti vari) serves as a water course of almost unlimited capacity for the surplus water to flow down and rejoin the river about three miles below. Except for one or two hillocks the saddle was moderately level, occupying an area of ground measuring about 1,200 feet by 650 feet. It had, however, to be lowered by some 10 to 20 feet to bring it to + 770, the required sill level of the surplus sluices.

The works relating to the surplus sluices may be classed under four heads :—

(i) Lowering the saddle to the sill level of the surplus sluices.

(ii) Constructing the surplus sluice bridge and the masonry piers for carrying the overhead platform for operating the sluice shutters.

(iii) Providing sixteen 60 feet by 20 feet barrage gates and an overhead regulating platform.

(iv) Providing a masonry apron in rear of the sluices.

These are described in some detail below.

Lowering the Ellis Saddle.—The original proposal was to provide 25 vents of 40 feet span each. The original estimated quantity of cutting to the sill level of sluices, viz., +770 was 17,199,000 units and the estimate cost was Rs. 9,12,000. It was, however, finally decided to substitute 16 vents of 60 feet span and, as a result, there was a saving in the total amount of cutting which, on completion, amounted to about 15,000,000 units and included the lowering of the whole area to level +768·5 (i.e., bottom of floor) instead of to + 770·00. A workslip was sanctioned for Rs. 6,00,000 in Engineer-in-Chief's No. 114-II.W. of 1928–29 during execution of the work. A second workslip was sanctioned for Rs. 4,71,000 in Engineer-in-Chief's No. 137-S.T., dated 5th March 1930, but the total actual expenditure was under Rs. 4 lakhs, after allowing credit for the quantity of stone taken from the cutting and used up on works.

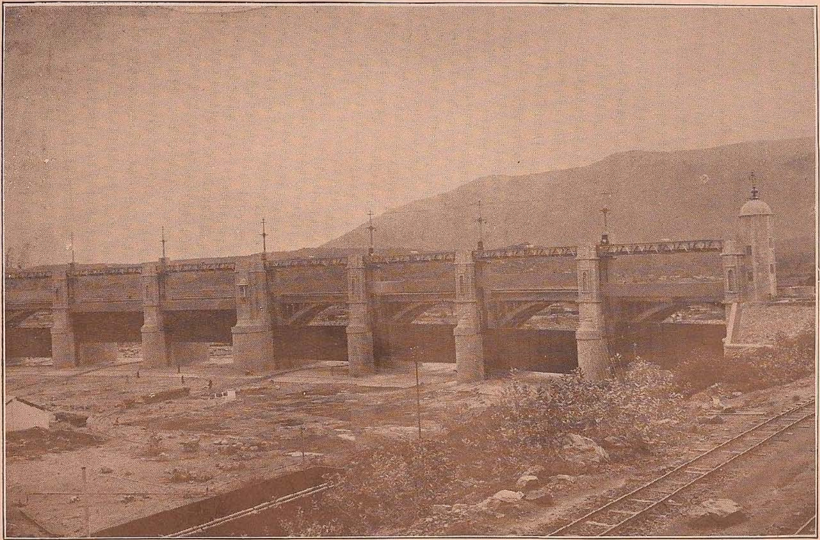
Surplus sluice vents and bridge—Size and number of vents and alignment of sluices.—Towards the right of the saddle there was a big knoll with its top at about level 810, 40 feet above the sill level of sluices. This was believed to be of fairly solid rock and the original surplus sluices were accordingly designed by Col. Ellis in two sets with 13 vents of 40 feet to the right and six to the left of the knoll. The two sets of sluices were so aligned that the discharge from one set would have impinged on that of the other at some point, on the downstream side of the knoll.

The maximum discharge provided for by Col. Ellis through the surplus sluices was only 120,080 cusecs on the assumption that the maximum discharge to be provided at times of maximum flood would be only 250,000 cusecs and that the supply sluices could be made to function as surplus sluices in addition to the main surplus sluices during floods. But as has already been stated, the unprecedented flood of 1924 brought down a flow of some 456,000 cusecs and this necessitated the entire reconsideration of the surplusing proposals. Finally it was decided with reference to working tables prepared for July 1924, when that flood occurred, to provide 16 vents of 60 feet by 20 feet for the surplus sluices at Ellis Saddle.

A straight line alignment between the two abutting hills of the saddle would have placed the sluices in a pocket in the valley between the two hills since the saddle itself took a curve to about 500 feet east of the hills. The sluices had, therefore, to be aligned on this curve, which is concave to the reservoir, in order to avoid the valley, and to provide sufficient length of escape to meet the requirements and afford good junctions between the ends of the sluices and the hills at either flank of the saddle. The alignment finally selected has a radius of 800 feet and was selected with the highest available foundations both for the sluices and for the rear apron retaining wall.

Design of the road-bridge over the surplus sluices—Level of roadway.—The present top level of dam is +801 (M.S.L.) but the dam is so designed that it can be raised to +810 if considered necessary at a future date. A level of 810 for the road over the bridge has accordingly been adopted. The springing of the arches is at +794·4. With an assumed M.W.L. at some future date of 805·00, with the water level through the bridge being reduced by afflux, the arch springing might be submerged to a maximum depth of 4·1 feet. As the arches are of the open spandrel type this need not be considered objectionable.

The road bridge consists of 16 spans of 60 feet each on the upstream side, the same as fixed by the requirements for the sluices. The bridge is of open spandrel type with four R.C. arch ribs and conforms to the standard requirements of a 'B' class bridge, the road width between kerbs being 18 feet. For the comparatively large span of 60 feet the arch rib design was found lighter and cheaper than a steel girder bridge with R.C. decking and so this has been adopted. The R.C. deck slab is divided into panels of 5 feet by 5 feet supported on T beams at all the four edges. The



VIEW OF PORTION OF SURPLUS WORKS AT ELLIS SADDLE.

R.C.T. beams rest on R.C. pillars which are in turn supported on the arch ribs. The four arch ribs are at 5 feet centres and are braced together.

Each arch rib is a parabola represented by the equation $Y = X^2/75$ where (Y) is the depth of the axis below crown at any place and X is the horizontal distance from the centre of the span.

The bridge is designed to carry a double track of tram lines, the tracks being at 10-foot centres. The maximum live load on each span allowed is for a train load of 60 tons on each of the tracks and a crowd load of 80 lb. per square foot on the remaining space. Actually only a single permanent line of tram track has been laid, the remainder of the space being open for road traffic. The rails are set flush with the road surface.

Parapets.—The parapets and kerbs are also of reinforced concrete with panels and pilasters except over the piers where they are of cutstone masonry. The surfaces of panels are given a pebble-dash finish of granite chips.

Piers.—Every fourth pier is an abutment pier having double the thickness of an ordinary pier. Even the ordinary pier is designed to withstand the pressure transmitted by the shutters when they are closed and when water stands in the reservoir at M.F.L. They are also designed to withstand the cross thrust due to water running full only in one of the two spans adjacent to the pier.

The front extension of the piers of the bridge have been given a modified section, raised for carrying the overhead regulating bridge platform.

There are two masonry towers of octagonal shape at the extremities of the bridge to give access by means of spiral stair-cases to the operating platform. These are provided with brass ornamental finials, reinforced concrete stair-cases and are surmounted by reinforced concrete domes. Masonry pillars rise from the piers of the operating bridge. These contain the switch-gear and also support R.C. posts carrying the electric overhead lines for feeding the operating motors, etc. Satisfactory illumination of the road and operation bridges is provided by lights suspended from brackets on the posts, efficient types of reflectors being employed.

The masonry of the piers and abutments is of first-class coursed rubble built in surki mortar, each course being one foot deep. The exposed faces of the stones are single line dressed throughout, and are cement-pointed.

Details of commencement and completion of work.—The masonry portion of work was entrusted to two contractors Messrs. S. Sambasivam Pillai and Ramaswami Goundan, surki mortar for the masonry and cement and sand for pointing, etc., being supplied departmentally.

Cement concrete in foundations and all the reinforced concrete work were done departmentally.

The laying of concrete in foundations was started at the north abutment on 15th July 1929. A memorial stone was laid in this abutment on the 5th August 1929 by His Excellency Sir Norman Marjoribanks, the then Acting Governor of Madras.

The deck-slab of the last span was completed on 20th June 1931, the whole of this somewhat imposing work thus taking less than two years to complete.

Special features and details of work.—This is the first open-spandrel type of ribbed arch bridge to be constructed in the Madras Presidency.

The arch-ribs are of parabolic shape with a span of 60 feet and a rise of 12 feet. The width of each rib is 1 foot 3 inches and the depth varies from 1 foot 6 inches at crown to 3 feet at the haunches. The weight of each individual arch rib is about 18 tons. One was pre-cast experimentally on the ground and raised into position but the handling difficulty was so considerable that this method of construction had to be abandoned. Timber centerings at such a height were disqualified as too cumbersome, and finally, three-hinged steel arch centerings were adopted. A pair of steel arches was used for each rib. Each half of an arch consisted of a bow-string type of steel truss. The two trusses forming an arch was connected by a steel pin 2½ inches diameter at the centre of the span. The haunch ends were supported on eccentric pins resting on special cast iron blocks placed on masonry corbels at the sides of the piers. The eccentric pins were readily rotated with the aid of a box spanner and the easing of the centerings presented no difficulty.

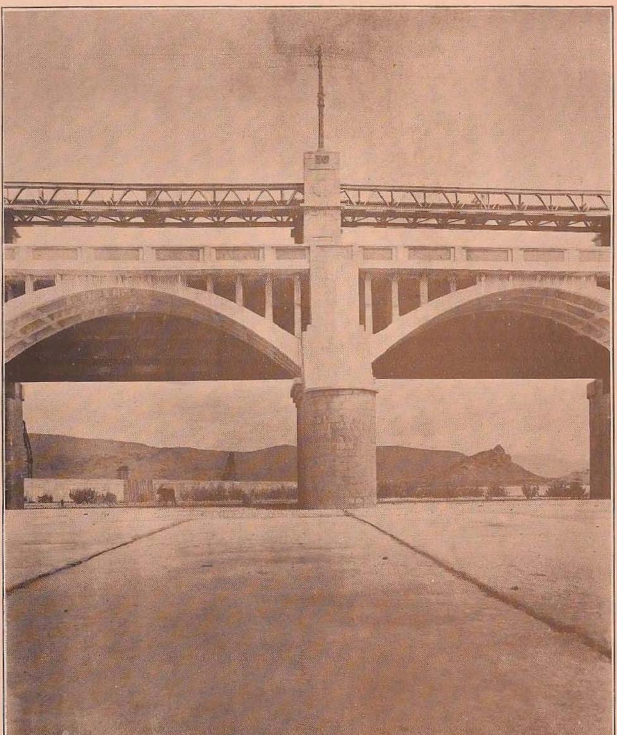
The steel arches were braced together by angles, and planks were laid over these arched trusses so that the whole formed a complete wooden arch over the full width and length of the span of the bridge. Wooden side forms for the reinforced concrete ribs and braces were attached to the planks. All the four ribs and the braces in each span were concreted in one day without cessation of work.

After removal of the rib centerings, the forms for the columns, tie-beams and deck slab were put up. The T beams and deck slab of each span were also poured in one continuous operation. There was some trouble at first with timber forms for the reinforced concrete work on account of warping and these were later replaced by sheet steel forms, which served very well, not only for the above work but also for the moulded parapets, kerbs, etc.

A small hand roller 6 feet long and weighing a quarter of a ton was found very helpful for the quick consolidation of the slab concrete.

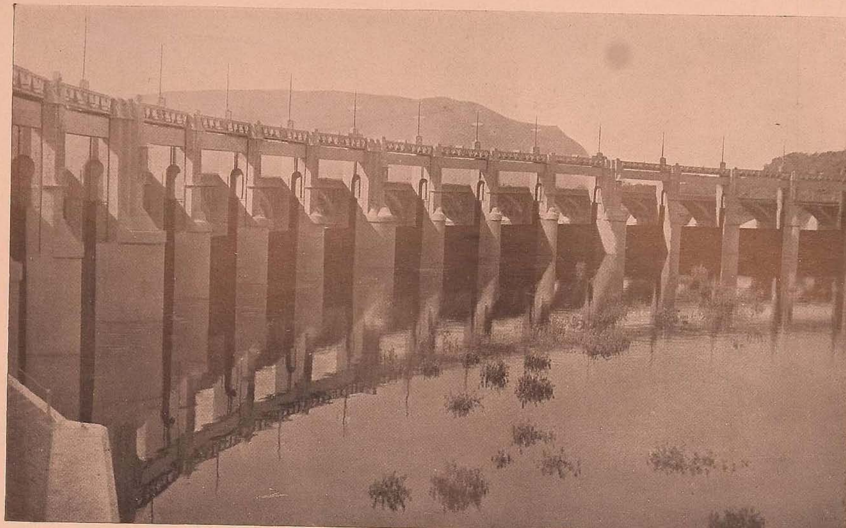
Super-elevation.—As the road runs on a curve of 800 feet radius a super-elevation of 0·38 feet for a width of 18 feet of roadway has been given. This super-elevation was effected by casting of the different rows of columns to different heights.

PLATE No. XXV.



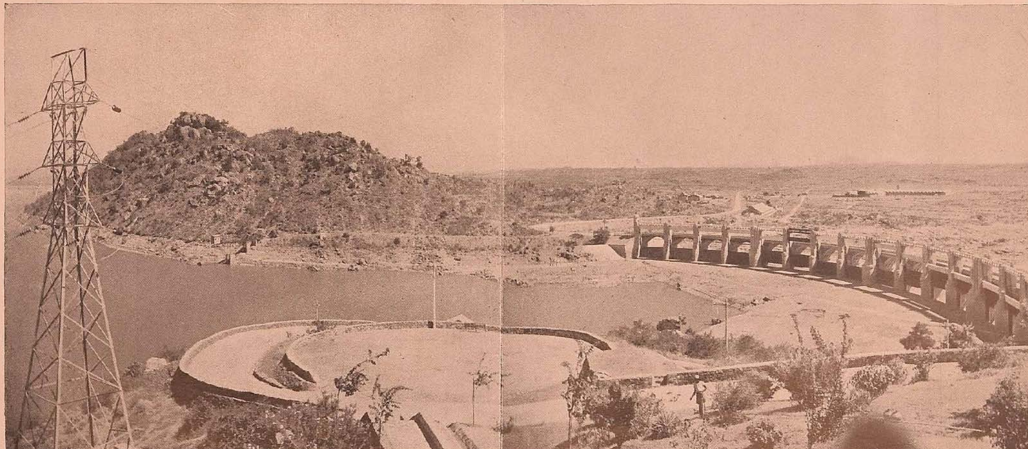
VIEW SHOWING ARCH-RIB CONSTRUCTION OF SURPLUS BRIDGE.

PLATE No. XXVI.



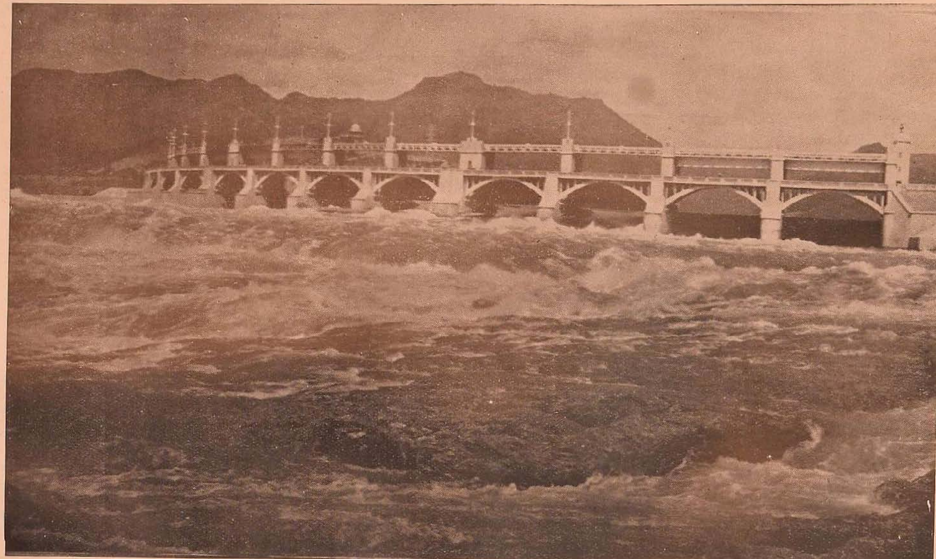
ELLIS SADDLE SURPLUS SLUICES.

PLATE No. XXVI-A.



ELLIS SADDLE SLUICES COMPLETED.

PLATE No. XXVI-B.



FLOODS THROUGH ELLIS SADDLE SURPLUS—REAR VIEW.

Provision for expansion and contraction of the R.C. slab.—To allow for temperature variations causing expansion of the deck-slab the masonry of the piers on which the ends of the slab rest was plastered smooth with cement mortar and two layers of oiled paper of the required width were spread before laying concrete.

During laying of the concrete for the slab a thin plank with wedges was fixed between the ends of the slab and the masonry face of the pier adjoining it. The plank and wedges were removed after the concrete had set and the $\frac{3}{4}$ inch gaps thus produced were filled with hot asphalt and jute fibre to serve as expansion joints. The road surface of the bridge was finished by laying a wearing course of 3 inches of 1 : 2 : $3\frac{1}{2}$ cement concrete divided at 30 feet intervals by " elixoid " expansion joints. These joints have proved very effective as they do not ' bleed.'

Floor of the vents.—The flooring consists of 1 foot 6 inches depth of what was known on the Project as red cement concrete of 1 : 3 : 6 mix. This is a concrete in which 20 per cent of the weight of the cement is replaced by surki. The floor of the vents has a rising slope of 1 in 16 from the front edge up to the steel sills of the sluices and is then given a fall of 1 in 200 in rear.

Retaining walls of random rubble surki mortar have been provided in front and rear of the floor, the width of the walls is 3 feet and the depth varies from 4 to 6 feet according to the depth at which suitable soil upon which the masonry retaining walls can be built. In the first span where hard rock was met with, the depth of the rear retaining wall is as little as 2 feet.

Grouting of ground under front apron floor.—The disintegrated rocky ground under the upstream apron floor was given special treatment as it was suspected to be fissured. It was drilled at 10 feet intervals in both directions to a depth of 10 to 12 feet and grouted with a liquid grout of cement and surki in the ratio of 5 : 1 before laying concrete for the floor.

Slits in floor in rear of shutters to relieve the upward pressure.—Vents $\frac{1}{2}$ inch wide and 9 inches long extend down to the bottom of the concrete floor downstream of the sill for relieving uplift pressure. They are spaced at 5 feet intervals along the sill.

Surki mortar for masonry.—This is the only work in which lime-surki mortar was used instead of cement. Surki mortar 1 : 2 : 4 (surki : lime : sand), being found cheeper than even 1 : 6 cement mortar, was used in the work for all masonry. No other reason for not using cement mortar for the whole of this work is forthcoming. The required proportions of unslaked, pulverized lime, sand and surki were mixed and fed into power-driven mills where water was added and the mortar ground, slaking of the lime being effected only while grinding.

The surki mortar thus manufactured was found to have hydraulic properties.

Provision for tram traffic on the bridge.—A single permanent track with guard rails and tie bars has been laid imbedded in the 3 inches wearing surface of the road over the bridge the top of rails being set flush with the top level of concrete. The centre of the track is kept 6 feet away from the face of the upstream parapet of the bridge. The above arrangement allows of the simultaneous use of the bridge by road vehicles and trains of tram trucks.

Apron and apron retaining wall in rear of the surplus sluice bridge.—The off-take from the surplus sluices takes the course of the existing natural vari called the 'Thottilpatti vari' down to the point where it rejoins the river. The original deep bed of the vari about 1,200 feet from the sluice line was 40 feet below the sill level of the surplus sluices. It was first proposed to negotiate this fall or drop of 40 feet by means of 3 or 4 masonry drops spaced 100 feet apart with aprons between the drop walls. Rough estimates were prepared and the scheme was dropped as it was found that the cost would be about Rs. 15 lakhs and the circumstances did not warrant such a costly scheme at the outset, it being considered preferable to allow the surplus water to cut away the softer rocks before coming to any decision as to the position of those drop walls.

The soil and sub-soil in rear of the surplus sluices for about 500 feet consists of very mixed disintegrated soft quartzite and hard granite. The small surplus flow allowed through the sluices during the 1934 and 1935 floods—both being bad years with very weak monsoons—has shown that the bed of the channel in rear of the surplus sluices is liable to considerable scour, and deep pockets and gullies have been formed in the softer masses of rock in rear of vents 9—12. At the time of writing, there has not been sufficient flow available to clear away much of this soft material by methodical scouring. When this becomes possible, and the harder rock is exposed it is likely that extensive cushion walls will have to be constructed so that the surplus discharge may be dropped in successive stages down to the point where the bed of the channel ceases to scour. Since the water will, of its own accord, trace out and remove all the weaker material, it is expected that very little excavation will be found necessary and rapid construction of the cushion walls will thus be possible during the brief season of each year when water level in the reservoir is below the sill level of the surplus sluices. One or two small masonry cushion walls have already been constructed between the harder rocks at the bottom of the gulley in the channel bed in rear of vents 9—12. These may be incorporated with the higher and more massive walls to be constructed hereafter. The piers and abutments are protected by masonry cut-off walls resting on fairly hard foundations and constructed in front and rear in line with the returns of the abutments, with a solid concrete floor 1 foot 6 inches thick laid between the cut-off walls. In addition to these, another long apron was constructed in rear further to safeguard the pipers against any serious cutting back of the surplus course.

The apron is 3 feet thick, 109 feet 9 inches wide and extends from the rear cut off wall to a retaining wall founded mostly on hard rock, but which may, in course of time, require further protection as indicated above.

The apron is of cyclopean masonry in surki mortar. Bondstones 3 feet deep and at 8 feet centres either way were first placed, with a one-foot layer of masonry built between. The remaining 2 feet depth of masonry was made up of large hammer dressed squared stones measuring about 2 feet × 2 feet by 2 feet set in surki mortar. A thin layer of fine cement concrete 1 : 3 : 6 was laid over the above apron to give a neat finish to the surface, though the life of this surface is somewhat doubtful. The retaining wall is of coursed rubble, third sort, and of gravity section with the front or downstream face vertical. The depth of the retaining wall is as much as 35 feet in places where good hard rock was not found at higher levels. The top 2 feet of the retaining wall is finished with cement concrete 1 : 2 : 4 with 1 inch broken stones, reinforced with two rows of old 24 lb. rails running throughout the length and anchored in masonry to enable it better to withstand the disruptive force of the water passing over it.

The rear apron has been divided into four sections by masonry walls built radially in line with three abutment piers of the bridge and to a height of 10 feet above the apron level so as to prevent cross or lateral currents developing and also to facilitate repairs in one section of the floor without interruption to flow of water through the sluices in other sections. At the flanks of the apron, side walls in extension of the abutments are also constructed to the same height as the above dividing or partition walls. The partition and end walls are built of coursed rubble, in surki mortar, the exposed faces being single-line dressed and pointed with cement mortar to be in keeping with the adjoining masonry of the piers and abutments of the bridge.

The slopes of the earth embankment above the side walls at ends and also the earth slopes for a distance of about 60 feet in front of the bridge have been finished with a cement concrete facing 6 inches thick 1 : 3 : 6. The concrete is provided with horizontal ledges on its under face, 3 inches × 3 inches projecting ribs at 3 feet spacing run horizontally throughout the length projecting into the earth so as to prevent the slipping of the concrete down the bank. To give a neat appearance, horizontal and vertical lines have been cut on the surface to a 'V' section and to a depth of about ½ inch, marking off the surface into panels of about 3 feet × 3 feet.

The concrete work and the supply of surki mortar for the masonry were done departmentally. In the interests of quick execution the earthwork and masonry construction was shared by four pieceworkers.

Surplus sluice shutters and overhead regulating bridge—Tenders and selection of contractors.—Tenders were invited for the supply of the 60 feet × 20 feet steel sluice gates, the details of the gates to be designed by the tendering firms. The following four tenders were received :—

(1) *From the Public Works Workshops, Madras.*—This was the lowest tender but the gate design was considered to be the weakest of all and the gate was also the lightest. The Public Works Workshops, Madras, had had no previous experience of the construction of gates of such a size. In the event of their estimate being exceeded during execution, a not unlikely contingency, the excess would have to be met by the project, while such would not be the case with private tenders. Under the circumstances this tender was set aside.

(2) *Tender by a Zurich Firm.*—Since mere outline sketches of the shutter design were sent by this firm, detailed scrutiny was not possible and this tender also had to be set aside.

(3) *and* (4).—Messrs. Ransomes and Rapier, and Glenfield and Kennedy were the other two tenderers. Glenfield and Kennedy's tender was the higher to the extent of Rs. 1 lakh but it was accepted for the reason that their designs were of massive construction. Ransomes and Rapier's design provided for lighter sections and the constructional details appeared to be too slender for a work of this magnitude and importance.

The multiple girder design of the Glenfield and Kennedy shutters ensured better support for the skin-plating and more even distribution of total load on to the end frames and rollers. Their rollers and roller cages were also of a better type.

Glenfield and Kennedy had a reputation for large high class irrigation sluices and their designs were preferred on account of their massiveness. Further, as the construction and supply of the irrigation sluices had already been entrusted to that firm, it was held advisable, from the constructional point of view, to obtain the whole of the sluices from them. The contract for the surplus works included the supply of sixteen free-roller sluice gates each 60 feet × 20 feet with rollers, rocking paths, staunching tubes cast iron roller grooves, staunching faces, rolled steel sill girders, built-up steel counter-balance boxes, steel channel guides for balance boxes, high level steel bridge to carry the operating gears, hoisting chains and the operating gear consisting of sprocket wheels, head-stock, shafting, roller bearings, etc., the operating gear being suitable for hand operation when desired. Electrical equipment comprising motors, contractor panels, limit switches, and also galvanized steel netting for fencing in the sides of the operation bridge were included in the contract.

CHAPTER XXXIII

"F" Saddle Surplus Weirs.

In the original designs for the Mettur Dam prepared by Col. Ellis, the provision allowed for the maximum capacity of the surplus sluices was 253,100 cusecs. This figure was not revised when the estimates were revised and submitted for sanction early in 1924. But after July 1924, when the record floods in the Cauvery occurred, the necessity for providing increased surplus facilities arose. It has been calculated that the maximum discharge of the Cauvery at Mettur in July 1924 came to 456,000 cusecs. One of the reasons for which the site of the dam was shifted to the upper site was to admit of increased surplus facilities so that, in addition to the Ellis saddle which was the originally designed surplus site, the F saddle on the right side of the river might also be utilized. However, up till the end of 1933, only the Ellis Saddle surplus escape had been constructed, the question of opening up the F Saddle escape having been left in abeyance.

From an examination of the files of the Engineer-in-Chief, the following information has been gathered :—

The design for the Ellis surplus sluices was taken up in December 1927, and as the question of the co-efficient to be adopted in the formula for the discharge over the escape was an important factor, Mr. Mullings was of the opinion that a value of 3·1 for C in the formula $Q=c.l.h.3/2$ would be suitable. There was, however, some discussion on this subject in the office of the Engineer-in-Chief and finally Mr. Mullings accepted a value of 3·4 for C and the number of vents in the surplus escape which he had originally intended to be 20 was eventually reduced to 16.

In August 1928, Mr. Mullings drew up a note on the maximum flood discharges in the river Cauvery at Mettur, the facilities for surplus provided in the dam and the probable reservoir levels for the stages of flood that had actually occurred in July 1924. In this note, two sets of conditions were examined by him. The first was that of the actual 1924 floods with the rises and falls that had been computed from information gathered at stations higher up the river. For the surplus discharge he assumed a co-efficient of 3·4 for the Ellis Saddle escape as had been approved by him in January 1928 and he also took the flood-moderating effect of the reservoir above the ordinary full reservoir level.

Before going further, it may be as well to note once again the main features of the dam-design on which this note was based :—

Sill of the Ellis Saddle Surplus sluices	+ 770
Full Reservoir level	+ 790
M.F.L. assumed under present conditions	+ 796
Road level over the dam	+ 801
Top of parapets with weep holes in the parapets at road level.	+ 804·5
Level of gravelled approaches on either side of the dam	+ 801

The section of the dam is designed to suit an eventual F.R.L. of +800, with a maximum flood level of +805, the top of the dam being eventually proposed to be raised to +810. Mr. Mullings came to the conclusion that for the first set of conditions referred to above, the water-level in the reservoir would have risen to 795·4, and it was presumably on the basis of this that the M.F.L. was taken to be 796. For the second set of conditions he assumed a flood 25 per cent in excess of that received in July 1924 right through the flood period and, in calculating probable water-levels in the reservoir under these conditions, he allowed not only for the discharge through the surplus escapes with the co-efficient of 3·4 but he took into consideration a supplementary flow through the irrigation sluices of 20,000 cusecs under these exceptional conditions, and also the flood moderating effect of the reservoir. He found that the maximum flood level of the reservoir under such conditions would have been 798·7. As this appeared to be safe for the design of the dam actually adopted, the question of providing an additional surplus escape at F Saddle was dropped.

In November 1929, however, Mr. Mullings, as Consulting Chief Engineer, Cauvery-Mettur Project, again took up the question and expressed the opinion that the value of C should be only $3\frac{1}{3}$ as against 3·4, the figure he had previously accepted with some reluctance. He was also of opinion that the reservoir should be safe for a discharge of 500,000 cusecs and he advocated the construction of the F Saddle escape after taking into account the assistance the irrigation sluices could render in passing the flood discharge up to the capacity of the channel in rear, viz., 30,000 cusecs. After further discussion with the then Engineer-in-Chief (Mr. Dowley), Mr. Mullings expressed the opinion that "we must be absolutely safe for all conceivable conditions and not only for all known conditions," but that he was quite willing to leave the matter to his successor (Mr. Hart) for settlement.

The question whether the Cauvery basin above Mettur was or was not outside the influence of cyclones and whether it was not possible to get heavy and continuous rain during the south-west monsoon both in the ghats and in the interior of the catchment of the reservoir, was referred to the Director-General of Observatories, but his reply was not quite definite. The Director-General stated that it was exceedingly improbable that heavy and continuous rain would fall during the south-west monsoon both on the ghats and in the interior but he added that it was possible to have heavy cyclonic falls of rain throughout the catchment during the months of October and November. This opinion of his did not lead to any definite conclusion on the question at issue and, as Mr. Mullings remarked " we were left as we were."

In May 1930, Mr. Mullings again took up the question and he then came to the conclusion that it would not be safe to allow any higher value than his original figure of 3·1 for C owing to the restricted access from the main reservoir to the site of the Ellis surplus; and he was of opinion that a flood discharge of 570,000 cusecs, that is, a discharge 25 per cent in excess of the maximum of 1924 flood must be considered as reasonable. He came to the conclusion that for these conditions an escape at the F Saddle would be necessary and he suggested that the ground here should be cleared to + 784 and an earth bank formed over it in such a way that the bank would breach when water-level reached + 795 or + 796. No further action was taken on this suggestion, as Mr. Dowley was of opinion that the value of 3·4 adopted for the co-efficient C needed no reduction.

During Mr. Hart's regime the matter was not further considered. The question was again raised by Mr. Barber, the Superintendent of Works, and the whole question was re-examined and the calculations and diagrams prepared in the past were again revised and fresh diagrams drawn.

In the first place, it may be mentioned that the deciding factor in this examination was the value of the co-efficient to be adopted in the discharge formula for the surplus escape at Ellis Saddle. Mr. Mullings started with a value of 3·1, accepted later a value of 3·4 when passing the design and about two years later, he came to the conclusion that the value that he had adopted was too high and finally recommended a value of 3·1. Unfortunately we have not got values derived from actual observations for such large surplus escapes as have been constructed for the Mettur Dam. The value of 3·4 originally accepted was taken from 'Parker's Control of Waters,' where a value of 3·4 and even up to 3·5 has been advocated, but with the proviso that the slope in rear should be at 1 in 10. At the Ellis Surplus, the rear slope is only 1 in 200, so far as the sloping apron is concerned. We have got some experimental values for the surplus sluices in the Krishnarajasagara Dam as a result of joint gaugings by Madras and Mysore and these give a value of 3·03 for the +80 sluices. The co-efficient worked out was for a depth of from 10·5 to 11·5 with "clear" or weir conditions. These sluices are only small vents 10 feet × 20 feet and there would be a lot of side contraction in them, whereas our vents are 60 feet × 20 feet and with such large vents we may reasonably expect a slightly higher co-efficient. The Chief Engineer for Irrigation, Diwan Bahadur R. Narasimha Ayyangar, was, therefore, of opinion that until we had the results of actual observations on our surplus escape, it would be safer to adopt a value of 3·1 as was originally suggested by Mr. Mullings when he took up the design of the surplus escape and eventually recommended by him in May 1930. There remained, however, the fact that we could not afford to wait for further experimental observations of the value of C, as a maximum flood might occur at any time, even before we had concluded our experiments. It was essential that a decision should be reached on the point as early as possible to ensure the safety of the dam.

The next point to be considered was the maximum discharge that we might expect in the river. It would be but reasonable and prudent to assume that we might receive a flood which would be somewhat higher than the maximum flood previously experienced.

The maximum discharges of the floods in the Cauvery at the Upper Anicut have been in—

1896, 313,000 cusecs
1911, 357,360 ,,
1924, 462,500 ,,

and this would have been about 488,000 cusecs but for the breaches that occurred higher up the river. Seeing that these figures have been on the increase, it would be reasonable to allow for a possible higher flood exceeding that of 1924 by 20 to 25 per cent.

In the case of the Krishnarajasagara Dam, the original design for the surplus escape of the dam as allowed for in the project estimates was for a discharge of 250,000 cusecs. It is observed that, during the peak stages of the flood of July 1924, the maximum discharge for a 12-hour period was 279,000 cusecs, as per corrected inflow in the regulation statements received from Krishnarajasagara. In the pamphlet printed by the Mysore Government regarding the Krishnarajasagara, the figure for maximum discharge was taken as 290,000 and they provided for a surplussing capacity of 350,000 cusecs. The above figures would indicate the general lines on which it was considered prudent that we should proceed.

In view of these factors the diagrams prepared by Mr. Mullings in connexion with his note of August 1928 were revised. A value of 3·1 for C was adopted in the revised calculations and the flood moderating effect of the reservoir was taken into account at the higher stages. It was also assumed that when the discharge to be passed is in excess of about 300,000 cusecs a supplementary discharge is sent through the high-level irrigation sluices also as a measure of safety. Though the discharging capacity of these sluices is nearly 50,000 cusecs, a maximum discharge of only 30,000 cusecs has been assumed for our purposes, this being the discharge that the channel in rear is capable of passing without overflowing its margins. For these conditions it was worked out that with the 1924 flood stage as it occurred, the maximum flood level in the reservoir might have reached +795·50. But if we had to allow for discharges 25 per cent in excess of the 1924 floods, culminating in a peak discharge of 456,000 + 114,000 or 570,000 cusecs, the water-level in the reservoir would have risen to + 800, if the F Saddle escape were not provided. It was not considered advisable to allow the water to rise to such a stage under existing conditions, especially with the possibility of waves breaking against the parapets, and it was therefore proposed to cut down the F Saddle to a reasonable level and have an additional surplus escape there. Under normal working conditions, once the south-west monsoon season is past, the reservoir will be maintained at about +790 in order to store as much water in it as possible. With a water-level of +790 and the surplus escape fully open, it is just possible to dispose of about 296,200 cusecs, 266,200 cusecs being through the Ellis Surplus and the emergency discharge of 30,000 cusecs through irrigation sluices together, giving a total of a little under 300,000 cusecs. Floods of over 300,000 cusecs will occur at very rare intervals and the F Saddle escape as now proposed would come into operation only when the reservoir level rises to +791, i.e., when the surplus discharge exceeds 316,400 cusecs. Taking into consideration the flood moderating effect of the reservoir, at the higher levels, a length of escape of 800 feet would, it was calculated, keep the maximum flood level at 798·8 for conditions with a discharge in excess by 25 per cent of the 1924 floods. The ground at the F Saddle was to be cut down to +791 with a masonry wall crest at +791 founded upon hard rock, and the rear sloped to a fall of 1 in 1,600. The main object of keeping this saddle at +791 and not at +790 was that there should be no flow over it during all ordinary floods or even high floods up to 300,000 cusecs. We should try to maintain a reservoir level of +790 during the greater part of the irrigation season if possible, and in case of any sudden rise in the reservoir level there should not be any flow down the F Saddle escape which would damage the road dam in the valley lower down.

The cost of this cutting was roughly estimated to be within 2 lakhs and this was considered but a small amount to pay for the insurance of such a costly work as the Mettur reservoir. Mr. Mullings had proposed to cut down the escape to +784 and form a bund over it which would breach when water rose to +795 or +796. As mentioned already, occasions when floods of more than 300,000 cusecs occur will be very rare and a bank that might have become consolidated for a number of years might not breach all along its length when a sudden emergency arose. Hence it was proposed to have an escape at +791 which would be at a suitable level above the F.R.L. which it was proposed should be maintained at present. The F Saddle escape would then come into operation only when the discharge to be passed down the river was in excess of 316,400 cusecs.

It will be observed that in the two main roads running through the Mettur township to the dam there are two road dams across the valley which forms the continuation of the F Saddle. Every time the water level in the reservoir rose above +791, there would be water flowing over these road dams in the valley, and the fall being great, there would be heavy scour preventing regular traffic over the road dams, and in such a case the approach from the quarters of the staff located at Mettur to the dam site would be cut off unless the staff resided on the Salem side of the reservoir. This aspect was taken into consideration and a suggestion was made to provide a foot bridge over the F saddle cutting, but in view of the fact that the F saddle would be submerged only very rarely and the purchase of a motor launch for use on the lake was under consideration this proposal was dropped.

In February 1934 the Superintendent of Works submitted an estimate for cutting down the F Saddle. It provided for an escape with a crest at +791, 645 feet in length at the eastern portion of the Saddle, and another 160 feet in length on the western side, a high spur occurring between the two. The estimates for the two cuts were Rs. 1,05,600 and Rs. 94,400 respectively. It was anticipated that the amount of rock cutting in the western cut would be very heavy, but when the proposals were sanctioned and the work was carried on in 1934, the extent of solid rock was found to be far less than had been supposed, and the cost was accordingly less than had been assumed the actual booked outlay being only Rs. 1,15,983. Credit was received for much of the useful building stone excavated from the top of the saddle which was later utilized in the construction of the foundations for the hydro-electric power station. The crest walls and abutments of the two weirs were constructed entirely with the stone excavated from the cutting. Since good rock foundations for the walls were met with near or at the surface of the cutting, their construction involved very little material and labour. In framing the estimate it was considered advisable to provide for masonry aprons in rear of the crest walls, but actually no such aprons were found necessary. With a depth of 7 feet over the crest the F Saddle is capable of surplussing about 40,000 cusecs. The work was completed before the end of 1934.

CHAPTER XXXIV

Annual Surplussing Arrangements during Construction.

To the uninitiated, the means by which a dam can be built across a river without interrupting its flow is always something of a mystery, and many a time the casual visitor to Mettur during the period of construction has asked "How is it done?" Well may such a question be asked, for the whole programme of work in the river-bed requires very careful planning in advance.

Without fairly accurate data as to the extent and duration of floods, as well as information regarding the "dry weather" flow, the Engineer might find himself in a fix. Since the river-bed is the lowest part of the work the river must be permitted to flow through or over the construction there until such time as the work reaches such a height that the flow can be diverted through some other channel at a higher level.

As we have already seen, the first essential is to divide the river-bed in such a way that the dry weather flow in the river may be diverted from one side of the bed to the other or split up in such a way that reasonable sized areas can be kept dry while foundations are excavated and refilled with concrete or masonry. The comparatively low-walled coffer dams were formed with this object. When one portion of the foundations is thus brought to river-bed level or a little above it, the dry weather flow is diverted to flow over it, thus releasing the area where the stream previously flowed for similar treatment.

Generally speaking, when the entire width of the river-bed has thus been covered, vents called construction sluices are built over the masonry at the lowest bed level, the dry weather flow being made to pass through these while the masonry on either side is further raised to some pre-determined level each season. These construction sluices must be so designed that they can be completely shut off and built up solid with masonry when the work has reached an appropriate stage—that is to say, when some other outlet through the dam constructed at a higher level is ready to receive the flow. Such an outlet will usually be a set of 'low-level' or 'scouring' sluices. In the case of the Mettur Dam the Hydro-electric pipes fitted with suitable valves performed this duty, being situated at a level about 15 feet above the river-bed, and on one side of it. It may be remarked that, wherever possible, the depth of water in front of a set of temporary construction sluices should be kept as low as possible for, with the increase of head, the closure of these sluices may become increasingly difficult and in any event will call for considerable ingenuity and forethought if a really satisfactory closure is to be effected. An unusually cheap and simple method worked out by the author for the final closure of the construction sluices at Mettur will be described in another Chapter. (*See* Part II, Chapter XVII.)

Now, construction sluices are intended to pass only the maximum dry weather flow that is normally to be expected. As soon as the flood-season commences and the flow at once increases considerably, it is passed over the work in the river section and all work there comes to a halt until dry weather conditions are restored in the following season. When the work is sufficiently advanced, the falling flood can be drawn off through permanent sluices situated elsewhere provided they are at a lower level than that of the masonry in the river-bed.

In the Cauvery, the working season in the river-bed was usually from January till the middle of June, but a particularly early or late monsoon could never be foreseen even to within a month of the normal date, so there was a good deal of speculation as to the actual duration of the working season, but where one season proved unusually short the next might be unusually long, so on the whole no very great variation of the programme was necessary.

Before the floods commence, it is essential that the work in the river-bed be secured against damage and that the downstream toe of the dam in particular be well protected from scour. If one can assume in advance that a normal high flood will have to be dealt with, it is not very difficult to provide the necessary protection by constructing a suitable water cushion in rear of the spillway. The rear coffer dam wall was accordingly designed to hold up the requisite depth of water to form an efficient water cushion. Small vents were left in the wall in order that the water could be drained off when the flood subsided. As the drop over the dam increased, this wall was raised in two successive years to form a deeper water cushion.

Let us now study very briefly the actual conditions in the river section during the successive years of construction of the dam.

When the 1927 flood season commenced only the coffer dam walls had been constructed up to their first stage and very little excavation had so far been done, and that consisted mainly of the removal of rock boulders and shingle overlying the river-bed within the right coffer dam. The flood passed harmlessly over the walls.

In 1928 the conditions were similar, but some of the coffer dam walls had been raised and excavations had extended. At the end of that flood season a quantity of sand and silt had to be removed from the excavations before work could be resumed. The only masonry constructed up till then was on the high rock at the right bank which had been constructed as a bulk-head between the river and the "deep-hole" excavations.

By the time the flood came down in 1929 work in the river-bed had made some progress.

The masonry had been raised to river-bed level in the right coffer dam and the walls for the construction sluices had been raised some 6 feet above their sills. On the 6th June 1929, work was still in progress when the floods started unusually early and on the following day the entire work in the river-bed was submerged. While the water was rapidly rising, strenuous efforts had to be made to remove the concrete mixers, rails and other small plant from the river-bed to a place of safety, within the course of two or three hours. Between the construction sluices and the high masonry on the right bank a large block of masonry had been completed to a somewhat higher level than the sluice area in order that work might be resumed there some considerable time before the sluice area again became accessible when the flood fell. On the 1st October 1929 work was again in progress on this portion of the dam.

By the end of June 1930, when the first floods of that year came down, the masonry above referred to had been raised to a height well above high flood level and the track for the Red Tower had been constructed over the rear of the westernmost set of construction sluices. Very little construction had so far been done in the central coffer dam but a cut-off wall had been raised on the left bank to protect the excavations there as also the black tower which was still in course of erection. The flood passed over the work in the river-bed without causing any appreciable damage, as the drop, even over the construction sluices, was only a few feet. When the 1931 flood arrived the foundations of the dam for the full width of the river-bed had been raised several feet above bed level, averaging about 10 to 12 feet. The Red Tower by this time had been working for nearly a year and the masonry on the right bank had risen uniformly to about +677 level or 52 feet above river-bed level. On the left bank progress had been slower and there was a race against the flood to raise the bulk-head wall in time to prevent the flooding of masonry works in rear. Till now almost the full width of the river was available to pass the floods.

The width of the spill way was now restricted to 630 feet in order that the works on either flank should not be endangered, and when the 1932 floods arrived the masonry in the spill way was between 30 and 40 feet above river-bed level. The flood that year came down rather unexpectedly and the masonry in the rear portions of the spill way was still of rather irregular shape when work had to be suspended. In consequence, the water falling from a height on to the rear ledge did a small amount of damage to the ledge and Tower Track in one or two places, gaps in the masonry above causing the water to accumulate there. Despite this, it was surprising to observe that stones laid on the rear lip of the dam only an hour or two before the water passed over them were still in position and undisturbed at the end of the flood season. Had lime mortar been in use instead of cement there is no doubt but that much of that green masonry would have been washed away.

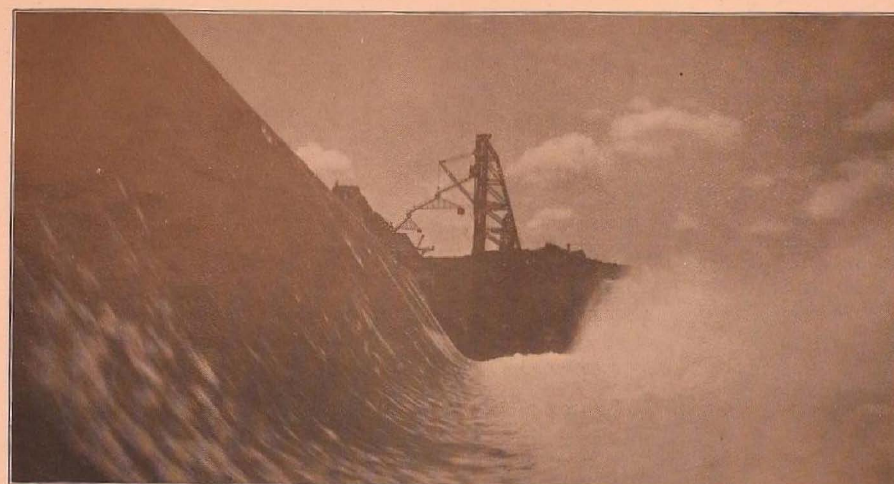
The 1933 flood demanded very careful preparation in advance, for the crest of the spillway had now risen to +725, a hundred feet above the river-bed, and it was necessary to pass the bulk of the Cauvery flood through the 630 feet spill way with this terrific drop in rear. It might be asked, "Where was the necessity to raise the surplussing section to such a height?" The answer to this is that, even with the crest at this level, there still remained 76 feet of dam to be constructed during the following brief season, and a carefully prepared programme of work showed that it would have been very difficult to raise the dam to a safe height before the 1934 floods arrived if a lower crest level had been adopted to pass the 1933 floods. It was essential that the whole of the 1934 floods should be passed through the surplus sluices and that the masonry in the temporary surplussing section should be raised above the highest reservoir level.

Now, in order that the rear of the dam in the spill way section should suffer the minimum amount of damage, a stream-line section was required. The crest of the spillway was therefore constructed in a curve on the downstream lip and the junction of the rear face of the dam with the ledge carrying the Tower Track was given a reverse curve to prevent impact at the bottom of the fall. Thus, the flood-water passed smoothly over the crest, down the 1 : 1·41 rear slope, and was then deflected horizontally to discharge over the ledge at the foot. The Tower Track ledge was at +648 level and above normal flood level, so a clear discharge was obtained into the water cushion formed by the rear coffer dam wall. With the flood at its height the jet shot some 50 to 60 feet clear of the ledge, well away from the rear toe of the dam. It was estimated that some two million horse-power was actually dissipated when the 1933 flood was at its height, and it was soon observed that portions of the coffer dam wall in rear had been displaced.

To avoid the necessity of cutting away a large mass of masonry to obtain a bond at the top of the spillway when the dam construction was to be resumed, two courses of concrete blocks with curved outer faces were pre-cast and secured by means of anchor bolts to the masonry. The holes in the slabs were cast so that the ends of the bolts and the nuts which secured the slabs were counter-sunk flush with the face of each slab. The slabs were backed with greased paper to prevent the masonry in rear sticking to them and making their removal difficult when no longer required. On removal of the slabs a ledge was left in the rear face at the tangent point where the curve met the straight face, and, by means of the bolts which had secured the slabs new masonry constructed in their place was securely bonded to the old work. Had these blocks not been provided, elaborate scaffolding would have been required to support the pneumatic tools and workmen on the rear face. Blasting could not be permitted for fear of cracking or otherwise damaging the masonry below. The only alternative to the form of temporary construction actually adopted would have been to construct the top of the curved portion of the crest in brickwork or other soft material which, while strong enough to resist erosion, could be removed with pneumatic picks or "road busters." This would have increased both the time and cost of construction and demolition. Nevertheless, it was later regretted that an easily removable skin of some sort was not provided over the top of the spillway for, at the end of the flood season, it was found that a variety of small shellfish had taken up its abode in the roughly finished masonry and the clearing of this surface was very difficult though wire brushes, air and water jets and pneumatic picks were all employed to scour and scarify the surface of the stone before further construction was started. To remove the top layer of stones in this random rubble construction would have involved blasting over the entire surface and this could not be tolerated. Subsequent floods have revealed a distinct line of seepage at the junction between the new and old masonry, though it is seen to be diminishing each season, and in all probability will stop altogether in a year or two. It is too slight to be of any real consequence but the rear face of the dam is somewhat disfigured by the lime deposited on the face below the junction.

The normal section of the dam has a 1 : 1 batter in rear below level +670 but in the spillway the slope of 1 : 1·41 was continued downwards and developed into a parabolic curve to join the horizontal ledge above the rear toe. This curved portion was faced with cut stone so as to be as smooth as possible. At the end of the flood season it was found that the 90 lb. rail tracks on the rear ledge, which had been subjected to the full force of the water

PLATE No. XXVII



1933 FLOODS PASSING OVER SPILLWAY SECTION IN DAM.

descending over the spillway, had been ripped out in several places, together with the concrete in which they were embedded. A small area of the cut stone face towards the left flank of the spillway had also been stripped. The damage, however, was quite superficial and easily repaired.

As for the rear tower-track, situated 80 feet away at the bottom of the water cushion, it was found that this, together with the massive reinforced concrete foundations on which part of the track was constructed, had practically disappeared along with the greater part of the coffer dam wall still further in rear. Large masses of masonry of which the wall had been constructed, and which had successfully withstood previous floods in successive years, were found several hundred yards further downstream in the river bed! The bed of the river within 30 or 40 feet of the toe of the dam remained practically in its original condition and had not been scoured at all. We must attribute this to the ledge, the height of which caused the water descending over the spillway to strike the water surface in the water-cushion for away from the toe of the dam. The force of impact at that point was terrific, and the spray rose to a great height. When the wind happened to be upstream, one frequently saw the spray passing back right over the dam into the lake 100 feet above!

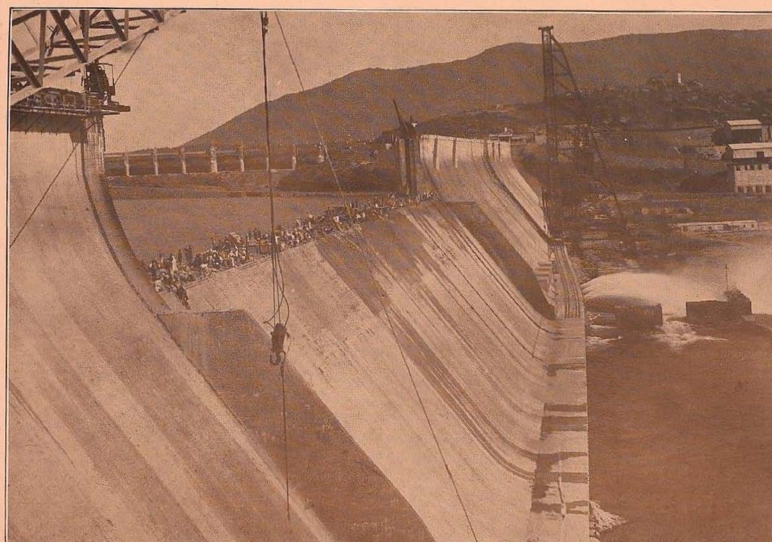
It was never possible to obtain a photograph of the spillway in operation when the discharge was very high as the entire site was veiled in a thick mist. Under more moderate conditions, however, when the wind was favourable, a good photo of the fall was obtained and is reproduced in Plate No. XXVII. It shows clearly how smoothly the flood passed over the dam in this 630-foot spillway, changing directions without any commotion as it reached the rear ledge. The line of white spray on the ledge is caused by the obstruction of the 90 lb. rails, though they projected only about $1\frac{1}{2}$ inches above the level of the ledge.

This passing of a Cauvery flood over the dam and dropping it about 100 feet was a somewhat awe-inspiring spectacle. It attracted visitors from far and wide, for never before had an artificial waterfall of such proportions been seen in this part of the country. It is unlikely, too, that those responsible for the work at that time will forget the moment when the rising flood reached the spillway level and commenced its wild descent which was to continue unabated for several months, for had anything serious occurred at the rear toe of the dam they knew that they would be powerless to do anything till the flood season was over. But the excellence of the materials and workmanship together with the safe design of the work left little or nothing to be desired and inspired in them complete confidence that it would stand the test.

As the 1933 flood abated, water was discharged through the low level sluices, and as soon as the water level in the reservoir fell to a foot or so below the spillway level the work of construction was very soon resumed. By the end of December 1933, the masonry had risen about 18 feet, and by the end of April 1934, the work was complete except for the road and permanent tramway construction and the erection of the parapet walls.

It had originally been presumed that the two towers would enter the river bed and complete the construction of the dam in the spillway section but it was evident to some (and certainly to the author of this book), that the possibility of the tower tracks in the river bed withstanding the onslaught of the 1933 floods was very remote, and events subsequently proved their surmise to be correct. The time required to reconstruct the rear coffer-dam wall and to relay the tracks for the towers at the end of the flood season would have been very great. Accordingly, no attempt was made to restore them. The two towers were brought down to the flanks of the spillway which had not been affected by the floods, and three steam cranes were erected on the top of the masonry on either side of the spillway. Stone and mortar were railed along the top of the dam from either flank and lowered by means of these cranes to the level of the work in the spillway. Meanwhile, the towers were usefully employed mixing and delivering mortar, and the side jibs on the towers hoisted truck loads of stone bodily from the tracks at the foot of the dam and delivered them on the spillway. By these means the construction went ahead rapidly. While raising the masonry on either flank of the spillway in the previous season, masonry steps had been provided in the centre of the dam so that labour could easily reach the site of these works in the spillway from the top at any time. Temporary iron ladders were also provided on the rear face, and these, offering the shortest route to the works, were despite their great lengths, much used even by the women labourers. Though, during the course of the work, one or two men fell into the lake and were rescued without injury, there was not a single case of a fall down the rear slope of the spillway. In order that the work might be well distributed, temporary tramway tracks were laid alternatively on the upstream and downstream sides of the spillway area, the trucks of materials, lowered from the top of the dam by the cranes at either flank, being run out on these lines and dumped wherever necessary.

The raising of the spillway section is clearly illustrated in Plate XXVIII. As the work rose and the width of the dam section became narrower the number of masons employed had, of course to be reduced. The closure was completed well in advance of the 1934 floods which, as it turned out, were so small that the water level in the river did not rise above +774 at any time.



CONSTRUCTION OF MASONRY IN SPILLWAY SECTION (1934).

CHAPTER XXXV

Progress in the Construction of the Dam.

It would bewilder the reader if an attempt were made to describe the progress of construction in detail month by month. In the various reaches of this mile of dam so many methods of construction were adopted, each to suit the conditions obtaining there that to describe them would be quite beyond the scope of this book.

Briefly, two main methods of construction were adopted. The bulk of the dam between L.S. 615 and 2800 was constructed of concrete by the two great concreting towers. Here both upstream and downstream faces were built of coursed rubble, this being done by hand in one section generally while the tower in each case was working in an adjacent section. The speed of construction of the face walls, however, was such that it was often found possible to be raising the walls at the same time as the tower was laying concrete in one and the same section. The advantage of this method was that a tower was required to move from one section to another less frequently. Each time a tower moved half a day's work was lost; so, in the interest of the work, the towers were moved as little as possible.

In the sections of the dam not commanded by the two concreting towers, only a limited quantity of concrete was laid by means of what was erroneously termed the "Preliminary Plant" power-driven concrete mixers having capacities of $\frac{1}{2}$, $\frac{3}{4}$ and 1 cubic yard per batch. These mixers did yeoman service from the earliest days right up to the time of completion of the dam, and through this agency the greater part of the dam was actually constructed.

The wear and tear on these machines while used purely as concrete mixers was heavy and the renewal of mixer blades and liners was frequently necessary. When, however, they were used solely as mortar mixers, a function which they performed admirably, the wear and tear was very considerably reduced, the life of a set of blades being five or six times longer than formerly. Hence breakdowns and overhauls became far less frequent and a higher rate of outturn was maintained when the machines were employed as mortar mixers. As we have previously observed, a batch of mortar from a one-cubic yard mixer suffices for over two cubic yards of masonry; so, with a given number of machines, the rate of construction was more than doubled when masonry replaced concrete, sufficient masons being available to cope with the mortar supply from the mixers. This fact, no doubt, contributed considerably to the substitution of masonry for concrete and, generally speaking the great bulk of the dam outside the range of the towers was constructed entirely of masonry. The rate of progress of the masonry work surprised even the most optimistic. This class of construction had an advantage over the towers in that it could be carried out simultaneously in a hundred different places while the tower concreting was limited to the section in which a tower happened to be working. As a result the portions of the dam constructed in masonry rose at a more or less uniform rate.

The monthly rate of progress both in excavation of foundations and construction of the dam graphically shewn in Plate XIV has been tabulated and will be found in Appendices D and E. Construction was started in a very small way in June 1928 by the first construction division. By the end of that year 814,335 cubic feet of concrete and masonry had been placed. In March 1929 a second division was created, the first being then known as the Construction division, West, operating from about the middle of the river towards the right flank of the dam, while the new division known as the Construction division, East, operated from the river-bed towards the left flank. By the end of 1929, the two divisions had constructed 3,522,247 and 1,491,335 cubic feet, respectively, totalling a little over 5 millions cubic feet of concrete and masonry.

From June 1930, a third division was created, operating on the extreme left flank of the dam. By the end of that year the total outturn by the three divisions was over 13 millions cubic feet.

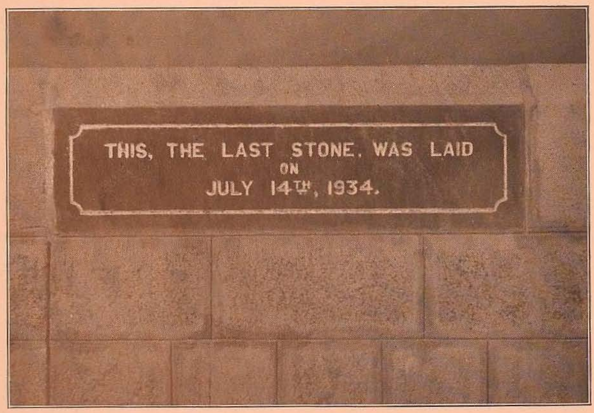
By 1931 a very high rate of progress had been attained, and previous records were broken. The end of 1931 saw 30½ millions cubic feet of concrete and masonry constructed. During the month of May alone 1,770,939 cubic feet of work was done. In 1931, the same high average was maintained and that year saw the total raised to 46,406,553 cubic feet. By this time a length of the dam had been completed (except for the road surfacing) from the extreme right flank up to the site of the high level sluices, i.e., from L.S. 4,900 feet to L.S. 5,280 feet.

As the work rose higher all along the dam, the rate of outturn began to decrease, the working area becoming more and more restricted so that the feed of materials had to be limited.

By the end of December 1933, the three divisions had turned out 32,932,913, 14,825,619 and 5,926,009 cubic feet, respectively, bringing the total construction to 53,684,541 cubic feet.

The third division, known as the headworks division, was closed, so far as the dam construction was concerned, at the end of September 1933, thereafter the work being completed by the west and east divisions, the former in June and the latter in July 1934.

PLATE No. XXVIII-A.



THE LAST STONE LAID IN THE DAM.

The total content of the dam is 54,620,050 cubic feet.

On the 14th July 1934, the last stone was laid on the parapet of the dam at its highest point above the river-bed by Mrs. Barber, the wife of the Superintendent of Works, who had charge of the works from the time the post of Engineer-in-Chief was abolished in July 1933, till their completion.

It was a simple and entirely unofficial ceremony, attended only by the local engineering staff. Nevertheless, the common mason's trowel which was used to spread the mortar in which that last stone was " well and truly laid " is perhaps one of her most cherished possessions.

Thus concluded the construction of what was then by far the largest single piece of masonry of its kind in the world, though, within two years, it was to give pride of place to the great Boulder Dam, across the Colorado in the United States.

CHAPTER XXXVI

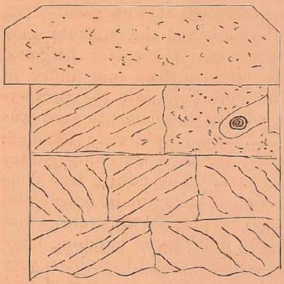
Surface Finish and Architectural Features of Dam: Use of Pre-cast Concrete.

The original design of the dam showed an elaborate series of arches carried on corbelled piers for obtaining the requisite width of roadway over the top. In actual execution these were entirely done away with. Reference is invited to Plate VIII, which shows the final profile adopted. In front, the masonry was given a reverse batter or corbel near the top, while in rear the vertical face was carried down to meet the curve of the rear face. By this means 15 inches was added to both upstream and downstream faces, thus increasing the total over-all width at the top of the dam from 18 feet to 20 feet 6 inches. The parapet walls are 2 feet 3 inches thick, thus leaving a clear roadway of 16 feet, which is sufficiently wide to admit of the conveyance of the largest emergency shutter for the sluices along the top of the dam. This form of construction gives in the finished work an impression of dignified yet simple solidity which is in keeping with the rest of the structure. The top of the dam has a clean appearance being devoid of the projections and obstructions so often found on dams elsewhere, where overhead gear in one form or another is employed for the operation of sluices. The sluice gear is entirely housed in chambers beneath the road surface and chequer-plate covers over the chambers are the only indication of their position to a person passing over the dam. The sluice chambers are reached by means of neat masonry gangways connected by flights of steps formed in the rear face of the dam. During the construction of the dam, numerous flights of steps were constructed on the rear face for obtaining access to any section direct from ground level, and these extend up to the road way over the top. Though provided with hand rails they are scarcely visible from a short distance and so do not mar the appearance of the structure.

The surface finish of the dam is the same throughout and is of coursed rubble. The courses are small being 7 inches to 9 inches thick only. The faces of the stones were all roughly squared before setting. On the upstream face, the joints are pointed with special cement mortar, while on the downstream face the joints are merely struck flush with the same mortar in which the stones are set, and, in view of the enormous size of the dam, the general effect is that of a clean smooth surface.

Pre-cast concrete blocks were freely used in place of large and heavy cut stones. Concrete string courses 15 inches thick run the entire length of the dam at road level on both faces. The parapet walls are of coursed rubble, the inner faces of the walls being finished in fine dressed ashlar. The coping blocks throughout are also of pre-cast concrete, and are each 3 feet in length and 12 inches thick.

The parapets possess some unusual features. Few people would suspect that for a considerable length of the dam both high-tension and low-tension cables are carried in ducts in the upstream parapet wall. The top course immediately beneath the coping is provided with a line of special pre-cast duct blocks designed to carry the cable. Small closing blocks, cemented into position, seal the duct. This system admitted of the laying of the cable with a minimum of trouble. The cable was laid out on the road and merely lifted into the duct. Junction boxes are provided at intervals so that the cable may be drawn and replaced at any time, without difficulty. At the contraction joints copper plates shield the cable duct and prevent the ingress of moisture.



In the sections where the Goliath Cranes work, 90 lb. steel rails are embedded in specially pre-cast coping blocks provided with dove-tail grooves, the rail being grouted into position after careful aligning and levelling. The rails are open-jointed at every contraction joint in the dam, that joint being carried up to the top of the parapet, allowing free play for expansion and contraction. Intermediate rail-joints are also 'free,' the fishplates being rigidly coupled to one rail while the end of the adjacent rail is free to slide longitudinally.

As the top of the dam is subject to very great changes of temperature, undue stresses in the masonry in the parapets have been guarded against as far as practicable. Since the entire dam is exposed to the weather, fillets have not been provided under the projections of the coping blocks as they would serve no useful purpose.

A considerable amount of pre-cast concrete work was done both for the dam and subsidiary works and much time was saved in the construction, particularly where archwork was required.

The semi-circular roofing of the vents of the high and low level sluices as well as the construction sluices consists entirely of pre-cast arch-rings. Each ring was made in three sections two haunches and a central closing block. These were designed in such a manner that they were set without the use of any centering, a small gantry only being employed to lift and place the blocks in position. Since pre-cast work can be manufactured very accurately, very thin mortar joints only were required. Steel moulds were used entirely for such castings. A special concrete-block moulding yard was equipped with smooth moulding platforms over which thick steel plates were laid. By means of these a very smooth and clean finish was obtained to pre-cast blocks when desired.

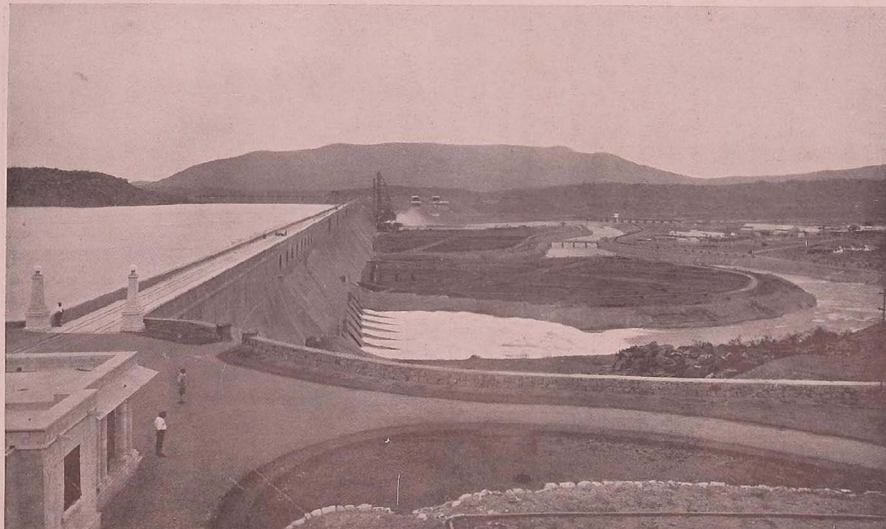
Much of the material used in the construction of the memorial pavilion and the shutter-houses was pre-cast at this yard. The materials for the large fountain in the park and the concrete seats were manufactured there, also the circular pillars for pergolas, etc. When it is remembered that no less than four miles of coping and string-course blocks alone were built into the parapets of the dam, it may readily be believed that the concrete yard was kept very busy for several years. The materials were handled, stacked and loaded on to trucks by means of a travelling gantry which ran the length of the curing yard. The curing was done mostly by means of sprinklers fed from a water main which also ran the length of the yard. The cost of pre-cast concrete is but a fraction of the cost of cut stone. The difficulty of handling large stones at the quarries in enormous quantities would have been very great, so much time and money was saved by the free use of pre-cast concrete manufactured at one central station under the supervision of a single maistri.

It may be remarked that even the dome of the pavilion which now graces the top of the hill at the left flank of the dam was entirely pre-cast. Had ordinary methods been employed there, it is certain that the pavilion would not have been completed in time for the inaugural ceremony, as the design of the building was received only four months before the ceremony actually took place. While the basement was under construction, the lintels, beams, chajjas, ornamental railings and the dome were all in process of being pre-cast in suitably sized sections.

At either end of the dam, massive pre-cast terminal pillars of simple design, surmounted by electric lamps, give a clear finish to the work. The electric light standards on the roads at both flanks and also on the surplus bridge are all of reinforced concrete manufactured locally.

In order that the coping blocks and other concrete features on the dam might match the masonry, their surfaces have been lightly chisel-dressed so that the concrete is not easily distinguishable from masonry.

PLATE No. XXIX.

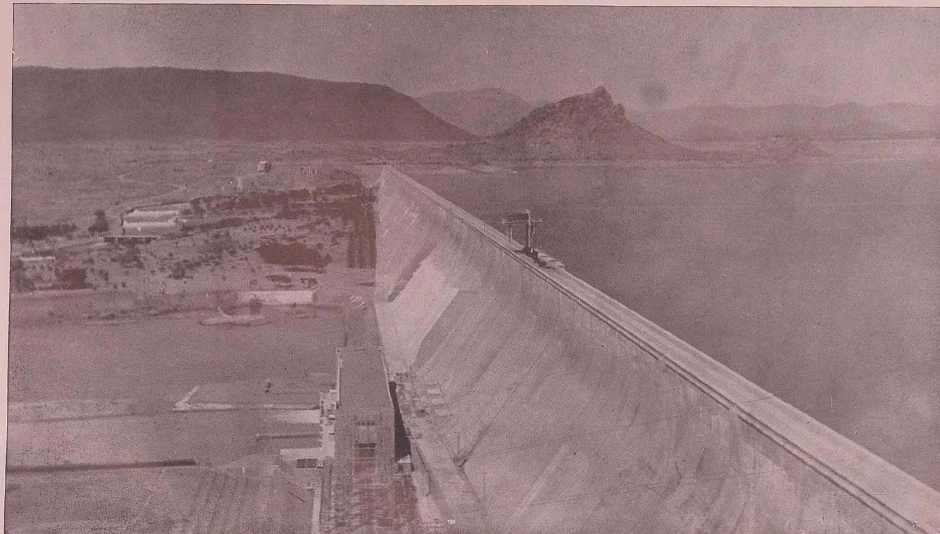


GENERAL VIEW OF DAM FROM RIGHT FLANK.

PLATE No. XXIX-A.

GENERAL VIEW OF DAM AND RESERVOIR.

PLATE No. XXIX-B.



GENERAL VIEW OF DAM FROM LEFT FLANK (AFTER REMOVAL OF CONCRETING TOWERS).

The roadway over the dam is entirely of rich concrete for which the stone was broken to ½ inch size. The tram rails which extend the entire length of the dam run into the emergency-shutter houses at either flank and also connect with the permanent tramway system from the railway station and the workshops. They were laid flush with the dam road surface. Special templates were used for striking the concrete to the finished cambered form in one operation, plastering being carefully avoided. The resulting surface, while being clean, is slightly rough and affords a very safe grip for the tyres of motor vehicles passing over the dam. Concrete side drains, formed at the time of road construction, effectively drain the surface during rains, and discharge through 4 inches shafts to the outer face of the dam at intervals of about 32 feet on either side. These are given a steep gradient and are short and straight so that they are easily kept clean. They discharge below the level of the string courses.

CHAPTER XXXVII

PREPARATION FOR INAUGURATION OF THE PAVILION AND PARK.

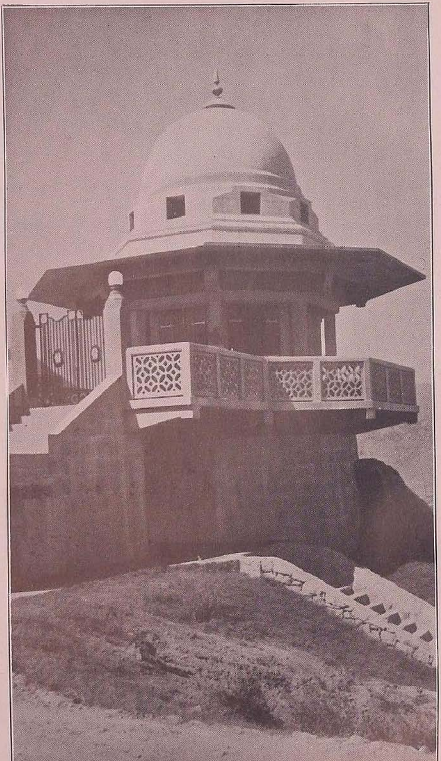
AS SOON as it was learnt that the construction of the dam was likely to be completed by about July 1934, there was considerable activity in making preparations for the inauguration of the scheme. The work carried out was of such magnitude and importance that the Government of Madras considered its completion worthy of special celebration. To commemorate the completion and formal opening of the system, therefore, an ornamental pavilion was erected at the top of the hill at the left flank of the dam while a large park was laid out in rear of the dam to the west of the river.

The site of the pavilion was chosen so that from it one obtained an excellent bird's-eye view, not only of the dam but also of the lake, the surplus works, the camps and the surrounding country. The site of the pavilion is near a point formerly known as "Mullings' Seat," which, as its name implies, was a vantage point from which Sir Clement Mullings, when Engineer-in-Chief of the project, was wont to view the works of an evening. During the hottest weather there was always a cool breeze passing over that hill, and it was deemed to be ideally situated for the erection of a memorial. The actual site of the pavilion was on a mass of large boulders a little to the north of the rocks which formed Mullings' Seat, and the stone used for the construction of parts of pavilion was to a great extent taken from these rocks. By their removal a large terrace was formed and this, after levelling, formed an excellent site for the entertainment of the large assembly of people who gathered there on the occasion of the inauguration ceremony.

A description of the pavilion which was designed by Mr. Dann, the then Consulting Architect to the Government of Madras, may be of interest to such of our readers who may not have had the opportunity of visiting Mettur since the work there was completed.

This building is of unusual design and workmanship. Since a view is to be obtained in all directions from the pavilion it has been designed in the form of an octagon. It stands on a massive stone basement perched on the rocks on the steep western face of the hill, the floor level being some 11 feet above the level of the terrace which extends to the south and east. A wide balcony extends all round the central room and is carried on cantilever

PLATE No. XXX.



VIEW OF MEMORIAL PAVILION

brackets. Over the veranda a wide roof extends. This also is carried on ornamental brackets and is entirely unsupported at its outer edges.

The building is surmounted by a hemispherical dome provided with an ornamental finial. The pavilion is approached from the eastern side by a balcony over an open arch-way by a flight of stone steps leading down to the level of the terrace. Ornamental wrought iron gates with pillars bearing lamps give access to the balcony.

The inside of the building is impressive. It is floored with black and grey marble. The walls for a height of about 9 feet are of fine dressed ashlar while, above a cornice, the walls are fine plastered, and formed as a series of arches. Immediately below the dome an upper cornice conceals a number of electric lights, the concealed lighting throwing a glow over the inside of the dome, which being white, produces a soft light in the room and throws no shadows. The door and the four windows of the building are provided with massive brass-studded teakwood shutters, while the windows are fitted also with ornamental brass bars. The remaining three walls of the room carry tablets. That facing the door is of delicately carved stone bearing an inscription surmounted by the Royal Arms in bronze, which stand out in high relief. The inscription, which is in sunk gilt lettering reads :—

> "This Tablet, commemorating the completion of the construction of the Mettur Dam, was unveiled by His Excellency Lt.-Col. the Right Honourable Sir George Frederick Stanley, P.C., G.C.S.I., G.C.I.E., C.M.G., Governor of Madras on the 21st of August 1934."

The tablet on the north wall is of brass on which is etched a profile of the dam and furnishes the main particulars of the scheme.

On the south wall a brass tablet of similar dimensions bears a list of officers who were engaged on the investigation and execution of the project. The list includes the names only of those officers of the rank of Executive Engineer or above who served for not less than one year on the project.

The greater part of the construction of this pavilion is carried out in reinforced concrete, a material particularly well adapted for this unusual type of structure. Even the railings round the balcony are of reinforced concrete, all but the actual floor of the balcony being pre-cast at the concrete-moulding yard. The sections of the dome were all pre-cast, the reinforcement at the joints being placed at the time of erection. The delicately carved finial which surmounts the dome is of concrete finely dressed by hand. Though small, the completed structure is pleasing and attracts many visitors.

A concrete road, suitable for motor traffic, has been constructed on and S shaped trace at a gradient of 1 in 12 from the foot of the hill near the surplus sluices to the terrace in front of the pavilion, while a flight of rough stone steps is constructed from the archway under the balcony down to a point on the road opposite the eastern end of the dam. Turfed banks with shrubs and flower beds have been laid out on the northern slope on either side of the steps.

The park which was opened by Lady Beatrix Stanley, comprises the whole area lying between the dam and the supply channel and covers about 34 acres. It is divided into two by the channel from the low level sluices. The upper park which is on steeply falling ground has been divided into a number of terraces supported by dry rough-stone retaining walls and contains several broad walks. Between gravelled walks along the centre of the upper park a masonry lined channel cascades, shady avenue trees and wide flower beds being planted on either side. The whole area is turfed, informal shrubberies being dotted about to break up the more open spaces. Pergolas, arches and fountains give the finishing touches.

The upper park is only accessible to persons on foot, entrances being provided over the gangways in rear of the high-level and low-level sluices.

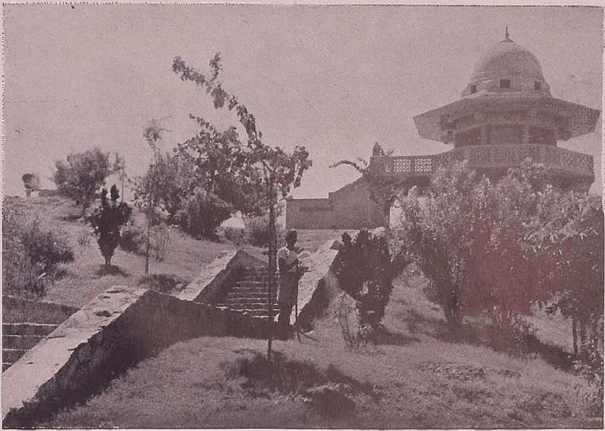
The lower park, which covers about two-thirds of the whole area is flatter and is not terraced. A large ornamental fountain is the central feature of this park, drives radiating from it in four directions. A road also runs completely round it between the dam, the river and the supply channels.

Masonry-lined channels for the conveyance of water for watering the grass and flower beds run alongside most of the roads. Water is supplied from the lake by means of a special pipe built through the dam at the upper end of the drainage gallery near the high level sluices. This supplies the channel in the upper park, whence it is distributed to the various branch channels. A second pipe supplies water to the fountains.

The trees in the lower park are mostly of the fruit-bearing variety, and in course of time it is expected that a considerable revenue will be derived from the produce of these trees. The avenues along the channel margins are lined with gold-mohur trees. These, during the hot weather, are ablaze with scarlet blossoms, while at other seasons their bright feathery foliage affords pleasant shade.

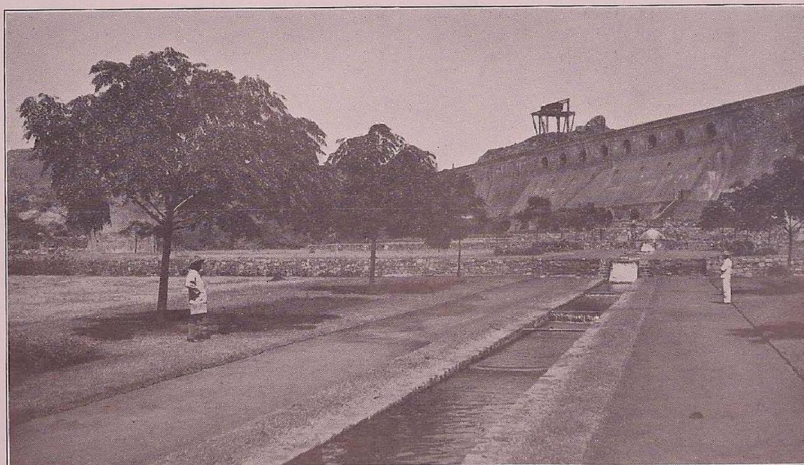
A view taken in the upper park early in 1936 will serve to illustrate how rapidly the trees have grown since they were planted less than two years previously.

PLATE No. XXX-A.



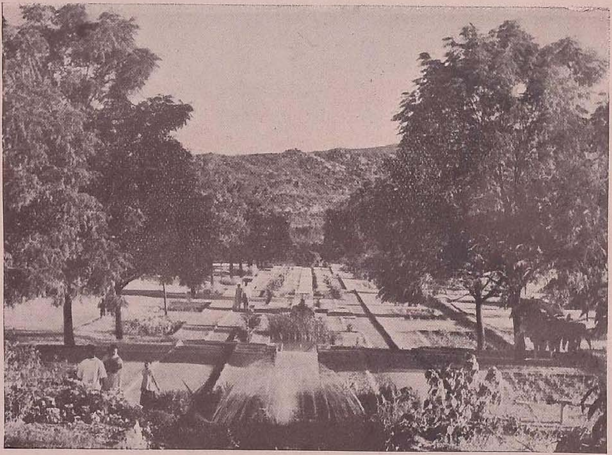
VIEW OF MEM ORIAL PAVILION.

PLATE No. XXXI.



VIEW TAKEN IN UPPER PARK.

PLATE No. XXXI-A.



VIEW OF THE STANLEY PARK.

CHAPTER XXXVIII

Inauguration of the Cauvery-Mettur System.

The construction of the dam having been completed in all respects during July 1934, the inauguration of the system was performed by His Excellency Lt.-Col. the Right Honourable Sir George Frederick Stanley, Governor of Madras, on the morning of the 21st August 1934, in the presence of a large and distinguished assembly of guests who came from all parts of the Presidency and the neighbouring Indian States. Many came from great distances both by road and rail and, for the convenience of those who arrived at Mettur the day before the ceremony took place, accommodation was provided in a number of the European and Indian quarters which had by now been vacated, the furnishing of the quarters and the necessary catering being efficiently carried out by certain Madras firms. The large halls in the central offices were converted into dining halls, while special car-parks were laid out and additional petrol stations were provided for the convenience of the very large number of guests who came by road. Special trains were run from Madras and Trichinopoly, and a fleet of motor cars and buses was provided for the conveyance of the guests who came by train.

Apart from those guests who had been invited to attend the ceremonies many thousands of people flocked to Mettur from all the surrounding districts, for the Indian dearly loves a tamasha at any time, and this was something special which could not be resisted.

For the accommodation of the guests at the pavilion where the ceremony took place, a large pandal had been erected and this, needless to say, was packed to capacity before Their Excellencies Sir George and Lady Beatrix Stanley arrived.

At 7-30 a.m. punctually, Their Excellencies left their special train, which had arrived a little earlier at the Mettur Dam station, and motored direct to the pavilion to the accompaniment of the usual salute of guns fired from the top of a hill near the railway station. The route, even at this early hour, was thronged with sightseers. On arrival at the terrace before the pavilion, they alighted to the strains of the National Anthem. His Excellency then inspected the guard of honour provided by the Reserve Police. Their Excellencies were received by Sir Archibald Campbell, the Honourable Revenue Member, and Diwan Bahadur R. Narasimha Ayyangar, the Chief Engineer for Irrigation, who conducted them up the flight of steps to the balcony of the pavilion.

The function opened with an address read by the Chief Engineer in which the history of the project was briefly related. This was followed by a speech by Sir Archibald Campbell.

His Excellency then pressed an electric button connected to the electrically-operated sluice gates and opened four of these great gates simultaneously, releasing the water from the reservoir down the new surplus course. Though there was no great depth of water against these gates at the time of the ceremony, the opening of the gates was an impressive sight, of which the assembled guests obtained an excellent view from their vantage point on the top of the pavilion hill which overlooks the surplus works.

His Excellency then opened the doors of the pavilion and unveiled the memorial tablet to which reference was made in the last chapter. To commemorate this great occasion a representative of the firm of Messrs. Glenfield and Kennedy who had supplied and erected the steel work for all the sluices both in the dam and the surplus escape, presented His Excellency with a beautiful silver cup. Thus concluded the inauguration of the Cauvery-Mettur system as it was henceforth to be called.

Leaving the pavilion, Their Excellencies then proceeded on a tour of inspection along the top of the dam to the right flank, stopping at intervals to inspect the "last stone," the various sluices and the obelisk which commemorates the initial inauguration of the work by His Excellency Lord Goschen in 1925, nine years earlier. They then proceeded via the right flank ghat road down to the park, where many of the guests had meanwhile assembled. Having arrived at a small pandal in front of the large ornamental fountain, the Superintendent of Works, Mr. C. G. Barber, then read an address giving a brief account of the park which he now requested Lady Beatrix Stanley to declare open. Her Excellency had taken a very great interest in the design and construction of the park and it was fitting, therefore, that it should be named after her.

Cutting a ribbon which controlled a lever on the water supply, Her Excellency opened the fountain, at the same time declaring the park open. This function over, Their Excellencies, after partaking of lunch, left by road for Ootacamund.

Then commenced a great round of sight-seeing by the guests and other visitors after a very well attended lunch, for many had not had a square meal since the night before. A number of guests stayed on to witness a display of fireworks at the dam that evening. During the afternoon a special feast had been provided at Government expense for a large number of men and women coolies in appreciation of the excellent work they had done in the construction of the dam. And so concluded a happy day which will live long in the memory of those who were fortunate enough to be able to attend the celebrations.

The speeches delivered at the inauguration ceremony are reprinted in Appendix F.

CHAPTER XXXIX

Administration of the Project and Establishment.

With the sanctioning of the project estimate, a special circle was created under the Superintending Engineer, "Cauvery-Mettur Circle." This circle commenced to function from the 21st May 1925. The office was first stationed at Coimbatore but later moved to Erode so as to be nearer the scene of operations. There were as yet no buildings available at Mettur for the location of an office there, while the opening of a new railway siding at Erode for the receipt of materials and machinery for the headworks and the construction of the road from Erode via Bhavani to Mettur constituted the first works of importance. A construction division for the headworks to carry out these works had its headquarters at Bhavani while a 'canals division' was created with its headquarters at Tanjore. At the end of 1925 the stores and tests division was created with its headquarters at Mettur.

To divest the engineers of non-technical responsibilities as far as possible the administrative functions of the project were, at this stage, entrusted to a senior officer of the Indian Civil Service who was appointed Commissioner for the project, and he was made directly responsible to the Government for its general management. His main duties lay in the rapid acquisition of lands for the project works and camps.

As the work developed, an Engineer-in-Chief having the status of a Chief Engineer of the Public Works Department was appointed from the 1st May 1927 for the exclusive charge of the project. Soon after, the post of Commissioner was abolished, his duties devolving on the Engineer-in-Chief.

With the appointment of the Engineer-in-Chief, progress in the development of the works became very rapid and several new divisions were constituted. At headworks, the original stores and tests division, which had till now been carrying out the investigation of lime, sand, and other materials required for the work, besides preparing schemes for the layout of the roads, camp and water supply and drainage schemes, became a stores and tests division in reality, and four more divisions were created to cope with the other branches of the work. They consisted of two divisions for the dam construction, a camps and buildings division and a workshops and machinery division. For all matters relating to the design, purchase and erection of special machinery and plant at headworks a special 'Superintending Engineer, Machinery' was appointed. For the canal works, a Superintending

Engineer was appointed to the Canal circle. Under him were three construction divisions for the canal construction works and later, a fourth 'special' division was added for the important work of delimitation of the ayacut. As works neared completion, the posts of the Superintending Engineers were abolished and the divisions were gradually reduced in number by amalgamation. The subdivisions and sections were similarly reduced in number, though some retained their original nomenclature to the end.

On the abolition of the post of the Superintending Engineer, Canals, the canal divisions were placed under the direct control of the Engineer-in-chief. Towards the close of the project in 1933, the post of Engineer-in-Chief was abolished and the work was placed in charge of a Superintending Engineer styled "Superintendent of Works, Cauvery-Mettur Project," working directly under the control of the Chief Engineer for Irrigation. On the abolition of the Superintendent of Works post at the end of September 1934, when the headworks construction had been completed, the number of divisions at headworks was reduced to one. This division, known as the headworks division, was then attached to the Coimbatore Circle, while the canal divisions, now reduced to two in number, were attached to the Tanjore Circle for administrative convenience. As the construction work in the various reaches of the canals was completed they were handed over to the regular maintenance divisions of the Tanjore Circle, the Grand Anicut Canal division being a new one created for the purpose.

Throughout the period of construction the staff employed was the minimum consistent with efficiency.

The work of the various divisions, particularly at the headworks, had been so well co-ordinated that considerable economy was effected in the strength of the establishment employed, while rigid control prevented wastage through the creation of any unnecessary posts. In consequence, despite the fact that the estimated construction period at headworks was exceeded by a year, and that for the canals by over two years, considerable savings in the cost of establishment were effected. On the headworks provision of Rs. 48,71,500 there was a saving of no less than Rs. 11,04,000, while the estimate provision for the canals, Rs. 25,55,400 was exceeded by Rs. 90,228 only. The excess in the latter case was by no means proportionate to the extension in the period of construction.

Concessions to establishment and staff.—All members of the establishment and staff engaged at headworks were granted certain concessioins in lieu of local allowances. In the early days Mettur was regarded as unhealthy and, ordinarily, special local allowances would have been granted to Government servants employed there. In view, however, of the special measures which were taken to render the place healthy, the Government withdrew the proposal but granted instead free housing, free electric lights, fans and water-supply, free transport of personal effects to and from Erode (or later, from Mettur Dam station when the new railway was opened). Fuel for domestic use was also issued at cost price to Government servants. With these generous concessions, the cost of living at headworks was kept down to a reasonable figure and there is no doubt that they contributed materially to the comfort and welfare of the staff.

The establishment of the project underwent so many changes during the course of the work that it is not possible to describe the details of establishment employed in each office and department. A table showing the strength in each year of construction will be found in Appendix G. From that table the reader will be able to see what posts were in existence at any particular period of the work and when they were created and abolished. A list of officers above the rank of Assistant Engineers, who served in the project will also be found in Appendix H.

Revenue and land acquisition.—A report on the subject will be found in Part II, Chapter XXIX. Here, therefore, it may only be necessary to state that for purposes of easy administration and the simplification of land acquisition, Mettur, with the lands concerned with the project, was constituted as a separate district under the control of the Commissioner. When the acquisition of lands at the headworks, including the greater part of the water spread area of the reservoir, had been completed, it was reduced first to a taluk of the Salem district and then to a Deputy Tahsil-charge. On the abolition of the Mettur taluk, the area was redistributed amongst the old taluks with some slight territorial changes now found necessary, and Mettur itself, formerly in the Coimbatore district, was included in Salem district for Police and administrative purposes.

Municipal administration.—From the earliest days of the work the civil and other municipal functions of the administration of the Government Colony of which Mettur was the centre, were vested in the Mettur Committee, a body composed of the local heads of the Public Works Department, Revenue and Health units. The Executive Engineer in charge of the 'Camps and Buildings' division at Mettur was also an ex officio member. The members were also the executives of the committee in implementing its decisions on matters normally lying in their sphere. The Commissioner, the Engineer-in-Chief and the Superintendent of Works were the Chairmen of the committee in succession.

The local medical and health units were directly under the administrative control of the committee, technical control being exercised by the District Medical Officer, Coimbatore, and the Director of Public Health, Madras.

It may be stated that this system of municipal administration worked admirably. On the completion of the works, it was presumed that the Mettur Township would be abandoned, and the hospital and other institutions closed, the former being converted into a dispensary with a few beds maintained for special cases and placed under the control of the Salem District Board. The Public Works Department officers at headworks continued to maintain the camps with their water-supply and drainage services. The main roads were transferred to the District Board, but were maintained on their behalf by the local Public Works Department Subdivisional Officer working under the Executive Engineer of the Salem division. When the Hydro-Electric Scheme was put in hand and the population of the Mettur Township again began to increase, this system of control was found rather unsatisfactory and at the present time the Government have under consideration a proposal to revert to the original system of municipal administration by a local committee with such modifications as may be found desirable. In the event of industries springing up at Mettur, there is no doubt that the place will become a centre of some importance and a further change in the municipal administration may be found necessary.

CHAPTER XL

Labour and Reasons why it was plentiful at Headworks.

The project was started in 1925 when the effects of the Great War were still being felt. Prices of foodstuffs were high and work was scarce. The villages round about Mettur, both in Salem and Coimbatore districts, were practically famine-stricken owing to the scanty rainfall during the years 1923–25 and the failure of crops. Large areas of land on the river banks were also rendered useless by heavy deposits of sand left by the extraordinary floods of 1924 and were thus unfit for cultivation. People therefore began to pour into Mettur from these villages, as soon as they found that work was available. The excellent housing arrangements which had been provided for labour, the plentiful supply of good water and other amenities were largely responsible for the influx of coolies who, on obtaining work, were thus assured of a steady living wage and the means of living a contented life throughout the duration of the work. Anti-malarial and other health measures vastly improved the health of the locality and the coolies, who had hitherto been too poor and ignorant to consider the interests of their health, soon appreciated the many benefits that Government had provided at Mettur.

Contrary to earlier beliefs regarding the scarcity of labour, there was little necessity to import labour from distant places, involving the payment of heavy travelling expenses, nevertheless the customary payment of advances to labour by contractors was fairly common even though it was mostly recruited in neighbouring districts. In the latter part of the construction even local labour had to be turned away as it greatly exceeded the demand.

The villages of Mettur and Thukkanampatti had a total population of under 500 people when the project was started. Most of the labour was unskilled and accustomed only to light agricultural operations. Yet when the project work was at its height there were nearly 11,000 coolies working in different capacities. The construction of the great dam required a large number of stone wodders and stone cutters and these were mostly drawn from places within 50 miles of Mettur.

Nearly 1,800 huts for coolies were built departmentally. All coolies working directly under the department were housed in these huts free of rent. Coolies working under the contractors were given free sites for building their huts. The huts were all built in rows in compliance with the rules laid down by the Health department and over-crowding was prevented. Water taps and latrines were put up near the departmental coolie huts and in the coolie camps constructed by the coolies themselves. In the earlier days of the project the labour employed came with no sense of sanitation or cleanliness in their habits of living and the health staff had a hard time maintaining the sanitation of the camps and works. In course of time, however, the labour began to appreciate the strict measures laid down and became educated to the necessity for cleanly habits. The sanitation of all the camps was carefully attended to and no pains were spared to maintain the coolie camps in a perfectly healthy state. This was beneficial to the project in the long run as the following account will show. In the middle of July 1926 and again in 1927 there were cholera outbreaks during the first freshes in the Cauvery river. There was no protected water-supply at the time. The coolies as was their wont drank and bathed in the river water contaminated by the villagers higher up. Due to the cholera outbreak in 1927 nearly all the contractors' coolies became scared and fled from Mettur and did not return until after the lapse of two or two and a half months. In many cases they would not submit to inoculation. After the introduction of the permanent water-supply there was no recurrence of such an outbreak, and there was no further dislocation of work. If such interruption had occurred in any of the years after 1928, the loss of interest on capital would have been anything from Rs. 1,500 to Rs. 7,000 per day. It was therefore necessary to take all possible steps to safeguard the health of all residing on the coolie camps.

When the labourers residing elsewhere realized that here was a healthy place to live in, with a good water-supply, they migrated to Mettur and settled in large numbers. So much did they appreciate the conditions at Mettur, that, later on, there was considerable difficulty in getting labour for the Thoppur-Mettur road construction, outside the limits of the protected project area, in spite of the fact that there was then very little work at Mettur. The coolies were not attracted to that road work in the Salem district where there was an absence of good water and malaria and other diseases were prevalent in the villages along the route.

Most of the labour that came from the surrounding villages was unskilled. Many of these unskilled men were gradually trained for semi-skilled work and eventually became masons, stone-cutters, plate-layers, fitter-mates, etc. The masons were largely in demand for the construction of mass masonry in the dam; a type of construction which was mainly adopted from July 1929 onwards.

Highly skilled labour had, of necessity, to be imported not only from all parts of Madras but also from Northern India, but they were, by comparison, few in number.

One happy feature of the labour situation at Mettur from the view point of the employer was the entire absence of strikes. Disputes were of a minor nature and easily settled. The wages that were paid to the coolies were not high but steady work, regular pay and domestic comfort kept them quite contented. Even on festival days and other holidays it was always possible to obtain labour for any urgent work, for there was always a good understanding between the employer and the employed and agitators, then so conspicuous in other parts of India, were few and could not get a hearing.

All coolies were regularly paid on Saturday nights or Sunday mornings in order that they might purchase their weekly foodstuffs in the local shandy on Sundays. This regular payment inspired great confidence in the coolies and was instrumental in securing the steady supply of all the labour required.

The results obtained at Mettur during the construction of the dam clearly show that it pays to provide good housing, good water-supply and other domestic services. Without these, such satisfactory results could never have been obtained and the dam might have taken years longer to build.

With all these amenities it is not to be wondered at that the coolies were reluctant to move out of Mettur, being aware that nowhere else would they be likely to find work under such happy and healthy conditions.

It is, perhaps, unfortunate that having thus improved the standard of living of so many thousands of persons it should have been necessary, on the completion of this great work, for them to return to their villages where no such conditions existed. If each one of them on his return home could have preached improved sanitation and cleaner methods of living to his brother villagers the work done for his benefit at Mettur would not have been in vain, though, until such time as it may be possible to provide protected water-supplies and improved sanitary measures in these villages, it is unlikely that any appreciable improvements can be effected.

When the next large project is taken up in South India we may be sure that many of those who were employed at Mettur will be only too ready to offer their services if similar facilities are provided for working under the healthy and happy conditions that obtained there.

CHAPTER XLI

THE AUDIT SYSTEM DESCRIBED.

IT MAY well be realized that for a work of this magnitude a very efficient system of accounts was essential to enable the Audit Department to handle successfully and rapidly the enormous volume of work which would pass through their hands. The prompt payment of labour and the settlement of contractors' accounts was essential for the proper progress of the work. The post-audit system employed in the regular divisions of the Public Works Department frequently involved protracted correspondence, and it was therefore the aim of the authorities to remove all obstructions to the rapid settlement of all financial transactions on the project.

The pre-audit system had already been adopted with some success during the construction of New Delhi and with certain modifications to suit the particular class of work it was considered that such a system would prove most suitable at Mettur. Mr. B. A. Harris, an officer of the Audit Department, who had had some experience of this system at Delhi and elsewhere was posted to Mettur to evolve a suitable system of pre-audit, and as a result of some very fine work done by him a system was drawn up.

Accordingly post-audit was replaced by pre-audit early in the construction period of the project. As a time saver, the latter proved to be an excellent arrangement.

Replies to audit objections, explanation of errors of commission and omission in previous accounts, etc., constituted the bulk of the correspondence with the audit branch under the post-audit system and these were reduced considerably through the adoption of pre-audit. This relieved the Engineers of much office work and left them more time to attend to their important duties connected with the construction. Prompter payments were made possible, and this went a long way to cement the cordial relationship between the engineers, contractors and employees, an indispensable factor in attaining the rapid and successful completion of the large project.

Preliminary.—The scope and advantages of the pre-audit system as applied to the Cauvery-Mettur Project are best summarized in terms of the opening remarks contained in the pre-audit circular of the Accountant-General which are reproduced below :—

> "The procedure after the location of the Audit office at Mettur provides for the audit of expenditure before payment and for the payment of bills by the Audit office.

The present post-audit conducted by the Accountant-General will be merely replaced by an audit applied before payment. Pre-audit does not necessarily imply any extension of audit though, in certain cases, audit now done at inspection is substituted by pre-audit. Apart from a reduction in the number of written audit objections which Public Works officers have ordinarily to answer, they will also not be required to furnish monthly consolidated accounts and they will be relieved of the duty of making payments. The Audit office may be freely consulted by divisional and other officers, and any question as to allocation, etc., may thus be settled before bills are sent in. Divisional Accountants may freely consult the Superintendents of the Audit office and vice versa unofficially."

As stated above, pre-audit did not involve any extension of audit but only helped in speedy and concurrent audit.

2. *Differences between post-audit and pre-audit.*—The main differences between post-audit and pre-audit systems are that,

(*a*) While only a percentage of bills are checked by the Audit office under the post-audit system, the whole of them are checked under the pre-audit system.

(*b*) Imprest accounts, petty bills, N. M. Rolls and work-establishment bills are under the post-audit system, subjected only to a test-check at the time of inspections, but they were all checked 100 per cent under pre-audit system.

(*c*) The results of audit under the post-audit system were not usually communicated to Executive Engineers till two months after the charges were incurred, so that it was very often too late to rectify the defects pointed out. Such delays were completely eliminated under the pre-audit system as audit-remarks were communicated and irregularities, if any, rectified before payment of bills.

The pre-audit system thus rendered audit more complete, speedy and effective.

Saving in work for Divisional and Subdivisional offices.—The Divisional offices were relieved of the undermentioned items of work which would devolve on them under the post-audit system :—

(*a*) Drawing of cheques.

(*b*) Maintenance of cash book.

(*c*) Maintenance of contractor's ledger.

(*d*) Compilation of accounts.

(*e*) Posting of minor works register.

(*f*) Control of expenditure statements.

The Subdivisional offices were also relieved of the work of maintenance of cash book and posting of works-abstracts, the latter work being done entirely in the Division office.

The saving in work, particularly under items (*b*) and (*d*) above, was fairly considerable and but for this it would not have been possible for the Division and Subdivision offices to deal with the very large volume of work which they did.

Contribution of pre-audit to speedy execution of work.—The introduction of the pre-audit system was one of the several factors which directly or indirectly contributed to the speedy execution of work on the Project. A considerable amount of clerical and office work which, in a regular division, would devolve on the Executive and Assistant Engineers was under this system, taken over by the Audit office, thus enabling them to devote more time to the supervision of works. The cash transactions of the divisions were so heavy when the works were in full swing, that the writing up of cheques and checking and attesting of cash books by Executive Engineer, in accordance with the usual post-audit system, would alone have taken them an hour a day. The concentration of audit and administrative offices in one building combined with the adoption of the simpler forms of agreements enabled all audit and administrative matters to be settled with the greatest expedition, and the time taken between the formulation of detailed proposals for the various subsidiary works and their actual execution was almost negligible as compared with the conditions prevailing in normal Public Works Department divisions.

Note on the pre-audit arrangements in force in the canal area of the Cauvery-Mettur Project.—The Audit office at Mettur commenced to function from 1st December 1927. Pre-audit of expenditure in the Headworks area was taken up with effect from 4th January 1928. In regard to the canal area, however, pre-audit was applied only to charges on account of establishment (both gazetted and non-gazetted) and contingencies. In regard to expenditure on works only "Post-audit" was in force till 30th June 1928 when this class of expenditure was also subjected to pre-audit under the direct control of the Audit Officer, Mettur. When, subsequently, a branch Audit office was opened at Tanjore on 17th January 1929, the pre-audit of the entire expenditure in the canal area was taken up by the Assistant Accounts Officer, Tanjore. This pre-audit continued till 30th November 1931 when, owing to the abolition of the branch Audit office at Tanjore, there was a reversion to the post-audit system of accounts in respect of works expenditure under the control of the Audit Officer, Mettur, while pre-audit was retained in respect of expenditure under establishment and contingencies. Even the latter was brought under post-audit with effect from 1st April 1934. It will be seen from the above that pre-audit was in force in the canal area for the period of

three years and five months in respect of works expenditure (1st July 1928 to 30th November 1931); and

six years and three months in respect of expenditure on establishment and contingencies (January 1928 to March 1934).

The printed instructions issued by the Accountant-General, Madras, with his No. 1124-C.M.P., dated 21st November 1927, gave a clear idea of the functions of the Audit Department under the pre-audit system. Being probably the first time that this system had been tried in this Presidency, its scope appears to have been restricted to the extent prevailing in other places in India where pre-audit was in vogue. The working of this system was watched by the officers at Headworks, and in every quarterly progress report submitted to Government by the Engineer-in-Chief, the satisfactory state of the system was commented upon. It was noticed that there was prompt recoupment of the imprest accounts and payment of contractors' bills and that there was absolutely no complaint from contractors and piece-workers of delay in payment. A comparison of the figures of expenditure on works during the pre-audit period with any other discloses the fact that the maximum rate of expenditure ever incurred in the canal area pertains to this period. It is seen, therefore, that the execution of works during the period was rapid.

Compilation of accounts in a Project division which spends on an average from Rs. 40,000 to Rs. 50,000 per mensem with a grant of not less than Rs. 5 lakhs for the year, would have involved laborious and tedious work, having regard to the fact that there were numerous petty works under the detailed head "C. Works." The pre-audit system that did away with the compilation of accounts in the Division office did a great service to the Project. The Division offices were, however, required to draw up work abstracts for minor works (though the maintenance of the register of minor works was not considered necessary), and to maintain 'suspense' and other registers. If these items of work had also been taken up by the Audit office, the relief to the division would have been immense. Even in regard to works bills, the scope of the audit undertaken was very limited and the check of measurements and other details was left entirely to the Division office. Any scheme of pre-audit in future should be a source of great help to the Public Works Department, if it widens the scope of audit so as to place only the upkeep of the major registers of works with the Divisional offices under the direct supervision of the Divisional Officer.

In regard to the maintenance of the suspense registers and the contractor's ledger, the procedure adopted in each division was for the Divisional Accountant to attend the Audit office once a month and get these registers reconciled. The question of the necessity or otherwise of the upkeep in the Divisional office of the above registers is worthy of consideration on the strength of the experience gained in the working of the system in the project when any such scheme is formulated in the future. Perhaps, with the Audit office and the Public Works Department offices functioning at the same place, the Division office need not maintain separate registers as was the idea of the originator of the scheme.

With regard to No. II Canal Division, one important matter connected with this division may be mentioned here. Long after the No. I and No. III Canal divisions had ceased to exist the reconciliation of the figures of outlay on the works in both the Vadavar and Grand Anicut Canal systems of the Project had to be taken up by this division, at the instance of the Audit Officer, in connexion with the preparation of the register of the completed works under the various detailed heads of the two canal systems. As it was not possible to have the reconciliation effected through correspondence, for want of a continuous record of expenditure in any of the three divisions, a clerk had to be deputed from the Divisional office to get the figures reconciled in the Audit Office under the instructions of the Audit Officer, Mettur. It took nearly a month and a half for the reconciliation to be satisfactorily completed. As a result of this reconciliation, it was suggested to the Audit Officer that the expenditure on works costing Rs. 1,000 and less should also be audited and the Audit Officer agreed to receive separate schedules of expenditure for petty works and to book the outlay in audit registers. Though the Code rules do not require that audit should be conducted against outlay on individual petty works, still, in a large project like this where the number of petty works was very great, the advantages of applying audit in a post-audit system to outlay on petty works will be obvious.

The object of the promoters of the pre-audit system seems to have been to retain the system till after the completion report for the Project had been sent up. The canal area did not, however, enjoy the full benefits of this system to this extent. Pre-audit gave place to post-audit nearly three years before the date fixed for the closure of the construction estimate. Under pre-audit, the Audit Officer had complete control over figures of outlay on individual petty works. The rules in the Code are in support of this, but the disadvantages that attended the post-audit system of differentiation between 'petty' and 'non-petty' works, leading to the tedious process of reconciliation, seem to warrant the abolition of this distinction altogether in respect of big projects. If pre-audit had been in force matters would have been different as no such distinction exists in that system. The object of the system is that errors of commission and omission in accounts rendered by the Division office have to be rectified in audit promptly, and so every item of expenditure on works in a project of this magnitude must be brought under audit. Pre-audit throughout is very desirable.

The chief advantages that the pre-audit system conferred were that—

> Relief was given to the executive staff (Subdivisional Officers and Section Officers) by taking away from them payments (except payments of petty sums from imprests and wages of labourers employed departmentally and of work-charged establishment). Here the Subdivisional Officers had better relief than the Section Officers.

The Division office also was saved the compilation of accounts and the maintenance of the cash book, the register of minor works, and a few other registers. There was however reduction of accounts staff in the Division offices after pre-audit was introduced and the relief was not, therefore, very great. As pointed out above the system of pre-audit to be conceived should be such as to take away all payments from the executive staff and entrust it to cashiers working under the Audit Department, so that the former can devote attention solely to execution of works and preparation of bills. The Divisional Officer should, as far as possible, be relieved of the bother of accounts even under the pre-audit system. His responsibility must cease with the passing of bills for work done and materials supplied or for labour and establishment employed.

So far as expenditure under establishment and contingencies is concerned, there was very little difference between post-audit and pre-audit, except that, while under post-audit certain travelling allowance bills were not subject to detailed audit, they were audited under the pre-audit system. In the case of contingencies, all vouchers, irrespective of the amount involved, were audited, while under post-audit only vouchers for payments exceeding Rs. 25 were required to be sent up for detailed audit.

That an effective system of pre-audit, with its scope widened for a project of this magnitude, will greatly facilitate the work of the Engineers and subordinates is a matter beyond doubt and is confidently recommended for adoption in any large project of this kind that may be taken up in future.

CHAPTER XLII

Cost of Masonry and Concrete: Rates Analysed.

A very carefully maintained record during the construction of the dam, in which the analysis of cost of every process of manufacture and construction was worked out, enables us to quote the final quantities, costs and average rates for both labour and materials used on the actual construction.

The total outlay incurred in the construction of the 54,620,100 cubic feet of masonry and concrete in the dam amounted to Rs. 1,95,11,834 and may be divided under the following six heads :—

—	Quantity.	Average rate.	Cost.
			RS.
1 Cement	205,959 tons.	Rs. 52–6–4 per ton.	1,07,91,564
2 Surki	48,329 ,,	,, 5–4–0 ,,	2,53,720
3 Sand	27,555,122 c.ft.	,, 28–2–9 per 1,000 c.ft.	7,76,190
4 Stone and metal ..	53,853,283 ,,	,, 5–14–7 per 100 c.ft.	31,83,734
5 Conveyance	546,201 units.	,, 2–2–4 per 100 c.ft.	11,71,214
6 Labour	for 546,201 units of 100 c.ft.	,, 6–1–9 per 100 c.ft.	33,35,412
Total ..	546,201 units of 100 c.ft.	Rs. 35–11–7 per 100 c.ft.	1,95,11,834

Two classes of work were adopted for the construction, (1) concrete, placed by machinery and (2) masonry, only a small proportion of which was constructed with the aid of the concreting plant, the smaller mixer units, hoists, etc., being mainly employed to supply the mortar. The following table shows the quantities of work and the rates at which it was turned out under the different heads :—

Concrete.

—	Quantity units of 100 c.ft.	Average rate.			Cost in lakhs of rupees.
		RS.	A.	P.	
By red tower	45,700	43	2	0	19·8
,, black tower	22,900	40	6	0	9·3
,, other plant	27,800	44	9	0	12·5
Total concrete ..	96,400	43	3	0	41·6

Masonry.

—	Quantity units of 100 c.ft.	Average rate. RS. A. P.	Cost in lakhs of rupees.
Red tower	45,400	34 3 0	153·5
Black tower	39,600		
Other plant	364,800		
Total masonry ..	449,800	34 3 0	153·5
Total concrete and masonry ..	546,200 units of 100 c.ft.	Rs. 35–12–0 per 100 c.ft.	Rs. 195·1 lakhs.

The above analysis shows clearly that masonry worked out a great deal cheaper than concrete, and that 82·35 per cent of the whole structure was built of masonry, 17·65 per cent only being of concrete.

Contrary to expectations, the availability of ample labour and the use of a number of small units of plant spread over the work were responsible for so large an outturn of masonry at rates which compared very favourably with concrete, involving a saving, if based on the above figures, of no less than Rs. 40·48 lakhs, as well as much time which, if analysed, would still further increase that figure.

These figures should therefore prove a useful guide to those whose duty it may be to select the methods of construction in any future work of this kind in South India. Experience at Mettur has shown that it is not necessary to go out of this country to study economical and rapid methods of construction, for the methods employed in other countries do not apply here. We must, of necessity, draw on Europe or America for most of the plant required for construction, but it may be limited to standard types of plant, generally in small units, which may be passed on profitably from one work to another. For the best class of work concrete, where it is to be used, must be 'placed' and not delivered to the work through chutes. Cement is preferable to lime for almost all forms of construction and, for dam construction, has no equal. It is manufactured in large quantities in India itself and a high standard of quality is maintained in its manufacture, so there is no excuse for not using it.

CHAPTER XLIII

Moderation of Floods by the Mettur Reservoir.

When a large dam capable of impounding a very large quantity of water is placed across a river it may to some extent have a moderating influence on the intensity of floods in the river below the dam. Extremely high floods are usually sudden and of short duration, but at the peak of such floods considerable destruction may be caused by the river overflowing its banks or causing breaches of flood banks.

Now the extent to which the Mettur Reservoir can act as a flood moderator, as in all similar cases, depends upon the water-level in the reservoir at the incidence of a flood. Given sufficient warning of the intensity and duration of a high flood in the upper reaches of the river, action can be taken to lower the water level in the reservoir by increasing the outflow through the surplus and high-level sluices, thus making room for the absorption of the greater part of the flood when it actually reaches the reservoir. The peaks of moderate floods can be absorbed without difficulty by such means and an almost uniform and moderate flow can be surplussed.

The worst condition occurs when an extremely high flood comes down the river at a time when the reservoir is already full. If only brief warning of such a flood has been received, or if it is of such duration that even timely warning does not admit of the reservoir level being lowered to any appreciable extent, the resulting surplus will be very great. The presence of the reservoir, however, will have the effect of cutting off the peak of the flood so that the highest discharge in the river below the dam will be less than it is above.

Careful calculations have been made to ascertain to what extent a flood of intensity and duration equal to the extraordinary flood of 1924 would be moderated by the reservoir, assuming the reservoir to be full at the incidence of such a flood, i.e., under the most unfavourable conditions.

At the time of the 1924 flood no gauging station existed at or near Mettur, so the actual flood at that place could only be estimated by deduction. The discharge of the Cauvery at Krishnaraja Sagara Dam on the Cauvery and at the anicut across the Kabbini river at Hullahalli were known, while the gauge-readings at the Bhavani bridge 26 miles below Mettur and at the Erode bridge 9 miles lower down were available. The river had never been gauged at such high discharges and the flow at all these places could therefore only be computed. By adopting the computed discharges of the Cauvery and Kabbini above the dam and allowing for the necessary time-lag in the flood reaching Bhavani it was found, after deducting the discharge of the Bhavani river which joins the Cauvery below the dam, that the combined discharge of the two rivers as recorded agreed very nearly with the corresponding Bhavani bridge reading. Thus, it was computed that at its peak the actual flood at the Mettur Dam site was about 456,000 cubic feet per second, and the duration and intensity of the flood, both before and after the peak was reached, was also calculated.

The capacity of the reservoir for every foot of its depth has been accurately determined, so, by computation, the effect of the reservoir on the flood was arrived at, and it was found that with the reservoir at F.R.L. at the commencement of the flood the peak discharge would have been reduced by about 15 per cent—that is to say, while the highest flood entering the reservoir was 456,000 cusecs the highest outflow would not exceed 387,600 cusecs. With the reservoir level at any lower stage the moderating effect would of course be considerably greater. Thus it is seen that the reservoir does have a very appreciable moderating effect on floods even under the most unfavourable conditions. Further, it is almost inconceivable that under such weather condition as caused the extraordinary flood of 1924, the officer in charge of the dam would so regulate the discharge that the reservoir would be full at the time such a flood arrived.

The rules tentatively drawn up for the regulation of flood discharge from the reservoir do not in fact admit of F.R.L. being maintained at any time during the flood season; so even the flood discharge calculated above is hardly possible at any future time. It may safely be assumed, therefore, that the devastation caused by the 1924 flood in the Cauvery Valley below the dam will never recur, though moderately high floods of longer duration will be probable. Such floods, however, should not be destructive if normal precautions are taken.

CHAPTER XLIV

THE TELEPHONE SYSTEM.

TO SIMPLIFY communication between the offices and all parts of the works, a telephone system was installed in the Project Headworks area. A sum of about Rs. 13,000 was spent on the telephone installation, comprising a 40 to 50 miles length of overhead lines serving 38 sub-stations through a central manually operated exchange. A continuous telephone service was maintained day and night. Through the Telegraph department, connexion was also maintained with Bhavani, Kodiveri, Erode and stations in the delta as far as Tanjore. It is to be recorded that the services of the telephone installation were fully utilized by the office and works staff, thereby reducing correspondence and minimizing delays in disposal of references or issue of orders. An average of Rs. 2,350 was spent annually on the upkeep and maintenance of the telephone installation, this amount including the pay of the exchange operators, etc. Had the telephone been installed by the Telegraph department and maintained by them, the Project would have had to pay an annual rental of Rs. 1,360 for the overhead lines alone and Rs. 54 for every one of the 38 instruments in use, or, in all, nearly 50 per cent more.

The average number of calls per day on the telephone exchange from November 1929 when the installation started operations, increased till 1932, when the busiest period was reached. At that time it was not unusual for as many as 400 calls per day to be put through, while towards the close of the work the average number of calls was nearly 250 per day.

In view of the great distances between one part of the work and another, as also of the officers' bungalows from the works and offices, much time was saved by the free use of the telephone system.

During the flood season the telephone line between Mettur and Sivasamudram, which was the property of the Mysore Government Electric Department, was invaluable for obtaining immediate information as to the extent and duration of floods coming down the river, for, while such information enabled the construction work to go on until floods actually arrived, it was also instrumental in preventing the loss of plant and materials, as timely warning of the approach of floods could be obtained from Sivasamudram.

The telephone line to that place was removed when the contract for the supply of power was completed. Thereafter, information regarding floods to be expected at Mettur could only be obtained by telegram, but since the construction of the dam was by then practically completed, the necessity for flood protective measures was no longer vital.

For regulation of supplies for irrigation in the delta, orders are conveyed by telephone from the Grand Anicut to the Assistant Engineer at Mettur so that such orders are immediately complied with, though, in view of the long time taken for water to pass from Mettur to the Grand Anicut—from 2½ to 3½ days according to the intensity of flow—even instant regulation cannot always satisfy the requirements of the delta and brief periods of excess supply or shortage are thus bound to occur.

Practically the whole of the delta system is now connected up by telephone with Tanjore, the headquarters of the Superintending Engineer of the Tanjore circle, so that the requirements throughout the delta can be rapidly communicated and supplies regulated accordingly.

CHAPTER XLV

Note on Deflection of the Top of the Dam due to Water Pressure.

Does the top of the dam undergo any displacement due to water pressure when the reservoir is full? A certain late Chief Engineer for Irrigation who was interested in this question calculated that there would be a displacement of several inches, and desired that his theory should be put to the test by actual observation on the completed dam.

Accordingly, during the dry weather of 1934, when the water in the reservoir was at its lowest, permanent centre-line marks were fixed in the centre of the roadway along the top of the dam at intervals of 500 feet, between L.S. 500 and L.S. 4,500. These consist of circular brass discs which are securely anchored into the concrete. By means of the two permanent theodolite stations at the flanks of the dam the centre line was found on each of the discs and fine lines were etched on them. This work was done during the night time in order that errors of observation due to refraction might be reduced to a minimum.

During August and September of that year, when the water level in the reservoir reached its highest, observations for deflection of the points marked on the discs were made. The water level stood at 772·5 or 147·5 feet above the bed of the river at the site of the dam, yet, the most careful theodolite observations did not reveal the slightest deviation of the lines marked on the discs, thus showing that the theory, to which we have referred above, must have been based on incorrect data. The addition of another 17½ feet to the depth of water to bring it to full reservoir level is not likely to make any very appreciable difference in the observations. For all practical purposes, therefore, we may say that there is no deflection of the centre-line at the top of the dam due to water pressure on the upstream face, even when the lake is full.

CHAPTER XLVI

Fuel, Wood and Coal.

After it was decided to use cement mortar instead of lime mortar for the construction of the dam, the large quantities of fuel which it was anticipated would be required for burning lime were not required, and the supply of fuel consequently became comparatively a minor item. The three main purposes for which wood fuel was used were :—

(a) Manufacture of bricks for making surki.

(b) Private sales to employees for domestic purposes.

(c) Starting fires in steam-driven plant, chiefly locomotives which burn coal.

2. Fuel was obtained from several sources, viz.—

(a) Trees acquired within the reservoir submersible area.

(b) Purchase of forest coupes in the Palamalai hills, nearby.

(c) Purchase of revenue porambokes trees from the Revenue Department.

(d) Issue of unserviceable sleepers.

(e) Old dead trees within the camp area.

The collection of wood fuel from the reservoir submersible area was eventually abandoned as the lead increased beyond the economical limit of cartage along rough tracks. Forest coupes were purchased at Rs. 7 per acre, and the average yield was about 7 tons per acre. Revenue poramboke lands were leased at Rs. 5 per acre with a yield of about 5 tons per acre. The latter were easier to work as they were not in hilly tracts like the forest coupes.

3. For the working of forest coupes the Forest Department have very rigid rules regarding the extraction of fuel, and their own staff supervise the cutting to see that these rules are carried out. It was therefore most important to see that the rules were made known to the contractors when calling for tenders, otherwise quotations at unworkable rates would have been submitted. The rules include coppicing of stumps, clearance of all thorny shrubs and creepers (excepting prickly-pear), and stacking these in lines, stacking of fuel at site before carting it away, and the stacking of all brushwood in neat lines. All these items involve labour charges which the tenderer should be aware of beforehand. The Forest Department also did not permit the removal of brushwood from

forests, while, from the revenue poramboke lands, the sale of brushwood in auction realized nearly Re. 1–4–0 per acre (Rs. 160 for 128 acres).

The quantity of fuel collected from commencement of work up to end of March 1934 was—

	TONS.
From reservoir submersion area ..	3,436
" forest coupes	7,638
" old dead trees in camp area	11
" unserviceable sleepers	186
" revenue porambokes	579
Purchased from local merchants *	1,913
Total ..	13,763

Fuel issues for various purposes were :—

	TONS.
Surki manufacture	3,745
" by purchase from local merchants *	1,913
Private sales to staff for domestic use ..	4,590
Other works, locos, etc. ..	3,439
Balance on hand at the end of that year	76
Total ..	13,763

* The surki contractor for a time supplied his own fuel and was paid for finished work, i.e., bricks. It is computed from his outturn that he supplied 1,913 tons of fuel for this purpose.

4. The average issue price of fuel from the commencement of the project worked out at Rs. 7–9–0 per ton for trees and Rs. 3–4–0 per ton for condemned sleepers. Billets were stacked with a cross sectional area of 4 feet by 2½ feet in stack as this facilitated arithmetical calculation of quantities. They were sold at 10 lineal feet of stack (100 cubic feet) per ton. Unserviceable sleepers removed from old tracks, were sold by weight.

Coal and coke required for use in locomotives and at the workshops, was obtained on contract from Madras and was delivered direct by rail at the Mettur Dam Station coal yard. Minor coal dumps were situated at different parts of the works for the convenience of locos. Trains were run as often as necessary to deliver coal to these dumps.

CHAPTER XLVII

Meteorological Observations at Mettur.

Prior to the occupation of Mettur by the Project staff there was no meteorological station at that place and no records, even of rainfall, were available. Early in 1927 a rain gauge was installed, but it was found desirable to record other conditions which might be of value, and in June 1928 a more elaborate equipment was provided. Mettur was subject to violent cyclonic storms and it was considered necessary to record wind velocities. Such information would be useful in determining the wind pressures to be allowed in the design of steel structures, particularly with reference to the gigantic concreting towers then to be constructed for use on the work. Records of temperatures and humidity were also required, while a record of the extent of evaporation of water was important for the calculation of losses by evaporation in the lake at the various seasons of the year. It had been estimated that the evaporation in the lake would amount to about 9 feet per year, representing an enormous loss of water. The daily water tables took into account both rainfall and evaporation as affecting the contents of the reservoir.

The Mettur Observatory was accordingly equipped with a Symon's rain gauge, thermometers and hygrometers, two anemometers, one for measuring wind velocities at the ground level and another above the terrace of the Test House, 21 feet above ground level, and an evaporation pan.

The whole was enclosed in a fenced area 25 feet square, wire netting 5 feet high extending all round to a height of 5 feet.

At a later date an anemometer was also fixed at the top of one of the concreting towers for recording wind velocities at a height of about 300 feet above ground level. An instrument shelter of standard design was provided to house the thermometers, etc. The evaporation station was installed and maintained in strict accordance with the specifications of the American Weather Bureau. The evaporation pan was 4 feet in diameter and 10 inches deep, and was made of galvanized iron supported on a levelled base, the pan being only one inch clear of the ground. The still well was mounted on foot screws in the evaporation pan. The level of the water in the pan was maintained at a level about two inches below the top of the pan. The water level was observed by means of a hook-gauge with vernier attachment enabling readings to be taken correct to a one-thousandth part of an inch. Readings were taken and recorded at 8 a.m. and 4 p.m. daily from

January 1928 until May 1934 when the observations were discontinued.

Early in 1936 the observatory was shifted from the old site near the Test House, which had by then been dismantled, to a new open site near the obelisk at the right flank of the dam. The old site being rather near the rear of the dam was liable to be affected by that great mass of masonry which cut off the breeze during the north-east monsoon and radiated a very appreciable amount of heat by reflection of the sun's rays at all times. The new station, being situated at a level slightly above the top of the dam and at the flank would be likely to give more accurate readings of the mean temperatures at Mettur after the completion of the construction and the filling of the reservoir.

It was to be expected that the creation of a reservoir covering an area up to nearly 60 square miles would have some considerable influence on the climate of Mettur and the amount of humidity in the air. Since, however, the prevailing wind is up the valley from the south for the greater part of the year the presence of a large expanse of water to the north of the town has actually no appreciable influence on the temperature.

Since the dam was completed in 1934 there had been two very weak south-west monsoons and the rainfall in 1934 and 1935 was far below normal. It is, therefore, too early to note whether the presence of the reservoir has any effect on the local rainfall.

The following tables show the monthly rainfall recorded at Mettur from January 1927 to December 1935, the number of rainy days at Mettur in each month, and the monthly evaporation recorded.

A table is also given showing the net effect on the reservoir level due to rainfall and evaporation. The quantity of water in the reservoir gained or lost by direct rainfall or evaporation of course depends upon the waterspread which is continually varying and this has to be worked out daily from tables prepared for the purpose, the waterspread at all levels being known. We see from the table that the average evaporation in March for the six years, 1929–1934, amounts to over 12½ inches, as recorded at the land evaporation station. The actual evaporation in the reservoir is assumed to be 67 per cent of that recorded at the land station. Owing to the violent disturbances due to high winds and storms it was not found practicable to maintain a floating evaporation station in the reservoir itself.

The average maximum and minimum temperatures recorded at Mettur are interesting and show the unusually high variations between the day and night temperatures, being about 30° almost throughout the year. A really hot night there is almost unknown, and, despite the high average day temperature even during the winter months, the compensation of cool nights makes Mettur a pleasant place to live in. Humidity is unusually low and the air is bracing. Tables showing the maximum and minimum temperatures recorded at Mettur are appended, also a table showing the number of days in each month on which the shade temperature was 100 degrees or above. April and May are the hottest months while January, February and March are the driest.

Violent thunderstorms are liable to occur in April and May. These are generally preceded by dust storms of considerable intensity. The heaviest rain usually falls during these thunderstorms. Heavy falls of hail stones are not unknown and sometimes the stones are of considerable size.

Earthquake shocks of slight intensity have been noted at Mettur during the past few years, and, from local enquiry, it is evident that tremors have been felt in the neighbouring villages on rare occasions in the past. It is somewhat extraordinary, therefore, that there are no records of such events. Little is known at present as to the cause and the actual centre of these disturbances, but they are evidently quite local. There was a fear expressed that the tremors recently experienced were due to the formation of the reservoir, but there are no grounds for such a supposition, as shocks were felt long before the reservoir came into existence. Their intensity and duration is so brief as to be of no consequence and the stability of the dam is never likely to be disturbed thereby. Usually a single shock is felt but, on one occasion at least, a double shock has been experienced.

STATEMENT No. I.

Rainfall (inches) at Mettur.

Month.	1927.	1928.	1929.	1930.	1931.	1932.	1933.	1934.	1935.	Average.
January ..	No record.	Nil.	0·44	1·61	Nil.	Nil.	Nil.	1·73	0·50	0·5
February.	Do.	2·57	0·14	7·60	Nil.	3·03	Nil.	Nil.	..	1·79
March ..	Do.	2·50	Nil.	1·46	Nil.	Nil.	0·15	Nil.	..	0·51
April ..	0·25	2·00	15·27	0·72	0·75	3·13	0·89	1·81	2·50	3·04
May ..	13·68	2·81	4·57	5·99	2·16	7·82	4·25	2·45	0·59	4·94
June ..	5·19	1·53	2·46	4·48	1·22	1·07	1·76	1·44	1·40	2·28
July ..	3·06	2·42	2·51	3·48	3·43	0·25	2·17	0·92	1·30	2·18
August ..	14·91	3·05	2·01	1·47	1·68	8·76	5·34	1·55	5·64	4·94
September.	7·61	1·71	15·39	4·05	5·02	1·14	5·97	0·81	2·20	4·88
October.	3·49	10·49	5·26	8·69	3·02	10·94	12·23	11·78	5·65	7·95
November.	3·52	2·64	3·19	5·56	5·57	4·77	0·80	3·13	4·65	3·74
December.	0·13	1·44	2·79	0·53	3·23	1·24	2·48	0·03	1·07	1·44
Maximum rainfall in a day.	**4·50**	**3·59**	**7·63**	**3·50**	**2·88**	**3·28**	**2·76**	**2·28**	**2·08**	**3·61**
Date of maximum rainfall.	1st Aug.	3rd Oct.	23rd Apr.	11th Feb.	4th Nov.	13th Aug.	20th Sep.	29th Sep.	5th Oct.	
Total rainfall for the year.	**51·84** from April only.	**33·16**	**54·03**	**45·64**	**26·08**	**42·15**	**36·04**	**25·65**	**25·50**	**38·19**

Statement No. II.

Number of rainy days in the month at Mettur.

Note.—Days on which there was only slight drizzle and no record have also been included under rainy days.

	1927.	1928.	1929.	1930.	1931.	1932.	1933.	1934.	1935.	Average.
January ..	No record.	1	5	2	1	Nil.	Nil.	4	2	1·9
February.	Do.	6	5	6	Nil.	5	Nil.	Nil.	Nil.	2·8
March ..	Do.	4	2	2	1	Nil.	3	Nil.	Nil.	1·5
April ..	4	11	18	5	8	11	8	5	8	8·7
May ..	11	11	11	10	12	10	18	11	6	11·0
June ..	10	14	23	13	17	13	13	7	10	13·3
July ..	3	10	13	10	22	13	16	5	2	10·4
August ..	11	17	17	14	23	20	13	9	14	15·3
September.	16	5	17	11	14	13	13	3	9	11·2
October.	7	23	15	30	17	22	24	22	9	18·8
November.	9	10	11	14	17	18	12	4	6	11·2
December.	5	10	10	6	16	5	5	1	4	6·9
For the year.	**76** from April only.	**122**	**147**	**123**	**148**	**130**	**125**	**71**	**70**	**113·0**

Statement No. III.

(Land) evaporation (inches).

Observed at the Mettur Observatory.

	1928.	1929.	1930.	1931.	1932.	1933.	1934.	Average.
January.	No record.	7·791	7·757	8·388	8·427	8·628	6·700	7·949
February.	Do.	9·202	7·671	10·369	9·295	10·393	9·508	9·406
March ..	Do.	12·990	11·179	14·256	12·528	12·666	13·509	12·855
April ..	Do.	10·585	12·599	13·649	12·048	12·920	12·866	12·445
May ..	Do.	11·625	10·565	14·535	9·898	11·181	12·805	11·786
June ..	8·773	8·021	9·342	11·180	10·598	9·903	Discontinued from June 1934.	9·636
July ..	8·187	9·133	11·132	9·030	9·868	9·139		9·415
August ..	7·536	9·434	10·417	9·873	8·170	8·577		9·001
September.	9·179	8·404	9·689	8·927	9·288	7·377		8·804
October.	5·580	7·675	5·178	9·297	6·428	5·585		6·624
November.	6·894	6·218	6·328	6·656	5·934	7·210		6·540
December.	6·409	6·619	7·210	5·510	6·599	6·939		6·548
Total per year.	52·588 for 7 months only.	107·697	109·067	121·670	109·081	110·478	..	110·989
Maximum per day during the year.	0·489	0·519	0·527	0·610	0·536	0·547	..	0·538
Date of maximum evaporation.	18th June.	2nd April.	19th August.	15th May.	11th April.	29th April.	..	..

High evaporation figures.

Average per hour.

Date.	Hourly evaporation.
	INCHES.
2nd April 1929	0·027
19th August 1930	0·034
15th May 1931	0·035
11th April 1932	0·032
29th April 1933	0·028

STATEMENT NO. IV.

Net effect on Reservoir Level due to rainfall and evaporation.

	1928.	1929.	1930.	1931.	1932.	1933.	1934.	Average.
January.	No record.	7·351	6·147	8·388	8·427	8·628	4·970	7·319
February	Do.	9·062	0·071	10·369	6·265	10·393	9·508	7·611
March ..	Do.	12·990	9·719	14·256	12·528	12·516	13·509	12·586
April ..	Do.	+ 4·685	11·879	12·899	8·918	12·030	11·056	8·683
May ..	Do.	7·055	4·575	12·375	2·078	6·931	10·355	6·603
June ..	7·243	5·561	4·862	9·960	9·528	8·143	Discontinued from June 1934.	7·550
July ..	5·767	6·623	7·652	5·600	9·618	6·969		7·038
August ..	4·486	7·424	8·947	8·193	+ 0·590	3·237		5·283
September.	7·469	+ 6·986	5·639	3·907	8·148	1·367		3·257
October ..	+ 4·910	2·415	+ 3·512	6·277	+ 4·512	+ 6·645		+ 1·815
November.	4·254	3·028	0·768	1·086	1·164	6·410		2·785
December.	4·969	3·829	6·680	2·280	5·359	4·459		4·596
For the year.	..	53·667	63·427	95·590	66·931	74·438	71·49	71·496

Figures marked + indicate in inches a rise where rainfall exceeds evaporation. Plain figures indicate a fall where evaporation exceeds rainfall.

STATEMENT NO. V.

Temperatures.

(*a*) Maximum temperatures in degrees Fahrenheit.

	1928.	1929.	1930.	1931.	1932.	1933.	1934.	1935.
January.	No record.	96·0	96·0	93·5	94·2	95·0	95·0	93·5
February.	100·0	101·5	97·0	98·8	96·0	99·5	99·0	98·5
March ..	105·1	105·3	102·5	105·3	100·8	104·0	104·8	104·5
April ..	108·0	105·0	105·8	106·0	106·2	107·0	106·0	106·5
May ..	108·1	106·5	104·0	109·8	106·2	105·0	106·0	108·0
June ..	105·8	100·3	99·8	105·8	100·2	99·2	104·2	106·5
July ..	101·0	99·8	102·9	98·8	99·5	101·0	100·5	100·0
August ..	98·3	99·2	100·5	98·2	100·0	98·5	100·5	101·0
September.	101·5	103·2	99·8	101·3	98·0	98·0	102·0	99·0
October.	101·5	98·0	98·0	98·0	97·0	94·5	99·5	98·0
November.	95·0	94·0	94·0	92·5	92·6	95·5	92·5	93·0
December.	93·1	92·5	92·8	90·8	92·0	90·5	89·5	91·0
Maximum for the year.	108·0	106·5	105·8	109·8	106·2	107·0	106·0	108·0
Date of maximum for the year.	2nd May.	16th May.	26th April.	21st May.	5th April and 4th May.	7th April.	25th and 26th April.	22nd May.

STATEMENT No. VI.

Temperatures.

(*b*) Minimum temperature in degrees Fahrenheit.

	1928.	1929.	1930.	1931.	1932.	1933.	1934.	1935.
January	No record.	60·0	61·0	63·0	57·0	62·0	62·0	63·0
February	62·0	69·5	59·0	64·0	59·0	64·0	59·0	64·0
March	64·0	67·0	65·5	70·5	65·5	66·5	60·5	67·0
April	66·0	73·0	71·0	74·0	69·5	72·0	70·0	71·0
May	68·6	71·0	70·0	71·0	68·5	70·0	69·5	74·0
June	71·4	74·0	73·0	75·0	72·0	72·0	71·0	72·0
July	68·0	73·0	72·2	73·0	72·0	72·0	70·0	72·0
August	69·0	74·0	73·0	73·0	70·0	70·5	73·0	70·0
September	70·0	69·0	70·5	72·0	69·0	70·0	73·5	70·0
October	66·0	72·2	71·0	70·0	70·0	66·0	68·0	70·0
November	65·0	67·2	65·8	66·0	65·0	67·0	63·0	60·0
December	64·0	61·8	60·5	60·0	59·0	60·0	62·0	61·0
Minimum for the year ..	62·0	60·0	59·0	60·0	57·0	60·0	59·0	60·0
Date of minimum for the year.	13th Feb.	5th Jan.	27th Feb.	30th Dec.	24th and 27th Jan.	29th and 30th Dec.	10th Feb.	30th Nov.

STATEMENT No. VII.

(*c*) Range of variation of temperatures (Maximum-Minimum) degrees Fahrenheit.

	1928.	1929.	1930.	1931.	1932.	1933.	1934.	1935.	Average
January ..	No record.	36·0	35·0	30·5	37·2	33·0	33·0	30·5	33·6
February ..	38·0	32·0	38·0	34·8	37·0	35·5	40·0	34·5	36·2
March	41·1	38·3	37·0	35·3	35·3	37·5	44·3	37·5	38·3
April	42·0	32·0	34·8	32·0	36·7	35·0	36·0	35·5	35·5
May	39·5	35·5	34·0	38·8	37·7	35·0	36·5	34·0	36·4
June	34·4	26·3	26·8	30·8	28·2	27·2	34·2	34·5	30·3
July	33·0	26·8	30·7	25·8	27·5	29·0	30·5	28·0	28·9
August	29·3	25·2	27·5	25·2	30·0	28·0	27·5	31·0	28·0
September ..	31·5	34·2	29·3	29·3	29·0	28·0	28·5	29·0	29·9
October ..	35·5	25·8	27·0	28·0	27·0	28·5	31·5	23·0	28·3
November ..	30·0	26·8	28·2	26·5	27·6	28·5	29·5	33·0	28·8
December ..	29·1	30·7	32·3	30·8	33·0	30·5	27·5	30·0	30·5

Statement No. VIII.

(d) *Number of days on which the shade temperature was 100° and above.*

	1928.	1929.	1930.	1931.	1932.	1933.	1934.	1935.	Average.
January ..	No record.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	..
February ..	1	4	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	
March	25	26	9	13	5	15	12	13	15
April	22	17	20	26	19	24	26	23	22
May	29	23	18	26	11	10	22	31	21
June	15	1	Nil.	12	1	Nil.	5	15	6
July	5	Nil.	1	Nil.	Nil.	1	1	..	1
August	Nil.	Nil.	1	Nil.	1	Nil.	1	1	1
September ..	7	8	Nil.	1	Nil.	Nil.	4	..	3
October ..	2	Nil.	Nil.	Nil.	Nil.	Nil.	..	..	..
November ..	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	..	..	..
December ..	..	..	..	..	..	..	..	..	..

Statement No. IX.

Wind.

21 feet above ground level at Test House at Mettur—Average per day (miles).

	1928.	1929.	1930.	1931.	1932.	1933.	1934.	Average.
January	No record.	84·5	75·9	95·1	88·8	96·5	92·9	89·0
February	Do.	99·7	77·7	97·9	96·5	98·6	90·1	93·4
March	Do.	119·4	78·8	134·6	114·8	99·6	106·2	108·9
April	Do.	133·2	104·3	141·9	124·3	123·2	100·9	121·3
May	Do.	124·2	116·5	143·4	110·6	119·3	73·6	122·8
June	163·3	119·1	109·2	132·2	106·7	108·3	Discontinued from June 1934.	123·1
July	141·7	121·7	125·3	120·5	118·2	109·9		122·9
August	136·4	110·2	128·4	143·5	86·6	98·0		117·2
September	126·0	109·2	125·8	108·3	103·4	81·1		109·0
October	82·6	71·9	81·2	91·8	68·0	67·4		77·2
November	94·9	73·6	88·9	91·6	78·3	78·7		84·3
December	90·5	80·1	77·4	91·3	74·2	105·3		86·5
Maximum wind per day during year.	228·6	239·9	221·4	220·8	197·5	405·2	..	..
Date of maximum wind	18th June.	4th June.	7th May.	2nd July.	24th May.	15th Dec.		

Remarks.—On 5th May 1928, there was a heavy storm and hurricane which caused heavy damage to the buildings in the camp. On 22nd May 1931 there was another violent wind (66·7 miles per hour velocity) when the chutes of the Red Tower were badly damaged. As the belt of greatest intensity of the latter did not pass through the site of the observatory it is evident that the velocity at the tower was very much greater, possibly 100 miles per hour or more.

CHAPTER XLVIII

Fisheries in Mettur Reservoir—Prospects

A brief but interesting note on the development of fisheries in the Mettur Reservoir has been contributed by the Director of Fisheries, Madras. Before perusing that note, the reader may be interested to learn something of the activities of fish observed in the river at Mettur during the construction of the dam. Prior to the construction of the dam the fish could pass freely up and down the river, but, when the dam in the river section was raised a certain height, they were unable to go upstream and, in consequence, collected in vast numbers in the waters immediately below the dam.

When the low level supply channel was cut, connecting the reservoir through the low level sluices with the river below, and the sluices were opened during the dry season of 1932, swarms of fish of all sorts and sizes swam up the channel, leaping the 4-foot and 6-foot drops on the way, and collected in millions in the water cushion in rear of the sluices. The rush of water through the sluices was then too great to admit of any but the most powerful fighting their way up into the reservoir. It was an amazing sight, however, to see these fish leaping into the sluice vents in a vain attempt to pass upstream through the sluices. The author was so struck by the possibility of adding very considerably to the stock of fish in the reservoir, that, when conditions permitted, he arranged a fish-ladder in one of the vents. This consisted merely of a series of baffles, constructed of heavy sleepers in the form of lock-gates which under the pressure of the water alone were secured in position at intervals of about 10 feet for the full length of the vent. The baffles formed a series of stepped compartments and considerably reduced the velocity of flow in that vent. When the fish ladder was completed and the sluice gate was opened, the fish, which had by now accumulated in solid masses in the water-cushion below, immediately took advantage of this means of access to the reservoir and passed up the ladder in swarms. At times one could count them leaping into the first of the compartments at the rate of about forty a minute and, since this process went on day and night for about $2\frac{1}{2}$ months, it may be roughly calculated that at least 3 or 4 million sizeable fish passed from the river into the reservoir during that period—a very satisfactory return for the small amount of labour involved in making and fixing the ladder. It was unfortunate that the process could not be repeated in the following dry season, but the progress on the construction was so rapid and the water level in the reservoir rose so rapidly that the depth of water over the sluices precluded any possibility of the experiment being repeated.

Most noticeable amongst the fish which passed up the fish-ladder were the Carnatic carp and Labeo, possibly because these fish are capable of leaping to a considerable height and were thus able to negotiate the 6-foot drops constructed in the channel more easily than other species. When the depth of water in the channel was great enough, numbers of Mahseer were also seen in the channel and, no doubt, many of these also gained access to the reservoir.

During 1933 and 1934, the Mahseer afforded very good sport to the keen angler in the channel between the low level sluices and the river. Though these fish appeared to run up to about 25 lb., the largest caught did not exceed 13 lb. They are tremendously powerful swimmers and could be seen lying in columns in the middle of the channel, even in white water.

The angler may be interested to learn that the Mahseer would not look at a spoon or other artificial bait, but would readily take boiled sweet-potato and plantain when floated down the stream in the most natural manner possible.

Unidentified fish of enormous size have been seen leaping in the reservoir from time to time and, during a recent inspection trip, the upper reaches of the reservoir in the gorge below the Hogainakal Falls were observed to be literally boiling with fish. There is no doubt, therefore, that the reservoir already contains an enormous stock of fish, and the proposals made by the Director of Fisheries for the scientific stocking and fishing of the reservoir is deserving of very early and earnest consideration. Even if his estimates of annual catches are considered unduly optimistic, there is not the slightest doubt that, with proper organization, an enormous revenue could be derived from the scientific stocking and fishing of the Mettur Reservoir, and as a start, the very early construction and stocking of a small fish farm is to be heartily commended. This important subject has not, so far, received the attention of the Government which it rightly deserves.

A 'Mugger' goes a-hiking.

Many 'tall' though perfectly true yarns could be told with regard to the fish at Mettur, but the strange adventure of another inhabitant of the Cauvery waters is worth relating.

One night about the middle of May 1936, the customary string of bullock carts was proceeding down the ghaut road near the left flank of the dam when the driver of the leading cart raised an alarm. Imagine the surprise and fright the party received when it was discovered that a large crocodile, proceeding up the road, barred their way! The alarm soon spread and, after some delay, a member of the engineering staff in the camp was induced to leave his bed and proceed to the scene of the disturbance with his rifle. The execution took place without a trial and the carts proceeded on their way. When it met its end the crocodile had already proceeded far up the ghaut road and had negotiated two hair-pin bends.

One associates crocodiles with marshes or river-beds, and the only possible explanation for this mountaineering adventure is that the creature, finding no other way of proceeding upstream, instinctively took an overland route with the intention of dropping into the lake after climbing nearly 200 feet up the hill at the flank of the dam.

Report by the Director of Fisheries on the Development of Fisheries in the Mettur Reservoir.

The Mettur Reservoir, the fourth largest in the British Empire, has a waterspread at the maximum water level of nearly 60 square miles, with an average depth of 50 feet.

2. The River Cauvery, which has been dammed to form this immense lake, is already well known for the abundance and variety of food and game fish found in its waters. In 1919 Col. Rivett-Carnac caught a Mahseer weighing 119 lb. in the Cauvery only a few miles above the section of the river now converted into the Mettur lake. This is the record for Mahseer, the largest Indian Carp and the most important game fish of India. Many other varieties of Carp, Labeo, Cat fish and other economically important species of fish are also to be found in the Mettur lake. A careful survey would probably reveal no fewer than 60 different kinds of fresh water fish, most of which are of some economic value.

3. The enormous productivity in a tropical country of this immense reservoir with permanent water and an unlimited food supply brought down by rivers will at once be apparent, without going into detailed and complicated calculations which might prove wrong. If Mr. H. S. Thomas, in a shallow artificial tank at Vallam (Tanjore district) fed by the same river, could get about 1,000 lb. of fish per acre without impairing the productivity of his pond, this enormous reservoir of nearly 60 square miles with such variety and wealth of fish, abundant food supply and permanent water, might be expected to produce more than 17,000 tons of valuable food fish annually with proper scientific development and exploitation.

4. In Germany, the ordinary annual yield of well-managed ponds where Carp are grown solely in a natural way and without any artificial feeding is about two cwt. per acre, with an average depth of water of 7 feet. On this basis the Mettur Reservoir should be capable of yielding 3,840 tons of fish yearly. But it must be remembered that fish in a cold country like Germany grow very slowly and during the summer months only. This estimate therefore for tropical waters is extremely conservative. Even estimating at a value of one anna per lb., which is a quarter of the usual retail price of fresh fish in the Presidency markets, the value of the yield according to the most conservative estimate runs to the surprising total of nearly Rs. $5\frac{1}{2}$ lakhs a year. Should, however, the figure based on Mr. Thomas's estimate be adopted, the value of the Mettur fishery reaches the enormous figure of nearly $2\frac{1}{2}$ crores of rupees annually. This, of course, assumes that such a vast area is capable of being fished.

5. Even a much smaller irrigation reservoir, the Madurantakam tank, which is only about 4 square miles in extent, is comparatively shallow, is easily poached, frequently dries up, and is dependant on its own natural stock of fish for replenishment, yields an annual average fish rent of Rs. 2,500 though the lessee has to provide the fishermen, watchmen and nets and then find his own profit.

6. Calculations so far made are on the basis of the natural resources of the river. There are, however, several favourable circumstances in the case of Mettur which may be taken into account when considering the potential productivity of the lake. The upper reach of the reservoir for 5 miles below Hogainakal Falls has been conserved for the last 20 years or more as a sanctuary for fish, though unhappily, it is seen that the crocodile has made this reach his favourite haunt since the lake came into existence. The Hogainakal Falls and the masonry dam at Mettur form effective barriers at either end of the lake to the egress of fish, thus confining the fish to the lake. These factors themselves will tend to augment the fisheries of the lake in course of time. In addition, since 1914, the Fisheries Department have been taking measures to improve the fisheries of the river. For the scientific improvement of the fisheries in inland waters various methods are available, but the most certain, the most easily carried out and, therefore, as a rule, the least expensive is the introduction of new kinds of fish suitable for the locality where for some reason or other they do not already exist. Besides conserving the fisheries of the Hogainakal Falls, attempts have been made since 1921 to stock the river with the valuable North Indian Carp-' Catla.' Owing to limited funds, the experiment could

be made only on a modest scale. Every year a few thousand Catla fingerlings were introduced into the river at the Falls. Recently a number of catla have been captured in the leased reaches of the Cauvery lower down showing the success of the experiment. The creation of the lake from 1934 has made even more easy and rapid the process of establishing catla, or for that matter, any other exotic fish.* This has already been successfully done by the Fisheries department in the case of another new irrigation reservoir—Mopad in the Nellore district. Cultural treatment will add materially to the quality and improve the quantity of the fisheries of the lake.

7. For the adequate cultural treatment of the lake, the establishment of a fish farm with trained staff at Mettur is indispensable. Investigation has shown the availability of an ideal site including an unfailing supply of water (without having recourse to expensive pumping) which are the primary requisites for a successful farm. It would be more economical to raise fingerlings for stocking on the spot than to transport them from a long distance with the attendant risk of casualties and the heavy freight over railways, which charge full rates for the conveyance of live fish. For intensive stocking operations, experience has shown that the maintenance of a fish farm on the spot would be far cheaper than stocking waters with fish brought from a distance.

8. It is to be regretted that the small investment required for the proposed Mettur farm—insignificant as it is compared with the value of the fisheries, it is intended to develop—has not so far been made available to initiate the work.

9. Equally important is the question of exploitation. We have already seen that the physical features of the lake are in themselves conducive to the successful development of fish. Conservation, stocking and cultural treatment of the waters will further augment the supply. If the maximum return is to be derived from the fishery, scientific exploitation should go hand in hand with protection and development. It is well known that fish, like most animals under favourable conditions, grow rapidly during early life. After reaching maturity, growth ceases, although the quantity of food consumed continues the same. It is uneconomical, therefore, to allow fully grown fish to continue in the lake, the waters of which can only support a given weight of fish at a time. A scientifically planned and continuous fishing of the lake, in order to remove the full grown fish and give the younger generation a chance to feed and grow, is the only way to

* Early in 1936, several large specimens of Catla in fine condition and weighing between 20 and 30 lb. each were netted in the river immediately below the Dam. These were weighed and measured by the author. Weight (in pounds) approximately = $1\frac{1}{2}$ times length cubed (in feet).

obtain the maximum yield. The indigenous methods of fishing are wholly inadequate to deal with so vast a sheet of water. Power boats and modern nets are needed for the task. Scientific exploitation is, therefore, the second important step in the development of the Mettur fisheries and a scheme for regularly fishing the reservoir is under preparation by the Director of Fisheries.

10. The third stage in the development of the fisheries consists in finding an adequate market for the fish produced. Conditions in the locality are not discouraging. There are several important towns in more or less close proximity such as Bangalore, Erode, Dharmapuri, Salem, Coimbatore, Tiruppur, Podanur, etc., whose markets could easily be supplied with fish by train. There are other important centres of population in the interior which are reached in a few hours by motor. From an investigation recently made, it was found that in these towns, for a major portion of the year, the supply is far below demand. The conditions of the market seem favourable for the development of the Mettur fisheries and their exploitation on a commercial scale.

Note by the Editor.—The existence of an ice-plant at Mettur is a feature which, during the earlier development of the fisheries at least, might prove of some value for the preservation of fish required for despatch to the more distant stations for distribution.

Canal System

CHAPTER XLIX

CANALS—SCOPE OF THE PROJECT.

HAVING NOW dealt with all the more important features of the work at the headworks, let us turn our attention to the development of proposals for the work in the canal system in Tanjore.

In Chapter II, a brief outline of the history of the schemes proposed for the improvement and extension of irrigation in the delta from time to time has been given, culminating in Mr. H. A. Moss' Scheme of 1904 which was submitted to the Government of India for approval in 1906.

As we have seen, his project provided for a reservoir of 40,000 million cubic feet capacity to be constructed at the Nerinjipet site. The object of the scheme was to protect all existing irrigation in the Cauvery delta and to extend the double-crop area to a total of 160,000 acres; to extend irrigation to a new area of 216,000 acres in the Tanjore district and to irrigate by channels taking off direct from the reservoir an additional 46,000 acres in the Salem and Coimbatore districts. The Inspector-General of Irrigation, for various reasons which we need not repeat, turned down the scheme and proposed several modifications. As a result of these proposals the re-investigation of the scheme was ordered, and Col. W. M. Ellis was appointed for carrying out this important work. The proposals made in his report submitted in 1910 and revised by him in 1916 have been referred to in Chapters II and IV.

As a result of the Madras-Mysore dispute, Colonel Ellis' Scheme underwent numerous modifications, and several revised estimates for the project were prepared. The revised rules regarding the sharing of Cauvery waters by Mysore and Madras, which had been provisionally approved by the two Governments in 1921, have been dealt with in Chapter IV. These necessitated further revision of the estimate in that year. Mr. Morgan was the officer deputed to make the necessary revision. The 1924 revision of the estimate which followed was mainly due to the abnormal rise in rates and prices generally as a result of the Great War, and affected the canals just as it did the headworks section of the Project, though to a lessor degree, since the construction of works for the canals did not involve the purchase of such vast quantities of special imported machinery or materials. The 1924 flood which necessitated the entire re-design of the dam and surplus works had little influence on the design of the canal works which required modifications only on a much smaller scale. Nevertheless, this great flood had a profound effect on the estimate prepared earlier in that year and necessitated yet further revision.

Despite the many modifications made in the revised estimates prepared after Colonel Ellis' Scheme was submitted, and despite the Madras-Mysore dispute which occasioned them, the fact remains that so far as the design of the canals system is concerned, Colonel Ellis' Scheme really underwent but few changes. The modifications in the ayacut did necessitate minor changes in the designs of the canals and channels, but his designs were generally adopted or at least formed the basis of the final scheme as actually executed.

The extent of Colonel Ellis' new area to be irrigated was 297,000 acres which differs but little from the area finally adopted. His proposal to construct a new canal from the Grand Anicut down to the Narasinga Cauvery, a large stream running from west to east in the Arantangi taluk, has in fact been carried out, though its alignment has been changed somewhat for reasons which at that time could not be foreseen, being occasioned by political rather than by practical engineering difficulties.

At the risk of repetition, let us now examine Colonel Ellis' 1910 scheme in greater detail so that we may follow more easily the changes which took place and which led to the adoption of the scheme as finally carried out.

The calculations for the whole of the distribution scheme were based on the working tables which had been carefully prepared on the observed flow over a period of several years at the Upper Anicut (or Cauvery Dam as it was more correctly called).

By means of these tables Colonel Ellis showed that, with the natural flow available at the Upper Anicut, considerable extension of irrigation would be feasible in addition to the improvement and protection of the existing irrigation in the delta. A new canal could be constructed to bring under irrigation the commandable land to the south of the existing irrigated area and the area irrigable by the Vadavar, amounting in all to nearly 329,400 acres. In addition to this single-crop area, it was estimated that second-crop irrigation of 75,000 acres could be developed in the new area, while that in the old delta could be extended by another 70,000 acres.

The extension of the new canal system south of the Narasinga Cauvery was also considered feasible but, as we shall see later, the land south of that stream is poor and contains such a large number of small shallow private irrigation tanks, that the proposal to extend the new canal there was abandoned. Colonel Ellis, it may be recalled, was of the opinion that an extension into that area should be considered only if and when experience in the higher reaches indicated the practicability of such an extension. It is to be remembered also that his proposals were made prior to the Madras-Mysore dispute regarding the rights of each State to a fair share of the Cauvery waters. When that issue came up for settlement, it was evident that, even if the decision proved to be favourable to Madras, the supplies of water on which the previous calculations had been based would not be available when the Mysore reservoir came into being. In consequence, if a fair supply was to be guaranteed to both the old and new irrigated area below the Grand Anicut, it was evident that some reduction in the extent of the proposed new area would have to be effected.

Accordingly, as soon as the award in connexion with the construction of the Mysore Dam at Krishnarajasagara was passed, no time was lost in making arrangements to revise the scheme and, in 1914, Colonel Ellis undertook the revision of his 1910 proposals. Provision was now made for the supply of water to a new area of 297,000 acres only. This was to be localized partly under the Vadavar, the southern branch taking off from the Vennar at the Vennar-Vettar head (see Plate XXXII which illustrates the canal system) by an extension of that channel to the west and south of Mannargudi, while the balance was to be limited to the upper reaches of the proposed Grand Anicut Canal extending to the south and west of that area. The lower reaches of the Grand Anicut Canal previously proposed were to be omitted, but might, should circumstances be favourable, be extended later on.

The second-crop area was reduced from 70,000 acres to 65,000 acres in the old or existing irrigated area, while the 75,000 acres in the proposed new area was drastically reduced from 75,000 acres to 10,000 acres.

By the time these revised proposals had been submitted for approval in 1916, joint gauging operations in the Cauvery by the Madras and Mysore Governments were being carried out in order that there might be no disagreement as to the actual flow observed in that river, for on this point the solution of the dispute mainly depended. The results of these joint gaugings were not available till later. They showed, however, that the flow in the river at different seasons had in the past been greatly underestimated and the prospects of being able to irrigate a larger new area than had been provided for in Colonel Ellis' revised scheme were again revived, though, at the same time, some doubt had arisen as to whether the provision made for supplies to the existing irrigation in the delta was sufficient.

In the past, it is to be remembered, the old area had never received steady supplies, and the question now arose as to whether flush irrigation would be necessary for that area, and whether, in that event, a greater supply of water than that provided for in Colonel Ellis' working tables would now be required. The Cauvery floods do not usually commence till the middle or end of June and doubts were expressed as to whether the supplies proposed for the early part of June in each year would suffice for charging the dry sandy beds of the rivers in the delta and leave sufficient for the first-crop area proposed.

It was only when the new dam had been constructed and the reservoir came into actual operation that these matters could be finally settled. Accordingly, it was decided to retain the same water duties * as had already been proposed, to limit the new irrigated area to the extent provided in the 1916 estimate, but to increase the second-crop area.

On this decision having been reached, the area contemplated for development under the new system was fixed at 301,000 acres. Of this, 20,000 acres were to be double-cropped, while the extension of second crop in the old delta was to be 70,000 acres. It may here be remarked that these proposals were later modified when the Project work was started. Revised Working Tables, based on the flow observations of the 12 years 1916–1927, were prepared in 1928 (the earlier tables had been based on the flow for the years 1896–1908). The question of allowing a certain minimum flow throughout the non-irrigation season for the generation of power at the hydro-electric station at Mettur now arose to complicate matters. Allowing 1,000 cusecs as the summer flow for this and general purposes it was still found that 75,000 acres of second crop could be allowed in the old delta, besides some extensions of second crop in the new delta. In reviewing the proposals, however, the Government considered that it was unlikely that the development of second crop in the new area would exceed 105,000 acres, and fixed this area as the permissible limit. At the present time, it does not appear that even this area of second crop is likely to be developed for a very considerable number of years, but circumstances so change that it is unwise to prophesy how further developments will shape themselves. This is written at a time of considerable industrial and agricultural depression and the ryot is at present neither able nor anxious to grow a second crop in the new area now in course of development.

Of the 301,000 acres of new irrigation under the project, some 31,000 acres are localized under the Vadavar extension canals,

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** 'Duty' is the number of acres which a given quantity of water will irrigate in a given period.*

the remaining 270,000 acres being under the new Grand Anicut Canal and its branches.

In the following chapters an attempt is made to place before the reader a brief account of the designs adopted and of the execution of the many works which combine to form the canal system. Beyond the fact that the flow of the Cauvery was now to be controlled and regulated at the Mettur Dam, the works there, which have already been described at some length, have no real connexion with the works carried out in the canal system. An entirely separate staff was engaged in the latter works though they were under the control of the Engineer-in-Chief who was appointed for charge of the whole project. Some 120 miles separate the headworks from the head of the canal system, the tail end of which approach a distance of 200 miles from Mettur.

At the beginning of the history, the reader was promised a more detailed description of the Upper Anicut and the Grand Anicut. This section relating to the Canal System may, therefore, open with a description of those works, since it is by means of their regulation that the supplies in the Cauvery which are distributed to both the old and new irrigated areas are, within certain limits, regulated.

CHAPTER L

Upper Anicut and Grand Anicut described.

The Upper Anicut and Cauvery Dam.

The Upper Anicut, constructed in 1836 by Sir Arthur Cotton, was a solid masonry wall across the north branch of the river where it divides at the upper end of the Srirangam Island. The primary object of this anicut was to divert the low supplies in the Cauvery into the southern branch which was the feeder channel to the old delta. Prior to its construction, the latter had been seriously silted up and the irrigation works generally had fallen into a bad state of disrepair. The construction of this anicut overcame, for the time being, the difficulty of water-supply to the Tanjore delta, but during the flood season the very over-abundance of water became instead a source of danger, causing serious erosions in the bed and banks of the Cauvery. This danger was curtailed when, in 1845, a grade wall (the Cauvery Dam) was built across the Cauvery or southern branch thus limiting the proportion of flood water that passed down that branch.

In 1899, the Upper Anicut was cut down and rebuilt. On its completion in 1902, it consisted of an open dam with 55 vents, 40 feet wide and fitted with lifting gates, a bridge being constructed above the vents connecting the island with the north or left bank. By this arrangement a much improved passage was provided for the discharge of flood water down the Coleroon while, by regulation of the gates, a one-foot greater depth of water could be diverted down the Cauvery.

To this day, the Upper Anicut regulates the distribution of water between the two branches. During the irrigation season, at times when the river above is not in flood, the gates are closed and the whole supply passed down the Cauvery to the Grand Anicut. When the flood exceeds a certain limit, indicated by the gauge at the Cauvery Dam, the Upper Anicut gates are regulated to surplus the balance down the Coleroon. When, during high floods, the gates are all lifted clear, no further regulation is possible and the two branches share the discharge in proportion to their capacities.

The Grand Anicut.

The name is loosely applied to the group of works which comprise (1) the Grand Anicut proper, a dam or weir with lifting gates constructed on the left bank of the Cauvery, (2) a group of scouring sluices and (3) the regulators at the heads of the Cauvery and Vennar, the two main channels into which the Cauvery divides for the irrigation of the delta.

The Grand Anicut is situated 20 miles below the Upper Anicut at the lower end of Srirangam Island, and is designed to regulate the supply which comes down the Cauvery from the Upper Anicut. When the supply exceeds the requirements of the delta channels (now, the Cauvery, Vennar and Grand Anicut Canal) the gates on the Grand Anicut are raised and the surplus is passed down into the Coleroon whence it proceeds down to the Lower Anicut. There, it is again regulated and utilized for irrigation by means of other canals, with which we are not here concerned.

The Grand Anicut, in its original form, is believed to be the oldest work in the Cauvery Delta, having been constructed many centuries ago, by the Chola kings. Its presence points to the engineering ability and resourcefulness of the people of those far distant days when a very fine irrigation system evidently existed in what is now the Tanjore district, but which later fell into a state of neglect. It was a plain masonry anicut, but about the year 1840 a bridge was built over it, the existing work being used as the foundation for the bridge piers. The anicut is 1,080 feet in length. The construction of this old work is interesting, for, on examination, it has been found to consist of a core of roughly dressed granite set in mud, covered with an outer facing of roughly dressed granite blocks set in lime mortar. Like most old irrigation works to be found in Southern India, the anicut was not of uniform section or shape. A portion of the crest was built in ogee form, while the rest was constructed in a series of steps, the foot of the solid dam being protected by a rough stone apron. In 1830, ten small scouring sluices, 3 feet wide and 4 feet high, with the cills at +179·6, were built. The crest of the dam was at 188·92 or a little over 9 feet higher. Dam stones were constructed on the top of the dam, projecting 2¼ feet above the crest.

By the construction of the bridge piers and the dam stones, the effective length of the dam was reduced to 735 feet. In 1886 the dam stones were removed and automatic falling shutters, 2 feet 10 inches high, were fitted on the crest. Four were fitted in each bay of the bridge for 27½ bays, the bridge consisting of 30 spans of 32 feet each. The remaining 2½ bays were occupied by the scouring sluices.

Thirteen years later, in 1899, the falling shutters were removed and replaced by 30 lifting shutters of 32 feet span and 5 feet height.

In the 1909 floods, three arches were washed away in the scouring sluice portion. These were restored, omitting the scouring sluices.

The Cauvery and Vennar Regulators.

Immediately downstream of and constructed almost at right angles to the Grand Anicut the imposing regulators of the Cauvery and Vennar head divide the main stream. They were built in about 1886 for distributing the available flow between the Cauvery and Vennar, and for excluding from both, during floods, the flood water which, prior to their construction, would have flowed down uncontrolled and would, at times have been far in excess of useful requirements for irrigation.

Since that date, they have undergone some modification in the shutter arrangements. The existing shutters are constructed of wood and are sometimes difficult to operate. These will no doubt be replaced by free roller steel gates in the near future.

Since Colonel Ellis wrote his report in 1910, various improvements have been made at the Grand Anicut. The construction of breast walls in the Cauvery and Vennar regulators afford facilities for entirely closing the regulators and excluding flood from the old delta.

New scouring sluices provided with radial shutters have been built between the anicut and the Cauvery-Vennar regulators. These are capable of discharging a maximum of 16,980 cusecs and prevent undue silting of the bed and keep open a low level water course as an approach channel to the sluices.

To protect the Grand Anicut foundations from scour, a bed regulator has been constructed for a length of 1,100 feet from the nose between the anicut and the scouring sluices on the upstream side with the object of deflecting the low water course away from the anicut towards the Vennar Regulator and thence to the scouring sluices.

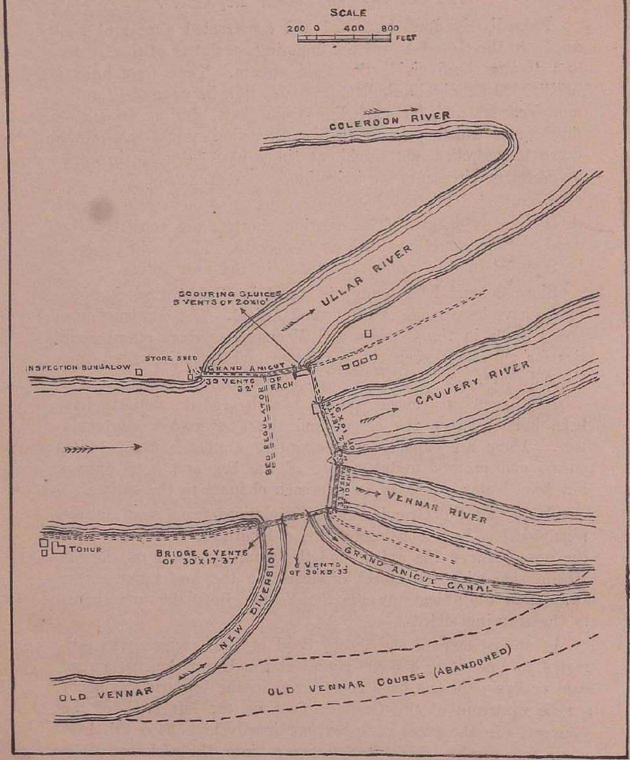
As an outcome of the record flood of 1924, which was estimated to amount to 475,000 cusecs at the Upper Anicut, a road dam or bye-wash has been constructed in the low padugai about a mile upstream of the Grand Anicut on the left bank of the Cauvery. In the event of an extraordinarily high flood this bye-wash can surplus about 98,600 cusecs into the Coleroon thus safeguarding the works at the Grand Anicut to a considerable extent.

The Grand Anicut Canal Head Sluice.

As has been related in the earlier history of the project it was, after much discussion extending over a number of years, decided that the new canal should take off at the Grand Anicut.

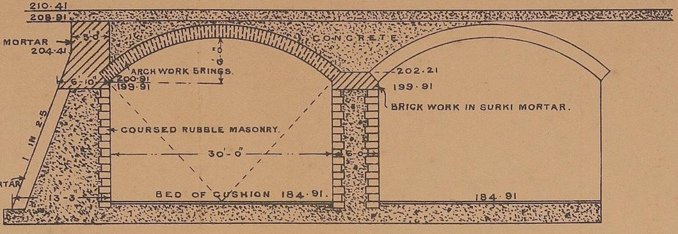
PLATE No. XXXIII

LAYOUT OF WORKS AT GRAND ANICUT

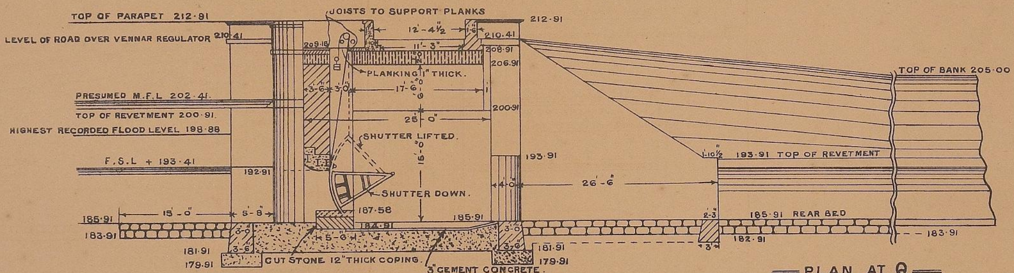


The head sluice for the Grand Anicut Canal, as constructed, is on the right bank immediately above the right flank of the Vennar Regulator. The old Vennar upland drainage course which formerly emptied into the Vennar below the site of the new canal head was diverted for a considerable length and now discharges into the Cauvery on the upstream side of the new canal.

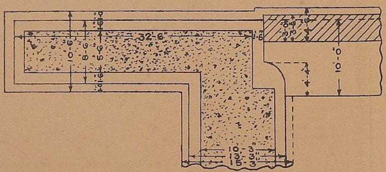
G



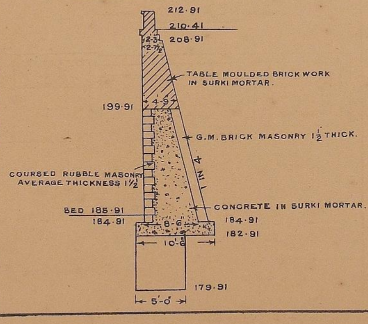
SECTION OF REGULATOR ON A.B.



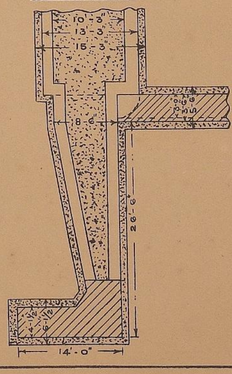
PLAN AT P



SECTION OF WINGS



PLAN AT Q



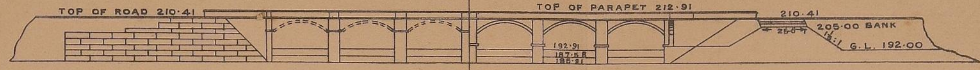
HEAD REGULATOR FOR THE GRAND ANICUT CANAL

SCALE

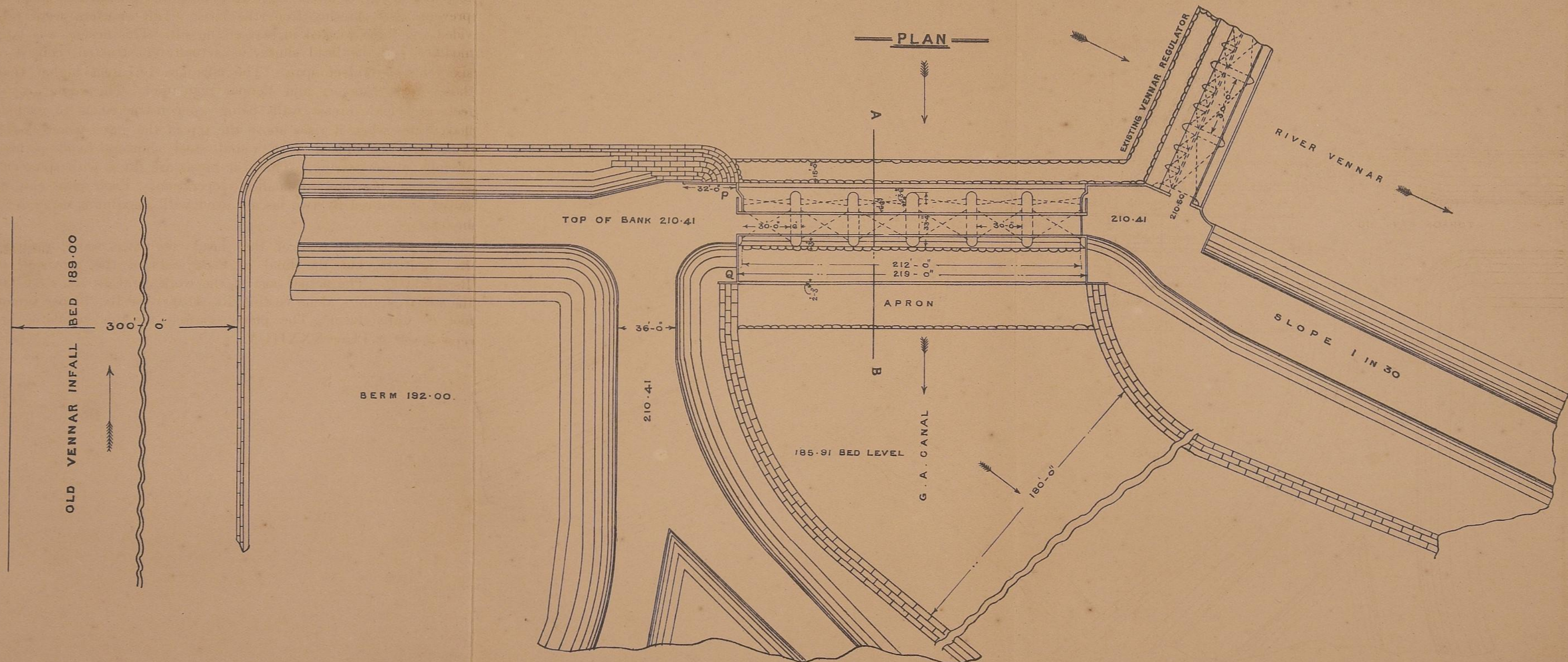
FOR DETAILS. FT.10 5 0. 10. 20.

FOR GENERAL PLAN & ELEVATION. FT.40 20 0 40. 80.

HALF FRONT ELEVATION — HALF REAR ELEVATION



PLAN



Helio-Zinco., Survey Office, Madras. 1939.

Bridges over the drainage course and the new canal head sluice make the connecting links between the Grand Anicut and the Trichinopoly-Tanjore road. Plate No. XXXIII illustrates the lay-out of the works at the Grand Anicut.

The head sluice of the Grand Anicut Canal as designed by Colonel Ellis provided for eight vents each of 30-feet span and 4 feet in height. A 3-feet high drop wall was provided in front to prevent sand entering from the river. Lift shutters were provided and these worked in rear of the sill. This design was later modified and the head sluice, as actually constructed, consist of six vents of 30-feet span. The cills are 1·67 feet higher than those of the Cauvery and Vennar regulators. The vents are $5\frac{1}{3}$ feet in height, breast walls being so constructed as to exclude flood water when it rises above the top of the gates when closed. The vents are fitted with radial steel shutters hand-operated through worm gearing. The gear boxes are fitted with spherical-seated ball bearings to facilitate operation. Each gate can be raised or lowered by two lascars even with maximum water level in front.

The estimated cost of the head regulator was originally Rs. 2,01,690, but the final estimate reduced the provision to Rs. 1,63,000. The actual cost of the work came to Rs. 1,33,700, the radial shutters alone costing Rs. 41,000 (or Rs. 43 per square foot of water face). The plans relating to this regulator are reproduced in Plate XXXIII-A.

CHAPTER LI

Distribution of water left down from the reservoir.

From what has so far been written it might appear to the reader that the Mettur Reservoir was designed solely with the object of affording protection to the existing irrigation in the Tanjore delta and of extending it by means of the new canal system.

It goes further than this, however, for, in its course of 120 miles between the dam and the head of the delta, the Cauvery is responsible for the irrigation of several old and new non-deltaic systems, which, though small in comparison, are of considerable importance to the districts in which they lie. During the north-east monsoon the Bhavani, which joins the Cauvery just below Bhavani town, contributes materially to the supply but, from June to September each year, they are mainly dependent upon the flow in the Cauvery. Of the flow sent down from the reservoir, therefore, an appreciable quantity is taken to satisfy the requirements of these non-deltaic irrigation areas.

The tables on which the requirements of the delta were calculated were based on the available flow at the Upper Anicut, or the quantity passing down the river to that point after satisfying the requirements of the Salem and Trichinopoly channels. But in estimating the capacity of the supply channel at the Mettur Dam the requirements of the delta only were taken as the basis of design, and it was designed for a discharge of 25,000 cusecs only. With the recent improvements and raising of the banks of the channel however the total requirements may be passed down.

Of the total discharge of nearly 33,000 cusecs to meet the maximum requirements of both non-deltaic and deltaic irrigation, some 4,000 cusecs may be intercepted by the former, while transmission losses down the 120 miles of river bed, particularly at the commencement of the irrigation season, are considerable.

The balance passes to the old and new delta systems. The relative importance of the old Cauvery and Vennar systems to the new Canal system is indicated by the fact that only about 16 per cent of the flow received at the Grand Anicut goes to the new system. The latter, on account of its design will be more efficient than the old scattered system and higher duties may be worked to, but the protection and improvement of the old system is the main object of the whole scheme. The main link between the two systems lies in the fact that the water for the new area under the Vadavar is supplied down the Vennar, of which the former is an offtake.

CHAPTER LII

THE NEW AREA DESCRIBED.

THE SOIL in the area commanded by the new Canal system is, generally speaking, of a loamy nature with varying proportions of sand and clay. With proper manuring and cultivation even the poorer areas should respond well to irrigation. The shortage of suitable fertilizers is, however, one of the matters which will need to be remedied as development takes place. In the upper and middle reaches of the new system the soil is generally more fertile than that at the lower end as it approaches the sea. The whole area, is fairly flat with a general fall in a south-easterly direction. From Tanjore southwards the fall is from 5 feet to 10 feet per mile while from west to east it is somewhat greater. The drainage of the land passes to the sea through a number of natural and well-defined drainage courses, between which low ridges run in almost parallel lines. Floods in the drainage courses are usually sudden and of short duration and they are more or less dry for the greater part of the year. A large number of rain-fed tanks, generally poorly maintained and having but little capacity, are dotted all over the area. These do not usually fill till late in October and, in the event of a failure of the north-east monsoon, on which the whole area depended in the past for its supplies for irrigation, the crops are seriously affected or fail completely. In passing through the new area prior to the opening of the new irrigation system one noticed that considerable areas of groundnut were grown, usually in small plots. Small shallow wells dug in the earth supplied water to these crops by hand baling when the rains failed or for maturing. In view of the uncertainty and irregularity of rains, cultivation of the land has been precarious and it is, in consequence, not at all unusual for the ryots in the area to take the precaution of storing food grains to last for two or more years. The area is naturally sparsely populated and vast areas lie uncultivated, sometimes for years together. Obviously, such conditions call for canal irrigation by means of which this land can be so easily enriched.

The villages lie widely scattered and have poor communications. There is only one metalled road at present serving an area of nearly 625 square miles, the rest being all mere mud cart-tracks. While these serve fairly well in the dry season, they become impassable during the rains. Few of the streams are bridged, and as their beds are of deep loose sand, transport of goods across them is at all times most difficult. The development of the tract has pointed to the urgent necessity of improving communications, a matter which is now receiving the earnest attention of the public bodies concerned. A branch of the South Indian Railway traverses the southern portion of the new area. The construction of a new line from Tanjore to Pattukkottai through the heart of the tract is now under consideration. Curiously enough, the tract is predominantly zamindari, only 30 per cent being Government ryotwari land.

CHAPTER LIII

THE GRAND ANICUT CANAL WORKS.

A BRIEF DESCRIPTION of the works at Grand Anicut including the regulator at the head of the new canal has been given and in the following pages the course of the Grand Anicut canal as actually constructed will be traced, reach by reach, brief reference being made regarding the size and capacity of the canal in each reach together with the more important works met with as we proceed downstream from the head. The channels taking off from the main canal together with the sluices are each referred to with their discharging capacities to suit their respective ayacuts. Thus stated the reader may not be wearied with a long description of each work. Such works as are deserving of special detailed description have been treated separately in Part II of this book. In such cases the reader has been referred to the chapter in which such description will be found.

Before proceeding to detail the layout of the Grand Anicut canal, however, an account of the ayacut that has to be supplied by the canal may not be out of place. In addition to the new ayacut of 301,000 acres irrigable with project water a block of the old or existing irrigation, the sources of which have been intercepted by the new canal, has also to be provided for. The area so intercepted comes to 17,826 acres, including the old area under the Vadavar, so that the Grand Anicut canal and the Vadavar are together required to irrigate 301,000 acres plus 17,826 acres plus the 13,000 acres accounted for as " Improvement of duty " on lands under the old Vadavar. Deducting the total ayacut of 61,538 acres under the whole of the Vadavar system, the balance, viz., 269,288 acres, or roughly 270,000 acres, has been localized under the Grand Anicut canal. To supply this irrigation at the normal duties allowed in the new area, a discharge of 3,700 cusecs is required, but the canal should have a margin over and above this quantity so that extra supply may be sent down, if necessary, both for purposes of flushing and for filling up tanks when such supplies are desirable and can be allowed. The canal as designed, therefore, provides for a maximum supply of 4,100 cusecs.

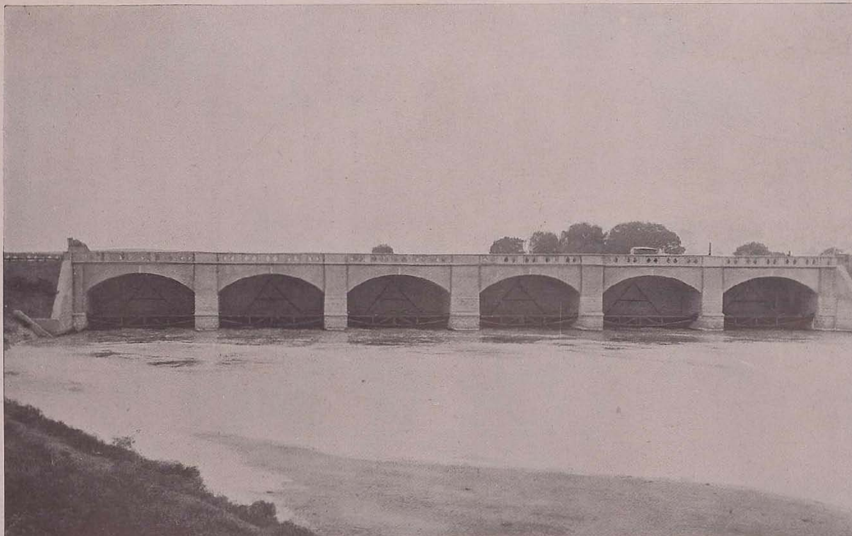
The fall of the land, as has already been remarked, is from north-west to south-east so that, being a contoured channel, very little land on its right side is commanded by the canal, and the extent of irrigation on that side is negligible. With few exceptions, therefore, the channels taking off from the main canal are all on the left or eastern side, and since the country is of a gently undulating nature, these channels are carried generally on the ridges so that they command the lands lying between the tops of the ridges and the bottoms of the valleys coming between. These valleys or depressions naturally form the drainage courses. They are not usually well defined and are occupied by tanks which, prior to the construction of the new canal system, intercepted and stored the natural run-off from the higher lands during the rainy season. For this reason it will be seen that the main canal crosses a number of tank-beds as well as a number of fairly large and important varis or drainage courses. The reader may see at a glance the general alignment of the canal and its branches if he will refer to Plate XXXII.

The bed width at the head is 180 feet and the full supply depth is 7 feet but where the branches take off, the capacity of the canal is gradually reduced so that at the tail end, where the canal carries 300 cusecs only, it is only 30 feet wide and 5·25 feet deep. The bed-fall, however, is gradually increased from 0·15′/1,000′ at the head to 0·165′/1,000′ at the tail to keep the velocities as high as practicable and economise on the section. The whole course thus admits of broad divisions into reaches each with more or less constant dimensions. A brief description of each reach together with the important works therein is given below in the order of their occurrence from the head.

To the reader accustomed to read distances in miles and furlongs, the standard of measurement adopted here may at first be a little confusing. All distances are referred to as "reduced distances" symbolized by the letters "R.D." The unit is taken as 10,000 feet, and as a decimal system is employed the distances between any two points is easily recorded to the nearest foot. Thus R.D. 4/2735 represents a distance of 42,735 feet from the head of the canal concerned. R.D. stones are planted at intervals of 500 feet on the banks of the canals and branches.

Reach I—R.D. 0/0 to R.D. 3/9446.—As already stated, the Grand Anicut canal head sluice or regulator flanks the main stream at the Grand Anicut and the canal flows southward as it issues from the head sluice. A short distance below, it crosses the abandoned course of the 'old Vennar' (see Plate XXXIII) the upland drain that has been diverted into the Cauvery just above the regulator. Below this crossing, a sharp curve is given to the canal causing it to flow parallel with and so close to the Vennar that for the next two miles, the right bank of the Vennar forms the left bank of the Grand Anicut canal. The only big work in the first reach is the siphon aqueduct of 7 vents (12 feet by 6½ feet) over the Adappampallam vari at R.D. 2/3423. There are also three 'C' class bridges (width 10 feet) over the canal in the reach at the crossings of existing inter-village cart-tracks. Five minor

PLATE No. XXXIV.



REAR VIEW OF THE HEAD REGULATOR, GRAND ANICUT CANAL.

off-takes, irrigating 2,114 acres in the aggregate, draw off some 68 cusecs of the canal flow which thus decreases to 4,068 cusecs at the end of the first reach. Throughout this length, the bed width and depth of flow are 180 feet and 7 feet respectively, and the bedfall is 0·15′/1000′.

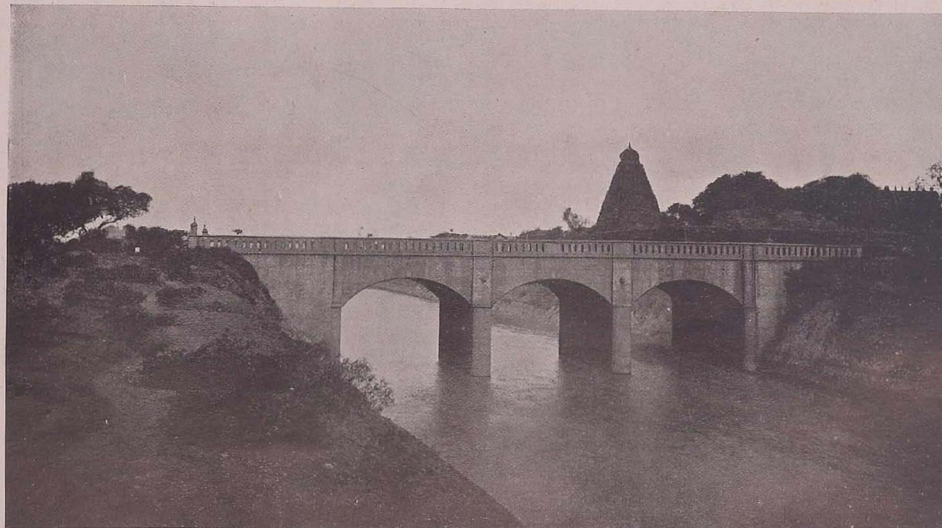
Reach II—R.D. 3/9466 to 9/0597.—The Sholagampatti vari, the largest cross drainage above Tanjore, is crossed at R.D. 4/0755 by means of a syphon aqueduct of 24 vents (12 feet by 7 feet) and then the canal crosses the Tanjore-Trichinopoly line of the South Indian Railway at R.D. 4/1418. A bridge of 5 vents 40 feet by 10 feet has been designed and constructed by the railway authorities, but the cost has been borne by the project. The Aiyanapuram vari (R.D. 5/5354) and Nandavanampatti vari (5/9930) are two other important drains crossed by the canal through syphon aqueducts before encountering the "Budalur cutting" which is about 2 miles long (6/30 to 7/50). The cutting through this ridge is about 17·5 feet at its highest point and in the valley beyond the ridge the Chithrakudi vari is crossed by a syphon aqueduct at R.D. 8/6560. The Chakkra Samantham channel which is the first important channel branching from the canal takes off at R.D. 9/0597 and supplies an ayacut of 4,815 acres. The bed width and depth of flow in the second reach are 177 feet and 7 feet respectively, and the total draw off down to the end of the second reach is about 180 cusecs for an ayacut of 8,534 acres. The width of the canal is reduced to 172 feet at the head of the third reach, the canal carrying only 3,956 cusecs from this point.

Reach III R.D. 9/0597 to 12/8899.—East of the Chithrakudi vari crossing, the canal runs through the Alakkudi ridge, the cutting being about 11 feet deep at the crown of the ridge. The second largest vari above Tanjore, called the Muthalai Muthu vari, is crossed by a syphon aqueduct of 12 vents (12 feet by 6 feet) at R.D. 9/9844, passing which the canal enters a stretch of flat land. To the right of this stretch is the Vallam ridge, composed of laterite stone, and to avoid a cutting of some 44 feet in depth through the ridge, the canal was, after several alternatives had been examined, taken through the Tanjore town. Col. Ellis was not originally in favour of the canal being taken through the town as he anticipated that the cost would be prohibitive, but Mr. Allan Campbell showed that this new alignment was more favourable and economical, to say nothing of the benefits which its passage through the town would afford to the inhabitants of Tanjore. Leaving the Vallam ridge to the right, the canal turns north-east and runs through the Ramanathapuram ridge in a cutting of 12 feet (maximum) near a village of the same name. This cutting was necessary, not only to avoid the high embankment involved in aligning the canal below the village on the lower side of the ridge, but also to secure headway at the railway crossing at R.D. 12/3315. This railway bridge of 7 vents (40 feet by 10 feet) is crossed on the skew and was designed and constructed by the South Indian Railway authorities at the cost of the project. Reddipalem vari is crossed over by a syphon aqueduct of 3 vents, 6 feet by 6 feet at R.D. 12/6050 and the canal then enters the Tanjore town cutting. There is no important irrigation off-take in the third reach and only 23 cusecs in all are drawn off by seven small channels; so the canal has the same bed width of 172 feet at the head of the fourth reach also. There is an important 'B' class bridge (width 18 feet) at R.D. 10/1807 where the canal crosses under the Vallam-Alakkudi road. Three foot bridges and one 'C' class bridge are also provided where existing communications in the reach are cut by the canal.

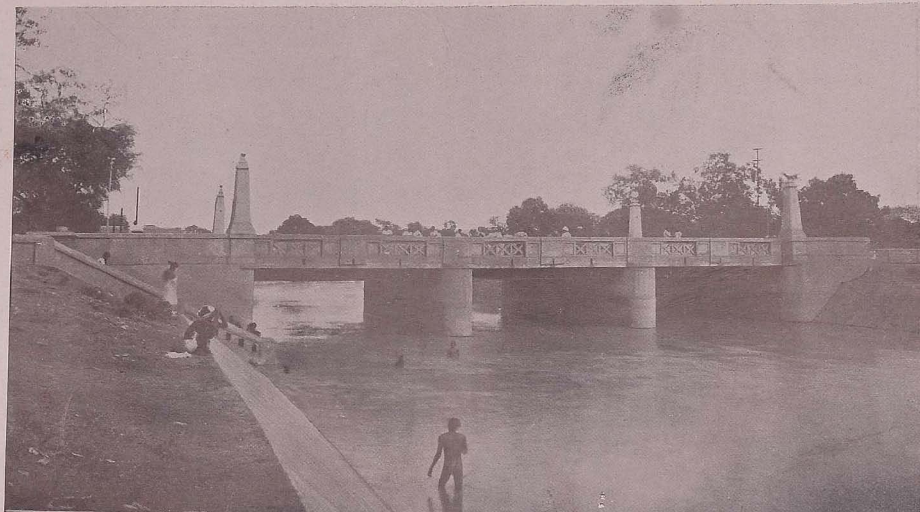
Reaches IV to VI—R.D. 12/8999 *to* 14/8565.—The "Tanjore town cutting" which practically begins at R.D. 12/8899 may be said to extend to R.D. 14/8565, a distance of nearly 4 miles. The approach to the town is in deep cutting (about 26 feet at 13/30) but through the town itself, the depth of cutting is such as to keep the full supply level as far as possible below ground level. The cost of land within the town limits was very high and it was not an economical proposition to maintain the normal width of the canal through the town. Besides this, the width of land available for the passage of the canal through the Muhammadan grave yard on the canal alignment was limited to about 80 feet which necessitated the reduction of the canal to this width by a special tapering from 172 feet to 84 feet and this had to be effected in a distance of 440 feet (R.D. 12/8899 to 12/9339). To make up for this constriction, the depth of flow has been increased to 10 feet and the slope of the canal to 0·205′/1000′. The increase in depth and slope results in an increased velocity and as a protective measure against scour, the whole course of the canal within the town has been lined with slabs of brick-on-edge plastered over with cement laid on a suitably prepared soil-backing. The full normal width and the full supply depth of 7 feet are restored beyond the town limits by a reverse taper between R.D. 14/1492 to 14/1932. In the tapered section between R.D. 12/8899 to 12/9339 the bed of the canal is given a slope of 7·29′/1000′ while in the reach R.D. 14/1492 to 14/1932, the reverse slope back to normal is 7·02′/1000′.

Immediately on entering the town, the canal has to cross the Seppu Naickan vari, supplying a tank of the same name. A foot bridge at R.D. 13/2989 provides access to the police "rifle range" on the left bank of the canal and then the canal runs through the south Fort ditch alongside the southern rampart of the big Tanjore temple of historic fame. The Vallam road crosses the canal near the big temple at R.D. 13/4932 by a special class bridge of 3 spans of 27 feet the roadway being 36 feet 3 inches in width. The

PLATE No. XXXV.



BRIDGE OVER CANAL NEAR TANJORE TEMPLE.



THE IRWIN BRIDGE AT TANJORE.

Muhammadan graveyard, split into two portions by the canal, is downstream of this bridge and a foot bridge, 5 feet wide, has been provided within the graveyard for the carriage of corpses from one side to the other. To prevent pollution of water, the sides of the canal are cemented in a pukka fashion where it passes through the burial ground area. The main road from the railway station is crossed at R.D. 13/6797 and the special class bridge here of 3 spans of 27 feet carrying a roadway 57 feet wide was opened (unofficially) by His Excellency Lord Irwin, Viceroy of India, on 11th December 1929. The bridge is named "Irwin Bridge" and a tablet in the "triangle" to the south of the bridge commemorates the event. A photograph of the bridge appears in Plate No. XXXVI. The canal then passes through the southern portion of the compound of the "Resident's bungalow" and crosses Cadell's road at R.D. 13/9075 under a "special class" bridge of 4 vents (20 feet) carrying a 27 feet roadway. There is another road bridge of 3 spans of 27 feet with a 27 feet roadway at the Negapatam road crossing at R.D. 14/0170. A short distance below, the canal is crossed on the skew by the railway line, this being the third crossing of the canal by the Trichinopoly-Madras main line of the South Indian Railway. The railway bridge of 4 spans of 40 feet has been constructed by the railway at the cost of the project. Below the railway bridge there is a combined bridge and regulator at R.D. 14/1932. The latter is designed to hold up water in the canal for the benefit of the town during the closure period.

There is no irrigation in the reach R.D. 12/8899 to 14/1932 and the canal carries a discharge of 3,933 cusecs at F.S.L. throughout this reach.

Reach VII—R.D. 14/1932 *to* 14/8565.—In the seventh reach, the Neivasal Thenpathi channel, carrying 115 cusecs and irrigating an ayacut of 10,800 acres, takes off at R.D. 14/8565 and 3 pipe sluices supply another 360 acres. The capacity of the canal is reduced to 3,808 cusecs at the head of the VIII reach from which point the width is only 166 feet.

Reach VIII—R.D. 14/8565 *to* 15/7880.—In the eighth reach the Vattacheri channel, taking off at R.D. 15/7880, carries 200 cusecs of the main canal flow and irrigates an ayacut of 14,700 acres. There is a 'C' class bridge at R.D. 15/2988 at the crossing of an inter-village cart-track. A pipe-sluice at R.D. 15/3175 irrigates about 230 acres.

Reach IX—15/7880 *to* 16/0172.—At the head of the ninth reach, the canal has a width of only 156 feet and carries 3,572 cusecs at F.S. depth of 7 feet. A drainage crosses the canal at R.D. 15/8855 and as the bed of the drain is about 2 feet higher than that of the canal at the crossing, the canal is syphoned under the drain through 8 vents of 12 feet by 6 feet 6 inches. A photograph of this syphon is reproduced in Plate No. XXXVII. The head-sluice of Kalianodai branch canal irrigating an area of 85,500 acres (roughly) is at R.D. 16/0104 and, just below the off-take, there is a combined regulator and ' C ' class bridge (at R.D. 16/0172) to pass the required supply through the canal with a head of 0·50 feet. The regulator has 14 vents of 6 feet by 7 feet and can discharge 2,352 cusecs with a depth of 7 feet. In order that the entire flow may be diverted from the reach below in times of flood or on other occasions of necessity, a surplus sluice with 8 vents of 6 feet by 7 feet (and capable of discharging 2,352 cusecs) is provided at R.D. 15/9374 where a drainage course is available for carrying off the flow.

Below the regulator the canal is required to carry less than 2,200 cusecs and accordingly its width and depth from this point are only 108 feet and 6·5 feet respectively.

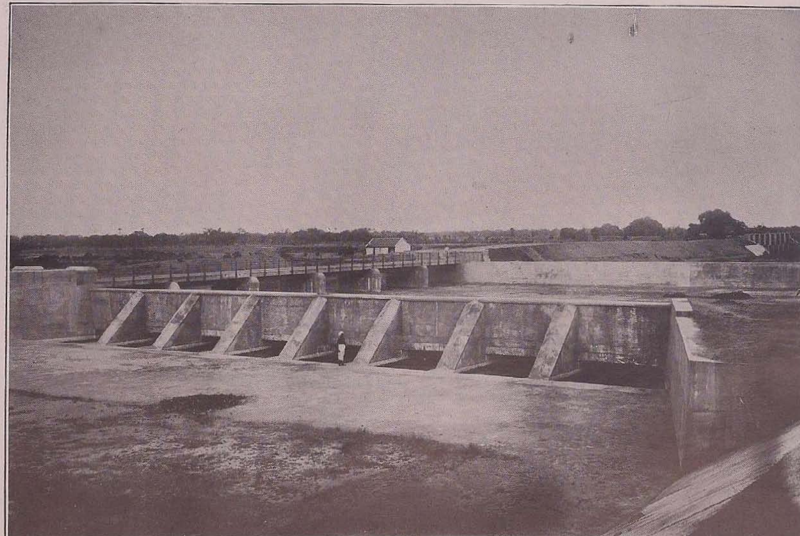
Reaches X to XII—R.D. 16/0172 *to R.D.* 18/4394.—Two ' C ' class bridges with 10 feet roadway and a syphon aqueduct of 6 vents of 6 feet by 6 feet over a drainage course at R.D. 18/0968 are the important works in the reach R.D. 16/0172 to 18/4394. In this reach three minor channels and five small sluices irrigate an area of 3,175 acres in the aggregate. The discharging capacity of the canal at R.D. 18/4394 is about 2,150 cusecs and the slope of the canal from R.D. 16/8708 is increased to 0·155 foot per thousand feet.

Reach XIII—R.D. 18/4394 *to* 19/2445.—The Rajamadam branch canal, the second largest of the branches of the Grand Anicut canal, takes off at R.D. 19/2406 just above a combined regulator and ' B ' class bridge situated at R.D. 19/2445. The head sluice of this branch has two vents of 6 feet by 4 feet and draws off 357 cusecs for an ayacut of 26,000 acres. The regulator has 11 vents of 6 feet by 6 feet fitted, as usual, with screw-gearing shutters, and can discharge 1,740 cusecs.

Reach XIV—R.D. 19/2445 *to* 20/05.—*From R.D.* 19/2445 *the* slope of the bed is increased to 0·16′/1000′ and the width is reduced to 96 feet from below the Rajamadam canal regulator. A minor channel and a pipe sluice with a combined discharge of 23 cusecs take off between R.D. 19/2445 and 20/05 and irrigate an ayacut of 1,700 acres.

Reach XV—R.D. 20/05 *to* 20/5715.—The Olavayal channel takes off at R.D. 20/5456 on the right side of the canal and irrigates an ayacut of 1,280 acres. A pipe sluice also supplies an area of 150 acres. The canal carries only 1,450 cusecs at R.D. 20/5715 and from here its width is reduced from 95 feet to 80 feet.

PLATE No. XXXVII.



CANAL SYPHON AT R.D. 15/8855.

Realignment of canal below R.D. 20/4750.—The course of the canal traced so far follows the course proposed by Col. Ellis with a very few minor changes in alignment. From R.D. 20/4750, however, an entirely new alignment has been adopted. As originally aligned, the canal was to pass through the eastern portion of the Pudukkottah State for the irrigation of certain lands in that State but, in view of difficulties which cropped up later regarding the control of irrigation supplies, the collection of revenue by the State authorities and the administrative control over the canal zones in that territory, that course had to be abandoned and it was found necessary to realign the canal so as to run entirely within Madras territory. The alterations due to this radical deviation in the alignment have been manifold. An area of over 20,000 acres has been thrown out of the commandable extent, since the shifting of the canal to the east has thrown part of the area over to the right or uncommandable side. The height of embankments crossing the valleys of the Maharaja Samudram, the Agniar and other important drainages have had to be increased as the canal has to cross them at a sufficiently high level to command the lands lower down. Besides these, the canal bed has had to be dropped through 27 feet in a succession of drops to enable the crossings of the valleys to be effected at practicable levels. The extra cost involved in these additional works has been considerable.

Reach XVI—20/5715 *to* 22/5420.—Leaving Col. Ellis's alignment at R.D. 20/4750, the canal now takes an eastern bend so as to avoid the Pudukkotah territory (which it approaches at about R.D. 22/00 in the present alignment) and then runs southwards. In the reach of the four miles between 20/5715 and 22/5420 there are a series of 8 drops (one of 4 feet, six of 3 feet and one of 2 feet) which lower the canal bed by 24 feet so that at R.D. 22/5420, the total drop in bed in the reach is nearly 27 feet. Sillathur channel, supplying 2,100 acres, takes off at R.D. 22/5420 and four other minor channels in the reach supply about 1,000 acres. Foot bridges are combined with four of the six 3 feet drops and there is also a separate 'C' class bridge at R.D. 21/7015. The canal carries 1,390 cusecs at R.D. 22/5420 where it is only 77 feet wide.

Reach XVII—R.D. 22/5420 *to* 24/30.—At R.D. 22/6305, where the canal cuts through a hamlet called "Vettikkad," a 'C' class bridge is provided to connect the two portions of the village. Another 3 feet drop, which is the 9th in the series, is constructed at R.D. 22/85. This point practically marks the entry of the canal into the valley of the Maharaja Samudram river, a large local drainage with a catchment of 153 square miles and an estimated maximum run-off of 28,600 cusecs. (For a detailed description of the embankment and aqueduct the reader is referred to Part II Chapter XXVII). This valley is over 2 miles wide and is by far the biggest encountered by the canal, the maximum banking in the reach being as much as 26·5 feet above the ground level. The syphon aqueduct across the river at R.D. 23/60 consists of 20 vents of 12 feet and is the second largest in the whole course. (The largest is the Agniar aqueduct at R.D. 30/25). The Akkaravattam main channel, designed for an ayacut of 2,800 acres, takes off from the left bank at R.D. 24/30. The total ayacut secured in this reach is about 3,300 acres.

Reach XVIII—R.D. 24/30 *to* 25/4656.—The Alivalam channel, designed to carry 100 cusecs, takes off at R.D. 25/4656 above a regulator at the same point. Besides the 6,300 acres under this channel, another 1,200 acres are supplied by sluices in this reach. At R.D. 24/4656, the canal carries 1,250 cusecs with a bed width of 75 feet. The bed-fall is increased from this point to 0·165′/1000′ (against 0·16′/1000′ in the reach above).

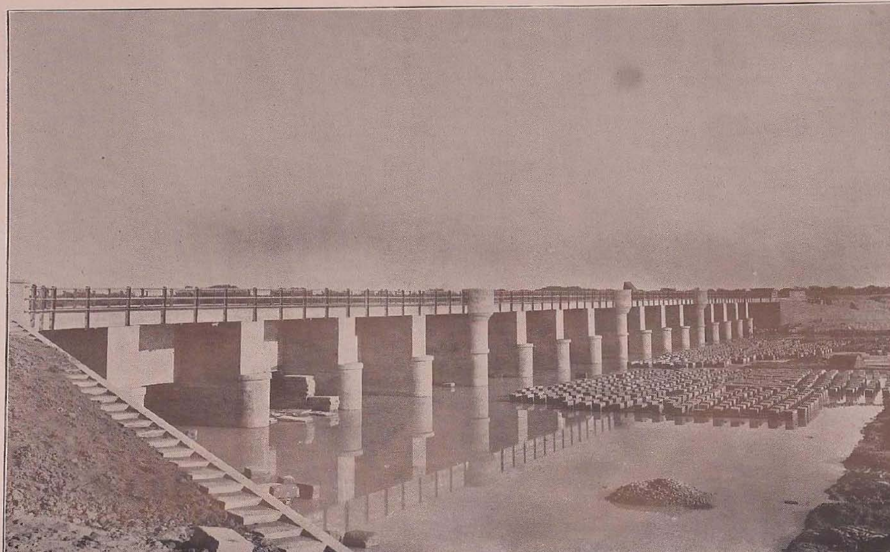
Reaches XIX to XXII—R.D. 25/4656 *to* 29/5990.—The Naduvikkottai, Kayavoor and Pannavayal channels are three important irrigation off-takes in this reach, and the ayacuts supplied by them are respectively 3,100 acres, 3,300 acres and 3,200 acres. It is, however expected that ultimately about 6,000 acres may be brought under irrigation through the Pannavayal channel by suitably extending it. The total ayacut supplied through channels in this reach is over 16,700 acres (excluding the area under the Pannavayal channel extension).

Reach XXIII—R.D. 29/5990 *to* 30/60.—The Agniar valley extends from R.D. 29/71 to 30/43, a distance of 7200′. A detailed description of the works in this valley is given in Chapter XXVI, Part II. The embankment across the valley is 15½ feet high at the deepest point and the syphon aqueduct at R.D. 30/25 is the largest of its kind in the whole course of the canal. The catchment of this river is 335 square miles from which area a potential flood of over 58,000 cusecs may reasonably be expected. The syphon aqueduct consists of 36 vents of 12′ × 11·5′. There is a combined regulator and 'C' class bridge at R.D. 30/60 and the Pudupatnam canal, designed for an ayacut of 31,500 acres, takes off above this regulator.

Reach XXIV—R.D. 30/60 *to* 35/80.—The canal at R.D. 30/60 has an ayacut of about 40,000 acres and discharges about 550 cusecs with a bed width of 40′, full supply depth of 5·5′ and a bed fall of 0·175′/1000′. It ends at R.D. 35/80 with a bed width of 30′ and full supply depth of 5·25′ from which point the channel continues under the name of "Grand Anicut Extension channel".

Reach XXV—The Grand Anicut Extension channel.—The Grand Anicut Extension channel has a bed-width of 29½ feet and carries a discharge of 312 cusecs with a full supply depth of 4·5′ and a bed fall of 0·2′/1000′. After running for a short distance through

PLATE No. XXXVIII.



THE MARUDANGUDIYAR AQUEDUCT.

Pattukkottai taluk, it enters Arantangi taluk. The Villunniyar, an important drainage is crossed by means of an aqueduct at R.D. 1/5102 (measured from the head of the extension channel) and the Mayavaram-Arantangi branch of the South Indian Railway crosses the channel at R.D. 2/82. There is also another aqueduct at R.D. 3/3684 across the Marudangudiyar before the final tailing off of the channel into what is known as the " Thiruvappadi channel " occurs at R.D. 6/56. A photo of the Marudangudiyar aqueduct is reproduced in Plate XXXVIII. The Thiruvappadi channel runs east and is 13′ wide and 3·5′ deep at its head.

The Excavation of the New Canal.

The formation of the canal system involved excavation amounting to 560 million cubic feet of earth at a cost of Rs. 42 lakhs, and about half this quantity was in the portions of the canal which carry more than 300 cusecs, over 6,500 acres of land in strips aggregating in length to no less than 2,650 miles had to be acquired at a cost of about Rs. 40 lakhs. The canal runs in a maximum cutting of 26′ depth just above Tanjore. At other places it is as far as possible in balanced cutting, while a maximum banking of over 30′ occurs at about the 45th mile where the canal crosses the wide valley of the Maharajasamudram river. A comparison of this heavy embankment, with the next two largest is made below in order that the reader may have some conception of the great amount of earthwork involved :—

Name of embankment.	Length in feet.	Maximum height in feet.	Average height in feet.	Earthwork million cubic feet.	Cost in lakhs of rupees.
1 Vettikkadu	10,250	30	20	29·0	6·5
2 Thattankulam	3,000	21	12	7·2	1·2
3 Agniar	7,200	15	6	7·6	0·8

It may be noted that the class of soil available at site for the construction of the heavy embankment at Vettikkadu was not well suited for the purpose and better classes of earth had to be railed from the neighbouring reaches. In view of the peculiar condition of the soil obtaining at the site, the " hydraulic gradient," the " earth cover " the final front and rear slopes and other engineering data to be adopted for the design of this embankment were determined by actual observation of the behaviour of an experimental tank (constructed on the canal alignment itself) when filled with water to various depths. The tendency for the saturated soil in the banks to slide was also carefully studied (see Part II, Chapter XXVII).

Disposal of Cross-drainage.

In its 70 mile course on sidelong ground, the Grand Anicut Canal intercepts a right side catchment of 780 square miles which can occasion a combined potential flood of over 80,000 cusecs. The streams crossed vary in size from quite insignificant ones to big streams such as the Agniar, which is capable of carrying a discharge as high as 58,300 cusecs. Any arrangement to absorb the run-off from this catchment in the canal itself, and to pass it off lower down by surplussing, was of course out of the question as the canal was designed to carry only a maximum of 4,100 cusecs at its head for irrigation purposes and far less than that quantity at other points lower down. Nor was it possible to traverse the cross-drainages as "level-crossings" as this would involve a definite lowering of the canal bed which in turn would make it impossible to command the lands in the lower reaches. By far the most practicable alternative was to exclude the water in cross-drainages altogether by means of aqueducts. This was accordingly done, and 43 syphons have now been constructed at a cost of some Rs. 23 lakhs. By this means, the design of the canal has been much simplified as its capacity at any point is now strictly limited to the requirements of irrigation alone.

The data assumed in the original estimates to compute the maximum run-off carried by these cross-drainages happened to be underestimated but this was fortunately discovered through the occurrence of unusual floods before the construction works were far advanced. The waterways of the syphons were considerably increased to provide an ample margin over the latest observations. Many of these works are of considerable dimensions and called for more than ordinary treatment in design. Brief particulars of four of the more important syphon aqueducts are abstracted below :—

Name of crossing.	Capacity of the canal at the point.	Catchment of the cross drainage.	Maximum discharge from catchment of cross drainage.	Vents of syphon.	Cost of the syphon in lakhs of rupees.
	CUSECS.	SQUARE MILES.	CUSECS.	WIDTH.	
1 Sholagampatti vari (4/0755).	4,070	107	15,500	24 of 12′	2·976
2 Muthalaimuthu vari (9/9844).	3,956	41	7,163	12 of 12′	1·465
3 Maharajasamudram river (23/60).	1,387	153	28,600	20 of 12′	2·450
4 Agniar (30/25) ..	1,000	335	58,300	36 of 12′	2·709

Instead of providing aqueducts at each cross drain it was some times found more economical to combine two or three small drainages into one where the fall of the country and the discharges carried by the drains admitted of such practice. In such cases, side drains leading to the main drain (or to the one more favourably situated from a constructional point of view) were excavated, and the waterway of the syphon was designed for the combined discharges of the drains thus connected.

The Vadavar Extension System.

The supply required for the Vadavar extension system is picked up by the Vadavar from the Vennar river. The Vadavar is a pre-project canal, about 20 miles long from its off take down to its infall into " the Vaduvur Eri ". The surplus course from this eri is known as the " Kannanar " which finally empties into the sea through the " Pamaniar " another pre-project distributary. Owing to the relatively unfavourable formation of the Vadavar canal with reference to its ayacut, the waters of that stream could not be utilized efficiently and about half of its supplies usually ran to waste.

Before any additional ayacut could be secured under the canal or before it could be extended, it was primarily necessary to improve the canal itself. The canal has now been regraded provided with regulators at important points and widened and straightened wherever necessary to convey the extra supplies for the extension of its ayacut. An additional head sluice has been built with eight vents each 5 feet square and " the Vadavar extension canal ", about 7 miles in length, starts from the 19th mile of the old Vadavar at a point just above its outfall into the " Vadavur Eri ".

As a result of these improvements, it was found possible to supply 28,000 acres of irrigation with the same quantity of water the canal drew previously for an ayacut of only about 15,000 acres The revenue from the extra 13,000 acres thus secured by improvement of duty is to be credited to the project, which has borne the cost of these improvements.

CHAPTER LIV

PRELIMINARIES AND INCIDENTALS.

IT is to the credit of the original designers of the project that all possible improvements were fully foreseen and provided for in these estimates. The designs for works in the canal area were worked out in those estimates in the minutest detail so that, when the scheme was sanctioned, it was possible to start constructional operations immediately and simultaneously throughout the area. Alignment of canals on the ground was followed by the acquisition of lands, manufacture or collection of materials, construction of store or work sheds, and then a start was made on the works themselves. Some delay in the early stages was occasioned by the somewhat unexpected differences which led ultimately to the exclusion of the canals from the Pudukkottai State lands. An increase in the waterway of the syphons, as we have arleady noted, was thereby occasioned, necessitating the re-design of some of the works, but as these changes did not affect the final scope of the project, the changes were adapted without much difficulty.

Considerable delay in the execution of works below the Agniar crossing was however caused by the agitation raised by the ryots of the Salem and Trichinopoly districts who claimed that their districts should first receive a share of the benefits which the construction of the reservoir afforded. In 1928 these ryots contended that part of the new area under the project should be found in their districts in preference to localizing it entirely in Tanjore. Investigations were then ordered by Government to see if such extensions would be economically feasible, but in so doing, they ordered that works in the canal zone below the Agniar should be kept in abeyance till a decision was reached with regard to the proposed irrigation in Salem and Trichinopoly. The investigations, however, showed that the Salem canal scheme would be three times as costly, acre per acre, as a similar scheme under the Grand Anicut Canal. In addition, the nature of the soil and topographical features of the Salem district were such that the irrigation of lands in that district was likely to prove most wasteful, the cost of heavy cutting and numerous cross-drainage works being very considerable. To make such a scheme pay, a water rate of over Rs. 30 would have been necessary and as the payment of such a rate was out of the question, the proposal was definitely abandoned as impracticable. As for the agitation from the Trichinopoly ryots, conditions were found to be more favourable and resulted in the proposal for the Kattalai High Level Channel scheme (since completed).

This scheme, however has been carried out as an extension by improvement of duty so that the new area under it does not form part of the project. Though the agitation from the ryots of Salem eventually ceased to have any effect on the final scope of the project, yet it contributed in no small degree to the delay in the start and completion of works in the area below the Agniar.

Regulators, syphons, drops and headsluices for branch canals have been constructed where necessary and bridges have been provided at average intervals of a mile and a quarter over the canals and at intervals of about 2 miles over the distributaries. Thanks to the convenient situation of Tanjore and Pattukkottai, two important and populous towns served by the South Indian Railway, nc elaborate arrangements for accommodation were necessary for the constructional staff. A few inspection bungalows were constructed at key points along the course of the canal and also a few office buildings at Tanjore and Pattukkottai but these would have ultimately been necessary, in any event, for the permanent maintenance staff of the project. Temporary sheds sufficed for housing the section staff. The temporary dispensary constructed at Vettikad was the only one of its kind found necessary in the canal area and this was provided and maintained out of the project funds.

Permanent telephone communications have been installed between Mettur (the regulating source for all supplies of water for the delta) and the canal divisions at Tanjore. This line has proved of immense advantage from the date of opening of the Cauvery Mettur System by facilitating judicious regulation and distribution of supplies to the delta. The Grand Anicut is now linked up by telephone with Mettur on one side and with all the important stations in the delta on the other, so that the officers, even at the more distant control stations, are in close touch with one another and advance information, more or less complete, of the probable state of the river at Grand Anicut can be obtained some two or three days in advance. During the north-east monsoon, the local rainy period, telephonic reports regarding the intensity of rain in any portion of the delta can easily be communicated and regulation of supplies at Mettur can now be made earlier than was formerly possible, so that wastage of water can be reduced to a minimum.

Labour and Machinery.

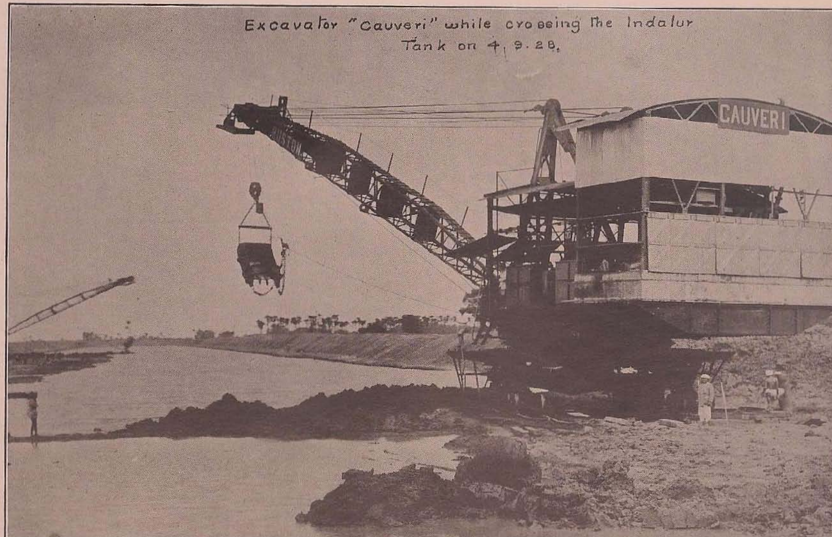
Scarcity of labour is a characteristic phenomenon in the delta as all available labour is concentrated in the periodic operations of transplantation and harvest of paddy when labour is required everywhere in the delta at the same time. There is, in view of the migration from one area to another, bound to be a general shortage of labour for some time to come. At present, there is a good deal of movement of labour from the uplands to the delta during the transplantation period and back again to the uplands for the harvesting of groundnut immediately afterwards. The deltaic cultivators pay the coolies liberally for their timely help for such relatively simple work. The attraction of such labour, therefore, for the strenuous work of excavating the canals, at wages none too tempting, proved to be a knotty problem, and it was feared that if discontent led to labour combines, progress in construction would suffer. It was, accordingly determined that, from the commencement of the canal construction, a good deal of the work should be done by means of modern excavating machinery to safeguard progress and keep down labour rates.

Madras, at the time the project was sanctioned, had not had much experience of the work of mechanical excavators, so Mr. (now Diwan Bahadur) R. Narasimha Ayyangar, then Executive Engineer in charge of the canal system, was deputed in December 1925 to study the working of the excavators and other allied machinery then in use on the Sukkur (Lloyd) Barrage and Sutlej Valley Projects. As a result of his report and that of Mr. W. P. Roberts, the Mechanical Superintending Engineer appointed to the project, it was decided to purchase two giant 200-ton Diesel electric dragline excavators, each costing Rs. $2\frac{3}{4}$ lakhs. Each of these did the work of nearly 1,300 coolies and they were used in excavating the difficult portion of the canal from the head at the Grand Anicut down to Tanjore, a length of nearly 26 miles, where the canal is broad and deep, the soil hard and the labour supply limited. The organization of the canal divisions and the charge of the portions to be done by the excavators devolved on Mr. R. Narasimha Ayyangar at the outset. The excavators proved competitive as well as substitutive for labour to the extent that they helped to keep down the rates for earthwork. It is satisfactory to record that the repairs and breakdowns were few. The other portions of the main canal and all the smaller channels were excavated by manual labour. It may be of interest to note that, of the 236 million cubic feet of earthwork involved in the main canal, nearly 100 million cubic feet were handled by the excavators. It is to be said here that it was found easier and more convenient to maintain and shift the two excavators (capable of travelling half a mile per hour) than to construct and continually shift camps for over 2,000 coolies in similar circumstances.

Constructional Materials—Bricks.

The Tanjore district, being of deltaic origin, is practically devoid of rock within workable distance of ground level and, in the entire

PLATE No. XXXIX.



ONE OF THE DRAG-LINE EXCAVATORS AT WORK ON MAIN CANAL.

absence of any suitable building-stone in the area, all masonry works in canal area had to be built of brick in mortar. Bricks of local manufacture were used, but the quality of clay available within easy reach of the canal works below Tanjore town was generally rather inferior. Good bricks, as used by the railway, could be manufactured at Budalur within a few miles of the head of the canal but the long leads which their use would entail in the lower reaches were considered prohibitive to their general use. Towards the tail reaches particularly, the clay available for brick manufacture was very inferior and became very friable when burnt. The transport of imported bricks by cart track to that area would have been very costly. For the latest works cement-sand blocks of 1 : 8 proportion were successfully used, but it was not until most of the more important masonry works had been built that the use of such blocks was proposed and adopted. Since sand was plentiful and cement had in any case to be imported it is unfortunate that use of such blocks in place of bricks was not attempted earlier. The maintenance charges for such of the small works as were constructed with this material should be very small when compared with those required for brick-work structures.

CHAPTER LV

AYACUT INVESTIGATIONS—INTRODUCTORY NOTE.

IN THE following paragraphs will be found an outline touching upon some of the more important and complicated investigations which had to be taken up prior to the actual opening up of the new area for cultivation by direct irrigation. These investigations, carried out by the special Revenue staff in close co-operation with the special Engineering staff appointed for the purpose, constituted such an important part of the work in the canal area that it has been considered desirable, to set them out in greater detail in part II of this book. Only by perusing those chapters can the ordinary reader realize the extraordinary amount of labour which the thorough investigation and provision for control of irrigated land involves. To those not conversant with irrigation operations, as practised in India, many of the technical terms employed in those chapters may be unintelligible. Accordingly, a glossary of terms has been prepared and will be found in Appendix M.

Field Bothies.

As in all earlier schemes, the Government, at the time of sanction to this project, undertook only to deliver water at a commanding point in each village leaving to the ryots the task of constructing the necessary "water courses" for conveying water from the Government channels to the fields, following the instructions of the irrigation officers only as to alignment. Even this was subject to the proviso that Government channels should be carried into or down to the border of the lands of each village when the area to be irrigated was not less than 100 acres in extent. On the other hand, the ryots were not to be called on to construct any channel having a capacity exceeding 5 cusecs.

However, during actual execution of the work, this policy was liberalised, and Government channels were excavated down to a point where they would deliver water for blocks of 150 acres or less. The rapid extension of irrigation and the avoidance of petty quarrels amongst the ryots has been further facilitated by the Government undertaking the aligning of field channels and of acquiring the land required for them down to a point where they are required to irrigate not more than 25 acres each. The excavation alone has ordinarily to be done by the ryots but, in particular cases where the excavation has been found to involve much labour, it has been done at Government cost.

Land Acquisition.

This is the first project in which the acquisition of land for field bothies has been undertaken by Government. The special Revenue staff appointed to deal with this work consisted of one Indian Civil Service officer and eight or ten Deputy Collectors with the necessary subordinate staff. Of the 7,000 and odd acres acquired in the canal area, nearly a third was for the field bothies.

Much of the land traversed by the canal system is zamindari unsurveyed land, and the adoption of the normal procedure would have involved considerable delay in starting the work. These difficulties were got over by sending out survey parties in advance, under the control of the Survey department, to prepare correct maps of the villages before land acquisition was started. Unnecessary formalities such as preparation of land schedules in the Public Works Department in the first instance were dispensed with. The initial organization of the proceedings was in the hands of Mr. P. T. Sreenivasachari, Collector and Land Acquisition Officer for the project, whose ability and tact had not a little to do with the smooth and rapid progress in the land acquisition proceedings.

Delimitation of Ayacut.

An artificial limit is set to the new irrigation permissible under the project by the terms of the Madras-Mysore agreement and the canals and channels have been designed only for that limited supply. To secure the best results in the circumstances, it is essential to prevent haphazard development which might lead to waste of water and to circumscribe the actual irrigable extent by having it regularly defined. All extensions beyond the limit thus fixed are to be discouraged by heavy penalisation. It has accordingly become necessary to introduce a "permit system" whereby the authorities "authorise" irrigation by the issue of permits which give the ryot the necessary title to the water for a particular field from a project source. Anyone taking water to his lands without such a permit will now be obliged to pay the penal assessment for irregular irrigation.

Before a project of this magnitude and complexity could be undertaken, it was necessary to prepare contoured plans both for purposes of localising the ayacut in the most suitable areas and to secure the best alignments of channels and field bothies in the interests of economy and efficiency. This, however, involved detailed investigation and the preparation of special maps with levels shown thereon. This preliminary and important work was entrusted to a Special Executive Engineer with two Assistant Engineers who worked out the engineering details and completed the work after obtaining additional information furnished by the Special Revenue staff. Block maps, showing in great detail the result of all investigations, have been prepared for the whole area. These are now printed and constitute a permanent record for easy reference.

The Ayacut Enquiry.

It was desirable to see that the maximum possible ayacut in each village was secured without detriment to future expansion of the village, and the "ayacut enquiry" by the Special Executive Engineer and Special Revenue Officer was designed to secure this end. This was a systematic invitation to the ryots of each village to represent their requirements and views for consideration, and at these conferences information as to the irrigability of their lands, the extent, if any, to which their lands would have to be lowered in order to be easily subject to gravitation flow was ascertained. Close collaboration between the Public Works Department and Revenue staff was ensured at each stage with a view to expedite formulation of proposals and the acquisition of lands. Village sites, roads, cart tracks, drainage courses, grazing grounds, cremation places, threshing floors and land for other communal purposes, that might reasonably be required in years to come, were all examined and specifically and permanently excluded from the project ayacut; comparatively high areas were reserved for residential purposes and, generally, the areas so reserved came to about 3 per cent to 5 per cent of the total area of the village. A thorough examination was also made of the need to retain such of the existing shallow tanks as might be useful in supplementing or serving as small storages for irrigation in future.

As a result of these investigations, extending throughout several hundreds of villages, it was found that, on an average, a gross area of 100 acres afforded an irrigable area of about 70 acres only. The earlier estimates, however, had counted on the availability of nearer 80 acres per 100 acres gross area to be available for actual irrigation. As a result of these ayacut investigations, the possible shortages were discovered in time and steps were taken to localise the anticipated shortage elsewhere in the best manner possible. The position will again be reviewed some ten years hence, when the lands have further developed and, if any of the fields now included are not irrigated by that time, their possible inclusion by the removal of defects in the system, or the localisation of an equal area elsewhere, will be carefully considered.

The "Ayacut Register" and "Permits."

A record of the results of these ayacut investigations to which we have just referred, clearly specifying in what manner each field is to be irrigated, is now maintained in an "ayacut register" and the permits issued to the ryots are merely extracts from this register. The ayacut register is thus a register of standing permits and copies of this register will be kept by the local Public Works and Revenue authorities to effect adequate check over irregular irrigation.

The ayacut register contains about 450,000 entries and, ultimately, about 430,000 permits will be issued. It has been found that the average number of permits per acre of irrigable area is 1·5 in the upper reaches and about 1·2 in the lower reaches. The early distribution of such an enormous number of permits was a problem which called for special measures. The Revenue Authorities expressed their inability to arrange for their distribution, so the work was entrusted to a staff of supervisors under the Special Executive Engineer who took the permits to the villages and delivered them to the ryots who were informed in advance when the distribution of permits would take place. All undelivered permits, now greatly reduced in number, were sent to the Revenue Department for distribution to the ryots through the agency of the village officers.

CHAPTER LVI

Effects of the Reservoir on existing irrigation.

While the arrangements for the conservation of water by the construction of a reservoir were being taken, the possibilities of effecting economies in the use of the water so conserved were also investigated, otherwise, the full benefits of storage could not be secured. It was decided to follow up the improvements in supplies to the delta storage with the remodelling of sluices and river conservancy operations. The deltaic rivers were of the inundation type and served as handy flood valves to supplement the Coleroon in times of flood. These naturally had a far greater capacity than is now required for irrigation purposes alone and when conveying merely the irrigation supplies, the rivers ran very low with resulting loss in command and relatively large wastage and losses in transmission.

During the pre-project days, the floods, usually coincident with the busy transplantation period used to be passed on to the delta without abstraction of its waters and what was not capable of utilisation simply ran to waste to the sea. These conditions with the advent of the Reservoir have now been entirely changed and, hereafter, floods of moderate intensity will be more or less completely absorbed while intense floods will be greatly modified. There is now little or no need for the use of these distributaries as flood-valves and this makes it possible to restrict their sizes as far as possible. It is hoped that eventually the remodelling and river conservancy operations now under way will ensure a more stable and economical regime and improve command in the delta.

System of Raised Sills.

Experience has shown that in nearly all gravitational systems the channels and sluices in the upper reaches usually take off a greater supply than is actually required and the cumulative effect is that the quantity that reaches the tail end of a system is disproportionately low. In order to ensure proportionate supplies to the lower reaches at the critical irrigation periods, it is advisable to arrange that the sills of channel sluices in the upper reaches shall be located at a level somewhat higher than the theoretical bed of the canal (or parent channel) so that, during periods of low supply, the water taken up by the upper channels is limited and sufficient water reaches the tail-end distributaries also. To obviate silt trouble in channels, scouring outlets are provided where practicable. In the Grand Anicut Canal System the principle of keeping the sills at the heads of branches on the upper reaches above the bed has been adopted, but in view of the limited supplies which can be passed down the main canal during the early years of development it has been hardly possible to maintain the requisite depth in the canal to command the supplies needed for the branches in the upper reaches. With the development of irrigation in the lower reaches, this difficulty will disappear, for the required depth will then be available near the head.

CHAPTER LVII

Reclassification of Sources.

Generally speaking, the project has effected a substantial measure of improvement in the supplies to the delta, and lands formerly classed as III or II class are now brought on a par with those irrigated from I-class sources. Many of the sluices have been remodelled, and direct sources of supply have been provided in place of the original drainage sources. Wherever possible, steps have also been taken to improve the drainage of lands which have in the past been subject to frequent submersion by drainage of lands situated at higher levels.

Where these defects have been removed and where the improvements carried out have secured improved supplies, the classification of the lands has been raised usually to the next higher class. Provision is made in the Project Revenue Estimates for extra revenues from this change of classification which is ultimately expected to yield about Rs. 5,16,000. Where the existing supplies have not been materially improved or the sources of irrigation still continue as drainage sources, the lands have been exempted from reclassification. Certain portions liable to submersion have likewise been exempted. Reclassification of sources under the Lower Coleroon Anicut has been postponed subject to an examination of individual cases later on. Each case will be treated on its merits after watching the effect of the Mettur supply for two or three consecutive years. The criterion for raising the classification of a source is the measure of improvements carried out to it and the supplies secured by such improvements. The classification will be raised only if these are satisfied and after other defects, such as, drainage difficulties and dangers of submersion of lands are permanently removed.

The Extension of Second Crop.

The extent of double crop in the delta is computed to be about 95,000 acres and it is proposed to permit its extension by another 70,000 acres. As the practice of second crop cultivation in the existing area is not confined to the head reaches alone, it is not proposed to restrict the second crop expansion in the delta by actual localization in these reaches. It is expected that this will facilitate a much wider and earlier development of second crop.

In the new area, the entire Vadavar System and the adjoining reaches of the Grand Anicut Canal will be thrown open for double crop in a compact block. This area is confined roughly to about 105,000 acres, but when second crop cultivation has reached 84,000 acres, further extension will be stopped. The principle in this localization has been to prevent haphazard development, particularly towards the tail ends of channels in the entire area which would lead to waste of water, especially in the earlier part of the season when the transmission losses are great and the duty relatively heavy. By restricting it to the upper reaches, this arrangement permits the closure during the second crop season of as large a length of canals and channels as possible. On the whole, there will be an extension of 154,000 acres of second crop yielding an additional revenue of Rs. 11,55,000 with a charge of Rs. 7–8–0 an acre.

There is also in vogue a certain amount of "udu" cultivation which is a rather interesting practice peculiar to paddy cultivation in the Tanjore district. Two varieties of paddy, one taking about 3 to 3½ months and the other about 6½ months to mature are mixed, sown and transplanted together on the same field. Both crops are cut when the early variety is ripe, the late variety sprouting again and being harvested in due course. This practice is a compromise between a single and double crop and is often resorted to in the central delta where the water-supply, though more than sufficient for one crop is hardly enough for two independent crops. Generally speaking, this system produces results inferior to those in which two separate successive crops are planted as the total yield in the case of the latter covers all the additional cost of extra manure, labour, etc., involved, and leaves a larger margin of profit to the ryot. The extension of "udu" cultivation in the delta or its introduction into the new area to the detriment of double crop is not considered likely as such cultivation is to be assessed as a 'dufassal' crop with the compounded assessment of both the first and second crops.

CHAPTER LVIII

Regulation of Supplies during 1934 and 1935.

Evidence of the inestimable value of a large reservoir on the Cauvery presented itself even in 1934, its first year of operation. The reservoir which benefited from the brief early freshes in that year, was able to meet the irrigation demand quite easily between July and September when, through the failure of the rains, the natural flow in the river fell to less than a third of the requirements of the delta just in the middle of the important transplantation period. But for the existence of the reservoir, the failure would have involved an enormous loss, but this was avoided by releasing the water which had been impounded in the reservoir during the earlier part of the season when the inflow was over 100,000 cusecs for more than a week.

The year 1935 was again a year with a delayed and weak south-west monsoon. Despite this, moderate supplies were maintained and irrigation was not seriously affected. But for the reservoir, the losses would have been very serious, as they were in many other parts of the country. We may be sure, therefore, that there need be no complaints regarding deficient supply hereafter, except in the case of failure of the monsoon in consecutive years. If complaints do arise, however, they must be due either to defective regulation of reservoir outflow or to defective distribution and these will be avoided when one or two years' experience is gained which may enable the executive to correct the data hitherto assumed, and to arrive at more exact methods of regulation of supplies to the delta.

[*Note.*—The 1936 South-West Monsoon has up to the time of writing (July) been far more satisfactory than in the two previous years, and the reservoir at Mettur is surplussing for the first time in its history. The benefits of storage should therefore be fully appreciated this year.]

Supply of Water to the New Area.

Though full supply to the whole area becomes available as soon as the dam and canal works are completed, the development of the full area takes time and must of necessity extend over a period of years. A certain amount of labour has to be spent on bunding and levelling the fields to fit them for paddy cultivation and, near the heads of channels, a general lowering of the fields by about a foot will in some cases be necessary. In view of these factors, the programme of work was originally devised to restrict the excavation of channels, etc., completing only those required to supply about half the area in 1932 and, thereafter to adopt a programme that would give supply to the whole system by 1938. By adopting this programme, it was estimated that a saving of about Rs. 15 lakhs on interest charges would have resulted while, at the same time, the area for which irrigation could be provided would be far in excess of the area actually likely to take water. This proposal was, however, given up on the general ground that whatever the rate of irrigation assumed, development is likely to be proportionate to the area for which water is available, and that, therefore, the wider the area for which water is made available, the greater the area that will take it. Then there was also the consideration that if excavation were delayed, the labour for excavation of canals would compete with the labour for preparation of dry fields for irrigation, resulting in a shortage for both. Further, when water is available for the whole area (and the object is to make it available to the full area as rapidly as possible rather than conserve the supply) it is a sounder policy to distribute water widely from the outset than to restrict it to certain reaches. Accordingly, the programme of works was so adjusted as to speedily throw open for irrigation as large an area as possible without hindering in any way the completion of the remaining works. The Vadavar system was opened in 1932–33 to command a new area of 20,000 acres. In 1933–34 the entire Vadavar system, intended to serve the ultimate new ayacut of 43,000 acres (including the area by improvement of duty) and the Grand Anicut Canal System down to the 37th mile, commanding an area of 150,000 acres, was also thrown open for irrigation. In 1934–35 the entire Vadavar and the reaches of the Grand Anicut Canal down to the 58th mile (with an ultimate ayacut of 220,000 acres) were brought into operation and water was made available in the canals and all their branches down to this point.

As regards the development of new irrigation, it has to be noted in passing that it is bound to be slow for the reason that the area thrown open for irrigation and the final ayacut are the same. A growth of an ultimate area of 300,000 acres in, say, a total of 400,000 acres, on the assumption of a 75 per cent development in ten years, would have admitted of a more rapid advance. The area actually irrigated under the project at the end of the fourth season, from the time water was made available, was 96,000 acres as against 104,300 forecast in 1932. It is believed that development would have been more rapid but for the present economic depression and for the fact that the new area is predominantly zamindari. Differences over the matter of sharing of payment of water-rate frequently arise between the zamindar and his tenants, and these differences take time to settle.

Propaganda Work.

Intensive propaganda urging the accelerating of the growth of irrigation is being carried on, and ryots are being induced to expedite the excavation of their field bothis and to begin the cultivation of the new lands in earnest. Concessional rates in the first and second years of opening are also allowed as an inducement to early development, and efforts are being made to secure the good-will of the people and their co-operation in promoting the development. For purposes of demonstration, more water is being sent down the canals than what will ordinarily be necessary for the ayacut at present irrigated. It is encouraging to note that most of the opposition is wearing down, mainly as a result of these demonstrations and propaganda. The ryots were at first very sceptical regarding the steady supply promised them, but when they saw with their own eyes plentiful supplies being maintained in the channels throughout the season there were many who changed their outlook. Not a few who had, before the advent of the water in the canals, declared that they would not take a drop of project water, were so impressed by the fact that it was available even in a bad year (which formerly would have restricted supplies in the old delta alone), that they now expressed their readiness to take it. Thus, the ryots who had till now evinced little interest in the project beyond agitating for the lowering of water rates, or for the construction of more bridges, have now quite changed their attitude. Wherever reasonable, their requests for more bridges have also been complied with. The reluctance of the ryot to appreciate the benefits promised them is after all not difficult to understand. The construction of the dam, which was to bring about such astounding improvements and guarantee supply of water to the lands, was over 100 miles away and their limited vision did not permit them to believe that it could so influence the conditions in the delta as to justify the raising of water rates to the extent which had been notified. Agitators and pessimists were ever ready to advise them against buying a 'pig in a poke' for the benefit of a Government who, it was represented, were out to bleed them of even the little that they possessed. Such ill-considered propaganda had to be countered, and the decision to let down water into the channels for every man to see was perhaps the soundest piece of constructive propaganda effected by the Government, for here, at any rate, was indisputable evidence of a promise come true.

Potentialities of the New Area.

The project has been immediately instrumental in the opening of new communications and removing dead-ends in cases where old inter-taluk roads had fallen into disuse. The Government have also sanctioned a loan of Rs. 1 lakh to the Tanjore District Board for the acquisition of land for new or improved roads. The taluk roads are now also receiving attention and some of them are likely to be metalled in the near future. Villages which had been almost abandoned are now reviving and green patches of paddy cultivation are springing up where formerly the land lay fallow and there was even occasionally scarcity of drinking water. In such places there are now plentiful supplies for wet irrigation, while the personal needs of men and cattle are amply provided for.

The South Indian Railway Company has recently surveyed a new direct railway line from Tanjore to Pattukkottai, through the heart of the new area and, if this railway project materializes, it will afford easy rail communication for the conveyance of crops, etc., in that area where the construction and maintenance of good roads present such difficulties. It is not easy to see how such a line can fail to be of immense benefit in the development of that stretch of country. Railways, however, are now having to meet such keen competition from rapid motor transport that there is naturally some hesitation in launching a new line at the present time.

The Government have opened an experimental agricultural farm in the area near Pattukkottai where several commercial crops, including varieties of sugarcane, are being grown. The ryots, it is hoped, may profit by the demonstrations which are being made there. When fully developed, the new area will produce annually more than 100,000 tons of paddy or other grains. The tract is as yet sparsely populated, the density of population being about 400 per square mile, while the minimum density in the neighbouring delta is about 700 per square mile. It is reasonable, therefore, to expect that the new area of 625 square miles will eventually attract at least 200,000 inhabitants to settle there permanently, and this aspect should be of more than local importance.

No Danger of Overproduction.

It may be argued that the relatively large area now thrown open for new irrigation will result in overproduction of raw materials and foodstuffs, especially in an area, which, for centuries, was noted for its high productivity. In broaching this subject, some observations by the Hon'ble Sir Archibald Campbell (Revenue Member, Governor's Executive Council), during the inauguration ceremony of the Cauvery-Mettur System, may again be quoted :—

> " It has been sometimes said that it is a mistake to encourage the irrigation of new areas for the cultivation of heavily irrigated crops, especially rice, owing to the danger of

overproduction. It is found, however, that during the 50 years 1881 to 1931, the area cultivated under irrigation rose by about $3\frac{1}{2}$ million acres or by about 43 per cent, while the area cultivated without irrigation rose by about 29 per cent. During that period the population in the Presidency rose by about 51 per cent. Even allowing for better out-turn with the adoption of improved methods of husbandry, it is most improbable that the irrigation of a further 300,000 acres will result in any excess of production. Enquiries which have been made all indicate that, at the present moment, this Presidency does not produce nearly as much rice as it requires. The Agricultural department has for some years been endeavouring to spread the cultivation of more valuable crops than rice, especially in areas where irrigation can be provided for longer periods than six months. The ryots are generally ready to take advantage of changes in crops or methods of cultivation when they are satisfied that the change will be to their benefit. In the five years ending 1933, the area cultivated with sugarcane has increased from 90,000 acres to 121,000 acres or by about 36 per cent, the area under plantains from 127,000 acres to 145,000 acres or by 14 per cent, whereas the increase in the area cultivated with paddy is only $4\frac{1}{2}$ per cent during the same period ".

It would appear, therefore, that the possibility of overstocking the market, necessitating the restriction of development by irrigation to prevent overproduction, is very remote. Competition from foreign countries which by some means or other are able to dump their goods in this country at very low rates is the most serious menace at the moment.

CHAPTER LIX

Review of Project Estimate and Actual Expenditure.

But slight reference has so far been made to the estimated and actual expenditure on the project.

The estimate was, as we have seen, repeatedly revised and it was not until 1928 that the final estimate was drawn up and approved. This estimate amounted to Rs. 7,37,08,000, and provided for the many changes in the design and scope of the scheme found necessary since the first estimate had been sanctioned in 1924.

In order to compare the expenditure with the estimate provision under the various heads and to condense the subject into as small a space as possible, the two are treated together, and are briefly reviewed in their several aspects below.

Closure of construction estimate.—In 1928 it was contemplated that it would be possible to utilize the storage and open new irrigation from the reservoir in 1932, to complete construction in October or November 1933 and to close the construction estimate in June 1934. However, on account of subsequent important changes found necessary in the construction of the dam, and the delay caused by the excavation of deeper foundations than had previously been contemplated, the re-alignment of the Grand Anicut Canal outside the Pudukkottai State, the extension of canal to a greater length to secure the full ayacut, etc., and the consequent delay in arriving at a decision in respect of these proposals, the completion of works was somewhat delayed. The works at the "Headworks" were completed by the middle of 1934, but the operations in the canals are still in progress and are not expected to be completed till the end of 1936. However, since the major portion of the canal system was thrown open for irrigation in 1933–34, the date of closure of the construction estimate was fixed as 30th September 1934, about a month after the inauguration of the Cauvery-Mettur System.

Cost of the project.—The project was started at a time when post-war conditions created a rise in the cost-index; this was followed towards the close of the project by a worldwide depression so that the tendency was for the cost of materials and wages to fall steadily during the construction period. This, together with the substitution of masonry for concrete, contributed largely to the savings of about Rs. 70 lakhs (about 9·6 per cent of the total) on the project estimate. The savings in the cost of headworks would have been even greater but for the increase in the amount of excavation, and the contents of the dam. In the canals, however, an excess of expenditure was incurred under " 3. Distributaries ", while there were savings under " 2. Main Canals and Branches ". Works under " 3. Distributaries " bear a definite relation to the proportion the commanded area bears to the gross area, and, owing to the reduction of the anticipated commanded area from 80 to 70 acres per 100 acres of the gross area, the available irrigable area down to the point in the system which was proposed in 1928 fell short of the estimated area by nearly 50,000 acres, which had to be made up by extending irrigation to a proportionately larger gross area, lower down. The consequent increase in the size of waterways, in the number and size of syphons, and the construction of a large number of additional bridges were contributory factors to the increase in cost. These were, however, more than compensated by the savings on the estimate as a whole. Another factor which resulted in extra cost was the acquisition of land for constructing field channels for blocks of about 25 acres, a policy adopted subsequently to expedite and facilitate the development of irrigation. A note is appended to the schedule explaining such deviations.

Classification of estimates.—One unique feature of this project is the complete separation of " Headworks " from " Canals ". The estimates for the " Canals " and " Headworks " were cast as separate entities from the beginning, and they are therefore arranged in this manner in the statements which follow. Each detailed head of the estimate and expenditure was further subdivided into numerous " Account Heads " which were comprehensively and distinctively arranged to cover each group of works of more or less the same nature. This was of very great convenience in preparing budgets and revised estimates from time to time, at the same time it enabled a better and more efficient audit control and check by systematising accounts.

In cases where a common work was carried on in the interests of two or more works, it was treated as a " suspense " operation It was estimated and operated on in the usual way but the expenditure was periodically relieved from the operation estimates by suitable credits by apportioning it on an outturn basis among the works concerned. (Quarrying and conveyance of materials were works of this class.) The purchase and issue of " Stock " was conveniently centralised under the control of one Executive Engineer.

The works in the " Canals " were of a more routine nature and the usual detailed heads were found sufficient for purposes of classification of esimates.

A noticeable deviation in the present schedules from the instructions in the latest circular of the Government of India in respect of preparation of estimates for Irrigation Projects is the merging of " V. Water Courses " in " III. Distributaries ". The question of re-arrangement of expenditure on the works to show the expenditure on the two heads separately was considered but was given up as it was found that the expenditure on the works was already too far advanced and involved, to admit of easy rearrangement of expenditure in the form prescribed. The original arrangement was therefore followed in the subsequent revisions and in the preparation of the completion report.

General abstract of the actual and estimated outlay.—By the date fixed for the closure of the construction estimate for the project, the major portion of the works had been completed and nearly 98 per cent of the anticipated net outlay had been spent. A general abstract summarising the " Capital " aspect of the scheme as it stood on 30th September 1934 will be found in Appendix J. The net outlay of Rs. 667 lakhs forecast comprises a positive expenditure of Rs. 697 lakhs set off by credits of about Rs. 30 lakhs realizable by salvage of plant, sale of buildings, etc. It is interesting to note that, of the total credits of Rs. 30 lakhs anticipated at present, Rs. 14 lakhs were actually realized even before the construction estimate was closed. The realization of the balance amount is entirely dependent on the disposal of plant and buildings which, in the nature of things, could only be gradual and would take time to accrue to the full extent of the forecast. (The position by March 1936, was, however, very much advanced as a further sum of Rs. 10 lakhs had been realized by that date, leaving only a balance of about Rs. 6 lakhs to make up the total.)

In respect of the salvage of the plant remaining to be disposed of, it is to be said that a considerable part has till now been reserved for use on the Lower Bhavani Project in the expectation of that project being launched in the near future. The transfer of the plant reserved for use on that project would fetch some Rs. 3 to Rs. 4 lakhs. Besides this, the development of industries at Mettur, proposals for which are receiving the consideration of Government, is likely to lead to further sales of plant and buildings and if any of the proposals fructify, amounts considerably in excess of those provided in the schedules would accrue to the project. Much of the plant is also being disposed of by open sale.

The ultimate probable savings of Rs. 70 lakhs forecast now forms 9·5 per cent of the total for the scheme sanctioned by the Secretary of State in 1928, and as only about Rs. 6 lakhs of the savings remained to be realized on March 1936, it may be said that a savings of Rs. 64 lakhs has already accrued to the project.

CHAPTER LX

Revenue Returns.

THE REVENUES realisable from the several sources (tabulated in Annexure V to Part II, Chapter XXVIII) are expected to amount to about Rs. 61,60,000, made up of Rs. 60,00,000 by 'direct receipts' and Rs. 1,60,000 by 'indirect receipts'.

'Direct receipts' may be subdivided into the four following categories :—

	RS.
1 New first crop (new area only)	39,10,000
2 New second crop (new and old area)	11,60,000
3 Enhancement of first and second crop revenue (old area).	7,40,000
4 Raising water rates (old area)	1,90,000
Total ..	60,00,000

The 'Indirect receipts' comprise two items, the more important of which is the "Interest on the sale proceeds of waste lands". Such waste lands include the beds of certain tanks. With the advent of assured project supplies, a number of shallow tank beds through which the canal system passes will cease to be of use for storage of water and, as such, will be abandoned. Considerable areas of 'waste land' commanded by the new system will thus become available for cultivation.

This proposed abandonment of tanks is based on the experience gained in the Periyar system in the Madura district. There, where the circumstances are very similar, a number of old tanks not required for communal purposes have been abandoned and the beds sold for cultivation purposes. The complete abandonment of the tanks and the sale of these beds are however to be held in abeyance, since there is likely to be little or no demand for such waste lands until the development of the new irrigation area has reached a more advanced stage. It is expected that more reasonable prices for these lands will be secured by deferring their sale until such time as a real demand arises. The extent to which the cultivation of abandoned tank beds may be taken up, and the results of such cultivation in the matter of yield, yet remains to be ascertained. Until the grain market begins to show a marked upward tendency it is unlikely that the ryot will risk experiments on such lands. It appears a wise step, therefore, to defer sales until the present depression is lifted.

Rates of Water-cess.

The practice in regard to assessment of irrigation in the delta is on the basis of acreage actually irrigated as distinct from the quantity of water consumed. The same procedure is also to be followed in the case of new extensions. The rates of water-cess proposed to be levied per acre of irrigation with the introduction of project supply are tabulated below :—

Description of land	New area.							Existing area.								
	First crop.	Second crop.		Dufassal crop.		Third crop.		First crop.		Second crop.		Dufassal crop.		Third crop.	
	RS.	RS.	A.	RS.	A.	RS.	A.	RS.	A.	RS.	A.	RS.	A.	RS.	A.
Dry lands converted to wet.	15	7	8	22	8	3	12	10	0	7	8	17	8	3	12
Manavari lands (ryotwari or proprietary) (rainfed irrigation).	14	7	0	21	0	3	8	9	0	7	0	16	0	3	8
Proprietary or minor inam wet.	10	7	8	17	8	3	12	7	8	7	8	15	0	3	12

A special feature in the "water-cess rules" is the provision for the levy of a charge on a third crop raised with project water. The zamindari or "estate" lands were to pay different rates of water-cess for "dry lands", "manavari lands" or "wet lands" and it was necessary therefore to prepare a record of existing conditions of irrigation in the areas affected by the project to facilitate assessment of irrigation on a proper basis when project irrigation was introduced. The record is called the "Record of Rights", for a detailed description of which the reader is referred to Part II, Chapter XXX.

Working Expenses.

It is customary to provide for "Working Expenses" on an arbitrary basis without any special reference to local conditions. "Maintenance charges" for instance, are provided for at a rate of Re. 1 per acre of irrigated land, while the revenue "Collection charges" are assumed at a rate of 5 per cent of the gross revenue. The former takes the area of operation into account and is based on general experience in irrigation projects, while the latter has no such basis.

When the project revenue estimates were prepared in 1928, the question was raised as to whether the usual 5 per cent "Collection charges" for purposes of the revenue estimates was justifiable. An attempt was accordingly made to forecast the actual cost of "collection establishment" required for this area.

Curiously enough, it was found that the 5 per cent provision produced an amount far in excess of that which might reasonably be required, particularly since a considerable portion of the revenue expected was to be contributed by the "enhancement of first and second crop revenue" and the "re-classification of sources" in the old or existing delta from both of which the collection of revenue entailed no additional establishment. Some additional establishment, however, appeared necessary for the upper reaches of the new area, while a wholesale re-shuffling of establishment was found desirable for the lower reaches of the system.

For this purpose the additional charges were estimated to amount to Rs. 94,000 under the following distribution :—

	RS.
1 Village establishment charges	38,000
2 Taluk establishment charges	28,000
3 Divisional establishment charges	16,000
4 Buildings, etc.	12,000
Total ..	94,000

To this amount the equivalent of the interest on the expenditure on the cadastral survey at 6 per cent on Rs. 6,00,000 was to be added. The total probable charges thus worked up to Rs. 94,000 plus Rs. 36,000, or Rs. 1,30,000. For practical purposes, therefore, a sum of Rs. 1,50,000 was considered ample, and with the concurrence of Government this figure has been adopted as "the collection charges" in the revenue estimates of the project in lieu of the usual "5 per cent of the gross revenue."

Development of Irrigation and Returns on Capital.

In framing the revenue forecasts it was assumed that irrigation in the new area would commence in the 1932–33 season for, though the construction of the Mettur Dam was not expected to be completed by that time, it was assumed that sufficient storage would then be available to admit of a start being made in the upper reaches of the new system. The forecast presumed that the new area would be fully developed in the season 1943–44. The rate of development for various seasons has not quite come up to expectations during the first three or four seasons. The area of single crop brought under irrigation in the Vadavar and Grand Anicut system for three years has been as follows :—

	1933–34.	1934–35.	1935–36
	ACS.	ACS.	ACS.
Vadavar	13,889	22,134	16,900
Grand Anicut canal	22,845	62,314	79,200
Total ..	36,734	84,448	96,100

It will be seen from the above that the earlier rate of progress has not been fully maintained. The development of the new area has been adversely affected by several factors which could not of course be foreseen when the revenue forecast was drawn up. The continued trade depression and the general fall in the price of agricultural produce to an uneconomical level has temporarily discouraged rapid development. Another factor which has contributed to this is the agitation for the reduction of water-cess which has been encouraged by the forecast of large savings on the project estimates. The question as to the manner in which savings on the construction estimate might reasonably be diverted to the revenue estimate has been under the consideration of Government and it has been decided that all that can reasonably be done to meet the present situation is to grant concession in the shape of annual remissions in the assessed revenue. It is improbable that circumstances will admit of any permanent reduction of water-cess. If the liberal concessions now being granted will tide over this period of industrial depression they will be of much assistance to the ryot. It is as yet impossible to say how long circumstances will render the grant of these concessions necessary though they are tentatively made for four years and it is accordingly difficult to foresee the ultimate effect they will have on the revenue estimates. The political situation throughout the world to-day is such that no man can forecast events even a few months ahead, so that a revenue forecast which looks several years ahead must of necessity be in the nature of a speculation. The revenue estimates as recently revised do not therefore provide for these contingent remissions. It is likely, however, that any losses in revenue which may be incurred in this direction will be set off by revenues from other potential sources which have likewise been excluded from the present revenue forecast pending a more detailed examination of the situation.

On the assumption made in the present estimate, it is seen that the estimated sum at charge is Rs. 824 lakhs, on which the net revenue of Rs. 57·13 lakhs gives a return of 6·93 per cent. If this is realized, the project will be definitely a paying concern.

Potential Sources of Revenue.

Of the potential sources of revenue which have been omitted from the revenue estimates the following are outstanding. The reclassification of sources under the Lower Coleroon Anicut system, which may materially benefit from the improvements brought about by better regulation of water in the Cauvery-Mettur System, is one which may be taken up if events appear to justify such a course.

The Mettur Hydro-Electric Scheme could never have been considered as practicable, but for the construction of the Mettur Dam and formation of the large reservoir. The propriety of debiting a portion of the expenditure on the construction of the dam and allied works at Mettur to the power scheme estimates (in addition to the cost of the Hydro-Electric pipe installation, etc., already debited to it) has already been considered, but, as it is estimated that such a course would render that scheme unremunerative, an annual contribution has been proposed instead. Much must depend upon the rate at which power distribution can be developed. Here again the maintenance of a steady load factor will depend upon the economic conditions which may prevail in the near future. It is to be remembered, however, that the power scheme is merely incidental, and that the reservoir is primarily designed for the requirements of irrigation.

The regulation of water is to be made for that purpose only, and the generation of power is only to be developed up to the limit which the needs of irrigation dictate.

In view of these considerations, the Government have decided that the surplus revenues from the power scheme shall, if and when it commences to pay its way after meeting all expenses, including interest and depreciation charges, be credited to irrigation revenues, subject to a maximum of Rs. 5 per horse-power generated.

Other potential sources of additional revenue include the annual leasing of surplus lands and buildings at Mettur, the sale of the usufruct of fruit trees and fodder in the Stanley Park, and the toll levied on visitors to the headworks—a new item recently introduced there. In the aggregate, the revenue to be derived from these sources should be very appreciable.

In addition, the revenues to be derived from the 13,000 acres under the Vadavar by " improvement of duty " is expected to fetch a net amount of Rs. 2·75 lakhs. All these may go far towards the write off of the deficit in the net anticipated revenue due to the remissions of water-cess and the retarded development of cultivation in the new area.

Conclusion.

The fundamental point that should be remembered in assessing the value of the Mettur Reservoir in its relation to the existing irrigation under the Cauvery—let alone the new area—is that its basic object is to safeguard irrigation against injury either on account of unseasonal incidence of the monsoons or the occasional shortage and inconvenience through the abstraction of flood waters by Mysore at the commencement of the season.

A good deal of criticism has been levelled against the scheme on the score that the benefits due to the reservoir have not so far been as great as was claimed. Perhaps there is some slender foundation for this argument because irrigation experience in the delta, dating from time immemorial, has evolved a system of cultivation which adapts itself to the peculiar natural conditions of supply in the Cauvery basin. The transplantation season coincides with the period of maximum demand on the stream flow and has, in the past, been timed to utilize the greatest percentage of the flood flow directly on the land. Irrigation in the delta in the past has been much less dependent upon storage than on direct flow but this, to say the least, is not an unmixed advantage. The actual supply that may be available later in the season cannot, by any means, be foreseen and by the time it is known cultivation is already far advanced. It not infrequently happens that a year of scanty rainfall furnishes as much water early in the season as a year of plenitude. In such years, the monsoon spends itself very soon, the supplies run low much earlier and the shortage is seriously felt towards the latter end of the season. A good deal of wasted labour and failure of crops has thus been a frequent experience.

It is true that the reservoir by itself could not augment the supplies if the drought were to continue over consecutive years, though it would certainly ensure a more even distribution of the available supplies and prevent any wastage other than that due to evaporation and transmission losses, both of which are inevitable. Stream flow records, covering a continuous period of several years, all show that periods of extreme drought as well as of extreme plenitude occur only at very long intervals and that a full supply to all the lands under the reservoir could be ensured in most years. In exceptional years like 1918, occurring probably once in a lifetime, it might perhaps be necessary to be content with less than a full supply for a short period; but, by a more judicious distribution and use of the available supplies and by the adoption of improved methods of cultivation, results could be obtained which would approximate to the normal even in those years. The reservoir is of particular value in such years of scarcity as it enables one to forecast the threatened shortage some 30 to 60 days prior to its occurrence and makes it possible for a modification of the cultivation operations to be put into effect much earlier in the season than could otherwise be the case. Where such a course is found desirable, it may even be advantageous to forego the cultivation of a second crop altogether or to restrict cultivation to an area for which a fair supply may reasonably be ensured. Such measures would prevent much wasted labour and loss of crops while the loss due to a few fields being left fallow would be less serious.

It is an admitted fact that the actual yield of paddy crops is not directly proportional to the amount of irrigation water used and that it is quite possible to reduce considerably the amount of water generally applied to the fields without material diminution in the yield. By judicious regulation of the available supplies from the reservoir, therefore, it should be possible to secure a far greater yield from the area as a whole than was possible when the natural flow of the river alone was depended upon.

The indirect benefits which must accrue from the development and improvement of irrigation in Tanjore and Trichinopoly districts and the resulting stimulus to industries and trade will certainly result in the greater prosperity of the people of these districts. Though a world-wide depression persists to-day, and though the development of irrigation has so far been slower than anticipated, we may reasonably hope that brighter days will return and that the project will prove to be a great contribution not only to the welfare of the Madras Presidency but also to that of India as whole.

PART II

Headworks

CHAPTER I

Hospital and Medical aid

The necessity for a well-equipped hospital was anticipated from the very commencement of the project. Mettur was then a malarial place like its neighbours, Boomanur in the north and Chinnapallam in the south (which even in 1933, were still highly malarial with a spleen index of 93 per cent), and continued to be so, until anti-malarial operations were carried out and the settlement was made healthy for habitation. The officers' Medicine chest, which was put to the fullest use at the commencement, was soon found to be inadequate and a regular dispensary was opened on 3rd May 1926 with a Sub-Assistant Surgeon in charge and was housed in a portion of the old church which was the only public building then available.

From June 1926, there was a regular influx of officers and subordinates and the labour force also was steadily increasing. Insufficient accommodation, consisting chiefly of thatched huts, with an unprotected water-supply made life in this jungly area, one of extreme hardship. To add to this, cholera broke out in July 1926 and there were several deaths. A regular panic ensued among the labouring classes and hundreds of coolies bolted. The resources of the Medical and Sanitary staff were taxed to the utmost but the epidemic was brought under control. Some 27 cholera patients were treated in the hospital during that out-break.

As the works were progressing it was not found possible to deal with all the cases with the available equipment. Several cases required hospital accommodation and such cases had to be taken to the Government hospital at Erode. As such instances became more frequent it was decided to maintain an ambulance car to take serious cases to Erode. This car was subsequently used for conveyance of accident cases from the workspot and serious cases of illness from the quarters to the hospital.

Meanwhile, the population of the area was steadily increasing and Mettur soon assumed the proportions of a town. The dispensary became inadequate and the work became too heavy to be managed by a Sub-Assistant Surgeon. Thereupon, in July 1927 a Civil Assistant Surgeon was appointed. After his arrival necessary instruments, equipment and drugs were indented for to cope with the increased demand.

In May 1927 the temporary hospital was shifted nearer the Workshops and was housed in a portion of the corrugated iron-shed as it was thought that accidents which were then rather frequent in the workshops and in the dam area close by, could be more speedily attended to.

Meanwhile, a pucca hospital was in course of construction and was completed in August 1927.

The hospital is called the Cauvery-Mettur Project Headworks hospital and is situated at an ideal site between the workspot and the quarters on the Coimbatore side of the river and is one of the best of its kind in the mufassal. It consists of a main central building comprising an open central hall with a set of rooms on each side for Medical Officer's office, Storerooms, and an European special ward, with bath rooms attached. The main operation room with sterlizing rooms, etc., is situated just behind the central hall. There are two spacious blocks on either side containing wards for the accommodation of 24 males and 20 females. The female ward has attached to it a delivery room and a labour ward with three beds. Besides, two sheds are provided, one for males and another for females, to give accommodation to cases suffering from venereal and other contagious diseases.

The European special ward was after a short time thrown open to all as a private ward at a nominal rent of 8 annas per day for project employees and their families and Re. 1 for outsiders.

On the right side of the main block of buildings was put up the out-patients block with consulting room, compounders' room, operation room and dressing rooms for males and females, and on the left side was put up the Nurses' quarters. All the blocks were connected by covered corridors so that patients could be moved about freely under cover at all times as necessity arose. The buildings were so designed that, in case of emergency, almost double the normal number could be accommodated inside and on the verandas.

At a distance of about two furlongs from the hospital two semi-permanent isolation sheds were erected to give accommodation for cholera and smallpox cases. Each of these could accommodate six patients.

The needs of the Salem camp had to be met by the opening of a dispensary in the Salem camp area. This was a pucca built one and was intended to be maintained permanently after the abandonment of the Mettur camp.

The Medical staff consisted of a Civil Assistant Surgeon, two Sub-Assistant Surgeons, one for the Headworks hospital and the other for the Salem camp, two nurses, three compounders, one clerk, nursing orderlies and other inferior servants. The Salem camp Sub-Assistant Surgeon was to be called in to the Headworks for assistance whenever there was a major operation to be performed. The Salem camp was temporarily closed on 1st August

1933 and may be re-opened later if further developments warrant such a measure.

The Medical officers and all the staff were given quarters near the hospital so that the whole staff could be mobilized at a moment's notice.

The usefulness of the hospital may be judged by the following figures taken from the hospital statistics.—

Total number of	out-patients treated during 1926 to 1935.	285,814
Do.	in-patients do. ..	7,285
Do.	operations performed	7,667
Do.	major operations performed	526
Do.	injuries treated	24,224
Do.	fever cases (excluding typhoid and pneumonia).	35,908
Do.	typhoid cases	96
Do.	pneumonia cases	378
Do.	cholera	122
Do.	dysentery	4,560
Do.	smallpox	179
Do.	labour cases conducted	694

Of these, the injury cases required special consideration. Of 24,224 cases of injuries 420 were major injuries caused on the project works. The remaining 23,804 include mostly cases of minor injuries caused in the project and some major injuries sustained outside the project work and in the villages, who were brought for treatment to the hospital.

The following tabular statement of major injuries will serve to explain the figures in greater detail :—

Report of accidents to workmen during the course of construction of the Project works Headworks only.

Cause of accident.	Project employees.			Non-project employees.					Classification.		Compensation paid.		
	Males.	Females.	Total.	Males.	Females.	Total.	Grand total.	Fatal.	Major, involving partial but permanent disablement.	Major, not involving permanent disablement and minor.	RS.	A.	P.
1 Tramway and rolling stock.	83	13	96	6	1	7	103	7	6	90	4,580	5	11
2 Blasting operations by black powder.	35	3	38	1	1	2	40	3	..	37	554	0	0
3 Blasting operations by L.O.X.	29	2	31	..	..	..	31	5	2	24	600	0	0
4 Other quarrying operations.	1	..	1	..	..	..	1	..	..	1	..		
5 Falling from a height.	28	7	35	1	1	2	37	4	1	32	1,406	12	0
6 Injuries by articles falling from a height.	63	20	83	..	..	..	83	2	1	80	..		
7 Entanglement in machinery.	30	..	30	..	..	..	30	2	5	23	2,334	9	
8 Drowning	4	2	6	..	..	..	6	6	..	..	..		
9 Electrocution ..	8	..	8	1	..	1	9	1	..	8	..		
10 Miscellaneous ..	44	8	52	17	11	28	80	6	..	74	5,552	1	0
Total ..	325	55	380	26	14	40	420	36	15	369	15,027	11	11

It is worthy of note that there were no indigenous cases of cholera after 1929, when the protected water-supply was inaugurated. The largest number of admission for dysentery was in 1929.

Maternity.—A yearwar statement of maternity cases is appended which clearly shows that the number of cases steadily increased till 1932, when the population showed the highest figures. Thereafter, although the population decreased, the cases continued to increase. This was the general feature of the hospital statistics. As the admissions of the project employees into the hospital were decreasing, the admissions of the non-project employees were steadily increasing, so that in 1934 we had in our wards people coming from villages within a radius of 30 or 40 miles, or even more.

The opinion of the Surgeon-General with the Government of Madras who visited Mettür on 17th June 1934 will be of interest in this connexion. He wrote :—

> " A very good hospital of its kind and though not intended as a permanent structure, it is obvious that it could function for many years to come. In these days of straitened finance this type of building could well be adapted for more permanent occupation. The wards are full and contain many interesting cases. "

> " The actual treatment is fairly efficient. Many cases come from surrounding villages and even from neighbouring districts. The hospital will be much missed if it ceases to function in the near future. Most of the outside village cases have very large spleen showing how prevalent is malaria outside Mettur. The total abolition of malaria and all water-borne diseases in the project area illustrates the magic which can be effected by modern medical methods which must have saved Government many lakhs of rupees. The moral is not far to seek.

Detailed statistics regarding the number of out-patients and in-patients treated as also of some of the more important diseases will be found in the following tables.

C.M.P. Headworks hospital, and Salem camp dispensary, Mettur project—Comparative statement of certain diseases to end of 1933.

Year.	Population.	Cholera.	Dysentery.	Enteric fever.	Malaria.	Influenza.	Pneumonia.	Pyrexia of uncertain origin.	Rheumatic fever.	Smallpox.	Injuries.	Total number of patients treated.		Operation.	
												In-door.	Out-door.	Major.	Minor.
1926	2,900	27	91	..	243	..	6	129	52	..	558	..	5,507	..	196
1927	12,000	43	598	5	1,006	534	21	240	99	..	2,149	57	16,893	..	440
1928	15,000	30	576	18	830	919	66	226	144	3	2,882	594	28,897	29	703
1929	15,000	1	1,072	10	1,449	2,083	56	593	271	4	4,170	992	47,186	71	1,052
1930	15,851	7	738	6	2,687	1,257	33	2,021	604	9	3,640	1,163	51,731	93	842
1931	18,387	10	444	27	5,676	885	68	597	267	22	4,309	1,432	50,173	107	1,406
1932	19,136	4	536	7	4,668	1,292	71	636	229	126	3,986	1,645	47,807	120	1,652
1933	15,170	..	505	23	3,683	290	57	1,602	496	15	2,530	1,404	38,070	106	850

REMARKS.—The Cauvary-Mettur Project Headworks hospital was started as a dispensary from 3rd May 1926. In-patients were taken only from 1928. The Salem camp dispensary was started on 1st February 1929 and was abolished on 1st August 1933.

Maternity cases.

Year.	Population.	Number of cases treated. In-door.	Number of cases treated. Out-door.	Birthrate per 1,000.
1926 ..	2,500	..	9	0·36
1927 ..	10,000	..	40	4·00
1928 ..	13,000	18	41	4·54
1929 ..	13,000	32	34	5·08
1930 ..	15,000	62	40	6·80
1931 ..	18,000	94	38	7·33
1932 ..	19,000	86	55	7·42
1933 ..	15,000	92	52	9·60

C.M.P. headworks hospital and Salem Camp dispensary.

Year.	Population.	Total number of out-patients treated.	Average cost of each out-patient.	Total number of in-patients treated.	Average cost of each patient.	Remarks.
			RS. A. P.		RS. A. P.	
1926-27 ..	2,500	7,399	0 5 5	..	..	
1927-28 ..	10,000	20,607	0 3 2	70	0 3 2	The expenditure for diet and medicine were combined and so separate figures could not be given.
1928-29 ..	13,000	32,374	0 2 5	745	4 6 5	
1929-30 ..	13,000	51,099	0 1 11	1,109	4 11 2	
1930-31 ..	15,000	50,822	0 1 9	1,230	5 15 0	
1931-32 ..	18,000	49,811	0 1 9	1,423	4 12 6	
1932-33 ..	19,000	48,198	0 1 11	1,698	3 10 6	
1933-34 ..	15,000	33,048	0 1 6	1,272	3 12 1	

CHAPTER II

Health and Anti-malarial Measures.

In cases of large irrigation projects in tropical countries it too often happens that malaria casts a shadow beneath the sunshine of an increased and improved water-supply. The explanation for this is not far to seek. Numerous excavations are made for quarrying stone or for digging earth and these get filled with water during the rainy weather and encourage the breeding of mosquitoes which carry malaria. A large labour force is imported into the camp, amongst whom there may be carriers of malaria. The malaria germs are rapidly transmitted by the mosquitoes from the carriers to healthy individuals and a severe outbreak of malaria in the labour force is the sequel. Such an outbreak causes much invalidism and consequent loss of efficiency and results in delay in the execution of the work.

Realizing this danger, the Government determined to wage war against the mosquito from the beginning of the Mettur Project.

Accordingly, a health officer, specially trained in malariology, with a suitable staff, was appointed to tackle the problem of malaria as well as the general sanitation of the camps.

A preliminary survey was made of the country round about the site of the dam which revealed the incidence of malaria in endemic form in all the neighbouring villages. About 25 per cent of the children examined had enlarged spleens, a sure sign of the extent to which malaria existed in the locality.

The ' Mettur camp ' on the right bank of the river Cauvery and the ' Salem camp ' on the left bank were treated as two distinct and separate units for the purpose of anti-malarial operations.

The area in which anti-malarial operations were carried out in Mettur Project is described below :—

The Mettur camp comprises the area lying between the Palamalai hills on the west and the river on the east. It is about two miles in length and 3,000 feet in width. The land slopes fairly steeply from the foot of the Palamalai hills to the river and the rainfall is therefore drained away to the river within an hour or so of its occurrence. There are three main ' varis ' or streams which carry the water from the hills to the river. These streams are dry for the greater part of the year and carry water only during the rainy season. The soil is alluvial, varying proportions of red earth and gravel overlying the rock which in places comes to the surface as sheet rock or in the form of boulders. The surface soil is very porous and most of the rain either passes into the ground or is drained into the river within an hour. But for this fact, the malarial problem, immense as it was, would have been almost insuperable.

The Salem camp is situated on the eastern side of the river Cauvery and lies between two ranges of hills, the Chettamalai hills on the east and the Vanavasi hills on the west. A big stream or vari, running near the foot of this camp and to the east of it, joins the river about two miles south of the camp. The bed of this vari is the chief breeding place for mosquitoes in the Salem camp area.

The river at Mettur runs from north to south. It is about 1,200 feet wide, but during the non-flood season the stream runs at the foot of the Chettamalai hills on the eastern side only where its breadth is only 200 feet. The bed of the river is rocky throughout and interspersed with sand shoals. When the floods subside, innumerable stagnant pools which act as breeding places are left, and these soon swarm with mosquito larvæ if no preventive measures are undertaken.

The chief breeding places of mosquitoes are, therefore :—

(1) the river bed near the Mettur camp which is the most difficult and expensive to keep under control. When the river is in flood, however, it runs as a continuous stretch of water from bank to bank and there is then no stagnation. Thus it requires no special attention between the months July to November (five months), but the pools require weekly oiling during the remaining months of the year.

(2) Varis or streams running from the hills into the river.

(3) *Hill bottom seepages.*—After rains, seepage appears in numerous places at the foot of the hills and, if left unattended, the damp areas breed innumerable mosquitoes in the shallow pools.

(4) *Sluice channels* : pools between rocks in the beds when the channels are not flowing.

(5) Stagnant water on masonry works.

(6) Rock pools on hills, where rain water is caught and retained.

(7) *Wells.*—Both irrigation and drinking water wells. The latter fell into disuse after the introduction of protected pure water-supply and became potential breeding grounds for mosquitoes.

(1) *Anti-malarial measures.*—The anti-malarial measures carried out by the health staff consisted of—

Systematic oiling of the numerous stagnant pools in the river bed with a mixture of crude oil and kerosene in the following proportions :—

Crude oil 2 parts.

Kerosene oil 1 part.

Castor oil 1 per cent.

One gallon of this mixture covers an area of about 4,500 square feet and costs 7 annas.

This mixture was sprayed by means of 'Four Oaks' knapsack sprayers. The river bed was divided into definite areas and each portion was oiled once a week regularly.

(2) *Paris greening.*—Paris green is another larvicide which was largely used for the destruction of mosquito larvæ. Breeding places on the dam which was watered frequently and where there were innumerable small pools of water, masonry works generally tanks for curing concrete blocks, etc., could not be treated with oil as oil is injurious to masonry and cement. For controlling such places, paris green was used. 'Paris green' is a green powder and is a compound of arsenic, highly poisonous to the mosquito larvæ. This larvicide was diluted with granite dust, obtained from the crushers, in the proportion of 1 to 100 and the mixture was sprayed either by hand over small pools or by means of dust-guns over larger areas. The supply channels were also controlled by the use of paris green.

(3) *Canalizing the streams.*—All varis or streams running from the hills into the river were "canalized" in an area extending for ½ mile around the camp. By this means streams which had been stagnant and covered with vegetation were converted into rapid and regularly flowing canals in which there was no chance for water to stagnate and larvæ to breed. Canalization consisted in the construction of small stone-lined drains in the beds of the varis into which the dry weather flow was concentrated, the banks and beds being kept clear of vegetation.

In addition to canalization, these streams were controlled by the introduction of 'Oil thattis' placed across them at suitable intervals. The oil thatti is made up of pieces of old gunny tied to a bamboo thatti suspended from a rod fixed across the stream and supported by two posts. These thattis were soaked in crude-oil for 24 hours and then tied up in the stream. By this means a continuous and fine film of oil was constantly applied over the entire surface of the stream. These were found to work much better than drip cans with the use of which it was found that the oil confined itself to the centre of the stream only. Each thatti was renewed once a week, the flow of oil being sufficient to last for that period.

For smaller streams, a mop soaked in crude oil was dragged against the current. This process cleans and oils the stream, particularly at the edges where the larvæ are likely to lurk. For still smaller streams and hill bottom seepages and for waste water flowing out of water fountains, cotton swabs soaked in crude oil were packed at the top of the stream. A stone was placed on the swab to prevent its displacement. A thin film of oil oozes from this swab and is carried down on the surface of the seepage water.

(4) *Wells were treated in three ways—Wells used for irrigation.*—Some of these were treated with paris green mixture bi-weekly; in others larvicidal fish of the variety 'Barbus' were introduced. The results were very satisfactory.

Unused wells.—Shallow wells were filled up, while deep wells were treated with crude oil mixture.

(5) *Pools in the lake.*—When the level of the water in the lake went down, many pools made their appearance at the margins. These pools were controlled by the use of *oil floats* placed on them. These floats consist of cylindrical tin boxes with oil swabs attached to them, the float being anchored to the bottom of the pit by a wire. This device gives out oil slowly and continuously and checks the breeding of mosquitoes. It is, however, not very effective, when a strong wind is blowing across the water as the oil is driven to one side of the pool.

(6) *Drainage.*—After rains, many springs used to arise at the foot of the hills. Narrow drains were suitably cut to lead away this water, generally to the nearest vari.

(7) *Rock pools on hills.*—Some of the hollows and pits which were accessible were filled up. Others were regularly oiled weekly.

(8) *Treating the malarial patients with quinine.*—In each ward of the camp observation coolies were posted. It was their duty to search the camp thoroughly and spot all cases of fever, headache and dysentery, such cases were brought before the Sanitary Inspector who took their blood-smears and sent them to the health laboratory for examination. These smears were examined by the Health Officer and positive cases were immediately put on a course of quinine treatment for 21 days. The quinine mixture was personally administered by the health staff to the patients. By this precaution another chain in the cycle of transmission of malaria was broken.

Mass quininization was also done as prophylactic measure. Ten grains of quinine sulphate were given on two consecutive days each week.

In addition to the above measure, regular and systematic collection of mosquito larvæ was carried out. They were bred in the laboratory in breeding cages and identified. The collection of adult mosquitoes was done with the use of Covell's bags, their identification and destruction were undertaken and records were maintained.

Results of the anti-malarial operations.—The results of the anti-malarial work carried out at Mettur have been remarkable. They are, however, only capable of negative proof. The original village of Mettur alone contained a population of 200, while in the head-works camp in its busiest periods there lived about 18,000 people. Notwithstanding such a large increase in population, a good number of whom were drawn from the neighbouring malaria stricken villages, the Mettur camp has been remarkably free from epidemics of malaria. This can be only accounted for by the fact that organized destruction and prevention of mosquitoes had been systematically carried out. Malaria, which at one time raged in the place, had been reduced almost to vanishing point. In the controlled area the spleen rate has been brought down to 1 per cent from 25 per cent whereas in the neighbouring uncontrolled areas the spleen rates are found to be as high as 32 per cent. Mortality and morbidity from malaria were greatly reduced. This enabled the coolies to attend to their work without break and enabled the dam to be built without delay due to sickness among the labourers. The Director of Public Health in a note on the subject of anti-malarial operations to Mettur has calculated that the annual saving in terms of cash as a result of these anti-malarial operations comes to at least Rs. 37,500 which was indeed an excellent return for the sum of about Rs. 12,000 spent annually on the anti-malarial works.

(1) *Sanitary measures other than anti-malarial works.*—All the officials and half the number of labourers were provided with comfortable Government quarters. The rest of the coolies were housed in temporary huts built by themselves. The location of these huts and their construction was personally supervised by the Health staff. Each hut was separate and had open space on all sides and care was taken to see that there was no congestion, the huts being laid out in regular well spaced rows.

(2) *Water-supply.*—The camp had an excellent protected water-supply. The latest type Paterson's rapid filters were used and the water was chlorinated before supply to works and camps.

(3) *Drainage, Mettur camp.*—There were three types of drainage and sewage disposal systems adopted in this camp :—

(i) There was an underground sewage system for the main portion of the Mettur camp. The sewage was finally disposed of by means of a sewage farm in which crops including plantains, chillies, castor and elephant grass were very successfully and profitably grown.

(ii) The sullage from officers' bungalows was disposed of by feeding the gardens attached to the bungalows themselves.

(iii) The sullage from kucha hut was drained into the river.

Salem camp.—The Salem camp was provided with surface drains only. A septic tank was installed here which successfully dealt with all the sullage and nightsoil. The effluent from this fed a small sewage farm where also crops like plantains, tobacco and chillies were grown.

(4) *Conservancy—Rubbish conservancy.*—Rubbish was disposed of by means of incinerators. The ashes were used as garden manure, after mixing with a suitable proportion of loam.

Nightsoil conservancy.—In the Salem camp, the nightsoil collected from the latrines was mixed with sewage and fed into the septic tank where it underwent decomposition and purification. The effluent was finally let into a sewage farm.

In the Mettur camp, there was an efficient water carriage system for the flush latrines in the cooly lines. The nightsoil collected from other places outside the several areas was dumped into the sewers at pail depots and so finally disposed of at the sewage farm.

(5) *Control of infectious diseases.*—An efficient system of control over infectious diseases was in existence. There were well-equipped isolation sheds where all cases of infectious diseases were at once isolated and treated. It is remarkable that although the camp did not come either under the Local Boards Act or the Municipalities Act, yet an efficient control over infectious diseases was exercised by the Health staff, thanks to the co-operation and help of the Engineer-in-Chief. Any person unwilling to get himself vaccinated or inoculated, or who refused to take quinine, was summarily removed from the camp.

In times of epidemic, vaccination, inoculation and quininization were very successfully carried out.

Thus, although stray cases of infectious diseases were imported into the camp, the disease was successfully kept under control and epidemic outbreak averted.

There was also an efficient check over dangerous and offensive trades.

The registration of births and deaths was carefully recorded. No dead body was allowed to be disposed of without the health authorities examining the body and ascertaining the exact cause of death.

(6) *Conclusion.*—During an inspection at headworks, Col. Webb, I.M.S., ex-Director of Public Health, has remarked "the big dam at Mettur and the large reservoir behind it will stand as a lasting monument to the great engineering skill and technique displayed in their construction for the promotion of economic prosperity of large tracts of this Presidency, but the smaller stones that helped in the construction of this huge edifice, namely, organized anti-malarial operations, should also receive their due appreciation from the authorities as well as from the citizens."

The Health department who carried out the work so efficiently at all times are deserving of the highest praise. The enormous benefits derived from their activities in this great work can never be over-estimated.

The following officers were in charge of the Public Health department, Mettur, at different times :—

(1) Dr. S. G. Masilamani, B.A., L.M. & S., from 1st July 1926 to 22nd March 1931.

(2) Dr. D. Balasubramanyam Pantulu, M.B.B.S., from 23rd March 1931 to 31st March 1934.

(3) Dr. V. S. Natarajan, L.M.P., from 1st April 1934.

Statistics relating to health and anti-malarial operations will be found in Appendix K.

CHAPTER III

Headworks Camps—Types of Buildings and Quarters.

In Part 1, Chapters X and XIII, reference was made to the general layout of the buildings in the Mettur and Salem camps. The number and types of the different quarters and public buildings may here be briefly described.

The quarters of the Engineer-in-Chief, Superintending Engineers and Executive Engineers were all two-storeyed houses with kitchens attached, motor garages and servants' quarters being situated in their respective compounds, generally in rear of the houses. The compounds were large and extending from about 4 to 8 acres. Many varieties of trees were planted in their compounds and grew well so that, in the course of 4 or 5 years, what had been a bare unsightly stretch of land became park-like and attractive. Flowers grew well wherever water was available, while excellent lawns were prepared from the short fine turf which was obtainable from the margins of the river nearby during the dry season. These buildings were all well designed and were admirably suited to the local conditions and requirements of the officers. They were constructed on economical lines. The basements and superstructure for the ground floor rooms were all built of coursed stones set in lime mortar and mud mortar respectively, while the upper storeys were constructed of burnt brick in mud mortar and lime-plastered throughout. Around all doors and windows lime mortar was used.

White-ant proof courses were provided in the ground floor walls about 16 inches above floor-level and proved entirely effective in preventing white-ants getting up into the walls and roof timbers, though in one or two cases wooden staircases were attacked. Each of these houses had a dining room, a drawing room and an office room on the ground floor, together with the usual servants' rooms, while upstairs, each had two good bedrooms with dressing and bathrooms. The higher class bungalows had good wide verandas on three sides on both floors, while the terraces over the drawing rooms served as excellent sleeping porches. Every house was provided with electric lights throughout while electric fans were fitted in all the more important rooms. Water was laid on to all bathrooms as well as to pantries and kitchens. All roofs were of Mangalore tiles laid over flat tiles, the terraces being of the Madras-terrace type or constructed of hollow tiles (Hourdies). The breakage of these tiles was heavy both in transit and during erection and they were employed only for the construction

TYPICAL QUARTERS FOR EUROPEANS AND INDIAN OFFICERS.

of the first three European Executive Engineers' quarters. As these houses were intended to have a life of about ten years, the cheaper varieties of timber only were used for all wood-work. With proper maintenance, however, the buildings remained in excellent condition even at the conclusion of the works in 1934, and many of these are still in use, and may, in fact, become permanent residences, particularly if Mettur becomes an industrial centre as it well may do.

Next in order come the Assistant Engineers', Supervisors' and foremen's quarters. These are single storey buildings constructed of the same materials as were used for the senior officers' quarters. They were designed locally to suit the convenience of the occupants. These again are all tiled buildings, the detached type being situated in small compounds, planted up with good shade trees. It was originally intended that all supervisors should be provided with detached quarters but in view of the great number employed on the works, only a few of this type were constructed, the remainder being grouped in blocks of four quarters each. This proved economical both in space and cost. The Indian, as a rule, does not like being isolated, and the block type of quarters became very popular in consequence.

All quarters for the lower grades of employees with the exception of six senior clerks' quarters, were constructed in blocks of from four to twenty quarters each. These were constructed with stone basements, the superstructure being of burnt bricks set in mud mortar and lime plastered throughout. As in other cases, doors and windows were all constructed of the cheaper varieties of wood, generally pillamarudu, while the tiled roofs were supported on bamboo rafters, wooden trusses and bressummers being used where necessary. All quarters had good verandas and kudams, with enclosed courtyards in rear. Quarters for peons, other menial staff and coolies were not provided with courtyards, but wide lanes were provided behind the blocks, the front lanes being comparatively narrow as they were little used. The rear lanes were provided with washing platforms. Large public flush latrines, located between the blocks in wide cross lanes, were provided at convenient intervals, while surface masonry drains running the whole length of each block, with water taps located at the head of each drain, were provided for the disposal of sullage from the quarters and washing places. The whole of the sullage was passed from the surface drains into the underground sewers. As a result of these provisions, the entire camp was always clean and tidy and entirely free from the obnoxious odours which one encounters in any ordinary South Indian town or village.

We will not weary the reader with details of construction of the various types of quarters which were provided to suit the many classes and grades of employees engaged at Mettur.

Lists showing the number of buildings and quarters of each type and the actual cost of construction of a quarter of each of these types both in the Mettur and Salem camps will be found in Appendix L.

The hospital buildings have been briefly described in a separate chapter.

Of the other public buildings the central offices, the combined Magistrate's Court, Sub-Treasury and Police station, the school and post office are the most important.

The combined central offices form the most imposing group of buildings at Mettur. These are constructed in two blocks, the main block being constructed round three sides of a square while the subsidiary block, with two shorter wings forms the fourth side of the square. A road-way runs between the blocks and crosses the square. The main building is a two-storeyed structure containing spacious halls with verandas all round on both floors, the main staircase being situated in a room in the middle of the block, with other staircases at the ends of the two wings.

By means of movable screens, the larger halls could be subdivided into separate offices, the sizes of which could be expanded or contracted at will to suit the requirements of each officer. As the staff and the number of separate offices varied a good deal during the course of the construction of the dam, this arrangement proved very convenient, while, for special meetings and entertainments, the screens could be removed and plenty of space made available.

The smaller block, which was of similar design but single-storeyed, accommodated the offices of two Executive Engineers and several Subdivision offices, while the offices of the Engineer-in-Chief, two Executive Engineers, the Audit Officer and several subdivisions were located in the main building. The telephone exchange was also in the main building.

Thus, all the more important offices were housed in one place and this arrangement proved to be extremely convenient and a great deal of correspondence was avoided, since officers could meet and discuss their problems without difficulty. Every means of cutting down local correspondence was availed of and this housing of all the executive officers in one building undoubtedly resulted in a great saving of time.

The Magistrate's Court, Sub-Treasury and Police station were conveniently situated near the main office. This building is of type design and calls for no special description. It was built entirely of coursed rubble and roofed with Mangalore tiles. The school and Post & Telegraph office also followed the type designs for those classes of buildings. They were built of brick, lime plastered throughout and whitewashed, as indeed, were all other buildings.

Before leaving this subject, it may be remarked that these public buildings all continue in use. The main building of the combined offices early in 1936 was transferred to the Educational department and has become a Training school for teachers (which was formerly poorly housed at Salem), and serves the purpose admirably. The smaller block of offices was transferred to the Hydro-Electric Department and has become the headquarters of the Superintending Engineer for construction of the Hydro-Electric System at Mettur.

The workshops and power-house have also been transferred to that department. It was originally intended that they should construct their own workshops, but the transfer of the buildings, completely equipped with all necessary machinery, has effected a very great saving of time and money. Small works required by the Public Works Department for the maintenance of the dam are carried out in the workshops by the Hydro-Electric Department and further economy is thereby effected.

CHAPTER IV

Water-supply at Headworks.

The first essential on any large construction project is the installation of a pure water supply system. At Mettur, in particular, it was realized long before the work started that an elaborate system would be required to safeguard the lives of the many thousands of men, women and children who would be employed there for a number of years. The villages in the neighbourhood were subject to annual outbreaks of cholera, while other water-born diseases notably hook-worm and guinea-worm were common. The local wells were nearly all polluted while, chemically, the water in them was most unsatisfactory for drinking purposes. The river, during the dry season was unsafe, yet it was customary for the villagers to draw their water for domestic purposes from that source. In fact, no cooly even went near the river without drinking from it. For the safety of the camps this had to be prohibited, but it could only be done by providing a safe and ample water supply at all places where the people lived and worked.

With this object in view the installation of a pure water supply system received very early consideration and in 1925 a preliminary scheme was prepared for the erection of a pumping station on the right bank of the river near the site of Col. Ellis's dam with a storage reservoir on the hill at the right flank. On further investigation, however, this arrangement was not found satisfactory as the right bank of the river did not afford a suitable site for an intake station, the bed being higher than at the left bank, while the proposed site for the storage reservoir was nearly a mile from the centre of the works. There were a number of hillocks on the right bank, but none of these were of sufficient area or elevation to serve the purpose of a gravity supply to the camps or works.

While this matter was being investigated, the original site of the dam had been found unsuitable and, until the final site of the dam had been fixed, it was not possible to locate the water-works. While the new dam site was being examined, an almost ideal site for an intake station was found at the left bank a short distance below the site finally selected for the Cauvery bridge, while it was seen that the high ridge of hills on that side of the river afforded scope for the construction of filter plant and storage reservoirs at any desired level to command not only the Mettur camp but the whole of the dam at any elevation as well as the Salem camp, surplus works and railway station sites. The scheme for the permanent water-supply distribution was accordingly based on the waterworks being located at this new site. The site of the intake was a deep rocky pool through which water flowed at all seasons and which never tended to silt up.

Necessity for a temporary plant.—While the permanent water works were to be situated on the left bank, and the larger of the two camps and two-thirds of the dam work were on the right side of the river, it was clear that a service main would have to be carried across the river. The Cauvery bridge, which would be utilized for carrying the service main across, could not be completed till 1928. The construction of the permanent water-works and the installation of filters and pumping plant also was bound to take some time as it was an elaborate scheme that required to be carefully investigated and planned. Accordingly, the construction of a temporary water-supply system on the right bank became imperative, especially as the simultaneous construction of all the camp buildings was to be pushed through rapidly. It was therefore decided to instal a temporary water purification plant of 100,000 gallons capacity per day (i.e., one-sixth of the ultimate estimated requirements) for the Mettur camp construction only. It was to be erected at a convenient site on the right bank at as low a cost as possible, with equipments which might conveniently be absorbed in the final water-works scheme. The use of Smith's Knoll was the only alternative to the far distant Campbell's hill and the purification plant was accordingly installed on top of the former, as it was much nearer the river.

Description of temporary plant.—This temporary installation consisted of two small portable pumping sets connected by a $3\frac{1}{2}''$ steel main to the reservoir and purification plant constructed on the top of Smith's Knoll. The difficulties of pumping with a variation of about 30 feet between the high and low water levels in the river were overcome by mounting a portable pumping set on a trolley. The track for this trolley was laid on a suitable ramp cut in the river bank alongside the delivery pipe and extending from low water to above high water level. The suction and the delivery pipes were of $3''$ flexible armoured hose. Special G.I. slants were provided at about every 100 feet along the delivery pipe for attaching the flexible pump connections.

The temporary pumping plant consisted of 2 units, one being kept as spare. Each unit consisted of one Gwynne's "Invincible" 2 stage centrifugal pump, $2\frac{1}{2}''$ suction and $2\frac{1}{2}''$ delivery, running at 1,875 R.P.M. and capable of delivering 6,000 gallons per hour against a total head of 110 feet. The pump was belt-driven by a 6·5 B.H.P. Ruston Crude Oil engine. The diameter of the rising main was $3\frac{1}{2}''$, reduced to $3''$ at the top end, the total length being about 1,600 feet. This arrangement was worked for more than a year. The oil engines frequently gave trouble in starting and, at times of sudden unexpected freshes in the river, great difficulty was experienced in disconnecting the pump connections and shifting the plant to a point above flood level. When the supply of electrical energy was made available, these troubles were overcome by installing a Worthington triplex pump 6″ × 8″, intended for the permanent water supply. This pump, mounted on a double bogie waggon and coupled to a 17 H.P. electric motor, was put into service at a suitable level on the river bank. The suction pipe was 600′ long, increasing from 4″ at the pump end to 5″ at the foot valve end in the deep river bed. This pump gave a discharge of about 8,500 gallons per hour and worked satisfactorily until the final change over was effected and the permanent water works came into operation.

The temporary purification plant consisted of a pair of 8′ × 4′ × 8′. Rapid gravity mechanical filters designed and erected by the Paterson Engineering Company. It had a capacity of 6,500 gallons per hour. It included one chemical storage tank 4′ × 4′ × 4′, one coagulation tank 32′ × 8′ × 8′, one 4″ × 5″ air compressor driven by a Petter Vertical 5 B.H.P. oil engine for supplying compressed air for washing the filters, one air receiver and one wash-water pump. The wash-water pump was driven by the Petter Engine which operated the compressor and delivered 12,000 gallons of water per hour against a head of 40 feet for washing the filters.

Chlorination and Storage (Preliminary stage).—One pulser type "Chloronome" with the necessary absorption tower, etc., and capable of sterilising 100,000 gallons per day was used for the sterilization of the filtered water. After purification and chlorination, the water gravitated to a pressed steel storage tank of 50,000 gallons capacity. The chemical tank, coagulation tank, filters and the pure water reservoir were all built of pressed steel sections, each 4′ × 4′. The daily dosages of alum and chlorine were prescribed by the Health Officer, varying according to the condition of the raw water.

Cost of Preliminary Scheme.—The total cost of the preliminary scheme, inclusive of filter plant, pumps, rising and distribution mains, etc., was Rs. 73,400. All useful equipment was later transferred for use in the final scheme.

Final scheme.—The permanent water supply scheme consists of the following works :—

(i) A pump-well on the left bank, for pumping raw water from the river.

(ii) A chemical house and mixing channel to treat the raw water with the coagulant.

(iii) Two sets of coagulation tanks.

(iv) A filter house with 3 units of Paterson's Rapid Gravity Filters with equipment complete.

(v) A low level service reservoir of 400,000 gallons capacity for water supply to Mettur town and for dam construction up to plus 728·00 level.

(vi) A high level reservoir of 200,000 gallons capacity to supply water for dam construction above plus 728·00 up to the top, and also to the Ellis Saddle works and Salem camp on the left bank.

(vii) The distribution system for works and camps in the whole of the headworks area including pumps, motors, transformers cast iron, steel and galvanised iron pipes for rising and distribution mains.

Necessity for a high level reservoir.—The main service reservoir situated on the slope of the hill could not command the camp on the left side as also the top portion of the dam. The head of pumping for storage in this reservoir was as high as 160 feet and, as the bulk of the supply would be for the lower portions of the dam and for the Mettur town, situated far below in the valley, the pumping of the entire supply to the top of the hill was considered neither economical nor necessary. A smaller high level reservoir was therefore constructed on the ridge behind the water-works to supply only that portion of the daily supply which was required for consumption at places above level plus 728. An auxiliary pumping plant was installed at the filter house for raising filtered water to this high level reservoir. The wash water for the filters was also drawn from this reservoir. This high level reservoir was the first to be constructed and was temporarily fed with raw water by means of a 4″ main from a temporary pumping plant consisting of a 22 H.P. Crossby oil engine and 6″ × 8″ triple-plunger pump, erected temporarily at the river intake station. This rising main was 1,000 feet in length. Water for the Salem camp construction, Ellis Saddle works and for the construction of the permanent water-works was supplied by this means. The pump was afterwards transferred to the filter house for pumping filtered water to the high level reservoir and the 4″ rising main was used as an auxiliary supply main to the right flank dam works and quarries. This temporary plant worked from April to November 1928. The stored raw water in the high level reservoir was daily treated with bleaching powder before supply to works and camps, as it was unfiltered.

Scope of final scheme.—The final scheme was designed for the filtration and sterilization of 600,000 gallons of water per day, the pumping machinery and filter plant being able to deal with this quantity in twelve hours and could yield, 1,200,000 in a day of 24 hours. The domestic consumption to Mettur camp was originally estimated for at 156,000 gallons per day which allowed for a population of about 6,000 at 20 gallons per head per day, excluding water required for flush-out latrines, pail-depots and other public purposes. The consumption for works to be supplied from the low level reservoir was estimated at 244,000 gallons per day, thus making a total consumption of 4 lakhs of gallons for camps and works on the right bank. The service reservoir was designed to hold a day's supply at this rate of consumption. The estimated requirements of the Salem camp on the left bank was 150,000 gallons, and that for works about 50,000 gallons. The high level reservoir was only designed for this capacity. Actually the above daily consumptions were far exceeded by as much as 80 to 100 per cent when the dam work was in full swing and the filter plant, while keeping up its rated output, successfully coped with the above demand and was often worked day and night without stoppage.

Unfiltered water to works.—It was originally proposed to supply raw water direct to works as it was thereby expected to effect a large saving in the water purification costs, but for various reasons the idea was abandoned. The actual water required for domestic purposes, including the quantity used at work sites by the coolies for drinking purposes, constitutes the major portion of the total supply. Raw river water, for the greater part of the year, is heavily charged with fine silt and is unsuitable for concrete mixing, loco-feed, ice plant, power house, etc., and it was found to be more economical to employ a single set of pumps and mains and supply filtered water through one system for all purposes. The cost of installing and running duplicate pumping plant and the laying of separate water mains for unfiltered water supply would have been very heavy, far exceeding the cost of filtering the extra water required for works only. Apart from questions of economy which could be effected by a common pure water supply for all purposes, the claims of health also urged the adoption of this system. When unfiltered water supply is available, the coolies, among whom a scrupulous hygienic standard cannot be expected, will always drink water from the nearest tap, irrespective of its wholesomeness. River water in the raw frequently carries cholera germs and if we give a chance for its introduction on works, there will be no protection from cholera despite the scrupulous preventive measures enforced in the camps. Prevention was better than cure and, under the circumstances, the supply of raw water to the work would not have been sound.

A brief account of the constructional details of the water-works and the method of purification of water is given below.

Pumping plant.—Raw water is pumped by three two-stage high speed Worthington vertical spindle centrifugal pumps each having 7″ suction and 7″ delivery. Two of the pumps work at a time, one being kept as a standby. The pumps are installed inside a water-tight well or pump house situated about 50 yards downstream of the Cauvery bridge. A deep rocky pool, quite close to the left bank, obtains here throughout the year. The foundations of the well are carried down to rock level. The pumps are erected at the floor level of the well at plus 626·00 and the suction pipes are taken through the side wall of the well and extended 30 feet into the river where they are carried on special steel trestles, the feet of which are secured in the rock. At the further end they dip into the deep pool, the foot valves being 2 feet below the lowest water level in the river. Each pump is connected by means of vertical shafting to a 3 phase, 50 cycles, 440-volts squirrel cage induction motor running at 1,455 R.P.M. The capacity of each pump is about 33,000 gallons per hour under a total head of 170 feet including friction. The three 7″ deliveries unite through a special three-way casting into a single 12″ main provided with a reflux-valve round which is fitted by pass arrangement for priming the pumps. The three-way casting was cast in the project workshops at Mettur. The delivery main is of 12″ loose flanged steel pipes and is carried up the hill slope partly on masonry piers. Two telescopic expansion joints are provided in its total length of 867 feet. A small 6 H.P. bilge pump of the same type as the main pumps, is installed for pumping out any seepage or leakage water that might enter the pump well. A special sump is provided beneath the main pumps for the intake of the bilge pump.

Pump well tower.—The foundation and basement of the pump well are of coursed rubble in cement, and the masonry above basement is of coursed rubble in surki mortar. The inside and outside of the well up to plus 640·00 from the bottom is plastered with cement mortar to make it watertight. The pump foundations are of cement concrete 4′ 0″ thick. The floor level of the motor house above the well is plus 664·00. The motor house walls are of brick in lime mortar and the house is roofed with Madras terrace. A foot-bridge of 3 spans connects the motor house with the bank. The motors and this bridge are well above highest floods level.

The cost of construction of the Pumping station was Rs. 19,000 and the cost of the three pumping sets and the bilge pump with motors and suction and delivery connecting pipes came to another Rs. 21,000.

Chemical house and mixing channel.—The raw water is delivered at a chamber in front of the chemical house and passes through a set of three stilling chambers. From the last stilling chamber the raw water is discharged into the mixing channel over a rectangular sharp-edged weir of 1′ 3″ width. Just at the foot of the weir the raw water is treated with a dose of alum solution, distributed uniformly by means of a perforated pipe. The alum solution is stored in three storage tanks inside the chemical house, each measuring 11′ × 6′ × 6′. The flow of the alum solution from the storage tank is regulated in precise ratio to the flow of raw water over the weir by means of a special automatically controlled module valve working in a constant-level feed tank designed by the Paterson Engineering Company. An automatic recorder called a "fluxo-graph," a patent of the same company, registers the quantity of raw water passing over the weir. The strength of the daily alum dose is determined by observing the turbidity of the raw water by means of a turbidity rod graduated logarithmically. This rod was supplied by the King Institute, Guindy, and is provided with a polished platinum pin at the lower end. This rod is gradually lowered into the raw water in the last stilling chamber and the visibility of the pin is watched. At the depth where the pin ceases to be visible the graduation on the rod is read and is taken as an index of the turbidity. The alum dose to be used with each index has been predetermined experimentally. The turbidity index varied from 5 to 5,000 and the corresponding alum dose is from 0·5 to 8·5 grains per gallon of raw water (1 lb. = 7,000 grains).

A series of staggered baffle walls, 4½″ thick and about 6″ high built in the floor of the mixing channel, help to mix the raw water thoroughly with the alum solution before it is let into coagulation tanks.

The walls of the storage tanks in the chemical house are built of brick in lime mortar, but for a depth of 9″ from the water face, they have been built of brick in cement and cement plastered. The partition walls are 9″ thick and are built of brick in cement and reinforced. The building is roofed with Madras terrace. The cost of construction (excluding cost of measuring gear, etc., included in Paterson's contract) was Rs. 4,970.

Coagulation tanks.—The coagulation tanks are in duplicate and are arranged Tandemfashion, each having an inside dimension of 68′ 0″ × 28′ 6″. Each tank is divided into four compartments with baffle walls and constructed in accordance with the Paterson Engineering Company's design, the object being to ensure as long a length of travel as possible at the lowest possible velocity for the alum-treated water. Each compartment is provided with a 9″ scour outlet fitted with a sluice valve. The floors of the compartments are sloped towards the scour outlet where the head at F.T.L. is 12 feet. Each set of tanks is provided with an overflow pipe. The walls of the tanks are of brick in lime mortar, the water faces for a thickness of 9″ are built of brick in cement and cement plastered. The flooring is of lime concrete, lined with a course of $4\frac{1}{2}$″ brick on edge set in cement and cement plastered. The compartments are connected alternatively by overflow weirs and submerged arches. The former trap the sediment and the latter the floating impurities. The cost of construction of the two sets of tanks was Rs. 18,800.

The capacity of both sets of coagulation tanks is 160,000 gallons and they afford about three hours contact at the full rate of working. Alum or aluminum sulphate, dissolved in water, forms insoluble aluminium hydroxide and sulphuric acid which latter re-acts with the alkaline materials present in the water to form the corresponding sulphate. This aluminium hydroxide throws down 60 per cent to 70 per cent of the bacteria and suspended matter in the raw water to the bottom of the tanks. The collecting channel at the end of each set of coagulation tanks conveys the water, after coagulation, to the filter beds. The water at this stage is almost clear but may still contain "pin-heads" or "flocks" of aluminium hydroxide in suspension. Each set of tanks is cleaned and disinfected once a fortnight to remove the sediment from coagulation. The large scour valves effectively draw off the sediment from the bottom of the tanks.

Filter house.—The filter plant consists of three units of rapid gravity Paterson Filters, each having a thickness of 3′ 8″ for the filtering medium. The top 2′ 6″ of the filtering medium is of fine quartz sand, the next layer of 3″ is of $\frac{1}{8}$″ coarse grit, the next 3″ of $\frac{1}{8}$″ to $\frac{3}{8}$″ pebbles, the next 3″ of $\frac{1}{2}$″ to $\frac{3}{4}$″ pebbles while the bottommost 5″ layer is of 1 to $1\frac{1}{2}$″ pebbles. A net work of compressed air pipes are laid between the 3rd and 4th layers. Perforated collecting pipes are laid on a special corrugated concrete floor, below the bottommost layer, to collect the filtered water, and these perforated pipes discharge into a central 9″ pipe and through a branch from its middle into the inspection boxes. From here the water, which is now crystal clear, is let into a masonry channel over a weir fixed in the wall of the inspection box. This channel leads to the foot of the chloronome.

The dimensions of the filter beds are 18′ × 12′ each, and they yield about 84 gallons of water per square foot per hour (totalling 54,000 gallons per hour for all the three filters). The water from the coagulating tank, containing the minute flocks of aluminium hydroxide, on entering the filters deposits these on the top of the filter beds and though this film helps filtration qualitatively, it gradually reduces the rate of filtration and tends to clog the filters. An arbitrary limit of filtration of 55 gallons per square foot per hour (indicated by a 4″ depth over the weir in the inspection chamber), is fixed as the point at which the filters require cleaning. Before cleaning, the water standing in the filter is partially emptied and the deposit is first agitated for about three minutes by the upward release of compressed air at a pressure of about 8 lb. per square inch in the perforated air pipes. Pure water, under pressure (through the 10″ main from the high level reservoir) is now led in at the bottom of the filter and, passing upward through the filtering medium, displaces the dirt which overflows into the waste sink along with the wash water. The whole process takes about 15 minutes. The compressed air is supplied by an air-compressor to one of two "receivers" whence it enters the filters through a net work of 1″ diameter pipes at about 8″ above the level of collecting pipes. The interval between the successive washes of a bed varies from about 80 hours during the dry season when the river water is fairly clear to about 8 hours during the turbid or monsoon season. The average percentage of wash water to filtered water delivered is 2·5. What is lost in the cost of additional alum during the flood season is gained in the dry season by the reduced percentage of wash water required so that the cost of purification per 1,000 gallons at all seasons remains very much the same, other factors remaining constant. The filter beds are never touched by hand. Once in five years, perhaps, what little sand has been lost while washing may have to be replenished. The filter beds and inspection boxes are provided with special automatic outlet control gears operated by floats to keep the rate of filtration constant.

Chlorination.—From the inspection boxes the water flows into a pure-water channel, at the middle of which it is treated with hypochlorous acid, a solution of chlorine in water, by means of a Paterson pulser type "chloronome" capable of adjustment to an accuracy of 1/100th of a millionth part of dosage. The chlorine dose varies from about 0·25 parts to 0·65 parts per million, depending on the quantity of bacteria present in the water. A special rubber baffle is suspended just below the chloronome to aid chlorination by promoting the agitation of water in the channel.

During the construction of the dam, about ⅔ of the quantity of chlorinated water was gravitated to the low level reservoir and ⅓ pumped to the high level reservoir. The pumping plant for supply to the high level reservoir originally consisted of the 3-throw plunger pump and one of the Gwynnes Invincible 2-stage centrifugal pumps which worked at the Smith's Knoll plant, but later, with the increasing demand, the three-throw plunger pump was replaced by two "Tangye-Tan Gyro" centrifugal pumps, each belt driven by a 25-h.p. induction motor. These pumps deliver 15,000 gallons per hour each, against a total head of about 100 feet.

The interior arrangements of the filter house have been adjusted to suit the working plans of the Paterson Engineering Company but the outside walls, etc., have been designed to suit the peculiar nature of this hill-side site. The filter walls have been designed for a head of 8′, the inside being lined with brick in cement for 9″ thickness and cement plastered. The walls of the filter house are of brick in lime mortar and the house is roofed with "Madras terrace" 9″ thick. The plant was completely erected and run on trial and handed over by the Paterson Engineering Company as per terms of their contract. The buildings and the masonry portions of the work relating to the fixing of the plant were erected departmentally. The cost of construction of the masonry part of the filter house was Rs. 22,000 and the cost of the three units of Patersons Filter plant including erection was Rs. 55,000.

Service reservoir.—The low level service reservoir consists of two compartments each with a superficial area of 57′ × 40′ with a depth of water of 14′ and a free board of 2′. The floor level is plus 760 and the capacity of each compartment is 200,000 gallons. The walls are of brick in lime mortar, the 9″ next to the water face being built of brick in cement and cement plastered. The floor is lined with $4\frac{1}{2}''$ brick-on-edge in cement laid over a levelling course of concrete and is cement plastered. The roofing is of corrugated G.I. sheets carried on steel trusses and supported at the ends by gable walls with door openings to allow of access into the compartments for periodical cleaning and inspection. Masonry cisterns 3′ × 3′ × 3′ have been built one in each compartment just below the inlet pipes to serve as a water cushion to break the impact of falling water when the reservoir is nearly empty. An overflow for each compartment is provided with a flap-valve having its sill level at plus 774·00. The supply main to the camp and works, which is a 12″ one, is fixed in the walls of the reservoir with sill 6″ above floor level and is fitted with C.I. bell mouths at the intake. A 12″ scour valve is provided for each compartment. To complete the germicidal process thechlorinated water is allowed a period of five hours in the reservoir before it is supplied to works and camps. The cost of construction of the reservoir with roofing, etc., was Rs. 35,900.

High level reservoir.—The capacity of the high level service reservoir is 200,000 gallons. The reservoir consists of two compartments with a floor area of 60′ × 25′ each and a floor level of plus 860·00. The depth at F.R.L. is 10′ and a free board of 2′ is allowed. The walls are of coursed rubble first class in surki mortar lined with $4\frac{1}{2}''$ brick in cement and cement plastered. The floor is also lined with brick on edge in cement over a levelling course of lime concrete and cement plastered. The roofiing is similar to that in the low level reservoir. Necessary inlet, outlet, overflow, and scour pipes are provided for each compartment. The cost of construction was Rs. 29,000.

The reservoirs were cleaned once a year, though there was practically nothing to be cleaned.

It will be noticed that brick on edge lining is provided for all tanks and reservoirs. Experience has shown that this form of lining, built in cement and cement plastered, is most satisfactory and remains water-tight while lime concrete floors, cement plastered, are liable to crack and become leaky.

Establishment.—The construction of the above work which was commenced about the middle of 1927 was, with the erection of the filter plant, etc., completed in September 1928, the first trial run of the plant being made at the beginning of October 1928. The plant was run regularly from January 1929. It was worked in two shifts daily from 6 a.m. to 10 p.m. The establishment in each shift consisted of one operator, two drivers, two cleaners and an alum coolie under the general supervision of a Waterworks Superintendent. During 1933, the daily consumption exceeded a million gallons in the summer months, and one more shift was temporarily introduced for a period of three months from April to June of that year.

Tests.—Tests were carried out regularly every day on the filtered water to determine the exact chlorine dosage required. At times of sudden changes in the condition of raw water the tests were conducted at more frequent intervals. The alum dosage was regulated for the particular turbidity, the quantity being read from a chart prepared for the purpose. The re-action in the coagulation tanks was frequently observed as a check against this.

The King Institute, Guindy, took samples of the raw and purified water at the various stages of purification as well as from the camp distribution system once every six months for chemical and bacteriological examination. The raw water was generally proved to be of a very poor quality, but the purified water was pronounced to be of uniformly excellent quality, testifying to the high efficiency of the plant.

Statistics regarding the total quantity of water pumped, cost per 1,000 gallons and the amount of chlorine and alum dose, etc., year war from 1929 to 1933 are given below :—

Particulars.	1929.	1930.	1931.	1932.	1933.	Average for one year.
1 Total raw water pumped millions of gallons ..	206·0	263·7	350·2	374·1	344·3	307·8

Particulars.	1929.	1930.	1931.	1932.	1933.	Average for one year.
2 Total cost per 1,000 gallons of filtered water delivered at waterworks .	Rs. 0–2–7	0–1–11·2	0–2–1·1	0–1–11	0–2–1·3	0–2–1·2
3 Average alum dose in grains per gallon of raw water ..	2·6	2·3	1·7	1·6	1·1	1·8
4 Average chlorine dose in parts per million parts of water.	0·63	0·43	0·38	0·38	0·3	0·42
5 Cost of electrical energy only, per 1,000 gallons of water	Rs. 0–1–5·6	0–1–0·8	0–1–4·5	0–1–3·3	0–1–5·2	0–1–3·9

The average cost per 1,000 gallons of filtered water delivered through the distribution system was approximately 2½ annas, which is below the average for a normal town supply.

Distribution system.—The sizes of mains in the distribution system were so designed as to be capable of discharging the full daily supply in a minimum period of eight hours, the maximum velocity allowed in 12″, 10″, 8″, 6″, 4″ and 3″ mains being 3, 3, 3, 2·75, 2·5 and 2 feet per second respectively. Cast iron mains with spigot and socket-ends were used wherever the mains were laid underground but the rising and distribution mains on the slopes of the hill at left bank, as well as the main carried across the Cauvery bridge and that in the drainage gallery of the dam being aboveground and exposed, are loose-flanged steel pipes. These loose-flanged steel pipes were obtained from England through the Director-General, India Store Department, London, and varied in length from 16 to 23 feet. The cast iron pipes were in standard lengths of 9 feet and were mostly obtained through the agents of the Bengal Iron Works. The cast iron mains and specials as well as the loose-flanged steel pipes and fittings were all tested to a head of 400 feet of water, which is about twice the maximum working pressure. Below 4″, the mains are all of galvanized iron, obtained from the local firms at Madras or Bombay.

The camps on the right side as well as the lower reaches in the dam area are supplied from the low level reservoir from which a 12″ steel delivery main is taken down the hill slope and along the bridge across the river where it is supported on stirrups hung from the cross girder of the bridge. Telescopic expansion joints are provided at either end of the bridge. After crossing the bridge, the 12″ main is of cast iron and is carried underground for a distance of 1,650 feet up to the south-west corner of Workshops where it bifurcates into two 10″ C.I. mains—one for dam and one for Mettur camp supply.

The 10″ main to the dam bifurcated into two branch mains, each of 6″, which ran along the rear toe of the dam, suitable branches being taken off those mains for supply to works. On the completion of the dam these mains were removed.

For supply to the Mettur camp a 8″ main was considered sufficient but the main was started as a 10″ main (to provide for any future extensions on the Kullavirampatti side). After crossing the Kullavirampatti vari it is reduced to 8″. This 8″ is again suitably reduced to 6″, 4″ and finally 3″ at its tail end according to the discharges required at the various branches. The total length of the distribution main for Mettur camp from the point of off-take from the 12″ main near workshops is 8,220 running feet. Branch connections for camp distribution are always looped with each other as well as with the distribution to maintain circulation and so avoid dead ends as far as possible.

The high level reservoir supplied the camps on the left side, the quarries on top of hills as well as the higher reaches of the dam. The left flank supply main starts as a 12″ steel main but is reduced to 8″ within a short distance. This 8″ steel main divided into two branches of 6″ at the foot of the hills, one going to Salem camp and the other to Ellis Saddle. These 6″ mains were of cast iron. The 6″ main to Ellis Saddle from which the Dam Railway station, shandy, and transport office, etc., took their supply was substituted by a new 4″ line over the Ellis Saddle bridge after the latter was constructed. Special expansion springs were provided for the 4″ line over the bridge, as it is exposed to the sun and is laid on a curve.

The main from the west side of the high level reservoir is also a 12″ one which, after a length of 100 feet down the hill slopes bifurcates into branches of 10″ and 6″. The former goes down to the main filter house for supplying the wash-water for the filters, with a branch to the alum house. The 6″ main ran along the 815 ledge and down the hill slope to the toe of the dam and thence through the cross drainage gallery at L.S. 800 into the main drainage gallery up to L.S. 3,560. From this 6″ main inside the gallery, vertical branches were taken off at suitable intervals and carried up the drainage shafts for supplying water for dam construction, being extended upwards as the height of the work increased. These branch pipes, mostly 1″ G.I., were screwed into special cast iron rings fitted in the 6″ line, the rings being tapped and threaded to receive the branch pipes. This method of supplying water to the top of dam was found most convenient and was adopted in prefernce to the usual method of carrying the pipes on the surface of the work where they often create obstructions.

House connections with brass bib-cocks were provided for all officers' bungalows, Subdivisional Officers', Foremen's, Erectors' and Supervisors' quarters, but in the case of mechanics, maistris, peons and coolies, etc., street fountains with single waste-not cocks were provided at the end of each block of quarters. In the case of clerks' quarters, fountains with single waste-not cocks were also provided at the end of each block of quarters. In addition to the above, water-supply was freely provided to all temporary coolie camps in and around the work sites all over the headworks. The pail depots, dumping pits and flushout latrines had their overhead tanks supplied from the distribution mains, and, in addition, separate taps were provided inside pail depots and flushout latrines for washing purposes. The permanent 'dry' latrines, particularly those in the Salem camp were also provided with taps for washing. Beyond the officers' bungalows at the south end of Mettur camp, a water main was extended to the "shandy" and later to Mathayankuttai village, three miles along the Mettur-Bhavani road, as a large proportion of the coolies working on the project resided that side and no other source of supply existed there.

All cast iron and galvanized iron pipes were laid in trenches at sufficient depth to protect them from injury and to keep the water cool. The lines, after being jointed, were tested for leaky joints to a safe working pressure of 80 lb. per square inch before re-filling the trenches.

Air valves at all the highest points and scour valves at all lowest points have been provided on the distribution mains. All valves are provided with masonry valve pits provided with C.I. surface boxes. Ten Fire-hydrants of $2\frac{1}{2}''$ size were fixed at suitable places to command conveniently, by means of a 600-feet lengths of hose, almost all the buildings in the camps (excluding officers' bungalows to the south and the workshops, power-house, etc., to the north of Mettur camp).

Water meters.—As the project estimates for works did not provide separately for water charges and as there was a special provision in the revised estimate for the project for the maintenance of water-supply, it was decided not to charge for water supplied to the works and camps but to introduce meters only at important places on the distribution mains to record the proportionate supplies to works and camps and also to help the detection of wastage and leakage. Accordingly, some meters were obtained and provided at important places, the sizes being fixed to suit the discharges required. Regular pro-forma cost accounts for water-supply to the camps and various works were maintained. Shop-keepers, non-official residents and the South Indian Railway were charged for the water supplied to them at a rate of one rupee per thousand gallons. They had to bear the cost of pipe connexions inclusive of centage charges as also 8 per cent on the capital cost of meter as its rent per annum. The amount realized from private parties towards water charges ranged from Rs. 50 to Rs. 85 per month and that from the Railway station Rs. 200 on an average.

Maintenance.—The maintenance of the distribution system has been looked after by a fitter and a turn-cock, the former looking to the repairs and renewals, etc., and the latter for the regulation of supply. The distribution mains were all scoured once a week.

There was no restriction of supply to camps during the day in the earlier years but later the rise in consumption in the camps became so great and so much wastage was detected that restriction had to be imposed. The supply to the subordinate staff quarters where wastage was greatest was cut off from 2 to 4 p.m. and from 9 p.m. to 5 a.m. daily.

The monthly consumptions of water for works and camps during the intensive period of the work on the dam, i.e., from July 1932 to June 1933 are given below :—

Months.	Consumption for *works* in lakhs of gallons (100,000).	Consumption for *camps* in lakhs of gallons (excluding supplies to private parties) (100,000).
July 1932	136	159
August "	125	144
September "	140	152
October "	174	134
November "	162	130
December "	174	138
January 1933	152	157
February "	157	151
March "	184	180
April "	183	186
May "	170	176
June "	167	152

The total cost of the water-supply scheme inclusive of the complete distribution system was Rs. 4,59,000, and the total cost of maintenance up to end of March 1934 was Rs. 2,81,000. The average maintenance charge was Rs. 46,000 a year, the maximum being Rs. 58,000. The daily consumption of water and its cost varied with the population within certain limits so far as the camps were concerned while the comsumption on the works varied more or less in proportion to the rate of masonry outturn.

CHAPTER V

Sewage Disposal at Headworks Camps.

Mettur Camp.—Towards the end of 1925 it was decided that the coolie lines, clerks' quarters, etc., required an underground drainage system, as the disposal of sullage by open masonry drains would be objectionable and dangerous to the health of the camp generally. The latter method would have necessitated the provision of dry latrines and very extensive trenching grounds for the disposal of nightsoil. The Director of Public Health strongly opposed the discharge of sullage into the river which was the natural outlet for any surface drainage scheme. It was therefore agreed that an underground drainage scheme would be necessary, the sewage, after suitable treatment, being put on the land for the irrigation of a small farm. In consultation with the Director of Public Health and the Sanitary Engineer, the principle of adopting the underground system to the main body of the camp and extending it to power-house, workshops, etc., if levels permitted without a disproportionate increase in the cost, was decided upon. On account of the change of site for the dam a final lay-out plan with details of levels could not be drawn up until the middle of 1927 when detailed estimates for the entire scheme were worked out. This was sanctioned at the beginning of 1928. Meanwhile, when the detailed estimates were under preparation, a preliminary estimate for the purchase of materials for the laying of sewers for connecting up all the quarters was prepared and sanctioned so as to enable the Executive Engineer to obtain the pipes and start the work promptly. This estimate was afterwards embodied in the final consolidated estimate.

Scope of the Scheme.—The scheme as finally sanctioned provides for the following :—

(1) Providing an underground drainage system for the main Mettur camp, inclusive of the hospital;

(2) construction of open masonry drains in rear of quarters and coolie lines (wherever the same were not previously constructed along with the buildings) for draining the house sullage into the sewers of the underground system;

(3) construction of pail depots and dumping pits at suitable sites for disposal of nightsoil and connecting the same to the underground system; and

(4) construction of a pumping station and installation of the necessary pumping sets inclusive of rising main, etc., for pumping the sewage on to a farm.

The scheme was designed for a population of 5,000 (taking the underground drainage area alone) and allowance at the rate of 20 gallons per head had been made. Coolies residing in the camps outside the drainage area totalled about 2,500, and provision for them was made only at 15 gallons per head. Besides the above there was the discharge from the flush-out latrines, pail depots and dumping pits for which an allowance was made at 34,000 gallons per day. An allowance of 3,500 gallons for discharge from the Recreation Club, slaughter-house, etc., was also made. Thus the total expected dry weather flow in the sewers was about 125,000 gallons per day. The camp was conveniently divisible into two blocks with reference to the position of the pumping station, about 90,000 gallons of the above discharge coming from the north and 35,000 gallons from the west side. The drainage due to rainfall is mainly led off to the river by a system of storm water drains but a small quantity falling into the open courtyards of supervisors', clerks', mechanics' and maistris' quarters finds its way to the underground system through the open drains. Thus, though it is common to design sewers to carry about 6 to 8 times the dry weather flow about double this allowance has been made in the design of the two outfall sewers mentioned above to allow for the small quantity of rain water entering the sewers and to provide for any possible future development.

General outline of Scheme.—The distance of the camp from the power-house and workshops with the deep Kullavirampatti vari coming between rendered the inclusion of these in the drainage scheme impossible except through the medium of a sub-pumping station which was considered too expensive. The workshops and power-house were therefore provided with permanent dry latrines. Regarding the dam, as the site of construction varied in concentration of labour, portable dry latrines were provided. The nightsoil from these latrines was removed by the conservancy staff and emptied into the dumping pit at the northern extremity of the drainage system near the maistris' quarters.

The officers' bungalows which are situated far from the main camp have large compounds, and sullage water was discharged through surface drains for irrigating their gardens. The nightsoil was removed and emptied into the nearest dumping pit at Thukkanampatti which is connected to the underground system.

The hospital buildings, being of importance, have their own underground sewers the sewage discharging into a special manhole whence it is lifted by means of an Adam's pneumatic ejector and discharged into a manhole at the head of the nearest gravitation sewer at the north end of the main system near the coolie lines.

The main body of the camp is situated practically across the line of the original site of the dam. It is bounded on the north by a slight ridge running from the north-west corner of the coolie lines to the hill known as Smith's Knoll, on the south by the Thukkanampatti vari, on the east by the old Sampalli road and on the west by the high rocky ridge known as the Campbell's hill. The underground drainage system was limited to this area. Later on, the scavengers' quarters at Thukkanampatti, with their flush latrine and dumping pit, were connected to the underground system by means of a 6″ sewer taken over a bridge at the Thukkanampatti vari crossing.

Quarters for subdivisional officers, supervisors, clerks, mechanic and maistris were all provided with dry latrines fitted with pans. Pail depots were constructed at convenient sites near the quarters and nightsoil from pans was directly emptied into these. The waste water from the bath-room, kitchen, courtyard and latrine of each quarter was conveyed by short open masonry drains through 4″ gully traps to the underground sewers.

The coolie lines, fittermates', police and peons' quarters were provided with suitable automatic flush-out latrines discharging direct into the sewer. A masonry surface drain at the rear of each block, carries off waste water from the fountains and sullage from the quarters. This drain terminates in a silt pit and gully trap with grating and discharges into the sewer through a short 4″ stoneware branch.

The two outfall sewers at the pumping station discharge through a junction manhole into a screening chamber, thence into a silt pit and then again through a finer screen into the collecting well. A 21″ masonry overflow conduit to the river is provided from the junction manhole for the disposal of storm water in the event of exceptionally heavy rains. The sewage from the collecting well is pumped up through a 7″ C.I. rising main to the sewage farm, the climatic conditions and soil of Mettur being favourably adapted for the disposal of sewage by this means.

Sewers.—The sizes of sewers used in the Mettur system are 4″, 6″, 9″ and 12″. Though generally the branch sewers were not smaller than 6″, 4″ sewers were used at the heads of sewer lines for short lengths where the house connexions were few. All the sewer pipes and specials are of glazed stoneware and are of "commercial first-class" quality. These were obtained from Messrs. Burn and Company, Limited, Calcutta. The prices per pipe f.o.r. Erode for the various sizes were 12″ Rs. 6–11–0, 9″ Rs. 4–8–0, 6″ Rs. 1–14–0, and 4″ Rs. 1–4–0, the length being 2′ 6″ each for the former two sizes and 2′ each for the latter two sizes. The gradients were so designed that a minimum self-cleansing velocity of $2\frac{1}{2}$ feet per second would be maintained with sewers running half full. In the majority of sewers, the gradients are self-cleansing under almost all conditions of flow. The maximum and minimum gradients actually employed for the various sizes are noted below :—

Diameter of main.	Maximum gradient.	Minimum gradient.
12 inches	1/85	1/181
9 ,, ...	1/46	1/150
6 ,, ...	1/36	1/125
4 ,, ...	1/36	1/ 84

The above gradients in the case of the 12″ pipes though a little steeper than those usually allowed, have been adopted on account of the natural fall of ground and the low ground level at the pumping station. Had the gradients been reduced, it would have been necessary to construct drop manholes of great depths, which were not considered desirable with the rocky subsoil of Mettur. The fault was on the safe side as the velocity was generally rather greater than that required to obtain self-cleansing conditions. As however, the sewers did not require a life of more than 10 years, the question of wear was of no consequence and all sewers remained remarkably clean with the minimum of attention.

The lengths of the different sizes of sewers as actually laid are—

4″—7,800′ (exclusive of house connexions).

6″—12,100′ (exclusive of flush latrine connexions).

9″—3,500′.

12″—1,895′.

The house connexions number about 336 and the size is 4″, the average length being 12′.

Gully-traps.—These connect the open drains in rear of quarters and coolie lines to the sewer and prevent the admission of sand and silt into the sewer line and the emission of sewer gas from inside the sewer. A cast iron grating placed on a square seating on top of the gully trap arrests any rubbish leaves, etc. In the case of block-quarters, such as were provided for supervisors, clerks mechanics and maistris and which are provided with twin latrines and kitchens, a single gully-trap is utilized to draw off the waste water from two adjacent quarters. In the case of fittermates', peons' quarters and coolie lines there is one at the end of the surface drain in rear of each block. The size for all the above is 4″. In flush-out latrines 6″ syphon traps are employed for connecting the manhole at the end of the latrine to the sewer branch.

Manholes.—These have been constructed at all junctions of main and branch sewers and at every 200 to 250 feet in straight reaches. They have been constructed also at every junction of the

6″ branch sewer from flush-out latrines with the main sewer line. The depth of the manholes is generally within 4′ 6″ from invert of pipes to the under side of the manhole cover, but in a few of the manholes the depth varies from 4′ 6″ to a maximum of 7′ 6″. All the manholes are of rectangular section with inside measurements 3′ 6″ and 2′ 6″ and are built of brick in mortar and cement plastered in the inside. The top is corbelled in to take the manhole cover frame which is 30″ × 20″ clear (inside dimensions). The cast iron frames with covers, not being situated in roadways, are of light pattern and were obtained from the South Indian Export Company, Madras, at a cost of Rs. 32 each, the weight being 276 lb. each. The covers are provided with four slit holes for insertion of keys for lifting and also for purposes of ventilation to a small extent. Drop-manholes have been constructed where necessary to avoid too steep gradients in sewer lines and, where the drop is more than 2 feet, special Tee branches and bends are fitted immediately before the manhole so as to discharge at floor level of the manhole. For smaller drops, a sloping channel is formed in the concrete itself inside the manhole.

Flush manholes.—To remove the silt deposited in the pipes owing to variations of flow, flush manholes of convenient capacities were constructed at the head of each sewer line, the capacity depending on the size and length of the sewer to be flushed. The three different sizes constructed at Mettur are 100 gallons, 250 gallons and 500 gallons. With a width of 2′ 6″ as for an ordinary manhole, and a depth of flush level of 2′ 7½″ the lengths for the three sizes work out to 2′ 6″, 6′ 6″ and 13′. Thus, an ordinary manhole itself with water-supply arrangements has served for the first size. In the case of the 250 and 500 gallons manholes, an overflow is provided by means of a tee-piece and bend. The mouth of the sewer pipe is provided with a flap door worked with a chain. Water is supplied from the water main through a ¾″ pipe with a stop-cock and trap in the delivery, to prevent sewage gases entering the water pipe and contaminating the water in it.

Flush-out latrines.—These are provided for the thickly populated lines, fittermates', peons', scavengers' and police lines as well as for the new and old market sites. The distribution of the latrines is as follows :—

Coolie lines (50 blocks of 20 quarters each) ..	12	numbers of	20	seat each.
Fitter mates (6 blocks of 15 ,,) ..	2	,,	20	,,
Peons lines (12 blocks of 15 ,,) ..	4	,,	20	,,
Police lines (2 blocks of 10 each and 1 of 3) ..	1	,,	8	,,
Hospital	1	,,	6	,,
Combined offices	1	,,	5	,,
New and old markets	2	,,	2	,,
	1	,,	10	,,
Post office and elementary school	1	,,	10	,,
Scavengers' huts 20 numbers at Thukkanampatti	1	,,	6	,,

The above distribution works out to about 1 seat for every 5 persons in the case of peons, fittermates and police and 1 seat for every 10 persons in the case of coolies and scavengers.

With few exceptions, all the latrines are provided with double rows of seats. Each row is arranged on either side of a partition wall with a washing platform at each end. Just outside the wall at one end two automatic flushing tanks (working on the syphon principle) of 30 gallons capacity each are fixed at a height of 7 feet. The tanks receive their water-supply from the water main through a 1″ pipe regulated by wheel valves. Across the centre of each compartment and running for the full length of the latrine there is a 'three-quarter' glazed stoneware pipe channel 9″ diameter with top opening of 7″ fixed in a bed of concrete. This channel pipe receives the excreta and washings and the whole is flushed from the upper end into the manhole situated at the lower end of the latrine. From the manhole the sewage is discharged through a 6″ syphon trap and a 6″ branch sewer into the manhole on the main sewer.

Pail depots and dumping pits.—There are altogether 14 pail depots and these are evenly distributed so as to command convenient groups of quarters. On an average, one pail depot serves about 25 quarters with an average of four persons each. The night-soil is dumped into a hollow glazed stoneware conical vessel (fixed in a bed of concrete) with a circular inlet flush at top and a flush out delivery at bottom. This bottom delivery is connected to a 4″ cast iron trap from which connexion is made to a small adjacent manhole, which in its turn, is connected to the manhole on the main sewer line.

The water for flushing out is obtained from a 3-gallon "pull and let go" flush-out cistern which in turn receives its supply from an overhead masonry tank 3′ 6″ × 3′ × 2′ 6″ constructed on the walls of the enclosure itself, the flooring of the tank being made of R.C. slab 4″ thick. The tank receives its water supply from the water main, the supply being regulated by a $\frac{3}{4}$″ ball valve.

The dumping pits are similar in construction to the pail depots but they are for dumping nightsoil on a large scale. The actual dumping pit is formed in concrete and a 2′ perforated loop pipe formed by jointing 2″ G.I. pipes and bends serves for the inlet flush, the water supply being obtained directly from an overhead tank measuring 4′ × 4′ × 3′ connected to the water main. There is one dumping pit at the north end of the drainage system for nightsoil removed from dry latrines at the Kullavirampatti camp, Workshops, Power-House and Work site and another at the south end at Thukkanampatti to serve the officers' bungalows and dry latrines at the Thukkanampatti quarters.

Ventilating shafts.—The sum of the total discharge of gases from the ventilators on a sewer should be not less than the discharging capacity of the sewer. This principle has been kept in mind and ventilating shafts consisting of special 4″ steel pipes have been connected to all manholes of pail depots, flush out latrines, flush manholes at heads of sewers and at intermediate manholes on the main sewers. The total number of vent shafts is 86.

A 4″ stone-ware connexion is taken from the manhole on the sewer pipe up to the basement of the nearest building ending in a 4″ bend which is enclosed in masonry. A 4″ steel pipe, 18′ high, fitted into a specially designed cast iron base, is also fixed in masonry just over the bend and secured to the wall of the building with clamps placed at suitable heights. A wire cage coronet is secured to the top of the pipe to prevent birds getting in.

Sewage Ejector.—The ejector is installed at the lower end of the hospital sewer system in a masonry chamber with an inlet manhole. It is of the Adam's automatic type working on compressed air and was obtained through the India Store Department for Rs. 1,300. The special inlet manhole serves as a collecting well in the event of a temporary cut-off of compressed air supply. The rate of discharge varies with inflow, and during busy periods it is capable of lifting 25 gallons per minute against a total head of about 21 feet, including friction. The compressed air supply was at first received through a 1″ pipe from the power-house and the supply pressure of 80 lb. per square inch was suitably reduced at the ejector to about 30 to 35 lb. by means of the pressure-reducing valve supplied with it. Later on, a horizontal air receiver 8′ × 3′ diameter was fitted in the air main near the ejector to admit of stoppage of the compressor at the Power-House for short periods when there was no demand for air for general purposes. An independent electrically driven auto-compressor was also installed at the ejector. This worked for some time but was removed afterwards as it was not found satisfactory.

Particulars of ejector.

Sill level of inlet sewer from hospital into the ejector manhole	668·37
Sill level of inlet sewer at end of 3 inches C.I. delivery main from ejector	687·18
Length of 3 inches C.I. rising main	400 ft.

Drainage Pumping Station.—The site is 100 feet to the west of East Main Road, at the south end of the old Mettur village. It is situated well away from residential buildings and was not objectionable. Its location admits of good gradients being adopted for all the sewers.

The two out-fall sewers, 12″ and 9″ respectively, discharge into a common manhole. Across the manhole is a weir over which the sewage flows when discharging into the overflow conduit. This overflow conduit is 21″ internal diameter and is of masonry formed of $4\frac{1}{2}$″ brick arch enclosed in concrete. The layout of the screening chambers, silt pits and collecting well is simple and efficient. From the manhole the sewage is led into a coarse screen chamber, the screens consisting of $1\frac{1}{2}$″ × $\frac{1}{4}$″ M.S. flats at 1″ centres, the flow being regulated by two disc valves 16″ in diameter through openings in the manhole wall. From the coarse screen chamber where stones, etc., are trapped the sewage runs into a large pit where all the heavier silt is deposited at the bottom. The floor of the silt pit is sloped towards one end so as to collect all the silt which is, at intervals, removed by hand. From the silt chamber the sewage flows into the collecting well through a finer screen consisting of $1\frac{1}{2}$″ × $\frac{1}{4}$″ M.S. flats at $\frac{5}{8}$″ centres. The screening chambers and silt pits are in duplicate to admit of cleaning of one set when the other is in use. The collecting well is 12′ diameter and 18′ deep and the sewage from this is pumped through a 7″ C.I. rising main on to the sewage farm.

Pumping sets.—The pumping station is equipped with three Rees Roturbo pumping sets, each set consisting of two single stage centrifugal pumps mounted at either end of a common base plate and arranged to work in series and coupled to a 28 h.p. protected type squirrel-cage induction motor 440 volts, 50 cycles, 3 phase, running at 1,420 R.P.M. The cost of the three sets with motors, etc., and with necessary suction and delivery connecting pipes was Rs. 6,300 f.o.r. Erode. Each set is capable of delivering 250 gallons per minute against a total head of 150 feet including friction. The suction is 4″ and delivery 3″ and all the three pump into a common 7″ rising main. A 7″ reflux valve is provided in the delivery main just outside the pumping station to prevent back pressure.

Two sets are worked together at times of maximum demand and the third set is always kept as a reserve. The busy periods of pumping are generally from 6 to 8-30 a.m., 12 to 2 p.m. and 4-30 to 7 p.m. The hours of pumping vary with the season. During the dry weather, when the camp was fully occupied, pumping was required for 9 to 10 hours a day and during rainy season it ranged from 12 to 18 hours, the average quantities of sewage pumped, being, 130,000 gallons and 220,000 gallons respectively. At that time the average quantity for the whole year per day worked out to 170,000 gallons, the cost of pumping being 3 annas per 1,000 gallons. During very heavy rains, when 2 pumps are not able to cope with the inflow, pumping is stopped and the sewage, being much diluted, is allowed to overflow to the river, after disinfection with bleaching powder. The pumping is resumed as soon as the overflow stops.

Rising main from pumping station to farm.—The normal dry weather discharge from the sewage pumps was about 250 gallons per minute. In order to maintain a velocity of $2\frac{1}{2}$ feet per second in the pipe (which is the velocity required to keep solids in suspension and prevent deposit in the pipe), the size of 7″ was fixed for the rising main. It is provided with four outlets at the farm within the last 815 feet at its tail end. The lowest outlet is a 6″ one and other three are 4″. The 7″ rising main extends only to the first outlet whence it is suitably reduced to 5″ and 4″. The total length of the rising main up to the last outlet is 3,691 feet and the static head of pumping to this outlet is 91 feet.

Execution of work.—Prior to the construction of the permanent underground system, the coolie lines, being the first buildings to be constructed, were provided with a temporary underground drainage system. 6″ stoneware pipes (obtained from the Feroke Tile Works) were laid and jointed with yarn and clay, the sullage being discharged into the river. These pipes were removed immediately the permanent system came into operation in 1928.

The excavation for the permanent sewers was started in July 1927. The actual sewer lines as well as the positions of manholes, etc., were completely pegged out on ground. Trenches to suit the required depths of the sewers were excavated to the proper slope. The blasting of hard rock had to be done in many places, especially in the trench for the 12″ sewer. Generally, however the soil was of hard gravel overlying decayed rock. In the case of 12″ and 9″ pipes, sets of three and in the case of 6″ and 4″, sets of four pipes were gallery-jointed with neat cement in advance and tested under a 6 feet head of water. These were then lowered and laid in the trenches with sockets facing the direction of flow of sewage. The correct slope of the line was checked in the usual manner with the use of boning rods and sight rails. The trench joints were then finished off with spun yarn and neat cement, special caulking tools being employed to drive in the spun yarn which was previously dipped in a solution of neat cement.

Testing.—This was done for each section of a line as the laying was completed. The open ends of the line, as well as those of house connexions in the middle were all plugged with special rubber stoppers. The main was tested by attaching a funnel with a $\frac{3}{4}$″ rubber hose pipe to the top end of the main and filling it with water completely through the funnel. The funnel was held at an average height of 6′ above the top end of the sewer. The jointing was approved if the 6 feet head was maintained for 30 minutes without the funnel emptying. If the funnel emptied in under 30 minutes, the line was considered defective and the sources of leakage traced and made good with cement concrete binders. The trenches were then refilled and the main again tested to the same head.

The laying of all the lines, including house connexions and construction of manholes, etc., was practically completed towards the end of August 1928, when the sewage pumps first started working, but the complete system with all pail depots and flush out latrines, etc., came into operation only from April 1929.

Maintenance.—The staff employed for the maintenance of the drainage system was as follows :—

(*a*) One gang of nine scavengers under the supervision of a maistri for cleaning open drains, gulleys, sewers, manholes, etc.

(*b*) One fitter maistri for looking after the working of the sewage ejector, flush out latrines, pail depots, hospital system, etc.

(*c*) Two drivers and two cleaners working in two shifts of 12 hours each for working the pumps at the drainage pumping station, besides a watchman.

(*d*) Four scavengers for cleaning, removing and carting the silt from the silt pits at the pumping station to the trenching ground on the sewage farm.

The removal of nightsoil from dry latrines and operation of pail depots and pumping pits was done by the conservancy staff of the health department.

The cleaning of sewers was done with a set of special drain cleaning apparatus consisting of 300 r.feet of best selected Malacca cane rods in 40″ lengths fitted with patent screw lock-joints and complete with brush head, brass cleaning wheel and cup, etc. (The greatest length between manholes is 300 r. feet). Apart from main sewers, the house connexions were provided with 4″ stoneware slants to serve as cleaning eyes immediately below the gulley traps, the open ends of the slants being plugged with stone-ware lids. These lids were removed in the rare event of house connexions becoming choked. The flushing of all sewers was done once a week.

Salem camp.—The proposals for a drainage scheme for Salem camp were considered along with those for Mettur camp as early as 1926. It was first proposed to have a water carriage system as for the Mettur camp but later on, on account of the smallness of the camp, and the natural facilities the site of the camp afforded for open surface drainage, the proposal for an underground system was given up. There is a steep natural surface fall of the country from west to east, and about 10 acres of land with good alluvial soil at a level lower than the lowest level of the camp was available about 2 furlongs from the south-east of the camp for use as a sewage farm. The night soil was disposed of by the dry system in trenching grounds available to the south of the camp.

The scheme as finally sanctioned provided for the construction of a completed system of open masonry surface drains for a maximum population of 5,000 with a water allowance of 20 gallons per head per day. The storm water falling in the camp area is excluded from the drains by employing suitable storm water drains and culverts through which it discharges into a vari below the camp. Provision was, however, made in calculating the sections of the sullage drains for a small extra quantity of drainage due to rain. The disposal of night soil was by the dry system, the officers' and clerks', mechanics' and maistris' quarters being provided with dry latrines and the coolie huts and market site being provided with a system of pan-type dry latrines. Later, the Sanitary Engineer to Government did not consider the system of disposal by trenching desirable and recommended the construction of a septic tank with a dumping pit in front of it. Accordingly these were constructed before the end of 1929 and the sullage water from the camp as well as the sewage from the dumping pit was passed through the septic tank and the effluent passed on to the 10-acre farm for irrigation.

Types of open drains.—The drains are of ovoid section and seven different sizes have been used, the particular size at each place being sufficient for the total maximum discharge at that place. The largest drains were designed to carry nearly three cusecs which is five to six times the maximum dry weather flow. As the slope of the country is more than the slope of 1/200 adopted for the drains, necessary masonry drops were provided as required.

The sullage from the peons', maistris', clerks', mechanics' and supervisors' quarters was conveniently led away to the south of the peons' quarters for irrigation of a small three-acre farm, worked independently of the main sewage farm.

Septic tank.—The septic tank was designed for a dry weather flow of 60,000 gallons per day and it is divided into two sets of compartments by a longitudinal partition wall in order to admit of the isolation of one set when necessary for removing the sludge and scum. Taking each set, the dimensions of the first two compartments are 12′ × 12′ and that of the last two 13′ × 12′ the depth of the tank being 8 feet. The connexion between the first and the second compartments is through two vents 2′ × 2′ situated at floor level. A partition wall 6 feet high divides the second and third compartments. The connexion between the third and fourth compartments as well as from the 4th to the drain outside, is by means of four 4″ bends fixed in the compartment walls with sills at 7 feet and 8 feet above the floor respectively. A free board of 2′ 6″ has been allowed between the surface and the 6″ R.C. slab covering of the tank for the collection of scum. A grit chamber has been provided in the open drain before it enters the septic tank. The chief action taking place inside the tank is the separation of the solid mineral matter and the digestion of the sludge as far as possible by encouraging the growth of anoerobic bacteria.

After the tank commenced to work in January 1930, the scum and the sludge required to be removed only once, in 1933. The septic tank functioned admirably.

The maintenance of the drainage scheme in this camp was conducted by the Sanitary staff of the Health Department.

General.—The total cost of providing the drainage schemes for both the camps was Rs. 1,70,000 and the cost of maintenance to end of March 1934, Rs. 70,000. Both the systems worked very efficiently throughout the period till the construction of the dam was completed in 1934. The Salem camp was then closed, while the Mettur camp with its water-supply and underground drainage systems continued to be occupied, though the population has been much reduced. With the development of industries at Mettur the township may again grow. In this event the existence of these efficient model services will be further appreciated.

Sewage Farm.

Mettur camp—Preliminary.—Along with the proposals for the construction of an underground drainage system, the problem of satisfactory disposal of sewage was also considered as early as 1926. The alternative methods considered were :—

(1) Discharge of the raw sewage into the river.

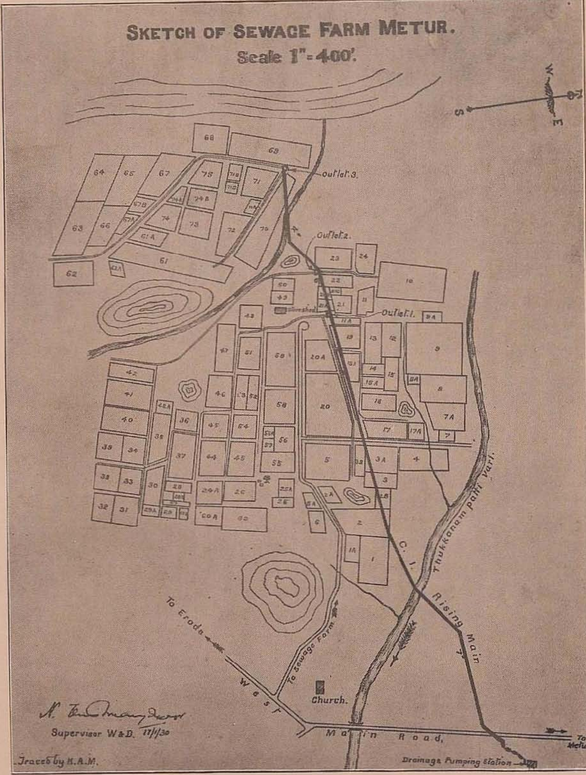
(2) Passing the raw sewage through septic tanks and rotary sprinklers and pumping the effluent to garden land for irrigation.

(3) Pumping the raw sewage to high land well away from the river and passing it through sludge tanks and percolating filters and afterwards discharging it on to land for irrigation.

(4) Pumping the raw sewage and applying it to land direct, without previous treatment.

Proposal (1) was considered objectionable from the sanitary point of view. Proposals (2) and (3) involved considerable cost. The fertile soil and climatic conditions of Mettur were favourable for the last proposal being adopted and it was accordingly decided to apply the sewage direct to the land for the development of a sewage farm.

Two or three sites were considered for the location of the farm and, finally, a site on the southern bank of the Thukkanampattivari at the foot of the Palamalai hills was selected. While not being



LAYOUT OF THE METTUR SEWAGE FARM.

far from the pumping station, this site is isolated from the camp and covers an area of about 45 acres. The soil is of a light, deep sandy or loamy nature. The whole site is situated on a gentle slope of 1 in 60 from west to east with a fall of about 1 in 100 from north to south. The slope of the country as well as the nature of the soil affords excellent facilities for sub-soil drainage.

Position of rising main and outlets.—A small ridge runs across the farm from west to east, dividing it into a northern plot of about 10 acres and a southern one of about 35 acres. The 7″ C.I. rising main, through which the sewage from the pumping station is pumped, runs along this ridge. Originally the main had three outlets, but later on, as a portion of the farm situated at the south-west corner had to be abandoned for semi-wet crops owing to its proximity to the officers' quarters, an additional outlet was provided between the second and the uppermost to bring in some more area on the north under cultivation. The sizes of outlets were fixed with reference to the area under each. The area commanded by the 6″ outlet is 20 acres and that by the other three 4″ outlets is 25 acres. Sluice valves to regulate the discharge through the outlets have been fixed on tees taking off from the rising main. Masonry cisterns 4′ × 3′ × 3′ are provided at each of the outlets. The heads of earthern channels which take off from these outlet cisterns are lined with brick on edge in mortar, for a short length, to prevent erosion.

Site clearance and excavation of channels.—As the primary object of the work on a farm is the intelligent distribution of sewage water which, in its turn, depends on the proper laying out of irrigation channels, much preliminary surveying work had to be done, including preparation of a site survey and the plotting of contours. The site had to be cleared of jungle growth and prickly-pear. The alignment and excavation of channels were next taken in hand. The earthern channels are of trapezoidal section with bottom width of 9″ and side slopes of 1 : 1 and have a bedfall varying between 1 in 150 and 1 in 200. Masonry drops of trapezoidal section have been provided where necessary to keep down the velocity in the channels and prevent scouring of channel banks.

Size of plots.—The levelling of plots between the channels was next done by means of ploughing. The plots generally vary in size from 0·3 to 0·5 of an acre but a few of the more level plots measure from 1 to 1·5 acres. The layout of plots and channels and position of the rising main and outlets may be seen in the accompanying sketch.

Type of outlets to plots.—Outlets to plots are made by open cuts in the channel banks which are turfed up as required to regulate the supply. But where the channel is above ground level 4″ stoneware pipe outlets have been provided. These consist of two pipes embedded in the channel bank at bed level with sockets facing the channel. No difficulty is experienced with regard to the drainage of the plots as the soil is mostly sandy or gravelly and is capable of absorbing 3″ to 4″ of irrigation at a time.

Working of the farm.—The farm commenced to work in August 1928. At that time the quantity of sewage was very little and was accordingly distributed over small areas in plots in the southern portion of the farm. But with the working of the pail depots and flushout latrines during the middle of 1929, the sewage began to increase and farming was accordingly extended. The total quantity of sewage pumped at one time amounted on an average to 17,000 gallons per day. With 3″ irrigation this quantity will cover about $2\frac{1}{2}$ acres. With irrigation once to twice a week, the sewage would be sufficient for 9 to 18 acres. Hence, from 1930 onwards, the cultivation under garden crops was confined on an average to 12 or 15 acres and that under dry crops to about 30 to 33 acres. It was decided to run the farm departmentally for the first few months in the beginning as an experimental measure with the idea of leasing it out afterwards if it should not be found to be a paying concern. Under instructions and advice received from the Agricultural Department and with the practical experience gained during the initial stages of working, it was soon found to be a profitable concern and the farm has been completely run by the department throughout the duration of the project with increasing annual profits, as the annexed table of expenditure and realization will show. A farm Superintendent with agricultural qualifications on a salary of Rs. 50—5—75 was appointed in June 1930. The employment of a qualified man has proved to be a wise step and has assured the farm being operated at a profit.

Establishment.—The permanent establishment of the farm consisted of a Farm Superintendent (as has already been mentioned), one head coolie to assist the above, two watering men and two plough men. Besides the above, casual labour is employed whenever necessary for sowing, weeding, harvesting and other operations.

Equipment.—The equipment of the farm consists of two Jat ploughs, one Meston plough, two country ploughs and one Guntakka (a species of weeding plough) besides an adequate number of mammooties, etc. Regarding live-stock, there are five bulls, one for conveying silt from the pumping station to the trenching ground at the farm and the other four for ploughing purposes. For initial ploughing before planting the first crop, the Jat and Meston ploughs are used. They have an advantage over the ordinary country ploughs as the furrows are deeper and rectangular in section and the soil is well turned, whereas the country plough works only V-shaped furrows leaving ridges of unploughed land between, and the soil is not turned. The latter, as well as the Guntakka or weeding plough, are mainly used for inter-cultivation. Hired country ploughs are also engaged when necessary for ploughing operations on a large scale in order to take advantage of summer rains A combined masonry store and bullock shed was constructed in 1929 for temporary storage of harvested crops and for sheltering the cattle at night. A gravelled road, 10 feet wide, leading from the main road to the store-shed was also formed in 1930. In the same year, the bullock shed in which there was previously accommodation only for four bulls was extended by one bay and an additional store-room was also constructed.

Disposal of night soil.—The sludge accumulating in the silt pits at the sewage pumping station is daily carted to the sewage farm and buried in shallow trenches. The average daily quantity during the full occupation of the camps was about 40 cubic feet. After about nine months maturing the sludge becomes a valuable manure. There was, however, no sale for it except for use in the officers' gardens. It was therefore used in the sewage farm itself for planting up new plantain patches. Latterly, large quantities of it were transported as manure for the ornamental park constructed in rear of the dam in 1934.

Care and management of the farm.—It was always kept in view that the primary object of the work in a farm is its general up-keep and cleanliness and not solely an expectation of rich yield from crops. No stagnation of sewage water was allowed at any time in the farm. Weeding and hoeing operations were done as frequently as necessary to aerate the soil and allow the sun's rays to work into it. Channel banks and field borders are always kept free from scrub and weeds. The flow of sewage water is always concentrated on to one plot at a time so as to allow the earthen channels to dry out between successive irrigations. When some of the plots in which elephant grass and other wet crops are grown become sewage sick, such crops are transferred to other portions of the farm and the irrigated area is levelled off and ploughed and utilized for dry crops until a change back is found necessary or advisable. The principle of rotation of crops is also being adopted with advantage. Thus, chillies have been grown in plots where plantains were previously irrigated. After growing chillies the plots have either been left fallow and ploughed, or sown with cumbu or some other dry crop. Some lands at the foot of the hills of the upper end of the farm are always kept fallow so that on rainy days the resulting excess sewage is diverted on to these lands from the uppermost outlets. When ploughing operations are done, care is always taken to see that the ridges and furrows in a plot are finished off so that they run across the slope instead of up and down it. This prevents the irrigation water from rushing down to the lower end at the risk of the top end not getting sufficient supply. In short, all precautions possible are taken for the efficient running and management of the farm.

Crops and classification.—The crops that are grown in the farm can be classified under two heads (1) semi-wet or garden crops which require watering not less than once a week and (2) dry crops which require occasional watering only during periods of continued drought. Under semi-wet crops, chillies, plaintains, fodder grass (Elephant and Guinea grasses), Cambodia cotton, ragi, cumbu, turmeric, pappaya, tobacco and sugarcane have been grown, and under dry crops, fodder cholam, castor, groundnut, gingelly and redgram. The most profitable of all the crops have been found to be chillies, plantains, elephant grass and fodder cholam. Sugarcane and tobacco were grown in the beginning and, though profitable, the former was given up later as the growing of this crop under sewage was considered unsafe and was prohibited by the Health Officer. In the case of the other crops they were not so profitable, mainly because of general overproduction outside Mettur, resulting in a low sale price only being obtainable in the local market.

Besides the above crops, certain vegetables were also tried. The growing of such vegetables as are usually eaten in an uncooked state was prohibited by the Health Officer. So only vegetables which are not eaten raw, such as brinjals, 'lady's fingers', beans, cabbage, and spinach were grown. The vegetable plants did not generally thrive when irrigated with the sewage water. They were commonly attacked by insect-diseases and were therefore given up.

For the benefit of those interested in the cultivation of crops, an account of the method of cultivation of some of the main crops as practised in the farm is given below :—

Chillies.—The sowing is done in the nursery in May or June. In July or August when the seedlings are 6 to 7″ high, they are transplanted. Ridges are formed 3 feet apart over the ridges. Inter-cultivation commences after the third week and the plants receive mammoty hoeing and earthing up every month till November or December. First picking commences in January and subsequent pickings every fortnight afterwards. The harvesting completely ceases by the end of April.

In the early stage when the seedlings were in the nursery and also soon after transplantation, they were frequently attacked by a disease called 'Leaf-curl' but with the advent of rains and proper cultivation, this disappeared. From 1930, the area under chilli cultivation steadily increased and the realization most satisfactory. The crop when maturing is usually auctioned out.

Yield per acre—100 maunds of 25 lb.

Expenditure to auctioning per acre—Rs. 85.

Plantains.—Next to chillies this has been found to be a pay-

Plantains.—Next to chillies this has been found to be a paying crop. The different varieties grown at Mettur are Mondan, Poovan, Pachanadan, Rasthali and Chakkarakalli. The last variety was obtained from Vizagapatam. Of these Mondan is grown as a green plantain to be used both as a vegetable and fruit while the others are grown only as fruit. There is a demand for Poovan by merchants in neighbouring towns.

The suckers are planted about 8 feet apart either way in pits $2' \times 2' \times 2'$ in the beginning of June and cattle manure is applied. Inter-cultivation commences in the third week. In about six months the tree begins to flower. The superfluous side suckers are removed to help the growth of the main tree, only the best of the sword suckers being retained for the second crop. This is done at the time when more than 50 per cent of the trees begin to flower. When the full bunch of fruit has formed, the flower at the end is nipped off to improve the growth of the fruits. The fruits take about three months for completely maturing. In the farm it has been found that the second crop always grows much better than the first one. Whereas in the first crop, there are only 6 or 7 skeins in a bunch, in the second crop there are usually 9 to 12 skeins.

A Mondan bunch (second crop) was sent to the Agricultural Exhibition held at Salem in 1933 and it was commended. It was more than 3 feet long, having 13 skeins with 13 plantains in each, thus bearing 169 plantains.

The Rasthali and Chakkarakalli fruits have always been esteemed by the higher classes while the poor take only to Mondan. Plantain leaves are also sold to the public the third crop being used only for this purpose. The area under plantains has been, on an average, 4 acres.

	RS.
Realization per acre per annum	350
Expenditure	150
Profit	200

Elephant grass.—This is one of the chief items of fodder in the locality for cattle and at one time was much in demand. About 5 acres of this have been planted.

Ridges are formed 3 feet apart and the slips are planted in the ridges at 3 feet intervals. Inter-cultivation commences in the third week. This crop consumes the maximum quantity of water and, once a week or more, about 5″ to 6″ of irrigation is allowed. The first cutting is obtained in 4 months and this is done before the grass flowers and seeds. After every cutting the furrows are broken up and cultivated and remade to encourage oxidation and to keep the land sweet. Six to eight cuttings are obtained in a year and the crop is a perennial one when properly inter-cultivated.

Yield per acre per annum	150,000 lb.
Realization	Rs. 300 to 400
Expenditure	„ 75

Guinea grass which is also another variety of fodder grass was cultivated on a small scale in the beginning, but as there was not much demand for it, it was given up.

Fodder cholam.—This crop commands a ready sale in the locality. Annually about 20 acres are grown and the crop is generally auctioned out in lots when approaching maturity. The seeds are sown broadcast, beds are formed and watering is done when necessary. The crop is cut when flowering has ceased about 3½ months after sowing. No inter-cultivation is done for this crop.

Yield per acre per crop	10,000 to 12,000 lb.
Realization	Rs. 30 to 60
Expenditure	„ 15

Groundnut.—The seed is put down in July or August in the furrows. After about a month and a half, hand-hoeing is done and the soil raked up and the weeds removed. After the rains in October and November the plants grow and begin to develop pods under the ground. During December and January the harvesting commences. The plants are dug out and the pods collected. The crop is generally auctioned out.

Yield per acre per crop	500 Madras measures.
Realization	Rs. 30
Expenditure	„ 18

Castor.—In June or July the seeds are dibbled behind country ploughs at 1½ to 2 feet intervals in rows 6 feet apart. Within a week the seeds germinate. When the plants are 6″ high inter-cultivation is done with a country plough to rake up and aerate the soil. Thinning is also done by eradicating the superfluous plants. The harvesting is done in

November. The average yield per acre is about 260 Madras measures.

Gingelly.—In the earlier days of the project this crop was paying well but, later, it was affected by an insect pest called 'Navai Poochi' which did great havoc consecutively for two years. Hence it was given up.

Turmeric.—This was grown during 1932–33. Though the crop was not affected by any diseases, the expenditure on inter-cultivation and curing was high and there was no corresponding demand; so it was discontinued.

Cambodia cotton.—This was one of the earliest crops to be grown. The seeds are sown in September 2 feet apart over ridges formed at 3 feet intervals. Inter-cultivation is done after a month and the plants are well earthed up. The picking commences in March and goes on till June or July. The yield was good but owing to the fall in the market prices, realization was not satisfactory. Also "Boll-worm" was a pest in the district and all growing crops had to be up-rooted in compliance with a general notification from the Government. This therefore was given up during 1931–32, but was again being grown in 1935.

Pappaya.—About half an acre of this crop was grown in 1932. The seeds are sown broadcast and in five months the crop is in flower. Thinning out of the male plants is now done leaving only about one per every 100 female plants. The female trees only bear fruit at three per node. Thinning of fruits is done, leaving the best of the three in each node and removing the rest to give sufficient room for the fruit to develop. The expenditure on cultivation is only Rs. 15 per acre. The fruit has a ready sale in the locality.

Besides the above, horsegram, blackgram, redgram, maize, cumbu and ragi were grown on a small scale in the beginning but were afterwards not cultivated as they were not paying crops.

Farm accounts.—The following accounts and records are regularly maintained at the farm:—

(1) Stock account, showing daily transactions.

(2) Cultivation account, with particulars regarding dates of ploughing, watering, sowing, harvesting and realization in each month, for each crop.

(3) Allocation register showing expenditure and realization for each crop.

(4) Monthly progress report for the general working of the farm.

(5) Cash and credit sales for various crops.

(6) Credit sales ledger.

From a perusal of the records, the position with respect to any crop at any stage is always known.

Table of Annual Expenditure, Realization and Net Profits.

Periods.	Expenditure.	Realization.	Net profits.
	RS.	RS.	RS.
1930–31	5,454	6,133	679
1931–32	4,373	6,171	1,798
1932–33	4,058	5,832	1,774
1933–34	4,377	6,071	1,694 plus 200 stock on hand 1,894

The average expenditure per acre on the farm was Rs. 95 and the average realization Rs. 135 excluding the cost of pumping and assuming the sewage to be delivered free on the farm.

Salem Camp Sewage Farms.—The two farms were leased out at an average income of about Rs. 500 per year. The lessee was allowed to grow whatever he liked, subject to compliance with the Health Officer's stipulations about prohibited crops. The profit on these farms to the lessee was chiefly realized on plantains and chillies. The departmental staff frequently inspected the farms and saw that they were maintained in good order. With the closing down of the Salem camp the lease of these farms were cancelled in 1935.

CHAPTER VI

Power-house during construction period.

As 95 PER CENT of the plant used for building the dam, was driven by electricity, it was essential that a well-equipped power-house should be erected.

2. Preliminary electric power plant was put into service in 1927, consisting of two 3-cylinder, 165 b.h.p., 300 R.P.M. Mirrcless Bickerton & Day, Limited. Diesel Oil engines, each driving a 125 KVA., 440 volt, 50 cycle, 3-phase Metropolitan Vickers Alternator.

3. The supply was fed through a 5-panel Metro-Vick polished slate switch board. During the execution of the preliminary works, this plant was used for supply to the workshops, waterworks, drainage pump motors, and the camp lighting.

4. As the work increased, the two units stated above were obviously too small, and instead of installing additional generating units in the power-house, as had at first been proposed, it was arranged with the Government of Mysore for bulk supply from their Hydro-Electric station at Sivasamudram, 63 miles away. The line had to be constructed through very rough country and elephant-infested forest. The current was transmitted at 35,000 volts, 3-phase 25 cycles. On receipt at the Mettur Power-House, however, the voltage was stepped down and delivered to the distribution high-tension busses at 3,300 volts at 50 cycles—three synchronous motor generator sets, changing the frequency from 25 to 50 cycles. The Mysore Government maintained their own staff at Mettur for supplying us this 3,300 volts current. The charges made for electrical consumption by the Mysore Government, were based on a sliding scale, and were as follows :—

> For a monthly consumption not exceeding 374,999 units the charge was at 0·75 anna per unit and was reduced to 0·55 anna per unit for a monthly consumption exceeding 550,000 units. The maximum units consumed during any one month totalled 447,000 units, the connected load being approximately 6,000 kilowatts.

5. The current was distributed by means of overhead transmission at 3,300 volts, to a number of sub-stations suitably located for supply to the different sections of the dam and camp. These were all Johnson & Phillips 500 KVA., 3,300/440 volts transformers and 125 KVA., Metro-Vicks Transformers of similar rating. All motors employed on the works were of the 400 volts 3-phase, 50 cycles type.

6. The most notable feature in the power-house was a battery of 7 Ingersoll-Rand Air Compressors. The first five compressors to be purchased and installed were oil-engine driven. These were Ingersoll-Rand's POC-2 type compressors, compressing 490 c.ft. of free air per minute, to a pressure of 100 lb. per square inch. When the Sivasamudram supply became available, however, it was decided to convert these oil engine-driven compressors to electrical drive. The engines were therefore removed, and the compressors were belt driven by 120 h.p. Crompton 440 volt A.C. motors. The other two compressors purchased later were electrically driven machines and were of the XCB-2 type, compressing 500 c.ft. of free air, at 100 lb. per square inch pressure. These two machines were driven by 120 h.p. General Electric Company motors. Two more compressors were purchased at a later date for supplying air to the quarries on the left flank of the dam. These compressors were of Swiss manufacture and of the 2-Stage Rotary type, each driven by a 120-h.p. General Electric Company motor. They also compressed up to 100 lb. per square inch. These were installed in a separate building on the left bank of the river in order that the length of air-lines should be kept to a reasonable length.

Of the other plant installed in the power-house building, perhaps the most interesting was the liquid oxygen plant which supplied the bulk of the explosives required for the excavation of foundations for the dam and the quarrying of the many millions of cubic feet of stone needed for the construction of the dam.

The power-house itself still stands and is an imposing all-steel structure of generous dimensions, the main bay being provided with a 10-ton overhead travelling crane capable of handling the heaviest plant installed in the building.

Prior to the receipt of power from Sivasamudram the maximum output demanded from the Diesel sets was 75,000 units per month and the power-house staff required to operate the power plant and air compressors consisted of 10 skilled men and 15 coolies. The cost per unit of electricity supplied was one anna.

With the introduction of the Mysore power supply the maximum consumption went up to 447,000 units per month, while the charge per unit fell to 9 pies.

CHAPTER VII

THE METTUR WORKSHOPS.

THE WORKSHOP at Mettur had a very small beginning. For repairing the simple tools and plant that were then in service in the project—a temporary shop was opened in September 1926 in a portion of a shed measuring only 50′ × 32′, erected at the southern side of the workshops area. In this shed were also housed the ice plant and a dispensary. The introduction of elaborate machinery at the crusher and dam sites, necessitated the erection of large workshops to admit of repairs to these costly machines and the fabrication of steel structures being undertaken locally. After the erection of the electrically driven machines for the crushing and concreting works, the activities of the shops increased considerably, so that, during the heaviest part of the construction period, over 3,000 work orders to the value of five lakhs of rupees were received and executed in a single year.

The workshops were erected and operated mainly for the benefit of the project. All steel structures for the various sheds and buildings, all subsidiary steel-work connected with the erection of crushers, towers, mixers, cranes, winches and power-house plant, including overhead and storage tanks were all fabricated locally. Very few jobs were undertaken by firms outside Mettur.

Accommodation.—To cope with the work a steel framed building, having a floor area of 14,500 sq. ft. was fabricated and put up at a cost of Rs. 66,300 in the middle of 1927. In 1928, a second shop having a floor area of 8,712 sq. ft. was found necessary and this also was fabricated locally and erected at a cost of Rs. 22,500, to the north of the main building. In the main shed carpentry, smithy, foundry, machinery and fitting sections were located. The other building was used as a Loco Repair shop and wagon repairs were also done in a portion of this building.

Equipment.—The workshops were fitted with necessary machines at an approximate cost of Rs. 1,30,000. The main mechanical equipment consisted of the following machines :—

Carpentry shop.

One saw-sharpening machine.
One Pendulum cross-cut saw.
Two Robinson's saw benches.
One wood-turning lathe.
One Robinson's single spindle boring machine.

Foundry shop.

One Cupola furnace of 10 cwt. capacity.

One All-day's sand and loam grinder.

One blowing fan.

One oil-fired core oven.

One Cupola of 3-ton capacity was manufactured in the shop and erected with a blower and a 20 h.p. motor at a cost of Rupees 2,500 during 1933.

Smithy shop.

Two fan-blowers.

One pneumatic power hammer.

Seven anvils and two blocks.

Seven furnaces.

Machine shop.

Seven lathes of various sizes and types.

Three drilling machines.

One plate bending machine.

One punching, shearing and angle cutting machine.

One pipe and bolt screwing machine.

One shaping machine.

Three hacksawing machines.

One Universal milling cutter.

One electric welder of 30 K.W. capacity.

One self-acting planing machine.

General.

One grind stone.

One Universal twist drill grinder.

Two oxy-acetelene cutting and welding plants.

Three simplex pneumatic drills.

Four portable hand drills (air).

One hydraulic tyre press (for lorries).

In addition to these, the shops were equipped with three Morris Overhead cranes. A Scotch Derrick Crane of 10-ton capacity and a pair of heavy shears were erected in the shop yard for handling heavy machinery that came in for repairs. The electrical equip ment of the shop was comparatively small. In addition to the four heavy duty electric drills and a 30 K.W. spot welder, seven motors with an aggregate horse-power of 106 were used for driving the overhead shafting.

Small tools such as hack-saw blades, files, twist drills, etc., to the value of Rs. 2,000 to Rs. 4,000 were consumed in the shop annually.

Establishment.—For supervision work the establishment consisted of a Superintendent on Rs. 600 a month. A foreman and 16 chargemen with pay varying from Rs. 100 to Rs. 150, while for accounting purposes, a maistri for registering work orders and despatching finished articles, a time-keeper, a work-taker and a tools-keeper with pay varying from Rs. 40 to Rs. 60 were employed. These men were charged to works and the monthly charges amounted to Rs. 2,500 during the busiest period of the construction of works.

In addition to the above work-charged establishment, a Supervisor and a Subdivisional Officer in the Provincial cadre were attached to the shops. Towards the close of the project the work-establishment was reduced to a shop foreman, a Loco Inspector and three chargemen, a time-keeper, a work-taker, a tools-keeper, a general fitter and maistri. The cost of the reduced establishment amounted to Rs. 1,000 per month. To cover this general on-cost, a labour centage of 10 annas on the rupee was levied in the earlier days of the work which was subsequently reduced to 6 annas in the rupee when efficiency increased and the overhead charges were cut down.

The strength in the shop during the busiest period was about 380 men and the strength did not go below 150 even during the closing stage of the project, on account of the heavy repair and reconditioning work carried out on the plant before it was disposed of.

The men were allowed incremental scales of pay noted below :—

	RS.
Superintendent	600
Shop Foreman	120—10—150
Loco Inspector	75—10—125
Chargeman, I class	70—5—100
Chargeman, II class	35—3—65
Head Syrang	70—5—100
Syrang	35—3—65
Maistri, I class	40—4—60
Maistri, II class	25—3—40
Work-taker .. .. } Time-keeper .. .. }	45—3—54

The pay of skilled labour varied from 12 annas to Rs. 2 per day, while unskilled adult labour received from 7 to 12 annas per day.

Boys received 4 to 6 annas according to the ability and length of service.

The labour employed in the shops was mostly recruited from this and adjoining districts, though a few trained artisans and chargemen were obtained from the Cordite Factory, Aravankadu and the Kolar Mines. No difficulty was experienced in getting suitable men for the various kinds of work undertaken in the shops. The supply was in fact usually greater than the demand.

Power.—Prior to the introduction of electrical energy for works, the shafting was driven by two 8 h.p. Peter engine installed in one of the shops. Subsequently, electric power was used for driving the machines and shafting. The average monthly consumption was about 3,750 units, costing roughly Rs. 200 a month.

Detailed consumption figures for three years are noted below :—

Years.	Units.	Cost. RS.	A.	P.
1931–32	47,535	2,640	5	0
1932–33	49,890	2,500	4	0
1933–34	37,290	2,263	13	0

The use of electrical energy was found both convenient, reliable and cheap. There were no electrical breakdowns.

The machines in the shops were divided into three classes, i.e., light, medium and heavy. The power required for running the light machine was taken as a unit, the factor for the medium and heavy being 2 : 3. Total number of factors thus worked out came to 62, of which 35 factors on an average worked throughout a year of 300 working days. Thus worked out, the rate per factor per day was 8 annas. This rate is unusually low. It included the cost of power, materials and labour required for working a machine.

Besides electric power, compressed air was used for pneumatic rivetting work, for forges, rivetting hammers, pneumatic drills and for testing jack hammers, road busters and air hoists.

Air was supplied from the power-house at a cost of 10 annas per machine hour at about 100 lb. pressure, but owing to heavy line losses and wastage on works the cost of compressed air rose to about Rs. 5–8–0 per machine hour and the quantity had to be restricted very considerably, and only the minimum requirements was availed of.

The cost of air consumed varied from Rs. 200 to Rs. 500 a month.

Oxy-acytelene plant was installed for welding copper staunchings for expansion joints in the dam and for cutting M.S. plates of more than $\frac{3}{8}''$ thickness.

Departments of the workshop.—The workshop was divided into several departments as follows :—

Carpentry.	Fitting shop.
Foundry.	Steel fabrication.
Smithy.	Loco repairs.
Machine shop.	Rolling stock repairs.

Each department was put in charge of a chargeman.

Carpentry.—This section of the shop consisted of three carpenters and three assistants. Neat work was turned out. The woodwork in the Memorial Pavilion is a sample of the good quality of the work done.

Work turned out.—Foundry patterns of machine parts, concrete moulds, replacing wooden parts of locos, trucks and machines, sluices shutters of all sizes to 12 feet for canals, doors and windows, and wood turning of various kinds.

Foundry—Work turned out—Iron castings.—Truck axle boxes, rollers, brake blocks, fire-bars, irrigation sluice gear boxes, gratings, beaters for disintegrators and mortar mills, spur wheels up to 3 feet diameter pulleys, pipes and specials.

Gun metal castings.—Bearings, pump impellers, pump door fittings, electric fittings.

White metal castings.—Large bearings and liners.

Work of considerable intricacy was undertaken in the foundry, light electrical castings were turned out satisfactorily. Individual castings varied from about ½ lb. to 18 cwt.

The rate for cast iron work varied from 9 pies to 1 anna 3 pies per lb. while the rate including moulding charges did not exceed As. 1–6 per lb. for castings weighing more than 50 lb. and As. 2–6 per lb. for individual castings of lesser weight.

The quality of castings turned out in this shop compared very favourably with those obtained from outside and in many cases the manufacturing cost was only half the price quoted by firms in Madras and elsewhere. At the height of the work the staff consisted of ten moulders and ten assistants and casting was done two or three times a week.

Smithy.—Forged parts for repairs of trucks, locos and for turned parts of machines, pumps, valves, constructional work and gates were prepared in this shop.

Staff.—Six smiths with hammer-men and boys were able to cope with the work.

Machine shop—Work turned out.—Replacement of parts for locos and wagons, cranes and winches, concrete mixers, stone crushers, electric motors, pneumatic and other rock drills and other machines.

Many complicated and difficult jobs were accomplished, including the cutting of mitre wheels and spur wheels. There were a few tempering failures with the hardened parts of spares for pneumatic machinery. Such parts were obtainable ready made only from the manufacturers at very high prices.

The maximum number of jobs handled daily was about 20. The maximum staff employed was—

Turners	12
Drillers	8
Coolies	15

Fitting shop.—The classes of work done in the shop are too numerous to mention. About the only jobs not undertaken were particularly delicate jobs such as repairs to clocks, mathematical and surveying instruments, fine chasing and stencil cutting. No less than 112 fitters were employed.

Fabrication yard—Work turned out.—The steel structural fabrication and erection of the entire power-house, loco repair shops, the structural work for the preliminary crusher plants, preliminary concreting plant, the three main units of crushing plant and the erection of the Cauvery bridge steel work. Steel concrete pipe moulds of sizes varying from 4 inches to 3 feet in diameter were made here. Other important work included the Cantilever bridges used in conjunction with the concreting towers. Portable bridges and coverings for high level and low level sluices and wet wells. Various types of points and crossings, turn-tables and turn-outs. Concrete chutes and chute liners were also manufactured. Hundreds of shutters of various shapes for the concreting work of the dam were entirely constructed at the workshops.

The yard staff consisted of 2 chargemen, 15 fitters and about 20 coolies.

Loco repair shop.—Repairs to the locos, half-yearly inspection and cleaning of boilers for the annual boiler inspection by the Government Boiler Inspector were attended to in this department. This section was always busy. Three to four locos were invariably in the shop at one time for one or other of the above items of work. Apart from the inspection and cleaning work, the chief repair work consisted of—

(*a*) Renewal of piston rings, valve setting and adjusting gears, crank bearings for the engines;

(*b*) changing of wheels and of worn-out chains;

(*c*) renewal of leaky boiler tubes;

(*d*) renewal of spring plates;

(*e*) renewal of super-heater coils;

(*f*) renewal of brake adjusting gear and brake blocks;

(*g*) renewal of axle springs and sprocket wheels;

(*h*) renewal of funnel bases and petty repairs to the canopies; and

(*i*) repairs to pumps and injectors.

Considering the nature of work on which the locos were used and the small amount of repairs actually done, it may be seen that they have rendered very good service. There was no serious trouble with the engines, boilers or pumps.

In addition to loco repairs, motor cars, lorries and all kinds of steam and oil-engines were also repaired and overhauled in this section.

The staff in this department consisted of a Loco Inspector and six gangs of workmen. Each gang consisted of a fitter and a couple of fitter-mates.

Rolling stock repairs.—The main items of repair work were—renewal of axle boxes and bearings—wheels and axles. Trucks were received occasionally for replacement of brake blocks and for break gear adjustments. About 70 to 100 trucks passed through this department every month. The spares required for the trucks were at first obtained from the manufacturers' agents in this country but later on they were manufactured locally at less than half the firms' rates.

For this work the staff consisted of a chargeman, 6 fitters and 18 coolies.

During the seven years of work in the shops there were no lock-outs or strikes neither was there a single accident resulting in death and there were only two accidents involving the loss of an eye, for which compensation was paid.

The shops were inspected by the Government Factory Inspector several times and no adverse remarks were made or irregularities noticed during any of these inspections.

Conclusion.—There was no slack or off-season for the workshops. All the sections were fully engaged throughout the whole period of the dam construction. In the initial stage of construction—fabrication and erection of preliminary plant and structures was the main work. During the period of intensive construction work, many orders for repairs and original works were carried out, while towards the close of the project all the plant and machines that were in use had to be reconditioned and returned to stores for disposal.

The activities in the shop may be gauged from the figures noted below :—

Year	Number of work orders.	Value of outturn.
		RS.
1927–28	2,000	2,15,000
1928–29	3,111	4,04,997
1929–30	2,416	4,85,057
1930–31	2,451	3,55,250
1931–32	2,300	2,49,425
1932–33	2,155	2,61,149
1933–34	1,645	1,84,812

The number of private work-orders not connected with the project with the approximate cost are furnished below :—

Year.	Number of work orders.	Value. RS.	A.	P.
1927–28	(Figures not available).			
1928–29	..	5,418	0	0
1929–30	73	698	0	0
1930–31	69	1,028	0	0
1931–32	137	2,094	0	0
1932–33	75	1,019	0	0
1933–34	122	774	7	0

The popularity of the shops for small repair work done for the general public indicates the competitive nature of the prices charged for the work.

From a perusal of the annual pro-forma accounts of the workshop it will be seen that the shops worked at a profit—the labour centage realized was more than the amount actually charged. The profits in successive years were :—

Year.	Amount.
	RS.
1928–29	6,614
1929–30	37,667
1930–31	33,508
1931–32	8,075
1932–33	13,393
1933–34	— 14,528 (loss)

The approximate value of outturn to the end of March 1933 was about Rs. 20,00,000. The total profit to the end of March 1933 was Rs. 99,257. This profit consisted of direct general charges actually levied on jobs and indirect charges not levied—but tallied for purposes of pro-forma accounts. During 1933–34, however, the working of the shops resulted in a loss. This was due to the fact that the working expenses during the year had remained almost the same while the outturn was much less than in the previous year. Consequently the receipts by levy of centage was less resulting in the loss referred to. This was however adjusted against the accumulated profits which after this and other adjustments stood at Rs. 84,428.

It was found by experience in this project that it is generally economical to manufacture locally the spare parts required for machines in use. A comparative statement of the prices of some of the spares manufactured in the shop with those charged by the firms is furnished below :—

	Name of spare.	Shop cost.			Firm price.		
		RS.	A.	P.	RS.	A.	P.
For pneumatic rock drills.	Front head bolt and nut	1	3	0	5	3	0
	Steel retainer lever bolts	3	13	0	10	10	0
	Steel holder plunger	0	5	6	1	8	0
	Rotation pawls	1	6	0	4	3	0
	Plungers	0	3	6	0	9	0
	Front head bolt for drifters ..	1	12	0	2	12	0
For trucks ..	Axle boxes for 1 cubic yard trucks with bearings.	3	8	0	6	9	0
	Axle boxes for 2 cubic yards ..	6	6	0	31	0	0
	Axle boxes for 3 cubic yards ..	10	0	0	28	0	0
	Wheels on axles, 2 cubic yards ..	14	7	0	29	0	0
	Wheels on axles, 3 cubic yards ..	18	0	0	37	0	0
For locos ..	Ebonite bucket rings for locos ..	0	2	6	1	0	0
	Injector lift tube for locos ..	1	1	6	4	12	0
	Stoking chute for locos	4	7	0	15	0	0
	Funnel buses for locos	9	10	0	14	0	0
	1½″ copper washer for locos ..	0	5	6	0	12	0
	Fire bars for locos	14	4	0	38	2	0
	Axle box oil retaining ring ..	0	14	0	2	4	0
	Brake blocks	4	4	3	8	8	0
	Valve gear for weir pump	1	14	0	3	0	0

Accounting.—A set of rules were framed for this workshop in May 1929. The rules gave detailed procedure for receiving work orders, estimating jobs, indenting for materials and charging of labour, etc., for individual jobs.

No practical difficulty was experienced in following these rules and the system worked well.

In April 1933, the system of job cards was introduced. The advantage of such a system is the reduction of clerical work required for the allocation of charges by jobs, thus making it possible to book the expenditure more promptly. The system provides in collective form all the original records pertaining to each job, so that the details of expenditure on a job may be directly examined. Job accounts can also be promptly closed when the work is over. A large number of cards have to be printed for the purpose but considering the advantage derived from the system, the cost is immaterial.

CHAPTER VIII

Surki Manufacture.

Surki manufacture on a large scale was found necessary when it was decided to add surki to cement mortar for construction work About 53,000 tons at a total cost of Rs. 2,78,000 were manufactured in this factory. A temporary corrugated iron shed measuring 137′ × 31′, with standard steel trusses on trestles and side walls, was constructed about six furlongs below the dam at a site to the east of the rocks known as Smith's Knoll. A length of 75′ of this shed was partitioned off for locating the five motor-driven disintegrators while the rest of the space was used for stacking surki in gunny bags. A small shed with an Avery Weighing Machine of 59 cwt. capacity was also erected near the surki shed for weighing bricks suppl.ed by piece-workers.

2. A tramway connected the factory yard to the main line leading to the dam, also a double line of track was laid to connect the factory with the brick kilns for the conveyance of burnt bricks to the disintegrators. The total length of the track laid in the brick fields and surki shed area was about a mile.

3. The employment of eight 1 cubic yard capacity tipping wagons and 16 women coolies sufficed to secure a regular supply of burnt bricks from kilns situated within a quarter of a mile of the factory to the d:sintegrators.

4. Five disintegrators by Christy & Norris (Type No. 3½) driven by 40-H.P. induction motors were installed in the factory. Four of these were provided with bucket elevators, storage bins and hopper fillers for bagging the powder directly from the machine. The scheme for dust prevention was devised by the suppliers of the disintegrators. The chambers into which the surki was discharged from each machine were each provided with a ventilating shaft and chimney to provide an induced draught into the machine and so reduce the dust. This arrangement was found entirely inadequate. The atmosphere of the shed was so thick with dust that one could barely see the length of the shed when the machines were working. The effect on the lungs of the workers must have been most deleterious. In addition, the chimneys belched red dust, the best part of the surki, which was continuously wasted and spread over the country side to the detriment of all. As soon as the machines were started, fine particles of surki powder escaped through the joints of the machines, elevator shafts, etc., and filled the room. Though the coolies were provided with respirators.

much inconvenience was felt in their use in such a hot climate, and the respirators were generally neglected. In any future large scale surki manufacturing operations, this trouble will have to be overcome by more scientific means. An arrangement of large sirocco fans, to induce draught, air-tight joints to all machines and ducts, ample air-cleansing devices and a far better ventilated shed are essential, if proper working conditions are to be obtained.

For the manufacture of surki, ground moulded burnt bricks were supplied by piece-workers at the weigh-bridge in the factory at rates varying from Rs. 3–10–0 per ton at first to Rs. 2 per ton towards the end of the work. The bricks were moulded from clay of quite satisfactory composition excavated from the banks of the river Cauvery near the factory site. For burning, about 50,000 raw bricks (corresponding to 80 tons by weight) were packed in an ordinary country kiln. One ton of firewood was generally required for about 10 tons of brick so packed. By arranging to have two kilns simultaneously packed, two kilns being burnt, two kilns of burnt brick ready for unloading and two kilns of burnt bricks in reserve, the contractor was able to make a regular supply of bricks to run all the five disintegrators. Attempts were made to burn bricks in Bull's Patent Trench kilns. The experiment was not, however, successful; the bricks were either sooty or were found to be either underburnt or overburnt. Several improvements were tried but with no satisfactory results; finally the original method of burning the bricks in ordinary country kilns was adopted. The bricks, after being weighed and passed, were broken by hand into small pieces of $1\frac{1}{2}''$ to $2''$ size and then fed into the disintegrators and so reduced to powder.

The disintegrators were found to be efficiently designed and their parts were interchangeable. The chief items that required constant renewal were the beaters and the screens. The rotor on which the beaters were fixed revolves at a high speed of about 1,800 R.P.M. The beaters were manufactured in the local workshops out of M.S. flats $3'' \times 1''$. The cost of these beaters varied from Rs. 2–4–0 each to begin with to Rs. 1–4–0 later on. A high degree of fineness was aimed at and screens had to be renewed very often. Sundry repairs, such as renewal of links in the elevator chains and the relining of bearings, had also to be done now and then.

The capacity of each disintegrator was from $1\frac{1}{2}$ to 2 tons per hour.

For every 40 tons or so of surki manufactured complete renewal of the beaters was found necessary. The disintegrator powder had to pass through the fine screen at the bottom of each machine and this required renewal for every 280 tons of powder drawn from the machine. The machines gave satisfactory service. There was no serious breakdown nor any stoppage of work due to any defect in the machines or lack of spares in the country. After being packed in gunny bags, the surki was weighed in scales situated near the hoppers. The bags were then stitched and stacked in store. Each bag contained half a hundred-weight of surki. The whole process was done by job work and women were mostly employed for the purpose.

Samples of surki powder from each of the machines were taken both morning and evening and sent to the test house daily. The standard of fineness insisted upon was that the residue on sieves 40 × 40, 76 × 76 and 100 × 100 mesh should not exceed 12·5 27·235 and 35·385 per cent respectively.

At the commencement of operations the cost of manufacture on a small scale was Rs. 8–4–0 per ton when manufacture was done at the Test Laboratory during the year 1928–29. When surki had to be manufactured on a commercial scale at the factory near Smith's Knoll and improved facilities for conveyance of bricks and manufacture were provided, the rate fell rapidly so that the cost of manufacture was only Rs. 4–6–0 per ton during 1932–33.

Since the chief processes were carried out by piece-work, the P.W.D. staff employed consisted only of an operator, a general fitter, a couple of cleaners to look after the machines and a maistri to supervise the manufacture and keep accounts at site of work.

The wastage, that is to say, the difference between the weight of bricks purchased and surki delivered, and which for the most part escaped into the air as fine dust, amounted to about 3 per cent.

CHAPTER IX

STONE-CRUSHING PLANT.

THE PRELIMINARY or auxilliary crushing plant, started up early in 1928, was situated between levels 814·00 and 712·00 on the right flank and consisted of two Edgar Allen 30″ × 18″ Swing Jaw Crushers and two Hadfields No. 5 Type Hecla Gyratory Crushers. These were originally driven by Ruston Engines but were later converted to electric drive, each of the Swing Jaw Crushers having an 85-BHP motor, and each of the Gyratories a 65-BHP motor. These motors were all of the G.E.C. pipe ventilated slip-ring type and the former were interchangeable with the motors driving the tertiary (Disc) Crushers of the main crushing plant.

The Main Crushing Units consisted of three sets of which two were situated at the left flank and one at the right flank of the dam. Each of these batteries consisted of one primary Hadfields 54″ × 42″ Swing Jaw Crusher, belt driven from a 175-BHP motor; six Hadfields 24″ × 13″ Secondary Swing Jaw Crushers driven by belt, through counter-shafts, by two 120-BHP motors; one tray and one belt conveyor, each driven through special gearing by one 15-BHP motor; two large rotary screens and two Hadfields 36″ Disc Crushers, belt driven by 85-BHP motors. Each unit had its own Johnson and Philips transformer. This was of 500 KVA. capacity and of the outdoor type, the ratio of transformation being 3300/440 and the connexions Delta/Star $2\frac{1}{2}$ per cent. 5 per cent and $7\frac{1}{2}$ per cent. H.T. tappings were fitted and were operated by means of an external switch. Lightning protection was afforded by means of horns and choke-coils on both H.T. and L.T. sides. The transformer in each case was installed as near as possible to the primary 175-BHP Crusher motor. Each motor was fed by a separate cable which was controlled at the transformer end by iron-clad switch gear.. Starters and separate switches were installed at each motor and push button trip control was provided in duplicate so that any motor could be tripped at any time from either of two distant control stations in addition to the control at the motor itself and at the L.T. Switchboard in the Primary Crusher House. The cables employed were 3-core paper-lead S.W.A., Jute-covered and single core paper-lead S.W.A., supplied by Messrs. Felteb and Guilleaume Carlswerk of Germany.

All the crusher motors were of the pipe-ventilated, wound rotor type, and were manufactured and supplied by the General Electric Company, Limited, Witton, England. They were fitted with large cloth filters, of local design and make, to exclude dust from the crushers.

Supply of stone to crushers.—The quarries supplying stone to the crushers were located at about the same elevation as the hopper chutes feeding the Primary Crusher of each unit. The stone, broken to sizes at the quarry suitable for manual loading, was loaded into 3 cubic yard side-discharge wagons, and conveyed by rail, drawn by Sentinel Steam Locos, direct to the crushers. The feature of these 3 cubic yard side-discharge wagons was the rapidity with which they could be discharged. The trucks could in actual practice discharge their contents into the hopper at the crushers without the train actually stopping. A very high rate of supply was thus maintained, and there was no difficulty at any time in keeping the crushers fed continuously.

It was originally intended that the wagons at the quarries should be loaded by means of mechanical shovels, but since ample labour was available at the quarries and it was found by experience that the cost of breaking stone to sizes capable of being man-handled was lower than would have been the case had mechanical shovels been employed for handling large stones, the proposal was dropped. Further, the use of large stones would have necessitated the purchase of larger wagons of special design since it was found that large stones tended to jam in the trucks and cause long delays in discharging at the crusher bins.

The use of stones not exceeding $\frac{3}{4}$ c. ft. or so in size also permitted a very steady feed through the Ross retarders at the main crushers, and choking of the crushers was thus avoided. When a main crusher became choked, a shut down was necessitated and several hours were needed to clear it. There was thus nothing to recommend the use of large stone.

The arrangements for loading of wagons with metal issuing from the crusher plant were simple and efficient. The storage bins, situated directly beneath the ' fines ' plant, were fitted with pneumatic-operated bin gates. Two to four gates were provided for each compartment and situated immediately over each of the two tram tracks. Trains, generally of 2 cubic yard tipping wagons, were run into the galleries under the bins, and could be loaded very rapidly from the appropriate bins with the various sizes of metal required. The bin operators became so expert that the loading of a train of 16 wagons could actually be effected in 20 seconds. The normal loading time was generally under one minute per train.

The premature closing down of the crusher plant was in no way due to the inability of the plant to maintain the required supply. The plant was in fact unnecessarily large and rarely worked up to anything like its full capacity, which, with the working hours adopted on the concrete placing towers, was in excess of requirements. As explained elsewhere, the substitution of masonry for concrete during the course of construction of the dam further reduced the requirements for metal from the crushers.

CHAPTER X

Concreting Towers.

A brief reference has been made in Part I, Chapter XXVI to the two enormous travelling concreting towers which were specially designed and constructed for placing concrete at any level both above and below ground level in the dam. The photographs of these towers (See Plates Nos. XV and XVI) will convey to the reader some conception of their size and intricacy of design, and a brief description of their composition and operation may here be of interest though, to be sure, it is improbable that anything like them will ever be built again and they have already passed to the Scrap merchant.

With the exception of the electrical plant in these towers all motors emloyed at headworks were of the alternating-current type but for the positive operation of hoists and for the main drives of the concreting towers the makers insisted upon the use of direct current motors only. Accordingly, it became necessary to provide for the conversion of AC. to DC., and, since the towers were to travel considerable distances along the rear of the dam, it was decided to install suitable sub-stations in the towers themselves, the power being conveyed from the high tension A.C. mains to the machines by means of an ingeniously designed system of 'trailing' cables.

Junction boxes were constructed in the rear ledge of the dam at convenient intervals, and along the outer side of the ledge at a level which would not interfere with the travelling of each tower a wooden trough with hinged lids was secured by means of brackets. A heavily insulated rubber-sheathed flexible high-tension cable, some $2\frac{1}{4}$ inches in diameter was connected at one or other of these junction boxes and laid in the trough up to the point where the tower was stationed. At the tower the cable passed between suitably designed rollers and was guided up to a platform on which was mounted a large cable drum on which it was carefully wound. The end of the cable on the drum was connected through a slip ring contact to a similar cable leading to the transformer situated near-by in the sub-station, a room erected on the lowest main staging of the tower construction. The drum was provided with reduction gear so that it could be rotated without difficulty by two or three men operating cranks at a speed equal to the normal travel of the tower (10 to 12 feet per minute). The cable was of such a length that it admitted of the tower being travelled two 'stations' on either side of any junction box, that is to say, 2 × 126 feet or 252 feet either way. Actually the cable was about 300 feet in length to allow for over runs which were sometimes required. Each junction box was equipped with a main switch and was normally kept locked. As the tower moved away from the junction box the cable was paid out from the drum on the tower and lay along the box or trough on the face of the dam-ledge, and, in the reverse direction, the drum took up the cable so that there was never any possibility of loose lengths or loops forming in the cable. Throughout the years these towers operated the trailing cable arrangement never gave the slightest trouble, neither was it found necessary to replace a cable at any time, for they were as electrically sound at the end of the work as when they were first installed and were, in fact utilized for a part of the permanent high tension wiring for the operation of sluice gear in the dam after the work was completed.

Let us now examine the sub-station in the tower. First, the transformer to which we have already referred. This was a step-down oil-cooled transformer of 405 K.V.A. capacity, the supply voltage being 3,300 A.C. and the secondary 306 volts supplying a 370 K.W. six-phase rotary convertor with automatic voltage regulation converting the 306 volts A.C. to 440 volts D.C. The necessary switch and instrument boards were all mounted on panels in the same building as the transformer and converter and were immediately under the eye of the operator.

For the various operations of the tower no less than fifteen motors, all 440 volts, D.C. machines, of various types and sizes, were employed. These varied from 5 h.p. to 130 h.p. The travelling of the tower was controlled through three motors, one for each of the front bogies and one for the rear group of track wheels. Powerful machine-cut trains of cast steel gears gave the necessary reduction between the motors and the track wheels and the gearing was so designed that every pair of wheels received a direct drive. Breaking was provided for by means of solenoids, so that the instant power was cut off the solenoid brakes, mounted on the motor shaft extensions, brought the machine to a standstill before it had travelled more than 6 inches. With a little experience the Mechanical Superintendent in charge of the tower was able to stop the 1,800 tons of moving steel within a fraction of an inch of the point at which it was to be anchored prior to concreting operations being started.

Two more motors operated the powerful jacks on the two front bogies, through which the levelling and raising and lowering of the main body of the tower were controlled. During concreting operations the front frame of the tower was lowered on to solid timber packing to relieve the two front bogies of the bulk of its weight. The functions of the remaining motors were mainly for the operation of a number of powerful hoists.

We may now study the operations in which these motors played important parts.

Trains of materials—Stone, sand, cement and surki—were run in at the base of the tower at the level of the rear ledge of the dam. By means of large turn-tables the truck loads were dumped into large skips which were conveyed up the tower to their respective storage bins by means of electric hoists operating in cages with suitably designed guides and rollers. For the stone and sand, which constituted the greater part of the ingredients, two lifts were provided with skips each of 4 cubic yards capacity, mounted on either side within the main structure of the tower. These materials were then hoisted to a height of about 186 feet at which point, by an ingenious system of electric controls, the speed of hoisting was reduced and the skip turned slowly over and deposited its contents in the mouth of a steel hopper, whence it was directed through trunks or chutes into one or other of the compartments of a huge 500-ton capacity storage bin.

Cement and surki brought to the base of the tower in trucks, and packed in bags, were conveyed by a smaller lift to a central store-house situated above the main concrete mixers. The stone and sand from the bins when required for use was drawn from the bottom of the bins through a number of pneumatically operated bin gates combined with measuring boxes, by means of which the quantities of stone of the various sizes and sand were correctly proportioned before delivery to the hoppers, and trucks leading to one or other of the two-cubic yard concrete mixers. Surki and cement, already proportioned by the contents of each bag were similarly delivered from the store shed in the tower by means of a roller conveyor to the hopper which fed these materials also to the mixers. A small storage tank mounted higher on the tower and supplied by means of an electric pump delivered measured quantities of water direct to the mixers. The mixers were of the double-cone tilting type driven through gearing by electric motors, and require no description.

On the front of the tower two main hoists operating from a point below the mixer platform to the top of the tower contained the skips which received the concrete from the mixers and delivered it at any level to the hopper at the head of the chutes through which it was delivered to any part of the works on the dam lying within the reach of the chutes. The chutes were carried on a massive sliding frame which, by means of wire rope tackle connected to suitable winches, could be raised or lowered as desired to suit the level of the work in hand. This frame carried a heavy jib from which the end of the first or topmost chute was suspended and this in turn supported the lower balanced chutes. Additional jibs were mounted on the main frame of the tower for suspending chutes and these were found very useful for lifting materials from ground level on to the dam even while concreting work was in progress, and by their means thousands of trucks of stone for building the faces of the dam were raised bodily from the feed track near the base of the tower and deposited on lines laid on the dam at different levels as the work increased in height. For signalling to one another the various operators in charge of the tower hoists had electric bells but a system of whistles seemed more popular. For signalling between the concrete hoist operators and the maistri in charge of the concrete laying on the dam a system of flags was employed as the noise, due to the operation of so many machines and hoists together with the roar of concrete passing down the chutes, made conversation impossible.

For the rest, we may conclude by stating that the towers travelled on 48 wheels of which 32 were in the two front bogies and 16 in the rear carriage. The two front tracks were 80 feet from the rear track. Each track was of 2-foot gauge and was constructed of special flat-footed 90 lb. rails embedded in cement concrete and anchored at frequent intervals. The rails were fish-plated and 'bonded' so as to act as an 'earth' for the tower and render it safe from electric shock either from lightning or in the event of leakage at any one of the many points where the armoured cables were attached to the tower structure. The entire tower structure was designed to travel on a maximum gradient of 1 in 20, and could negotiate curves of radius of not less than 1,500 feet either in a horizontal or vertical direction. It was designed for stability in any position with a wind pressure varying from 30 to 50 lb. per square foot, a very much higher pressure than is normally allowed in the design of towers and bridges, but, in view of the very violent cyclonic storms which had been experienced at Mettur before the towers were constructed and our lack of information as to what the wind pressure at heights up to 300 feet above ground level might be during such storms, it was deemed safer to err on the high side and allow 50 lb. per square foot for pressures at the top of the tower, for the collapse of such a structure during a storm would have been tragic and could not be risked. The highest wind pressure to which either of the towers was subjected was probably during the storm on the night of the 22nd May 1931, when the steel concreting chutes of the Red tower were torn to ribbons. Unfortunately, the wind velocity on the tower at that time was not recorded. The fact that stout cast-steel hooks attached to pulley blocks were straightened out and heavy steel wire ropes were snapped like pieces of string indicate that a very high wind pressure must have been exerted when the storm struck the tower.

The Red and Black towers were exactly similar in design, the only difference in their operation being that, while the feed of trucks of materials to the Black tower was intended to be only along the upper tower tracks, traversers being employed to transfer the trucks from those tracks to the bridge within the tower structure, the red tower was provided with two steel bridges, hinged at their front ends, and capable of being raised by means of winches, by means of which trains of materials could be fed direct to the feed hoppers from the rear of the machines. An elaborate network of tramways was laid out to enable trains to be run in direct at each of several tower-operating stations. The ground on the right bank of the river where the red tower was mainly operating enabled this tramway system to be constructed without difficulty, while the slope of the ground at the left flank of the dam was too steep to admit of such a system being adopted on that side. The comparatively high rate of outturn of work maintained by the red tower was mainly due to the facility with which materials were fed to it. The rated outturn of the mixers of over 160 tons of concrete per hour was never actually attained, the best outturn being 940 tons in 8 hours, mainly due to the impossibility of feeding materials sufficiently rapidly to keep pace with the mixers. For such classes of machinery, a regular outturn at 60 per cent of the rated outturn may be considered good and it would be unreasonable to expect a higher output. In ordering concrete mixers and concrete placing plant for a project, the number of machines required should be based on an actual outturn not exceeding 50 per cent of the rated outturn of each machine, for many factors conspire to reduce outturn, mainly those due to unavoidable delays at times in the feed of materials and stoppages due to cleaning, adjustments, power failures, etc. In estimating the outturn of the concreting towers, unfortunately, no allowance had been made for the many little things which bring down the outturn. In consequence, the estimated outturn of 2,000 tons per day of 16 hours was never approached and the proportion of the dam constructed with the aid of the towers was far less than their sponsors had expected.

CHAPTER XI

Portable Concrete Mixers and other Small Plant.

Most of the standard types of small concrete mixers are so well known that no description of those used on the Mettur Dam construction is necessary. But the work they did shows how extraordinarily useful a number of small mixers can be even in the construction of so large a work. Their portability is one of their best features and the ease with which they can be shifted from place to place where masonry work is in progress enables them, with suitable feed arrangements for the raw materials, to maintain a high and steady outturn over a large area. As we have seen, the conditions at Mettur were such that the smaller units employed there alone contributed to the construction of about 40 millions out of the 54·6 million cubic feet of masonry and concrete in the course of under six years.

The first concrete mixers received at the work spot in 1926 were a set of four Jaeger mixes each of only 11 cubic feet capacity. These were items of surplus plant received from the Bombay Development Department. These were oil-engine driven and, being second-hand some gave trouble through engine failures, but when electric supply became available, they were all converted to electric drive by substituting 5 b.h.p. Crompton Parkinson S.C. type motors for the old oil engines. For this change a belt driven counter shaft was fitted for operating the mixer and the side loader. After their conversion these little mixers gave no trouble and required little attention beyond the periodical repairs and renewals of bearings, etc., and they continued in service up till the completion of the work. They were never idle. Three one-cubic yard "Victoria" mixers, by Stothert & Pitt, mounted on undercarriages provided with road wheels and belt-driven by 23 b.h.p. Campbell Oil Engines were also received during the earliest stages of construction. Here again the main difficulties were with the engines. These mixers were also converted to electric drive with 15 b.h.p. ventilated slip-ring motors with suitable reduction gear, and gave such excellent service under the most trying conditions that a repeat order for three similar mixers was placed, all with electric drive. These mixers were used both for mixing concrete and mortar for masonry. The wear and tear was so much less when mortar was employed that repairs were few and far between when masonry to a great extent replaced concrete. The hard angular stone obtained from the Mettur quarries was very abrasive and destructive to mixer-blades, chutes, baffles or any other steel with which it made a rubbing contact, so that while concrete was in general use the wear and tear on mixers and chutes was unusually heavy. Three electrically-driven 'Rex' mixers, each of 21 cubic feet capacity were also taken over together with a light steel concrete chuting tower from Messrs. Tata & Sons on the completion of their Mulshi dam. These mixers were not equipped with loaders, and the top hopper arrangement necessitated an arrangement for overhead feed. The maintenance and running charges for these mixers was high and they required motors of 20 to 25 h.p. to drive them. Experience on the Mettur works shows that mixers equipped with automatic loaders which can be fed direct from trucks at ground level are the best type for general use, as there are many places on a work under construction where overhead feed is not at all convenient. The one-cubic-yard Victoria Mixers are heavy machines and for this reason were generally mounted on bogie trucks to simplify transportation from one place to another.

Where it was not convenient to place the mixers on the actual work, various devices were employed for the conveyance of concrete and mortar from the mixers to the work spot. Both electric and air operated hoists were used, operating trucks on ramps. For light jobs the "little Tugger" Hoists, supplied by Messrs. Ingersoll-Rand, gave most excellent service. Some Holman air-hoists of larger capacity were also employed, but were not of such robust construction. Several small steam winches operating on compressed air were found most useful on long ramps as their drums had a good rope capacity. Three steam cranes of 5 to 10 tons capacity did invaluable work both in lifting truck loads of spoil from foundations and lowering materials for construction.

The Mettur work has taught us that, even where ample labour is available, it is economical to employ a quantity of light, portable machinery. Hand-mixing of cement mortar is never satisfactory and machine mixing even in small units is always desirable. The use of a large number of small units distributed over a wide area of the work makes for rapid and easy construction and is more satisfactory and, in the end, far cheaper than the employment of fewer and heavier machines having larger outputs. Steam cranes and winches can conveniently be operated with compressed air when an air-distribution system is made available. In out of the way places where the laying of air lines is not practicable steam is to be advocated. In the case of the electric hoist this adaptability is absent. For stationary hoists of all sorts the electrically driven variety is best. In rock drilling and excavation of hard material the pneumatic drill and pick are best but, in view of the high cost of operation and maintenance, hand drilling may often be employed with advantage where labour is available in sufficient numbers. For the conveyance of material over any but the shortest distances the employment of good rolling stock and small but powerful steam locomotives is essential. It pays to use the best of its kind whatever type of plant is under consideration for, on a long job, the first cost is of little import if heavy and constant repairs are necessary. Constant careful supervision and the maintenance of efficient repair shops and stores are a *sine qua non*.

CHAPTER XII

SENTINEL STEAM LOCOMOTIVES.

FOR HAULAGE of stone, sand, cement and plant, etc., 2 feet gauge Steam Sentinel Locomotives were purchased and used throughout the project. The staff of each loco was—

	Scale of pay per mensem.
	RS.
One driver	40—5—70
One stoker	15—2—25
One cleaner	15—1—20

These three men were in sole charge of each rake of trucks while in motion. Except at important points, all switching, coupling and uncoupling, braking on rakes, etc., was effected by these three men in addition to their work on the engine.

The particulars of the locomotives are as follows :—

Net weight of each in running order	7 tons. 5 cwts.
Net weight light	5 ,, 15 ,,
Gauge	2 feet.
B.H.P. of engine	80.
Normal speed M.P.H.	$7\frac{1}{2}$.
Maximum recommended	15.
Wheel base	42 inches.
Overall dimensions	12′—$11\frac{1}{4}$″ long; 6′ wide; 10 high.
Wheels, diameter and face	Diam. 20 inches, face $4\frac{1}{2}$ inches
Capacity, water tank	200 gallons.
Capacity, fuel bunker	6 cwts.
Drawbar pull (*starting*)	4,000 lbs.
Drawbar pull at $7\frac{1}{2}$ M.P.H., early cut off	2,575 lbs.
Gross load (tons of 2,240 lbs.) hauled on level in addition to running weight of loco at 5 M.P.H. Condition of track fair. Good coal	160 tons.
Gross load (tons of 2,240 lbs.) hauled up an incline 1 in 100	84 ,,
Gross load (tons of 2,240 lbs.) hauled up an incline 1 in 50	50 ,,
Gross load (tons of 2,240 lbs.) hauled up an incline 1 in 20	20 ,,

Maximum incline climbed	1 in 15.
Boiler. Rated evaporation (Indian coal)	850 lbs.
Boiler. Rated evaporation (Welsh or other good coal)	1,300–1,400.
Working pressure	230 lbs. per sq. inch.
Engine, cylinders No.	Two.
Bore and stroke	$6\frac{1}{4}'' \times 9''$.
R.P.M. Normal	500.
B.H.P. Normal	80.

The cost of one of these Locomotives was approximately Rs. 11,000 ex works, and Rs. 13,750 delivered at Mettur. From experience gained on this project, the following particulars as to the running costs may be of interest :—

	APPROXIMATE RUPEES.
Running staff for one locomotive per month ..	100
Fuel, waste, etc., for one month	250

For safety, a locomotive driver had instructions that no more than fourteen—3 cubic yards trucks (or a larger number of smaller trucks in proportion) were to be hauled at any one time, and this on more or less level track.

The running of each loco cost on an average Rs. 28 per day, inclusive of repair charges. Each loco handled daily from 250 ton-miles to 320 ton-miles of stone and 500 ton-miles of sand. Conveyance of stores and cement cost Re. 0–1–5 to Re. 0–1–10 per ton-mile, depending on the gradients negotiated. The conveyance of sand from long distances cost, Re. 0–0–11 per ton-mile. Assuming ten years of life for a loco, we should add about 1/6 of the above charges on account of depreciation. These rates are for the locos only and do not include the charges for trucks or track and their maintenance.

It was found to be beneficial for the locomotive to be returned to workshops approximately every 45 days for overhauling. With normal handling, the locomotive repairs did not exceed Rs. 50 per month. In addition to this overhauling each loco had to be inspected and passed annually by the Government Boiler Inspector. The process of preparing for the inspection took about two days. In view of the above, some 30 per cent of the locomotives were at one time in the workshops either for overhaul, breakdown repairs, or boiler test, and it was therefore necessary to have 30 per cent of locos in excess of the number required for actual work on hand in order to maintain a steady outturn.

Some 38 Sentinel locomotives were in use. These locos were found to be one of the most useful items of plant on the project and proved their worth over and over again. Derailments were few and easily rectified and the wear and tear on the track was far less than in the case of the old type of slow horizontal type reciprocating engine direct coupled to driving wheels. The ability of these locos to start and run trains on very steep gradients was remarkable. On a gradient as steep as 1 in 14 a loco could haul six fully loaded one-cubic yard trucks.

A feature of these locos is the complete accessibility, replaceability and interchangeability of all parts.

CHAPTER XIII

TYPES OF HEAVY DRILLS.

The Calyx drill.—For obtaining samples of rock at various depths below the bottom of the foundations of the dam the Calyx drill was generally used.

This type of rock drill makes an annular cut and produces a core of the rock. By collecting a series of such cores the exact nature of the rock can be ascertained. Its angle of dip is clearly indicated by the veins in the cores and the presence of faults are at once revealed.

Two methods of cutting the rock are provided in the calyx machine. For cuting soft rock a 'Davis' cutter is employed. This is a tool with teeth like those of a saw arranged round the bottom of a Tubular cutter. The simultaneous rotation and lowering of the cutter produces a cylinder of the material cut which, as the work proceeds, is forced up into the core barrel.

For boring hard rock, a plain cylindrical bit having a single slot is used, the cutting being effected through the agency of small chilled steel shot of somewhat irregular shape. These, being forced against the rock under the bit, bite into the surface of the rock and cut a circular groove, the rest of the operation being the same as in the first case. The Davis cutter used for cutting through the softer rock in the exploration of the dam foundations was resorted to in places on the left flank. Most of the drilling elsewhere was done by the chilled shot method which is best suited for hard rock drilling.

Four shot bits are supplied with each outfit so that while one is working extra bits may be prepared with the slots made to proper size and angle to be ready for use when necessary to change over bits.

The principle of working of the calyx drilling machine is briefly as follows :—

An oil engine or electric motor supplies power to rotate the hollow drill spindles to which the core barrel and shot bit is attached. Water and chilled shot (calyxite) are fed through the swivel head at top of the machine and fall to the bottom of the hole being drilled. The pressure of pumping is so adjusted as not to force the shot upward round the outside of the barrel, but leaves them under the bit. As the bit rotates over the chilled shot a circular groove is cut in the rock, as already stated, and as the bit penetrates the rock the unbroken core of the material drilled rises through the hollow bit into the core barrel which is situated immediately above the bit. When the barrel is nearly full, a few small pebbles of suitable size are introduced at the top of the hollow spindle. Being of irregular shape the pebbles become jammed between the core and barrel and the core is thus secured to the core barrel. When the drill with the barrel is raised by means of the winch attached to the machine the core breaks away from the rock and is carried to the surface in the core barrel where it is dislodged by gentle tapping. It is then carefully examined, numbered and preserved in a core box placed nearby. The length of cylindrical core obtained of course depends upon the frequency at which faults occur in the rock.

In drilling with calyxite a few points must be observed to ensure success.

(i) *The amount of shot used.*—This should be carefully regulated. When too little is used the bottom of the shot-bit merely becomes worn away by the rock. When too much shot is fed, a ball bearing effect is created, allowing the shot to rotate under the bit with no cutting effect. The behaviour of the drill indicates to the operator whether the shot is working properly. Granite requires ordinarily 1 to 2 lbs. of shot per foot of drilling for a $2\frac{1}{2}''$ core to be obtained.

(ii) *The amount of water used.*—The pump must be adjusted so as to give sufficient velocity to the water to carry the shot through the shot feed down the hollow drill rods but the stream should not be so strong as to lift the shot from under the drill bit.

(iii) *The pressure on the rod* must be sufficient to make the bit sit tight on the shot. The bottom of the bit, when working under normal conditions becomes somewhat rounded and roughened. When the quantity of shot is insufficient and does not get under the bit, the latter tends to show a square and smooth bottom, while, when too much water is used, the bit becomes belled out on the inside.

Setting up of calyx machine.—It is always necessary to provide a firm level surface of sufficient area to accommodate the drill with its pump and the oil engine. A tarpaulin shelter is also desirable to protect the man and machine from the weather. The G 31 and F 3 types of calyx drills used in this work require a level space about 10 to 12 feet square. The machines have to be well protected from damage by flying stones when blasting takes place nearby. In the earlier stages of foundation drilling 10 H.P. oil engines were fitted up to supply power to drive the machines, but later, when drilling through masonry, electric motors were substituted. Actually it was found that a 10 H.P. oil engine was not powerful enough for the heavy cutting and there was continuous trouble through over-loading. On conversion to electric drive a 12 H.P. motor was used and gave no trouble whatever.

When the rock does not extend to the surface and the hole has to be started through an overburden of earth, sand, pebbles or other loose materials, a casing or drive pipe in odd lengths and of diameter ½″ larger than the maximum outer diameter of the core barrel is driven or rotated down as the drill penetrates deeper through the soft layers to the point where rock is met. The drive pipe is driven hard against the rock so as not to allow water to escape or sand to flow into the casing. Often to prevent this, the outside of the casing would be sealed with cement grout. When drilling through crevices and broken rock very little water should be used, and the shot has to be fed continuously and in small quantities, a small spoon-shaped measure being used.

When drilling with the Davis cutter, the main essentials are slow speed and the use of plenty of water.

Record of calyx drilling.—During the boring operations, a carefull record of the calyx bore holes was maintained in the form of a register written up daily. A chart showing the exact location as well as the section of the bore hole with the nature of strata passed through daily was also maintained for premanent record.

Cores.—The cores, as already stated, were of 2½″ dr. and were carefully preserved in wooden core boxes with the serial numbers of the borings painted on the sides and ends. The first core of each hole was marked ' 1 ', the second ' 2 ' and so on. Generally, the cores were embedded in cement mortar in the boxes to prevent them becoming dislodged or mixed. The total length of cores actually obtained was usually from 80 to 90 per cent of the depth of the hole, the difference being due to the crushing of rock at the joints. Unbroken lengths of core, sometimes 3 to 4 feet in length were obtained, but averaged two feet or under.

Drilling.—The speed of calyx drilling in the Mettur granite varied from 6 feet to 8 feet per day. Attempts were made to drill at night but the operators were more liable to jam or damage the drills as a result of which no more work was often done in three 8 hour shifts than could be done during 8½ hours of day light. Night work was thus discouraged as it was both unsatisfactory and costly.

The cost of calyx drilling in granite varied from Rs. 3 to Rs. 3–8–0 per foot, exclusive of the cost of spares. Including occasional overhauling, and the cost of spares, repairs and renewals to drill parts, the cost worked to about Rs. 5–4–0 per foot drilled. The average expenditure on spares was Rs. 300 per mensem per machine, excluding charges for heavy overhauls.

The average establishment required to work one machine was for an F.3 calyx—

One operator on Rs. 80 per mensem.

An assistant on Rs. 30 per mensem.

One cleaner on Rs. 18 per mensem or Rs. 128 per mensem or about Rs. 4–4–0 a day.

Allowing for idling days during breakdowns, repairs and shifts, the average cost of establishment for operation only worked up to about Rs. 2 per r.ft. and the cost of materials to Re. 1–5–0 to Rs. 1–8–0 per r.ft.

Repairs and renewals and shifts per r.feet of drilling cost approximately Re. 1–7–0 or for an average monthly outturn of 150 r.feet about Rs. 255.

Each shifting of machine from one site to another cost from Rs. 7–8–0 to Rs. 10 according to the distance transported.

Using electric power the charges per foot run of drilling was observed to be more or less the same. An F. 3 electrified machine worked in the rear of the Hydro-Electric section for the purpose of exploring the rock foundations of the future power-house between 16th February 1933 and 1st April 1933. The depth of holes drilled was 221½ feet and the cost Rs. 224 :—

	RS.	A.	P.
Cost of electric power as per debits—			
1,184 units at 9·84 pies	60	10	11
384 units at 10·3 pies	20	9	7
	81	4	0
Cost of materials calyxite 287 lbs /Rs. 45–14–0 per cwt ..	132	0	0
Grease 7⅝ lbs. at 3 annas per lb.	1	6	0
Waste 11¼ lbs. at 0–1–6 per lb.	1	2	0
Lubricating oil 4 gls. at Rs. 2–1–0 per gallon	8	4	0
	224	0	0

or, say, about Re. 1 per r.ft. Adding cost of establishment as worked out above (Rs. 2) the total comes to Rs. 3 per r.ft. of hole drilled, excluding cost of heavy repairs, renewals and break downs.

Below we give the rates for operating a hand driven calyx drill as used at the Periyar Dam :—

(i) in earth Rs. 1–10–0 per r.ft.

(ii) in soft rock Rs. 2 per r.ft.

(iii) in hard rock Rs. 5–3–0 per r.ft.

(iv) in stone concrete Rs. 4–9–0 per r.ft.

The total footage of calyx drilling done in the Mettur dam foundations was 8,754 r.ft. and cement injected for grouting amounted to 6,387 cwts. The footage in masonry was 3,909 feet and cement injected was 969 cwts. Cement pumped for grouting averaged 0·28 cwts. per r.ft. of bore hole in rock and 0·15 cwts. in masonry.

The number of calyx machines used was five, distributed over the whole length of 5,300 r.ft. of the dam. Regular operations commenced early in 1928 and continued to February 1931 so far as the foundations were concerned. Further work was then done in connexion with the testing and grouting of the masonry dam. The boring and grouting operations had to precede the concreting and masonry in the foundations and well in advance and away from it, as any blasting necessitated as a result of the boring test was likely to shake the adjacent masonry. As the speed of the calyx is rather slow, it was necessary to work the machines continuously in shifts except during night when, for reasons already stated, drilling had to be abandoned.

Boring a 40′ hole took usually 8 to 10 days, then grouting and testing another week, so that boring in any reach had to be at least a fortnight ahead of the actual starting of masonry construction.

Tripod drills.—This type of drill was used to supplement the information obtained from the calyx and to enable sealing of the fissures and crevices by cement grout in portions of rock which had not been previously tested by the calyx bore holes. The diameter of the hole bored is $1\frac{3}{4}''$ on an average. As no core was obtained with this drill, the operator was the only man able to give information regarding the strata drilled through. A register of this drilling, similar to that maintained for the calyx machines was written up daily by the subordinate in charge, the operator furnishing a correct and intelligible record of the days' work from his note-book. A plan showing positions of all holes drilled was carefully maintained for reference during construction.

Tripod drills described.—The drills used were of the "Leyner Ingersoll Rand" Drifter type X71 & X72 worked by compressed air. The principle of working is briefly this. A jet of water under pressure mixed with compressed air is forced through the hollow drill rod to the bit at the drilling face. This removes the pulverised rock sludge from the bottom and keeps the hole clear of cuttings. For dry drilling the water is excluded, and only air is blown in via. the drill rod and the blower. The rotation of the drill is effected by means of a sergeant rifle-bar and ratchet mechanism. The rifle-bar imparts rotation to the piston on the upstroke. The portion which is fluted engages with a chuck or rotation sleeve located in the drill front head which receives the shank of the drill steel. The principle of drilling is by percussion and rotation. The percussion is effected by a series of rapid blows mechanically applied through the pneumatically operated piston, the loosely coupled drill meanwhile being rotated slowly by the rifle-bar mechanism. The drill is mounted on a Sergeant Tripod fitted with 30″ shell and weighs about 214 lbs. Three men are able to operate and shift the drills.

The following example represents the average working data for conditions at Mettur.

X. 72 *Tripod drill.*—This machine worked in the reach of dam L.S. 2,900 to L.S. 3,400 between 17th July 1928 and 11th August 1928 for 22½ days. The total r.ft. of holes drilled was 650. The cost of operation is given below :—

	RS.	A.	P.
Labour and petty supervision	159	0	0
D.T.E., oil	6	5	0
Cotton waste	2	5	6
Air for 22 days at Rs. 4–10–8 per day	104	12	3
Total ..	272	6	9

Therefore for 1 r.ft. drilled the cost was Re. 0–6–8½.

To this must be added the cost of sharpening drill bits. The cost of sharpening 100 bits came to Rs. 50, each bit being used for drilling 2 r.ft. of hole. The cost of sharpening the drill bits for every foot run drilled was thus 4 annas.

The total cost of tripod drilling per foot run was thus Re. 0–10–8½. During this period, the helpers and operators were actually under training and there were some delays. The figures given above therefore are rather excessive.

Below is given workable data where men with some experience are employed on the drill.

	RS.	A.	P.
One operator Rs. 1–8–0 per diem	1	8	0
Two helpers (assistants) 12 annas	1	8	0
One-eighth gallon of D.T.E. oil at Rs. 2–11–0 per gallon ..	0	5	4½
Half lb. of cotton waste at As. 6–6 per lb.	0	3	3
Air for 8 hours per day as per W. & M. E. E's. No. 3921, dated 24th September 1928	4	10	8
Drill carriers 2 men 8 annas per day	1	0	0
Petty supervision charges at Re. 1–0–0 per diem	1	0	0
It is presumed that one chargeman can look after several machines and other works as well.			
Cost of sharpening drill bits 20 Nos. at 8 annas per bit ..	10	0	0
Total ..	20	3	3½

About 40 r.ft. of hole can be drilled per day of 8 hours allowing time for shifting, etc. On an average the cost per running foot of hole works to As. 8–1 or say 8 annas.

Working at higher levels on the dam when drilling through masonry for testing purposes, the cost worked to 12 annas per r.ft. on account of increased shifting charges and increased cost of compressed air pipe connexions.

The air consumption for this machine is about 140 c.ft. of air per minute at about 85 lbs. pressure. The average speed of drilling rock being about 12 r.ft. per hour. Allowing time for shifting the drill, etc., about 40 r.ft. will be the outturn for a day of 8 hours, so actually the drill will be working only $3\frac{1}{3}$ hours at 12 r.ft. per hour.

Assuming 5 c.ft. of free air compressed to 100 lbs. as being equivalent to 1 B.H.P. the energy consumed per day

. $140/5 \times 3\frac{1}{3}$ B.H.P. hours or $140/5 \times 3\frac{1}{3} \times 1/1{\cdot}34$ K.W.H.
72 K.W.H.

Cost of electrical energy supplied was approximately 1 anna per unit. The cost of air, therefore, was approximately Rs. 4–8–0 a day for one drill unit.

On the whole 16 drills of the "Leyner Ingersoll Rand" type (4 of "X. 72" and 12 of "X. 71") were working.

The total footage drilled in foundations was approximately 11,479 r.ft. and total footage in masonry was 21,789 r.ft. The quantity of cement injected was 3,996 cwts.

The total cement grout pumped into the foundation through these tripod holes was 1,622 cwts. in addition to the 6,387 cwts. injected into the calyx holes.

The cost of an X. 71 or X. 72 tripod drill is approximately Rs. 2,280, complete with accessories.

CHAPTER XIV

Cement and Cement Grouting.

All cement used on the project was of the "Char Minar" brand obtained from the Shahabad Cement works through the agency of Messrs. Best and Co., Limited, Madras. The quality was found to be very uniform and well above the B.S. Specification. All cement was obtained and delivered in gunny bags containing 1 cwt. each.

The total quantity of cement obtained was .. .. 220,745 tons.

Its nett total cost per ton was Rs. 52, as indicated below—

	RS.	A.	P.
Cost at Shahabad, per ton	31	7	0
Railway freight from Shahabad to Mettur dam, per ton ..	22	13	0
Incidental charges in handling, etc.	0	4	0
Credit for empty bags returned to Shahabad, per ton approximately	—2	8	0
Nett cost per ton ..	52	0	0

The empty cement bags returned from the works were cleaned in a special sack cleaning machine installed at the transport yard. The bags were efficiently cleaned in the machine and the cement shaken out of them was screened and bagged. This screened cement was sufficiently satisfactory for use on minor works. The quantity of cement thus obtained from each empty bags ranged from ¼ lb. to ½ a lb. Such of the cleaned empty bags as were not torn or otherwise damaged were returned to the Shahabad Cement factory for being used again for bagging cement. A rebate of Rs. 20 per 100 was allowed by the firm on these bags.

In handling cement in bags, the percolation of a certain amount of cement through the material of the bags is unavoidable. Such cement was found on the floors of railway wagons bringing in the cement consignments and also on the floor of the cement shed where the bags were stored before issue. The floors were swept and this "sweeping cement" was separately bagged and similarly issued to works other than the main dam.

The judicious collection and utilization of the screened and sweeping cement resulted in a considerable saving to the project. In all, some 464 tons of sweepings and no less than 8,640 tons of screened cement was recovered and used on subsidiary works. It is thus seen that where large quantities of cement are used it is economical to install a sack cleaning machine and to provide smooth cement-plastered floors in all sheds where cement is stored, so that the sweepings are clean. The quality of such sweepings, if taken while fresh, is only a little below that of new cement and is entirely satisfactory for ordinary building work when a very high standard of quality is not essential. At Mettur the use of sweepings or screened cement in the dam itself was prohibited.

All cement and other materials used on the construction of the dam was regularly tested at the well-equipped Test house at Mettur. Samples of mortar were taken daily from the mixers on the works and a high standard of quality was maintained. If any samples on Test were found to give results below the standards required, enquiry was immediately made to ascertain and correct the causes. Any slackness in proportioning and mixing was thus detected and on the results of many thousands of tests, the correct water cement ratios were accurately determined and maintained. It frequently happened, however, that the laboratory requirements and the actual requirements to suit the conditions of work did not entirely agree, for, while the laboratory tests aimed at ideal proportioning to obtain maximum strength and density for any particular mix, such proportioning was found to be unworkable in the actual execution of work. In the case of concrete which was conveyed to the work down the tower chutes, a considerably higher water cement ratio had to be maintained to render the mixture sufficiently fluid to slide down the chutes. With a dry mix the concrete would not flow properly and much segregation of the stone from the mortar took place, causing lamination of the concrete when laid. Too much water had a similar effect, and with the lean mixers employed for the rear portion of the dam much difficulty was experienced in keeping the concrete of uniform consistency, though the mixing was carried out with the greatest care. It is evident that if segregation is to be avoided the chuting of concrete will have to be abandoned and it should be placed in batches by other means, particularly where the proportion of cement used is low.

Even when chuting mortar which has been perfectly mixed, the segregation of sand for the cement takes place. This is particularly noticeable where the chutes are inclined at a steep angle, as was sometimes found necessary when conveying mortar by this means from mixers stationed at ground level down to the work at the bottom of deep trenches in the foundations. In such cases there is a tendency for the cement to adhere to the sides of the chutes while the sand, rolling down at a high velocity, throws off the cement adhering to the particles. During the construction, therefore, chuting of mortar was avoided as far as possible and it was found that mortar delivered in tip-wagons direct from the mixers to platforms at the site of the actual work remained in its original condition and required but little turning over and remixing before use.

For roughstone masonry works a certain amount of fluidity of the mortar was found essential. It was found that the densest work was obtained when the mortar was sufficiently fluid to enable it to be displaced when a stone was forced into it. This ensured the surface of the stone being well covered with mortar and prevented voids between adjacent stones. With a somewhat drier mortar displacement as described above was not possible and porous work was the result. Thus the water-cement ratio had to be maintained at a higher figure than was found best by laboratory tests and a compromise had to be effected between the two.

Cement Grouting.

The type of grouting machine used at Mettur consists of two horizontal steel cylindrical drums mounted on flat trucks for easy transport on rails. They are 4 feet long and 2 feet 6 inches in diameter, each with a capacity of 120 gallons. They are provided with openings 1 foot diameter on the top through which the cement slurry is poured and secured by air tight covers fitted with fly. nuts. They are provided with other fittings, such as, valves for admitting compressed air and discharging cement grout. A horizontal spindle, filled with steel paddles and rotated by hand, keeps the cement in suspension throughout the grouting process. The spindle is fitted through air tight glands built into the ends of the drum.

Working.—The holes to be grouted are capped with pipes 3 feet long and of diameter suited to the diameter of the holes of which one foot is made to project above the rock or masonry, as the case may be. A reducer is screwed to the top of the pipe which in its turn is connected to a one-inch armoured rubber hose pipe through which the cement grout from the grouting machine is forced under pressures up to 85 lbs. per square inch.

The holes are cleaned perfectly before grouting. This is done by pouring water and blowing in compressed air. This removes all the dirt, pebbles, etc., which may have fallen in after boring.

Before grouting a hole, a water test on the hole is done first. For this, the grouting machine is filled with water which is forced from the bottom of the cylinder under pressure into the hole by compressed air admitted at the top. If it takes more than one hour to empty the drum under a pressure of 80 lbs. per square inch in the case of rock and under pressures, in the case of the dam masonry, varying from 80 lbs. per square inch at 625·0 to 30 lbs. per square inch at 740·0, it is considered that the rock or masonry is good enough and no grouting with cement is required. If the drum is emptied earlier, grouting with cement is to be done. The grouting of masonry above 740 was not done as the width of the impervious portion was less than four feet, thus bringing the hole too near the face of the dam for the grouting to be effective. There was risk also of the masonry being cracked or blown out under such high pressure near the upstream face.

The proportion of cement to water by volume varied from 1 : 16 to 1 : 8 in the case of rock foundations, and from 1 : 8 to 1 : 4 in the case of masonry. Generally, the operation was started with a thinner grout and closed with thicker grout to increase its range of effectiveness. The cement is mixed with a small quantity of water in a G.I. tub, mounted above the machine so as to form slurry and is then diluted down to the required proportion when admitted to the grouting drum. Once the grout is passed in and the cover on top of the drum is secured firmly the grout should be continuously stirred by rotating the paddles as already described. Thus, the cement is kept continuously in motion and prevented from settling or caking in the drum or in the hose pipe. Once grouting is started, it should be continuous, as even with a short stoppage of a few minutes, a hole which was taking grout profusely may refuse entirely in re-starting, as the cement sets on the surface of the hole itself. This is the main reason for using two grouting cylinders, so that when grouting is being carried on with one, fresh grout is being prepared in the other and the operation is continuous.

Cocks are provided in the grout pipe very near the top of the hole and are tested frequently to ascertain if the grout is flowing freely. If, during the operation, the hole refuses to take any grout for one hour, it is considered that the hole has been grouted to refusal. The drums and hose pipes are then carefully washed out with water and kept ready for the next hole.

Figures of grouting are furnished in the Chapter on " Boring. "

The pipes, capped in the calyx holes in the rock foundations, were extended up through the masonry to the gallery level for the purpose of observing percolation, if any, and for grouting them again in case any water is subsequently found to flow through them. When water was impounded in the reservoir, a small flow of water was observed in 83 holes between 160 feet and 4,500 feet in L.S. All these holes were grouted to refusal again in the summer of 1934 with the maximum pressure available, viz., 80 lbs. per square inch and except in two or three cases, the leakage was entirely stopped.

It was observed that percolation had a tendency to decrease with time probably through the fissures in the rock in the reservoir bed becoming closed with silt under the high pressure due to the great depth of water impounded in the vicinity of the dam.

CHAPTER XV

Tests of Materials.

The necessity for the Test House at the Project Headworks was realized even while the preliminaries in connexion with the project were being worked out. A small Test laboratory was opened in October 1926 in the vestry of the old church which was then being utilized as the Executive Engineer's Office. A Bailey's double-lever cement testing machine, an Adie's single-lever cement testing machine of 1 ton capacity, half-a-dozen cement briquette moulds and a Vicat needle apparatus for testing the setting time of cement were then the only items of equipment. In course of time, however, the necessity for more apparatus for carrying out extensive tests on materials other than cement or lime was keenly felt. The immediate want was for a decent building near the dam-site where the equipment could be installed and where testing operations could be carried on in close proximity to the construction work. Sanction to build a suitable Test House was accorded, and the building was ready by the middle of 1927. More testing equipment was purchased, the more important items being an Amsler's 100 ton compression testing machine and a permeability tester by the same makers. The compression testing machine started work in March 1928. When the actual dam construction started, necessity was felt for still more accommodation and increased staff. An extension to the Test House was built and four laboratory assistants, with necessary labour to carry out the work, were appointed. All materials likely to be used in the construction of the dam or allied works were tested for quality and suitability for the kinds of work for which they were intended.

The most important part of the work of the Test House was the taking and testing of samples of the concrete and mortar laid in the dam. Preliminary tests were also carried out to arrive at the most economical mixtures consistent with strength and durability, to fix the water cement ratios for mixtures, mixing time and method and period of curing, and to evaluate the allowances to be made for the bulking and moisture contents in aggregates. It is needless to say that the expenditure incurred on the maintenance of the Test House more than justified itself by effecting economies in the cost of construction of the dam, and by ensuring a uniformly high class of work, reliable for its strength and security. As the quality of the construction work turned out every day was always under critical observation, the construction officers were, through their close co-operation and useful consultation with the Test House Officer, able to build the dam at a much lower cost than was anticipated in the beginning, yet without any sacrifice of quality either in the materials used or in the finished work.

The total expenditure incurred till the end of March 1934, on conducting tests, including equipment and establishment, was Rs. 51,834–2–6.

Tests carried out at the Test House at the Mettur Project Head-works may be classified under four heads, dealt with individually below :—

(i) Tests on materials used for work on the dam and allied jobs.

(ii) Follow-up tests—On compressive and tensile strengths of concrete and mortars laid on the dam and permeability tests on the finished structure.

(iii) Miscellaneous tests carried out in connexion with specific problems arising, from time to time, during the construction of the dam.

(iv) Tests carried out on materials sent to the Test House by outside parties.

(i) *Tests on materials used for work on the dam and allied jobs—(a) Cement.*—The cement used throughout the work was the well-known "Char-Minar" brand manufactured by Messrs. The Shahabad Cement Manufacturing Company. One of the stipulations in the agreement between the Government and the suppliers was that the cement would not be accepted if a sample taken on receipt at Mettur, failed to satisfy the British Standard Specification requirements. The agreement provided that, if any consignment was found to be of inferior quality, final opinion could be taken, on demand from the company, from the Government of India Test House at Alipore. It is gratifying to note, however, that during all these years, there was not one occasion when the quality was in doubt. The quality of cement supplied was always well above British Standard Specification.

The routine procedure adopted at the works for testing the cement supply was as under :—

Immediately a waggon was received at the transport yard, unloaded and stacked in the cement stores, the Transport Officer took a representative sample from the consignment and sent it on to the Test House in an air-tight tin container with all necessary particulars. The duplicate bill for the consignment was also forwarded to the Test House. Tests on setting time, tensile strength, both for neat cement and for mortar of proportion 1 part cement to 3 of standard sand by weight, were carried out after a curing period of seven days. A certificate containing the results was attached to the duplicate bill and passed on for payment. The Transport Officer was authorized to issue the consignment for works only after receiving intimation from the Test House that the sample had satisfactorily passed the seven-day tests. Twenty-eight days tests were done on each consignment as a matter of routine and the results recorded. Other British Standard Specification tests such as "fineness tests, soundness tests", etc., were carried out occasionally. If the samples proved defective in the setting time and tensile strength tests, these tests also were made.

The averages of many thousands of tests recorded at the Test House are given below :—

—	B.S.S. minimum.	Actual observed average.
	LB. PER SQUARE INCH.	LB. PER SQUARE INCH.
Tensile strength—		
Neat 7 days	600	798
Cement : Sand (1 : 3) 7 days. ..	325	437
Do. 28 days. ..	356	497

Setting time—

Initial not less than 30 Min. ..	1 hour 35 minutes (Minimum observed. 0 hours 39 minutes).
Final—Not more than 10 hours ..	5 hours 49 minutes.

These tests were carried out by the Vicat Needle apparatus.

The standard sand for the mortar tests was made locally out of crushed quartz, properly screened. The tension specimens were made in gun-metal briquette mould sets made to specification. The tests were made on an Adie's Single lever testing machine—capacity one ton and fitted with oil dash-pot and automatic brake.

It will be worth while to mention here that the cement supplied latterly was of a more rapid hardening variety recording very high early strengths without in any way affecting its slow-setting properties or other qualities. A few results, taken at random are compared with those for normal cement.

Cement mortar 1 : 3 by weight (Cement and Standard sand)—

Period of curing.	Tensile strength	
	Normal cement.	Rapid hardening cement.
	LB. PER SQUARE INCH.	LB. PER SQUARE INCH.
Two days	325	390
Three ,, ...	363	390
Five ,, ...	385	435
Seven ,, ...	437	445

Weight and density.—As a result of test weighings the average weight of 1 cubic foot of cement was found to be 93·3 lbs. and for construction purposes, a cwt. bag was assumed as 1·2 cubic foot.

(*b*) *Surki.*—The idea which was uppermost in the minds of the officers in charge of the construction of the dam during the early days was how best to effect economies in the cost of construction consistent with strength and durability. As a result of the close study of the history of similar structures in other parts of the world, the practicability of replacing a portion of the cement contents with some kind of pozzuolanic material was realised. A definite advance in this connection had been made in the construction of the Sennar Dam on the Blue Nile, in Egypt, where the cement was adulterated with 20 per cent of pulverized burnt clay. The procedure adopted was to mix the burnt clay with cement during the final stages of grinding. This was possible at that place because they manufactured their cement at site. For the whole of that work, this cement-surki mixture was used. The results reported were encouraging. Besides reducing the cost of the structure, it was definitely claimed that the presence of the pozzuolanic surki improved the impermeability and durability of the dam. While surki is not necessarily cementitious by itself, it possesses constituents which will combine with hydrated lime at ordinary temperatures in the presence of moisture to form stable insoluble compounds of cementitious value. When present in concretes and mortars made with Portland Cement, it imparts to the material an increased degree of resistance to various agencies which are normally liable to cause disintegration by the transformation of the free lime, invariably residual in cement mortars by the time they have reached the inert condition. A cement structure exposed to, or in close proximity to water is known to show indications of decay after a long lapse of time due to the lime separating from the cement in the presence of moisture. This disintegrating effect will be more noticeable in the case of structures which are not perfect in the matter of impermeability. The presence, therefore, of a material which will readily combine with the liberated free lime to form insoluble and cementitious compounds is highly desirable. If, as in the present case, its addition also reduces the cost of mortar, a further great advantage is gained.

The savings that would accrue, estimated to be about 15 lakhs of rupees, and the beneficial effects due to increased impermeability, durability and permanence of the dam (due to the chemical potentialities of surki in deterring the deleterious effects of the free lime, which it was anticipated would gradually be liberated from the cement in course of time) were the factors which finally resulted in the decision to use only "Red Cement" (4/5 cement—1/5 surki) in the construction of the dam. The saving by the use of red cement worked out to from Rs. 4–8–0 to Rs. 5–5–0 per ton.

Excellent clay was available in large quantities behind Smith's Knoll and the manufacture of surki has been described elsewhere in this book.

The results of chemical analysis on the Mettur clay are given below :—

	PER CENT.
Sand	56·7
Silica	21·2
Alumina	5·3
Ferric oxide	4·7
Lime	4·0
Loss on ignition	7·0
Other substances	1·1
	100·0

Tests were made to determine the effect of the fineness of the added surki on the strength of concrete.

In a 1 : 4 : 8 concrete (28 days curing), the following results were obtained :—

Fineness of surki.	Final crushing strength. TON PER SQUARE FOOT.
Passing through 20 × 20 mesh	55·6
Do. 50 × 50	68·0
Do. 100 × 100	72·8

It was seen that the finer the surki the higher the compressive strength. But the consideration of practicability had to limit the degree of fineness of grinding.

A working fineness was therefore fixed as follows :—

				PER CENT.
Residue on	20 × 20 mesh	not to exceed	..	3·625
Do.	30 × 30	do.	..	8·575
Do.	50 × 50	do.	..	18·065
Do.	76 × 76	do.	..	27·235
Do.	100 × 100	do.	..	35·385

Samples were taken daily from the output of each of the disintegrators, tested for fineness and the results reported to the officer in charge of the manufacture, to the Executive Engineer concerned and to the Engineer-in-Chief.

A few tests were made to study the comparative values of strengths of concrete using pure and red cement. The red cement concrete at the end of four weeks was invariably the weaker. The relative strengths of the pure and adulterated cement concrete were roughly proportional to the volumetric ratio of the cement in the different kinds of concrete.

Cement concrete versus red cement concrete, 28 days curing.

Proportion.	Load at final failure. Cement concrete.	Red cement concrete.	Remarks.
	TONS PER SQUARE FOOT.	TONS PER SQUARE FOOT.	
1 : 4 : 8	182·0	147·6	Using crusher metal.
1 : 4 : 8	234·0	205·6	Using hand broken metal.
1 : 2¾ : 5	266·4	209·6	Crusher run.
1 : 2¾ : 5	271·6	234·4	Hand broken metal.

(*c*) *Lime.*—Samples of limestone received from the quarries were delivered and stacked at Mettur and tested for lime contents. Random samples were also sent to the Chemical Examiner to Government for complete analysis. No stack was accepted if a sample from it gave below a 50 per cent lime content. The limestones were slightly overburnt in open country kilns near the surki factory and the burnt material was ground in the disintegrators. The fineness of grinding was carefully controlled by daily sieve-analysis of the product. The slaking and the admixture of surki took place only in the mortar mill at site of work. It was observed that the resulting mixture was excellent and exhibited very high strengths after four week's curing. It was possible to immerse samples in water without disintegration a day after moulding. The proportion used for the Ellis Saddle surplus bridge works was 1 : 2 : 4 (surki : lime : sand) the maximum strengths recorded at 28 days being 114·8 tons per square foot for compression and 354 lb. per square inch in tension. Total number of limestone samples tested for lime contents at the Test House was 463.

To arrive at the best mixture with the quality of lime and surki available, a series of tests were made, the results of which are given below :—

Surki—Lime—Sand—Mortar.

Tensile strengths at 28 days—Proportions by weights.

Proportion.	Tensile strength.		Lb./Sq. inch.
Surki : Lime : Sand.	Country kiln, Pakkanad.	Campbells' kiln, Pakkanad.	Campbells' kiln Perumal-Goundanoor.
1 : 1 : 1	112	146	122
1 : 1 : 2	110	131	123
1 : 1½ : 1½	187	133	130
1 : 1 : 3	153	99	116
1 : 1½ : 3	148	139	118
1 : ½ : 1½	114	..	30
1 : 1½ : 2	143	152	147

The proportion 1 : 2 : 4 by volume finally selected for the work corresponds to a proportion by weight of 1 : 0·91 : 4.

The early strength of the surki mortar was a very noticeable feature. The crushing strength of the surki mortar was 50 tons/square foot after 28 days or 12·5 tons safe load after 28 days.

(*d*) *Sand*.—Mettur was fortunate in possessing near the site of the dam a supply of sand of a quality surpassing all expectations. Millions of cubic feet of this sharp, clean well-graded sand were collected from the Cauvery river bed for the construction of the dam at a ridiculously small cost. Consulting Engineers from outside the Presidency were struck by its excellent nature and quality. They sampled it, subjected it to the utmost scrutiny and proclaimed it to be one of the best variety obtainable in India. The chief points in its favour, as a desirable fine aggregate for concretes and mortars were that it was clean, being remarkably free from silt and animal or vegetable matter and was composed of sharp, well defined grains. It was also so thoroughly and judiciously graded by nature that the percentage of voids was beneficially low, averaging a little over 31 per cent only.

The percentage of voids in the fine aggregate was the main factor, which decided the quantity of the costliest material—cement

—which had to be used to produce the required strengths. It is needless to say that had Mettur not been blessed with such an excellent quality of building sand, it would never have been possible to construct the dam at the present cost, neither could such lean mixes have been employed in its construction.

Mechanical analysis of Mettur sand.—Two typical examples of sieve-analysis of Mettur sand are given below. A typical sample of known weight was taken and screened through sieves having different mesh openings and the percentage by weight passing through each was observed :—

I

Size of mesh per inch square.	Percentage by weight retained on sieve.
4 × 4	1·63
8 × 8	4·34
10 × 10	7·64
15 × 15	4·35
20 × 20	35·64
40 × 40	17·23
76 × 76	19·47
100 × 100	2·71
150 × 150	6·11
180 × 180	0·07
Voids 34·1%	99 19

II

Fineness Modulus 99·19/100 or 0·9919.

Size of mesh per inch square.	Percentage by weight retained on sieve.
4 × 4	0·00
8 × 8	1·78
10 × 10	1·21
15 × 15	3·05
20 × 20	8·30
40 × 40	18·84
76 × 76	53·33
100 × 100	4·37
150 × 150	7·63
180 × 180	0·08
Voids 38·5%	98·59

Fineness Modulus 0·9859.

Voids.—From daily tests on sand samples taken from different work centres every day, the voids have been calculated.

	PER CENT
The average voids for the whole period works out to ..	31·3
Maximum voids observed ..	43·3
Minimum voids observed ..	21·2

Bulking and moisture contents.—It is a well-known but regrettable fact that, in the past, little attention has been paid (in South India) to the curious and, from the engineering point of view, important behaviour of sand when it contains moisture. It would be better if the Madras Standard Specifications were modified to include a safety allowance to provide for this phenomenon, which is important in any large work and, in a gigantic masonry structure like the Mettur Dam, was of immense importance.

It has been stated by eminent Engineers, after close and elaborate study of the subject that sand occupies more or less the same volume when it is absolutely dry and packed and when it is completely inundated with water. If water and dry sand are mechanically mixed; then for intermediate stages between the sand being fully dry and fully wet, the sand will bulk larger than it will for either of the two limiting conditions. The amount of bulking depends on the grading of the sand. As the water content increases, the bulking or increase in volume attains a maximum (it varies for different sands) and then again diminishes till, when completely inundated, the sand finally assumes the volume it had when perfectly dry.

This fact has been borne out by tests made at the Mettur Test House. Results obtained from a number of tests are given below. Unfortunately, no two samples were exactly alike and as the relation between moisture contents and bulking depends on the grading of the different sizes of sand particles, no definite law could be formulated on this point. The characteristic is, however, well worth further study and more elaborate and extensive scrutiny. The project has gained much by making a study of this 'bulking' of sand. If no allowances had been made for the bulking of sand when mixing concrete and mortars for the dam, considerably richer proportions than were actually required would have been used, involving an excess both in the quantity of cement and cost. An idea of the loss the work would have suffered had bulking not been considered may be gained from the following figures :—

The dam contains—

	8,150,000	cubic feet of masonry built with	1 : 2¾	mortar.
	37,050,000	do.	1 : 4	do.
and	9,460,000	do.	1 : 5	do.

Assuming that the mortar consumed for the masonry was on an average 40 per cent of the masonry, the following quantities of mortar have been used :—

	C.FT.
1 : 2¾ mortar	3,260,000
1 : 4 ,, ...	14,820,000
1 : 5 ,, ...	3,784,000

The average bulking of sand for the period of construction was approximately 20 per cent.

If bulking allowances for sand had not been made the different mortars would have used up—

(1) 43·7 per cent of sand instead of 36·4 per cent involving 7·3 per cent excess of cement.

(2) 30 per cent of sand instead of 25 per cent involving 5·0 per cent excess of cement.

(3) 24 per cent of sand instead of 20 per cent involving 4·0 per cent excess of cement.

The extra cement in these three cases would have been—

(1)	237,980 cubic feet.
(2)	741,000 ,,
(3)	151,360 ,,
	1,130,340 or 47,097·5 tons

and the extra cost at Rs. 52–8–0 per ton would have been Rupees 24,72,619 or Rs. 25 lakhs roughly.

It is, perhaps, not out of place to point out that the whole cost of the Test House and its establishment for the construction of the dam has been paid for fifty times over by this single saving.

Daily Tests on Sand.—Samples of sand were taken on all working days from different work centres and tests on bulking and moisture contents carried out. Results were reported daily. The moisture contents were reported to the construction officers by phone immediately the results were ready, to enable them to make suitable allowances in the quantities of water added for the various mixes.

The procedure adopted for determining the quantity of moisture present in the sand was to weigh a measured volume of sampled sand, roast it to complete dryness and to find the loss in weight. The moisture contents were expressed as so many gallons per cubic feet of wet sand.

Bulking tests were carried by the aid of a simple apparatus locally designed. Individual sets were manufactured and supplied to the different work centres to enable the construction officers periodically to evaluate the bulking of the sand they were using.

The apparatus used consists of two steel cylinders closed at bottom, open at top, with an internal diameter of 6″ and internal depth of 15″ and 10″ respectively. A wide mouthed funnel to fit over the top of the cylinders, a $\frac{3}{8}$″ mesh sieve and a scale complete the apparatus.

Procedure.—The smaller cylinder is filled up with the sampled sand and the top struck off. Into the first cylinder water is poured to a depth of 5 inches and with the help of the funnel and screen the sand from the smaller cylinder is screened into the water in the larger one. Pebbles, etc., caught in the sieve are periodically dropped into the cylinder. The object of letting the sand fall into the water through a screen is to eliminate air pockets in the inundated sand. The depths of sand and the sand below the top edge of the larger cylinder are measured. The height of sand under the water is the basic height and 10 inches is the bulked height. From these figures the bulking percentage is calculated.

The volume of the voids in the sand is the difference between the original volume of water introduced into the larger cylinder and the volume of water standing above the sand.

Average figures for bulking and moisture contents are given below :—

Moisture contents.

Average ..	0·24 gallons per cubic feet of moist sand.		
Maximum ..	0·65	do.	do.
Minimum ..	0·01	do.	do.

		PER CENT.
Bulking—Average	..	18·7
Maximum	..	33·7
Minimum	..	1·6

(*e*) *Coarse aggregate for concrete.*—The coarse aggregate used for the dam construction was broken granite. Granite of high compressive strengths and durability was obtainable in sufficient quantities from the quarries in close proximity to the dam site. The variety obtainable offered a very high resistance to abrasion, and absorbed practically no water, being free from voids. It contained only very little of that injurious substance mica, and even that was of the dark variety (biotite). When construction in concrete was given up and roughstone mass masonry was substituted, blasted and hammer-broken rubble stones with rough and angular faces and about ⅓rd of a cubic foot in size were used. In the early stages, samples of stones from different localities were periodically tested and their qualities reported.

A few test results on the material are added below :—

Description of sample.	Density. Lb./C.ft.	Compressive strength, tons/sq. ft. First crack.	Final failure.
1 Coarse grained variety of dark granite streaked with black grain.	169·8	484·2	721·8
2 Fine grained black granite ..	171·5	289·8	627·3
3 Coarse grained variety with quartzlike crystal formation.	172·4	531·0	825·3
4 Dark grey fine grained granite.	171·4	631·8	855·9
5 Coarse grained variety of grey granite containing biotite.	169·3	543·6	814·5

Bulking in the coarse aggregate due to presence of moisture was found to be practically negligible and no allowance was made for this throughout the construction.

Hand-broken granite metal and metal broken in the crushers was periodically analysed and the grading, voids and density of loose metal reported. A few results are given below :—

(1) Voids in hand-broken metal 3 inches 47·7 per cent.
Do. $2\frac{1}{2}$ inches 47·7 per cent.
Do. $1\frac{1}{2}$ inches 44·8 per cent.
Do. $\frac{3}{4}$ inch 41·6 per cent.

(2) Voids in crusher-run metal varied from 36·82 per cent to 45·62 per cent.

The lesser voids in the crusher-run metal were due to the better grading of different sizes occurring therein. Hand-broken metal is usually of uniform size. This is all very fine for road construction, but for concrete is most unsuitable as a high percentage of voids is the result.

Mechanical analysis of a well-graded sample of crushed metal gives the following result :—

Size of metal according to B.S.S.	Percentage by weight.
Above 3 inches	7·41
3 inches	13·09
$2\frac{1}{2}$ inches	23 08
2 inches	14 57
$1\frac{1}{2}$ inches	9·04
1 inch	7·24
$\frac{3}{4}$ inch	7·28
$\frac{1}{2}$ inch	6·46
Below $\frac{1}{4}$ inch or 'sand'	11·83
	100·00

Voids 36·82 per cent.
Density of loose metal, 106·97 lb./cubic feet.

According to B.S.S. 3″ metal is that which will pass through a 3″ ring in any one direction, but will be caught on a $2\frac{1}{2}$″ ring, and the longest dimension should not be more than $3\frac{1}{2}$″.

Mechanical analysis of hand-broken metal 3″.

	PER CENT.	
Over 3 inches	0·2	
2 inches	13·3	
$2\frac{1}{2}$ inches	47·4	
2 inches	28·7	Voids 48·4 per cent.
$1\frac{1}{2}$ inches	8·1	
Under $1\frac{1}{2}$ inches and dust..	2·3	
	100·0	

To test the voids in metal stacks a weighed quantity of metal was carefully stacked, closely packed. The volume of the stack was measured and the voids in stack calculated on the assumption that the density of solid stone was 168 lbs. c.ft. The following results were obtained :—

Size of metal.	Dimensions of stack.	Voids in stack. PER CENT.
$2\frac{1}{2}''$ to $1\frac{1}{2}''$ crusher metal run through screens.	$10' 0'' \times 2' 6'' \times 1' 1\frac{1}{2}''$	40·1
3″ hand-broken to B.S.S.	$6' 6'' \times 3' 6'' \times 1' 3''$	42·9
Rubble-stone 8″ to 10″ size ..	$10' 0'' \times 10' 0'' \times 2' 0''$	40·0

(*f*) *Water and water-cement ratio.*—For mixing concretes and mortars, purified water, as supplied for drinking purposes, was used throughout the work.

The necessity for strict regulation of the quantity of mixing water in concrete and mortars was fully realized from the first, and thorough investigations were made to fix suitable water-cement ratios for different mixes with a view to obtain maximum strength and workability. It was found that the use of the maximum strength-producing water-cement ratios did not produce a workable mix in the case of the richer concretes. Due allowances had, therefore, to be made in fixing the final ratios to be adopted by the construction officers.

From actual tests, it was found that the richer mixes gave maximum strengths with a lower water-cement ratio than was required for the leaner mixes. Amongst the richer mixes, drier concrete proved more workable than in the case of the lean mixes.

The maximum strength-producing water-cement ratios for different mixes used on the dam were found to be as under :—

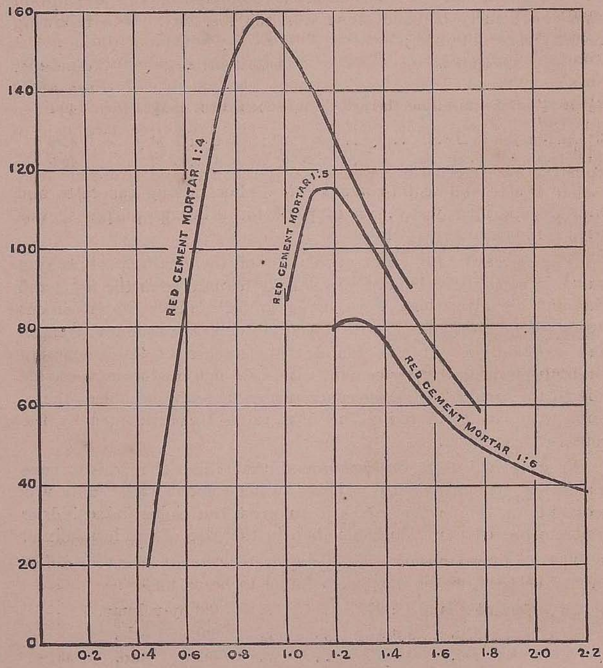
Cement : Sand	$1 : 2\frac{3}{4}$	0·6	by volume.
Do.	1 : 4	0·9	do.
Do.	1 : 5	1·2	do.
Do.	1 : 6	1·3	do.

For considerations of workability, these figures were slightly modified and the water-cement ratios in actual use were :—

$1 : 2\frac{3}{4}$	0·8 to 0·9
1 : 4	1·0 to 1·1
1 : 5	1·2 to 1·3
1 : 6	1·3 to 1·4

An idea of the effect of water-cement ratio on strengths of mortars can be formed from the curves here reproduced. It will be seen therefrom that, in the interests of workability, some of the higher strength proffered by the richer mixes had to be sacrificed.

PLATE No. XLII.



EFFECT OF WATER-CEMENT RATIO ON STRENGTH OF MORTAR

(*g*) *Follow-up tests on compressive and tensile strengths of concrete and mortars laid in the dam—Permeability tests on the finished structure.*—From the very beginning of the construction work samples of concretes and mortars mixed for the dam were taken daily and tested for compression and tension after periods of curing of 7 and 28 days. The samples for compression tests were 6 inches cubes, and for tension tests the usual B.S.S. briquette. The samples were cured in moist air and 24 hours before test, under water.

(*h*) *Compression tests.*—These were carried out with an Amsler 100-ton compression testing machine fitted with oil pump and pendulum dynamo-meter, indicating the load on the dial with an automatic recording arrangement. A standardizing box was also used to check the accuracy of the recording of the machine from time to time. When work on the dam was in full swing, as many as twenty mixers were functioning and samples were taken daily from all of them and tested. The results were reported in special forms printed for the purpose, copies being sent to the Executive Engineer in charge of Tests, to the Engineer-in-Chief and to the concerned construction Executive Engineers. If the observed strengths were below normal, an examination of the tested samples was made, and the probable causes of low strengths were given in the remarks column of the reports.

Averages of results recorded for different mixtures and for different periods of curing, etc., have been calculated for the whole period and have been appended below for information :—

Averages of compressive strengths and densities recorded for different mixtures.

(Curing 28 days.)

Compressive strengths.

(*a*) Concrete—

Proportion.	Crushing load tons/sq. foot. Average.	Maximum.	Minimum.
1 : 2 : 4 (pure cement)	275·8	390·0	156·6
1 : 2¾ : 5 do.	266·5	324·2	158·8
1 : 4 : 7 do.	220·6	310·2	94·8
1 : 4 : 8 do.	169·8	249·3	93·2
1 : 2 : 4 (red cement) (surki : cement 1 : 4)	254·1	333·6	197·6
1 : 2¾ : 5 do. ..	196·3	278·0	111·6
1 : 3½ : 7 do. ..	135·4	201·2	62.8
1 : 4 : 7 do. ..	173·8	274·8	97·6
1 : 4 : 8 do. ..	131·7	219·2	72·8

(*b*) Mortars—

Proportion.	Average.	Maximum.	Minimum.
1 : 2¾ (pure cement)	241·6	294·8	184·8
1 : 3½ do.	199·1	236·9	161·2
1 : 4 do.	142·9	179·9	120·8
1 : 2¾ (red cement) (surki : cement 1 : 4).	182·9	296·0	70·3
1 : 3½ do.	166·3	259·1	94·0
1 : 4 do.	120·9	259·6	50·4
1 : 5 do.	79·8	187·2	26·0
1 : 6 do.	74·3	98·8	59·2

Averages of densities of different mixtures.

(a) Concrete—

Proportion.		Density lb./c. foot. Average.	Maximum.	Minimum.
1 : 2 : 4 (pure cement)	.. .. ..	159·1	164·3	147·2
1 : 2¾ : 5	do.	157·5	160·8	153·9
1 : 4 : 7	do.	155·5	159·5	151·4
1 : 4 : 8	do.	154·8	159·1	149·6
1 : 2 : 4 (red cement) (surki : cement 1 : 4).		159·2	163·7	157·0
1 : 2¾ : 5	do.	158·0	164·1	153·7
1 : 3½ : 7	do.	154·3	158·6	145·5
1 : 4 : 7	do.	154·3	163·2	147·2
1 : 4 : 8	do.	157·0	163·1	148·0
(b) Mortars—				
1 : 2¾ (pure cement)	.. .. ..	146·0	149·3	142·4
1 : 3½	do.	144·0	146·2	141·9
1 : 4	do.	142·4	145·2	138·8
1 : 2¾ (red cement) (surki : cement 1 : 4).		146·7	159·6	137·1
1 : 4	do.	143·9	155·9	127·0
1 : 5	do.	142·3	157·6	132·2
1 : 6	do.	138·4	141·4	135·8

Averages of tensile strengths of mortars.
(Curing 7 days.)

Proportion.	Tensile strength. Lb./sq. in.
1 : 2¾	373
1 : 4	280
1 : 5	208

Surki mortar used for Ellis Saddle Surplus Bridge.

Surki : lime : sand	1 : 2 : 4—curing 28 days.
Average tensile strength	171 lb./sq. in.
Maximum	354 do.

Surki-lime-sand mortar (1 : 2 : 4) used for Ellis Saddle Surplus Bridge.

Compression tests.	Average of results. Average.	Maximum.	Minimum.
Final crushing load tons per square foot at 28 days	49·5	114·8	4·2
Density—Lb./C.ft. at 28 days	131·5	138·5	123·6

The results of lime mortar tests show far less uniformity than those of cement mortars, and indicate the necessity for a much higher factor of safety being allowed on structures where lime or surki-mortar is employed.

(*i*) *Permeability tests on the finished structure.*—The dam is divided transversely into individual sections or blocks by contraction joints. In different sections of the dam, when there was a cessation of work, a series of holes were drilled vertically into the finished structure at definite intervals across the dam, more especially down into the "impervious" front layer of the dam. These holes after being 'capped' were tested for their power of retaining water forced into them under definite pressures depending on the levels of the bottom of the holes. The tests were conducted by the help of an apparatus fitted up locally, comprising a positive water meter, a pressure gauge and a regulating valve connected in series with suitable flexible pipe connexions. After measuring the depth and diameter of the hole, water under pressure was passed through the system into the hole. When the hole was filled with water, the pressure was regulated to the required quantity by the valve and the test was started. The quantity of waterflow recorded by the meter during a specific time interval (10 minutes) was noted. The percolation per minute per square foot of hole area was then calculated and reported. If this figure exceeded the allowable maximum fixed previously, the area surrounding the hole was grouted to refusal.

The allowable maximum rates of percolation fixed by the Engineer-in-Chief were as under :—

For upstream area	..	0·01 gallon per min. per square foot.
For downstream area	..	0·05 ,, ,,

Pressures used for different levels for upstream area.

Level of bottom of hole.	Pressure.	Level of bottom of hole.	Pressure.
	LB./SQ. IN.		LB./SQ. IN.
+ 790 above M.S.L.	15	690	60
780	15	680	65
770	20	670	70
760	25	660	75
750	30	650	80
740	35	640	85
730	40	630	90
720	45	620	95
710	50	610	100
700	55	600	105

Total number of holes so tested was 484. Two hundred and twenty-six holes were in the upstream area, 253 in the downstream and 5 holes in rock foundations. The number of holes which satisfactorily stood the tests were 109 in the upstream area and 110 in the downstream area. All the holes in the foundation were satisfactory.

(*j*) *Miscellaneous tests carried out on specific problems arising from time to time, during the construction period of the dam.*—The results of the more important and interesting tests are given in this section.

Relation between compressive strengths in tons/sq. foot and tensile strengths in lb./sq. inch.

It is a well-known fact that tension tests can be carried out more easily and with less expenditure on equipment, etc., than compression tests. As such, it has been the aim of construction engineers to find out a suitable relation between the tensile and compressive strengths of a particular specimen. The result of investigations shows that no definite law can be arrived at for defining the relationship of the two strengths. Various investigators have in the past suggested approximate factors for converting tensile into compressive strengths.

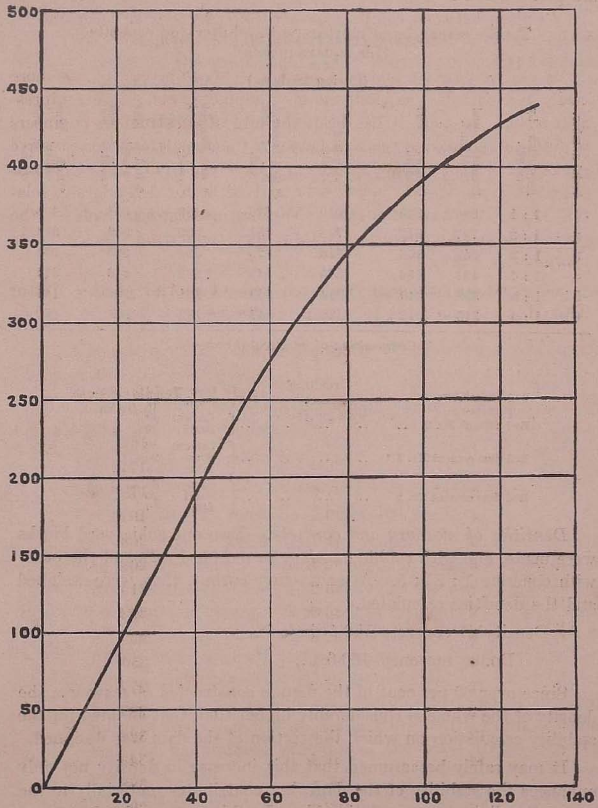
Observations made on 1 : 4 red cement mortar at the Mettur Test House yielded the following results :—

(Curing 7 days.)

Serial number.	Crushing load tons./sq.foot.	Tensile strength lb./sq.in.
1	34·8	160
2	36·0	177
3	37·6	178
4	39·2	197
5	41·7	203
6	42·4	208
7	43·2	215
8	46·0	222
9	52·8	239
10	56·4	250
11	57·2	277
12	68·0	289
13	72·8	328
14	82·4	348
15	96·8	388
16	103·6	398
17	116·4	408
18	136·4	456

Plate No. XLIII shows the relation between compressive and tensile strength for this mortar.

PLATE No. XLIII.



RELATION BETWEEN COMPRESSIVE AND TENSILE STRENGTHS OF MORTAR.

Tensile strengths of mortars with adulterated cement.—A series of tests were carried out on cement mortar of various proportions, the cement being adulterated with a definite precentage of surki and lime. The tensile strengths obtained have been tabulated and are given below :—

Tensile strengths of mortars with adulterated cements (Lb./square inches).

(Curing 28 days.)

Serial number.	Proportion by weight.	Cement and local sand.	Cement and surki.	Cement and standard sand.	* Red cement No. 1 and sand.	* Red cement No. 2 and sand.	* Red lime cement No. 1 and sand.	* Red lime cement No. 2 and sand.
1	1 : 1	860	843	1019	577	599	656	498
2	1 : 2	717	612	798	451	509	549	373
3	1 : 3	642	368	546	325	398	386	231
4	1 : 4	487	258	385	249	282	246	213
5	1 : 5	388	240	292	209	221	206	187
6	1 : 6	315	222	236	147	182	188	160

* *Composition of adulterated cements.*

Red cement No. 1	Cement	70	per cent.
	Surki	30	,,
Red cement No. 2	Cement	80	,,
	Surki	20	,,
Red lime cement No. 1	Cement	80	,,
	Surki	20	,,
	Lime	5	,,
Red lime cement No. 2	Cement	80	,,
	Surki	20	,,
	Lime	10	,,

Densities of masonry and concrete.—Two one-cubic yard blocks were made, one with rubble masonry in mortar 1 : $2\frac{3}{4}$ and the other with concrete 1 : $2\frac{3}{4}$: 5. After 28 days curing, they were weighed and the densities calculated.

Density of concrete 158·4 lb./c.ft.

Do. masonry 160·6 ,,

Since over 80 per cent of the dam is constructed of masonry, the density of the whole is considerably higher than that adopted for the stability calculation on which the section of the dam was designed.

It may safely be assumed that this increase in density not only enhances the stability of the dam, but contributes materially to the unusually slight seepage noticeable. In this respect the dam compares very favourably with many other works of a similar nature constructed of concrete in other parts of the world.

(*l*) *Water-proofing compounds.*—Various water-proofing compounds were tested for their properties, though practically none of them was used anywhere in the construction of the dam. Only the more active form of 'sika' water-profing compound was advantageously utilized in the construction sluice and Hydro-Electric sections and in the foundations at the left flank where the structure had to be built under extremely adverse conditions.

The more important properties of the compounds tested are given below for information :—

(*a*) *Sika No.* 1.—The addition of Sika No. 1 to the mixing water in the proportion sika : cement—3 : 100 improves impermeability as the following laboratory tests show :—

For a pressure of 6·43 tons/sq. foot.

Permeation for a block treated with sika was 488 c.c./Hr.

Do. untreated was 2125 c.c. Hr.

The compressive strength is also increased

For 1 : 4 : 8 concrete not treated with sika 92·4 tons/sq.ft. was the final crushing load.

For 1 : 4 : 8 concrete treated with sika 121·6 tons/sq.ft. was the final crushing load.

The setting time was not affected by the addition of sika in this proportion.

Quantities and cost.—One and a half gallons of Sika No. 1 are required for 1 c.yd. of concrete.

Cost Rs. 10 per gallon at ports.

Costs for concrete Rs. 60 per 100 c.ft. of concrete.

For rendering 1″ thick Rs. 11 per 100 sq. ft.

No. 3 "Sika" which has the property of causing cement to set very rapidly was employed on a small scale in the construction sluice section where, in the earlier part of the construction, water was found to be penetrating the walls of the westernmost set of construction sluices. Cement mixed with a small proportion of this liquid preparation sets in the course of 30 to 40 seconds. A jet of water sprouting from a leak in rock or masonry can be arrested by applying a handful of the mixture to the point of leakage and maintaining pressure of the hand above. In the course of half a minute or so the cement sets, and on removing the hand, it is found that the cement had adhered to the face of the masonry or rock, as the case may be and has stopped the leakage, thus enabling concrete or masonry to be built in a place which previously was too wet to admit of any satisfactory construction.

Anti-hydro-water-proofing compound.—This compound improves impermeability. The following permeation was observed in a test.

Permeation.

Pressure.	Sample. Treated with compound.	Not treated with compound.
100 lb./sq.in.	Nil.	178 c.c./Hr.
200 ,,	,,	283·2 c.c./Hr.

It accelerates setting time.

	HRS.	MIN.
Setting time—initial—for—sample treated ..	0	20
Do. untreated ..	1	10

Quantities and cost.—For concrete 1 : 2 : 4, anti-hydro : mixing water 1 : 10 to 1 : 15 or 1 quart of anti-hydro for every bag of cement.

Cost Rs. 9–8–0 per gallon f.o.r. Bombay, cost of concrete Rs. 50 per 100 cubic feet of concrete.

Rendering Rs. 9–8–0 per 100 square feet.

(*c*) *Silicate of soda.*—Improves impermeability.

Three coats of P. 84 silicate of soda on a sample of 1 : $3\frac{1}{2}$: 7 concrete produced—

Nil percolation for a pressure of 100 lb./sq.in.

$\frac{1}{2}$ C.C. percolation per hour for a pressure of 200 lb/. sq.in.

65 C.C. ,, 380 lb./sq.in.

The silicate of soda is mixed with water in the proportion of 1 : 4 by volume and is superficially applied on the specimen to be water-proofed after it has set and dried.

One gallon will suffice for 400 square feet. It is thus effective and economical.

(*d*) *Masscrete*—

(i) The addition of masscrete tends to accelerate the setting time :—

	Setting time. Initial. HRS.	MIN.	Final. HRS.	MIN.
Sample net treated with compound ..	0	55	6	25
Sample treated with compound ..	0	8	2	20

(ii) The presence of masscrete improves impermeability. Samples treated and not treated with masscrete were tested and yielded the following results :—

	Permeation.	
	100 lb./sq.in.	200 lb./sq.in.
Sample treated with compound ..	14 c.c./Hr.	113 c.c./Hr.
Sample not treated	178 ,,	183·2 ,,

(iii) Masscrete is added to a mixture at the rate of 0·3 gallon per cwt. of cement.

(m) *Relation between strength of concrete and the curing period.*—Though no individual test was made to show the variation of strength with different periods of curing, a few results have been selected from the records available with the help of which an approximate idea can be formed.

Results are given below :—

Final compressive strength tons/sq.ft.

	7 days.	28 days.	Months. (2)	(3)	(4)	(5)	(6)
1 : 2¾ : 5 Red cement (Surki : cement 1 : 4) Concrete	116·0	196·3	273·1	302·1	308·4	..	..
1 : 4 : 8 Red cement (Surki : cement 1 : 4) Concrete	..	131·7	160·2	162·6	174·4	..	..
Surki-lime-sand mortar 1 : 2 : 4	..	49·5	56·3	72·9	82·9	93·6	113·2

The results have been plotted and are reproduced in Plate XLIV. From the curves, one interesting feature is clearly evident. Cement concrete increases in strength very rapidly in the early stages of curing, but, after two months, the increase in strength is only very gradual. Lime-surki-sand mortar, on the other hand, continues to increase in strength for a much longer duration, though its strength is, of course, much lower than that of cement concretes.

(n) *Quantity of metal required for* 100 *cubic feet of finished concrete.*—The quantity of metal required for 100 cubic feet of finished concrete depends on various factors, the more important of them being :—

(1) The percentage of voids in metal.

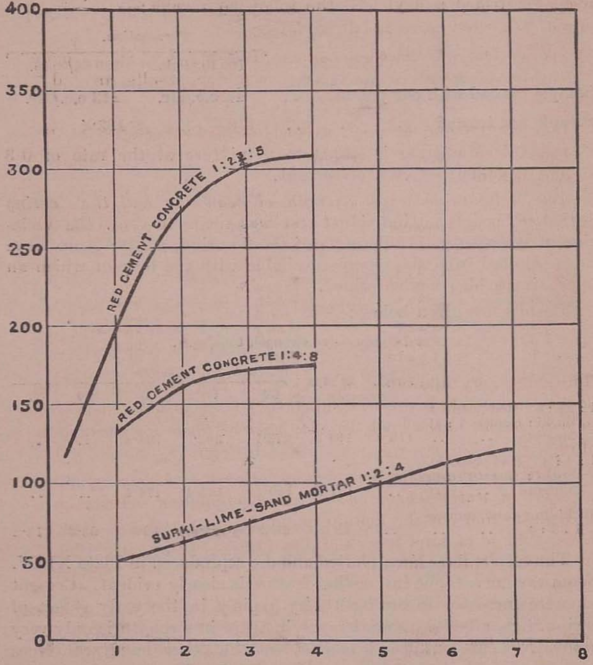
(2) ,, sand.

(3) The amount of water added to the mix.

(4) The nature of treatment while laying.

(5) The method of measurement of aggregate.

PLATE No. XLIV



RELATION BETWEEN STRENGTH AND CURING PERIOD OF CONCRETE.

As all the above five factors are variable quantities, no hard and fast rule can be enunciated on this point. Theoretical calculations can, however, be made on assumptions of definite and ideal conditions. A report on this was submitted on a reference from the Superintending Engineer, Bezwada, showing the theoretical quantities of metal required for 100 cubic feet of finished concrete for different proportions of mixtures and on specific assumptions. A general statement can, however, be made. So long as the aggregates are measured accurately and are well-compacted, in concretes, where the mortar is in excess of the voids in the coarse-aggregate, less than 100 cubic feet of metal only is required for a finished unit of work. Where the mortar is insufficient to fill the voids in the coarse-aggregate 100 cubic feet (and no more) of metal will be required, but the concrete will be porous.

A special test was conducted in the Test House with materials the qualities of which were known. The results are tabulated below :—

Coarse aggregate used—$\frac{3}{4}''$ screened metal having voids 44·8%.
Fine ,, sand ,, 33·8%
and cement.

Serial number.	Proportion.	C.ft. of stacked metal required for 100 c.ft. of finished concrete.	As per theoretical calculations.
1	1 : 2 : 4	92·3	88·8
2	1 : $2\frac{3}{4}$: 5	91·4	90·2
3	1 : 3 : 6	95·5	95·0
4	1 : 3 : 7	100·0	100·0
5	1 : 4 : 7	86·1	89·2
6	1 : 4 : 8	93·2	95·5
7	1 : 5 : 10	94·6	95·5

The customary allowance of $112\frac{1}{2}$ cubic feet of metal per 100 cubic feet of concrete is thus not supported by actual tests made with clean hard metal, unless such an allowance be made for wastage in handling.

(*o*) *Bulking of mortars over volume of sand—Determination of the weight of water which enters into combination.*—Tests have been made to find out the definite bulking of dry and wet mortars over the volume of sand used and also to evaluate the quantity of water which enters into combination. Results are appended below :—

Serial number.	Proportion.	Water cement ratio.	Percentage of bulking of mortar over volume of sand.		Percentage of weight of water combined on the wt. of cement.
			Dry mortar.	Wet Rammed mortar.	
1	1 : $2\frac{3}{4}$	0·55	33·7	31·4	27·9
2	1 : 4	0·9	27·3	16·67	42·95
3	1 : 5	0·9	20·63	13·33	40·95

(*p*) *Comparative strength and cost of clay bricks and sand-cement bricks.*—The quality of burnt clay bricks available in the Tanjore delta for works in the canal construction is generally poor. Some tests were therefore made to compare the strength and cost of such bricks with artificial bricks made of sand and cement mixed in various proportions. Some delta bricks had previously been tested in Madras and were found to have an average crushing strength of 14 tons per square foot. This, therefore was taken as a standard for clay bricks. Sand-cement bricks of the same dimensions were moulded at the test house, the sand being an average sample received from the canal zone. Tests on these bricks produced the following results :—

Proportion Cement-Sand.	Final crushing load tons sq-ft.	Relative strength cement bricks clay bricks.	Relative cost cement bricks clay bricks.
1 : 8	42·9	3·06	1·23
1 : 9	40·9	2·92	1·11
1 : 10	32·7	2·35	1·02
1 : 11	28·4	2·03	0·94
1 : 12	25·4	1·81	0·87

It is thus seen that while a brick composed of even a 1 : 10 cement-sand mix is 2·35 times stronger than a clay brick, the cost is about the same. If larger blocks are moulded, the cost of manufacture is reduced, while the amount of mortar and labour required for construction with such blocks is also reduced. Where available bricks are of poor quality, therefore, as in the Pattukkottai taluk, it is better to substitute sand-cement blocks for brick-work, the necessary sand being readily available throughout the delta, though its quality is poor when compared with the excellent sand available at Mettur. A few small works have been constructed with sand-cement blocks, while such blocks have also been used in the later works for the construction of aprons at aqueducts in place of the poor quality blocks made of broken brick in surki mortar used in the earlier works.

Comparative compressive strengths obtained in cement mortars using Mettur and Canal System sands are given below :—

Compressive strengths—final—at 28 days' curing. Tons/Square foot.

Proportion.	With Mettur sand.	With canal system sand.
1 : 5	..	76·8
1 : 6	98·8	73·0
1 : 7	86·8	49·8
1 : 8	67·2	42·2
1 : 9	58·4	40·9

The above tests indicate clearly the extent to which the strength of a mortar depends upon the quality of the sand employed. Tanjore delta sand is of a quality found in the beds of most streams and serves to show up the extraordinarily fine qualities of the sand utilized in the construction of the dam at Mettur. Its superior qualities may be attributed to the fact that the sand found there has not travelled great distances and is therefore sharp in texture, while, since it is deposited on a clean rocky river bed, it is far more free from foreign matter than is normally the case with sand taken from a deep sandy bed. The summer flow in the Cauvery is clear and automatically washes the sand clean.

CHAPTER XVI

Diversion of River Flow duration construction.

Construction of coffer dams in river bed—The right coffer dam.—This was built in the right half of the river between L.S. 1,620 and 2,250 as measured along the centre line of the dam. It consisted of walls on three sides, the north wall being 630 feet in length, the east wall 360 feet, and the south wall 540 feet, the river bank forming the fourth side. The tops of the walls were at plus 633 level. Vents of 10 feet width with their cills at 625·00 (river bed level) were built in both up and down-stream cross walls at the lowest places to pass the summer discharge of the river. The vents were constructed originally with grooves so as to take galvanized iron sheet shutters inserted vertically, with horizontal rails to take the thrust. The walls were built of cement concrete, the proportion of materials used being :—cement : sand : single : : 2 : $3\frac{1}{2}$: $7\frac{1}{2}$. The top width of the wall was generally 3 feet, increased at the piers to 5 feet. The wall had a front batter of 1 in 8 and rear batter 1 in $2\frac{1}{2}$.

This work was first started in March 1926, after diverting the flow towards the left bank. The right coffer dam construction was in progress during the dry seasons of 1926–27 and was only completed by March 1928 with the top of the walls further raised from 633 to 635·50. The cost of this work was about Rs. 57,500. Progress was very slow in the beginning since suitable pumps to tackle the heavy river springs were not then available.

Central coffer dam.—This was built in the central deep portion of the river between L.S. 1,310 and 1,620 measured along the central line of the dam. The design of this coffer dam was similar to the design adopted for that on the right. A working estimate was sanctioned for Rs. 64,700 for this coffer dam. To discharge the summer maximum flow of 6,000 cusecs, 20 vents of 9′ 4″ each on the upstream wall with cill at 627·25 for 14 vents, and at 626·00 for 6 vents were provided. The piers were 3 feet thick and 6 feet long with a batter of 1 to 8 in front and 1 to 2 in rear for the upstream and downstream walls and 1 to $2\frac{1}{2}$ in both faces for the cross or dividing wall between the coffer dams which had to resist water pressure from either side. Twenty-two vents of 10 feet span with cills at 625·50 were provided in the rear wall. The front vents were built with grooves at sides so as to take the 3′ × 10′ steel shutters that had been prepared for use as shuttering for concrete construction of the dam. This work was started in April 1927. It was in progress during the dry season of 1928 and was completed by the dry season of 1929. During the course of execution it was found, due to changes in the condition of the river margins that the height of the walls was insufficient and in order to prolong the working season in the river bed, the walls were raised to 637·00 and completed by May 1929.

When the excavation of foundations for the dam in the central coffer dam area was started in December 1929, it was considered necessary for ensuring uninterrupted work, to further raise the upstream central coffer dam wall and a portion of the side walls to 641·00. So the vents were all closed and solid wall was built up to 638·00. The further raising to 641·00 was done with 10′ × 3′ steel shutters fitted between piers. These were completed in the dry season of 1930. During the early floods in 1930 it was found that the steel shutters could not withstand the heavy flood and the impact of floating tree trunks that passed over them. So, to ensure uninterrupted work for the dry season of 1931, the vents were all built up and the whole of the front wall and the side wall up to the left coffer dam were built up to 641·00. For the same reason, to prevent backing up of water from downstream, the vents in the rear wall were also built up to 635·00. The above items of work were completed by March 1931. The total cost of constructing this coffer dam was Rs. 63,450.

Left coffer dam.—This consisted of a series of vents 25 in number connected with the east wall of the central coffer dam from L.S. 1,310 eastwards up to the high margin of the river at the left bank. These vents were situated just on the upstream side of, and nearly parallel to the dam line. They were of 8 feet span on the skew and 7 feet when measured at right angles to the stream. The piers were 2 feet wide and 11 feet long and built with top level at 634·00. This arrangement was intended to dispose of the summer flow and also to form a bridge for the carriage of materials and for the passage of labourers for works in the river bed. The arrangement is clearly seen in Plate XII. This work was started and completed in the dry season of 1928. The rear wall of the left coffer dam was 290 feet long connecting the east wall of the central coffer dam with the left bank of the river. The wall was built with a casing of concrete (1 : 5 : 10) all round, and had a hearting of rough stone. Seven vents of 10 feet width, with 3 feet thick piers between them, were also provided. The estimated cost of this work was Rs. 11,200. It was started in December 1928 and completed in February 1929.

During the dry season of 1929 excavation of the dam in a portion of the left coffer dam adjacent to the left bank was in progress after diverting the summer flow with the help of a ring bund through the other portion of the left coffer dam adjacent to the central coffer dam. In order to isolate the former portion, the front vents of the left coffer dam wall in that area were blocked up with concrete and the blocked up wall as well as the piers in the other half were all raised to the same level as the left coffer dam wall. Thus the area of the waterway in the left coffer dam was reduced and was for some time left as a " construction channel " to assist the construction sluices in discharging the summer flow when the dam construction was in progress. The left coffer dam work was completed by June 1929. Thus, the main construction of the three coffer dams was completed by the dry season of 1929.

Diversion of water.—There was no deep channel in the river bed at this site of the dam as in the old site " D," so the diversion of water was conveniently effected with the help of ring bunds during the course of construction of the coffer dam.

The foregoing descriptions may be summarized thus :—

Dry season of 1926.—Coffer dam work was in progress in the right side only and the water was diverted to the left side with the help of ring bunds.

Dry season of 1927.—Work was in progress both in the right and central coffer dams when water was diverted with the help of ring bunds into the left coffer dam area as well as into the right half of the right coffer dam through the vents already built.

Dry season of 1928.—Coffer dam work in all the three sections was in progress. Excavation of foundations for main dam was also in progress in the right coffer dam area, so the summer flow was completely cut off from that area. Between the central and left coffer dams water was diverted with the help of ring bunds according as to whether work was in progress in the one or the other of them.

Dry season of 1929.—Excavation of foundations for the main dam was in progress in the right coffer dam as well as in the left coffer dam except for the portion occupied by the construction channel. So the dry season flow was diverted through the central coffer dam and the construction channel.

Dry season of 1930.—By the dry season of 1930 construction sluices in the body of the main dam had been built in the right coffer dam. So the dry season flow was diverted through the construction sluices and the construction channel in the left coffer dam. Excavation of foundation or masonry work for the main dam were simultaneously in progress throughout the river bed except in the construction channel area.

Disposal of dry season discharge when work is above river level.

Dry season, 1931.—The same procedure as for the previous season for the diversion of water was followed at the beginning of this season. Latterly, when the flow was at its minimum, water was passed through construction sluices alone, the dam construction having been started in the construction channel area also. In this season the dam masonry was in progress throughout the river bed section and was built to level 642·00 (i.e., 17 feet above the normal river bed level). Thus the construction sluices which were intended for the disposal of dry season flow when the dam work rose above the river bed level functioned as such during this season for the first time.

Dry season, December 1932.—In the early part of this season, the dry season flow passed through the construction sluices. When the work of Hydro-Electric pipe fittings were completed, the flow was passed through these pipes and the construction sluices were closed in March 1932. The closure of these construction vents by means of hinged flap shutters is explained in a later chapter. So, in the latter part of this season, the power pipes functioned as construction sluices. To meet emergencies, temporary construction sluices with plugging arrangements were also built near the construction sluices in the body of the dam with cill levels at 642·00 and above, so that, in case the power pipes could not discharge the full flow and water level rose in the river during the plugging of the construction sluices, the temporary sluices could discharge a portion of the flow. But this contingency did not arise at all as the power pipes were able to discharge the full flow. By the end of the dry season the dam had been built to level 677·00 at the overflow section which was fixed between L.S. 1,250 to 1,880; the dam on either side of the overflow section having been raised to levels varying from 705·00 to 720·00. It was now possible to allow the flood to pass over the construction sluices also as they had been plugged with masonry and the dam made solid.

Dry season, 1933.—In this season the lake had been formed to the maximum water level of 677·00 or 52 feet above river bed and the dry weather flow was discharged through the low level sluices and power pipes. With the completion of the High Level irrigation channel, these and other sluices functioned. The dam was completed throughout by the dry season of 1934.

The total expenditure incurred on diversion works was Rs. 2,21,872.

CHAPTER XVII

TEMPORARY CONSTRUCTION SLUICES AND THEIR CLOSURE.

THE CONSTRUCTION sluices, designed to pass the summer flow through the dam in the earlier stages of the construction were built in two groups. Each comprised seven vents of 6 feet width, the eastern group being situated between L.S. 1,725′ and 1,788′ and the western group between 1,854′ and 1,914′. The front cill levels of these sluices were + 628 and + 627 respectively, the vents being given a gradient falling to + 626 at the rear of the dam.

When the masonry on either side had been raised sufficiently high, the western set of vents were closed. This closure was effected in the following manner. On the 7th December 1931, when the discharge in the river was 5,000 cusecs, the work of closure was started by forming in the river bed a diversion bund of big stones some distance above the coffer-dam wall opposite the west construction sluices, with the object of diverting the main stream and producing still water in front of these sluices. The top level of this bund was at + 639·0, the top width was 6 to 8 feet with side slopes 2 to 1. Spoil was thrown in front of this bund for filling in the interstices in stones and reducing the leakage.

In rear of this bund and immediately above the construction sluices another water-tight ring bund with its top at + 641 was formed of red earth with sand bag revetment in rear and covered by a thick layer of rock spoil in front to prevent the earth being washed out. The bags were held in position by walings composed of rails and sleepers resting against a number of "horses" constructed of 24 lb. rails butting against the front face of the dam.

To prevent the rear water from backing up into the sluices an earthen ring bund was formed with its top level at + 635·0. Two 25 H.P. motor-driven pumps 8″ × 6″ one in front and the other in rear were able to cope with the leakage through the bunds. Other pumps were also kept ready at site in case of emergency. The pumps were placed outside the sluice area so that masonry in the vents was built under dry conditions. By the 16th February 1932, masonry in this section had been raised to + 645 in front and + 637 in rear. The horses, walings, sleepers, etc., were then removed and the space in front of the dam opposite this portion was filled with red earth to assist staunching, though no leakage whatever was apparent.

For the closure of the eastern set of sluices, different methods were adopted. The four vents at the western end of the group were provided during construction, with piers which extended beyond the normal face of the dam both on the upstream and downstream sides in order that sumps could be constructed in the extension of the sluice cills for the drainage of any water that might leak through the joints in the piles. These sumps were all connected with pipes through the piers so that, with a suitable pump working at one end, all the sumps could be effectively drained and the leakage water prevented from entering the vents. Interlocking piles were built into the piers on either side and were so spaced that a definite number of other interlocking piles could be fitted between them at any time, even while water was flowing through the vents. Cross beams were provided at suitable heights to prevent the displacement of the free piles due to water pressure from the outside. The closure of these four vents with this arrangement carefully planned in advance was a not too difficult matter, though the whole of the summer flow of the Cauvery was now concentrated through the seven eastern vents and was running at a considerable depth and velocity. To admit of the lowering of the loose piles, by reducing the flow temporarily through each vent, a curtain of 3″ pipes was put down in front of the piles, these again being supported by cross beams built into the piers above the line of sheet piling. The grooves of the piles prior to lowering were all packed with hard grease, part of which was displaced when the piles were interlocked a certain amount of leakage nevertheless occurred, and this was much reduced by releasing bags of ground cinders into the water immediately in front of the piles. The cinders, having very nearly the same specific gravity as water, were driven into the leaky places under the pressure of the water and, coming in contact with the grease, were held and effectively checked the leakage.

Since short piles only were available, it was found necessary to insert them in two stages. The tops of the first set were at +638, but, as the water level was expected to rise to at least + 640, a second set had to be superimposed. The horizontal joints between the piles were sealed with a strip of $\frac{3}{8}''$ thick rubber. This was held in place by the weight of the upper set of piles and so compressed as to make a really tight joint.

The sheet piles at the downstream ends of the four vents were similarly treated and placed.

A 5″ × 4″ pump drained the upstream sumps while a 4″ × 3″ pump was found more than sufficient for keeping the water level down in the downstream sumps. Thus, these four vents were kept free from water and, after carefully scraping and cleaning the rough faces of the walls masonry was built up solid to the top of the vents.

By the 15th March 1932, eleven of the fourteen vents had thus been closed and the masonry in that portion of the dam was raised to + 655 level in front, the rear being left at + 634.

The three easternmost vents were now carrying the whole of the dry weather flow. It had been calculated that these would be running full, and for their closure special provision was made. Prior to the construction of the piers of these vents a design for a special form of flap shutter had been prepared. These shutters were to be capable of being lowered to seal the mouths of the vents completely, the depth of water in front of the vent being too great to admit of any form of ring bund being constructed. On the complete water-tightness of these shutters depended the satisfactory closure of the last of the construction sluices, and considerable interest and speculation was aroused when the operation was actually carried out as to whether they would prove to be so.

Usually, where large vents are concerned, the shutters are machine-faced and fit against machine-faced seatings secured to the face of the dam, rubber staunching strips being employed to check any flow below the faces. Such shutters are expensive, and as the shutters to be employed here would be required to serve only for a few hours it was felt that something equally effective and far less costly could be constructed locally. The successful operation of the shutter actually designed and so constructed depended upon the water-tightness of a joint made between a frame constructed of flat bars $\frac{3}{4}''$ thick only against which the $\frac{3}{8}''$ thick rubber-faced flange on the frame of a hinged-flap shutter came in contact. It was calculated that the water pressure against the gate would cause the $\frac{3}{4}''$ edge of the frame to become deeply embedded in the rubber face of the shutter, and so ensure a perfectly water-tight joint.

The frames were therefore made up of $\frac{3}{4}'' \times 4''$ mild steel bars with angle cleats rivetted at the corners. Bent flat steel anchors were provided to secure the frames in the special concrete in which they were embedded, the outer edge of each frame projecting only $\frac{3}{4}''$ beyond the face of the dam at the vent. The size of the frame in each case was $6' \ 9'' \times 11' \ 0''$. The shutter, designed so that the frame made contact with the centre of the flanges all round, was built up of $6'' \times 3''$ channels, with channel stiffeners suitably spaced. A skin plate $\frac{1}{4}''$ thick was rivetted to both the frame and the stiffeners.

The $\frac{3}{8}'' \times 3''$ rubber strips were secured to the outer flanges by means of $\frac{3}{4}'' \times \frac{1}{8}''$ flat strips screwed through the rubber into the flanges.

The shutters were suspended from channel brackets built into the masonry above the vents through short links. The object of the links was to allow the shutter freedom to move bodily backwards or forwards on its seating and so ensure the rubber face making uniform contact with the frame from top to bottom. The links were secured to the brackets and gates by means of special turned pins. In construction, care was taken to see that the gate when lowered maintained proper alignment with the frame. To ensure this, steel horns were rivetted to the frames which served as guides for the shutters, the space between the inner faces of the horns being only $\frac{1}{8}''$ greater than the over-all width of the shutter. Great care was taken to see that the frames were not distorted while fixing. Common stock material was used for both the frames and the gates, none of the faces being machined.

When hinged-flap shutters are lowered against a head of water, there is a risk of the shutters slamming when they reach the nearly-closed position. To prevent this happening, provision was made for inserting needle shutters (consisting of a number of small-section channels) in the vent in rear of the flap shutters, temporary cross beams being inserted in slots left in the masonry walls to support them. As the leakage through these needles would be heavy a curtain made from tarpaulins, operating on a roller in a manner similar to that adopted for the drop curtain in a theatre, was secured in front of these needles, being lowered immediately before the actual closing of the flap shutters.

On the 16th March 1932 all was in readiness for the final closing of these three remaining vents. By means of steel cantilevers bolted to the top of the masonry constructed above the vents, the three hinged shutters were suspended in the ' open ' position, being regulated by means of rope tackle passing over pulleys attached to the cantilevers and to the bracket provided on each of the shutters. The tarpaulin curtains were then lowered in front of the needle shutters which more or less closed the vents and thus produced almost still water for a few moments in the neighbourhood of the flap shutters. These were then all lowered simultaneously and it was observed that they bedded down on their rubber-faced seatings without any shock whatever. As soon as the shutters were closed the water in rear leaked away gradually thus causing a steady increase of pressure on the shutters. It was gratifying to find, on examination of the vents immediately behind the shutters, that not the slightest trace of leakage was to be found, though the head of water due to the backing up of the river above the dam was steadily increasing, since it now had no outlet. Pipes for the drainage of water which might leak around the gates had been inserted in the masonry at cill level but these were not required. The work of cleaning the walls and cills and constructing mass masonry in the vents was therefore portion of the vents was completely built up, the rear portion being started immediately after the closure of the shutters and the front proceeded with more slowly along with the rest of the rear masonry in that section of the dam.

When the impounded water reached the cill of the Hydro-Electric pipes at +640 level the river again commenced to flow and gradually increased till the normal flow was being discharged through those pipes. For a period of about nine hours after the closure of the construction sluices the Cauvery ceased to flow below the dam.

To ensure that the joint between the top of the new masonry in the vents made close contact with the underside of the lintels and arches, pressure grouting was done.

Thus concluded, to the great satisfaction of all concerned, the successful closure of the construction sluices. Even with a head of 150 feet of water in the reservoir no leakage at the site of these sluices is to be found.

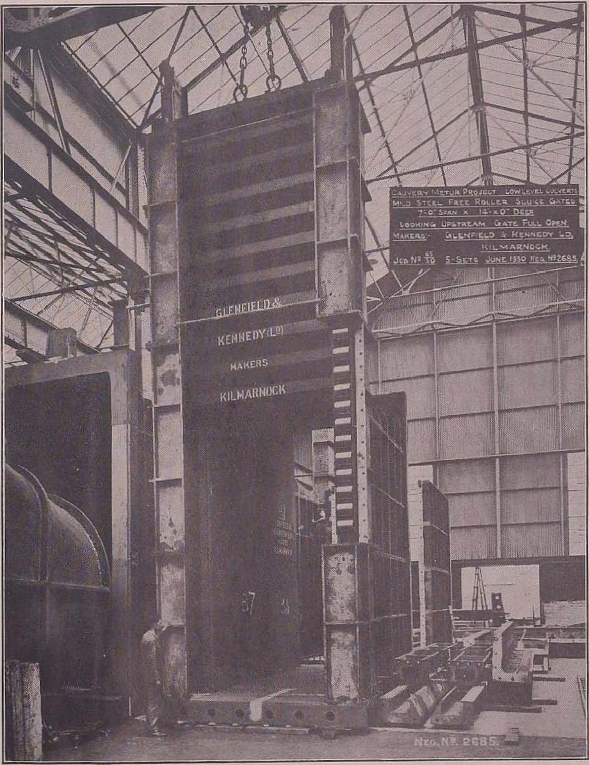
CHAPTER XVIII

Irrigation Sluices described.

Low-level Sluices.

The low-level sluices comprise 5 vents, each 7 feet wide and 14 feet deep at 32 feet centres with cill level at 670. Each vent is provided with a mild steel free roller culvert sluice gate working against hard cast iron free rollers moving in a cage on machined paths in cast iron grooves 27 feet in height. The gate is suspended at the centre line of the dam. The roller paths are articulated to ensure contact over the full width of the rollers. The gate is provided with side rollers to prevent it touching the side grooves while lifting. The overall dimensions of the gate are 9′ 7″ × 14′ 6″, the distance between the centres of the vertical girders (which are 18″ × 7″ × 75 lb.) being 9′ 0″. Between these two end girders 11 cross girders 16″ × 6″ are fixed horizontally at $16\frac{1}{2}$″ centres and over them a skin plate $\frac{5}{8}$″ thick is rivetted on the front side. The weight of the gate is 8 tons. The gate frame consists of side grooves, lintels and a cill piece all of cast iron $1\frac{1}{2}$″ thick and is very massive. These parts are all bolted together with flanged joints, the contact faces being truly machined for a perfect metal to metal joint. Every third bolt is a 'fitted' bolt which ensures the perfect alignment of all machined parts during erection. The gate has broad joints where it comes in contact with the side frames and lintel gun-metal adjustable staunching bars for sealing the side and lintel when the gate is in 'closed' position. The joint faces are given a taper of 1/32″ per foot so that the gate is in close contact with the frame when in the closed position and breaks free when lifted. The bottom of the gate fits against a machined high-carbon steel cill, securely embedded in the cast iron cill plate.

The gate is coupled to a counterbalance weight, consisting of 12—1″ M.S. plates bolted together, by means of linked steel suspension rods and Renolds steel roller chains passing over sprocket wheels at either end of the main shaft of the overhead operating gear. Each gate is provided with worm gear adaptible for either hand or motor drive suitable for lifting and lowering the gate under any conditions. The operating gear is housed in a chamber and supported on a steel girder platform fixed at 785·50 level thus leaving the roadway over the top of the dam perfectly clear. Plate XLVI is a photograph showing some sets of operating gear for these sluices erected in the makers' workshops before despatch to India. A rectangular opening on each sluice chamber is covered with a



ONE OF THE LOW LEVEL SLUICE CULVERTS WITH SECTION REMOVED TO SHOW FREE-ROLLERS.

PLATE No. XLVI.

HEADSTOCKS FOR LOW LEVEL SLUICES.

portable bridge which can be removed when necessary for extracting the gearing and gates by means of the Travelling Goliath Crane which runs on the top of the dam.

The speed for hand operation is half a foot per minute, while for electric operation it is 9 feet per minute. The head-stock is fitted with fool-proof interlocks, so that the operator cannot engage the crank handle for hand operation when the motor is in motion or vice versa. The motor engages with the gear through a centrifugal clutch.

The advantage of the balanced gate are firstly, that the system is easily operated and, secondly, the motor can never be driven by the weight of the gate but must always drive when lifting or lowering the gate. It is thus practically impossible for the gate to get out of control. Simple push-button control is provided for the motors, contactor panels being mounted in recesses in each of the chambers.

The gate is designed to withstand a static head of 145 feet on the upstream side with no back pressure and to operate under a working head of 80 feet.

The velocity through the sluice vent under a 60 feet head . is between 50 and 60 feet per second, and this is well within the safe limit permissible for dressed granite ashlar lining. However, the upstream bell-mouthed portion of the tunnel which may be subject to very disturbed hydraulic conditions when the sluice is discharging under heads up to 80 feet, has a cast iron lining $1\frac{1}{2}''$ thick throughout for a length of 15′ 0″. This eliminates any danger due to percolation and abrasion. The upstream edge of this cast iron lining is provided with a broad machine-faced flange receiving an emergency shutter (described below) for closing the vent to admit of easy inspection or repairs to the lining, the main gate or rollers and guides.

Downstream of the gate, the vent is lined with cutstone for a length of about 28 feet with squared coursed rubble masonry beyond that, and has a concrete arched roof. The floor slopes towards the rear on a 1 in 15 gradient from a point 5 feet behind the gate, giving a smooth discharge at all heads. Thus the escaping stream is supported and cannot fall below its natural free parabolic path. If a stream springs clear of the floor eddies will form under the main stream and tend to cause erosion at the foot of the walls. If the floor is kept level, backing up restricts the discharge which becomes more pronounced as the floor is raised above the natural free path line. On account of the high velocity of the discharge, the jet does not fan out immediately on its exit from the vent. but is seen to penetrate the water standing in rear of the dam causing it, as it nears the baffle wall, to boil up to a considerable height.

The original proposal was to line the whole of the vents with cutstone both in the floor and the sides. The length of this special lining was, however, limited to 28 feet, as mentioned above, to resist erosion immediately behind the gates where the turmoil would be greatest.

The original design of the vents allowed for a flat roof in rear of the gates. This flat roof would have had the disadvantage of being struck by the water as it emerged from the sluice with the likelihood of its causing a vacuum in the space behind the gates which would set up water-hammer action and cause severe 'chattering' of the gate. To prevent a partial vacuum, air vents were provided in rear at +770 level to connect the dry wells, and, by making the roof semi-circular, these defects were avoided as water could never reach the roof, and air could enter freely also from the rear of the vent.

The cast iron roof of the front of the tunnel had a relieving arch built over the top so as to limit the load coming directly on the lining, even though it could safely take a load of about $1\frac{1}{4}$ tons per square foot.

The section of the dam at both the low and high-level sluices has been increased both in front and rear. In front it is modified for providing the bell-mouth entrance to the sluice and also to provide a straight path for emergency gate. In rear the width of section is increased to compensate for the reduction of masonry due to wells and vents and thus maintain the stability of the dam in the sluice sections.

Design of emergency shutters.—The emergency shutter for the low-level sluices is constructed on a somewhat novel principle, and consists essentially of a number of large hollow steel rollers mounted on bearings in a rigid steel frame of such dimensions that the rollers completely close the entrance to the sluice vent. The rollers which are $14\frac{1}{2}''$ in diameter are mounted at $15\frac{1}{2}''$ centres so that they are not in contact with one another but are free to roll independently when they come in contact with roller paths down which the whole gate slides, or when in contact with the machined cast-iron sides of the sluice entrance. The parallel space between the rollers are closed by smaller free rollers of the same length but of 4″ diameter only. Small roller stops attached to the side frames are provided to prevent these staunching rollers falling out of position but, at the same time, permit them to have free play within certain limits. Thus, when the gate is subjected to water pressure on the upstream side the small rollers are forced into close contact with the main rollers. Being truly cylindrical and machined to a fine smooth finish, each staunching roller makes a line contact between adjacent main rollers and effectively seals the gap between them. When the main rollers rotate while raising or lowering the gate the small free rollers naturally rotate with them but in the opposite direction. The friction when raising or lowering the gate, even under high water pressures, is thus almost negligible, for every part of the gate is a free roller in itself. The massive steel frame in which the rollers are mounted does not make contact with the face of the dam but serves merely as a carriage for maintaining the rollers in their true relative positions.

A certain amount of end clearance between the rollers and the side frames is inevitable and here most of the leakage through the gate occurs, but, to reduce this as far as possible, specially shaped flexible phospor-bronze staunching strips are mounted on either side of the frame so that, under high pressure, a seal is created on either side of the gate. When in its lowered position the bottom roller of the gate makes contact with the machined cill of the sluice entrance, while one or more of the top rollers make similar contact with the lintel or top of the sluice frame, thus closing the entrance effectively. For this type of gate to remain efficient it is essential that the rollers be kept scrupulously clean. If they are permitted to become rusted or pitted, leakage will occur between the rollers, but as an emergency gate, as its name implies, is used only for short periods while painting or repairs are being carried out to the main sluice gate which it temporarily replaces, it need never be in use for long periods. It may be remarked that the three bottom rollers of the gate are made of special toughened steel to resist abrasion.

For the protection of the gate when not in use it is housed at the end of the dam in a special shutter house. It has been found that the emergency shutters lose some of their efficiency when the machined face of the sluice entrance becomes foul and uneven. There is a tendency for small fresh water barnacles to form in clusters on the face of the casting and unless these are removed they tend to hold the emergency shutter away from the face and thus permit considerable leakage at the sides and top of the vent. In practice these barnacles are crushed and loosened from the face when the shutter is raised and lowered a few times, but it would be better if a scraper-frame were designed and used for scraping the faces clean before the emergency shutter is lowered. The growth of these barnacles was never suspected at the time the shutters were ordered and no provision was made for cleaning the machined faces of the castings.

The low level emergency shutter weighs about 15 tons. The high-level shutter which is similar in design but considerably larger, weighs about 20 tons. The dimensions of the former are 20 ft. × $9\frac{1}{4}$ ft. overall, while the latter measures about 23 ft. × $12\frac{3}{4}$ ft.

Both shutters are operated by the 50-ton electrically operated Goliath Crane which runs on the top of the dam, and which is described elsewhere. The emergency shutters are kept on special bogie trucks which run on rails between the shutter houses and the sites of the sluices.

High level sluices.—The high level sluices consist of 8 vents, each 10′ 6″ wide and 16′ high located at 32′ centres with cill level at +720. These are located between L.S. 4,647 feet and 4,903 feet and occupy a length of 256 feet of the dam. Each gate is fitted with a mild steel free roller culvert sluice gate measuring 16′ 6″ deep × 13′ 1″ overall, with side rollers, rocking paths and staunching seals similar to those provided for the low level sluice gates. The gate is made to fit into a hollow cast iron sluice frame with protected side grooves. The cill, lintel, and extension frames for the side grooves are all machine faced. The total height of the cast iron grooves is 29 feet. The counter balance and the gearing arrangement are all similar to those of the low level sluice gates but larger. The weight of each gate is 10 tons.

The general arrangement of the gates and their construction is similar to that of the low level sluice gates. The only difference is that the upstream sides and floors of the vents are not lined with cast iron between the main frame and the frame on which the emergency shutter rolls, but are constructed of massive cutstone blocks. The roof has a deeply ribbed cast iron lintel constructed in three sections, over which the masonry has been built in the form of a relieving arch to reduce the pressure on the lintel.

The rear of each vent is lined with cutstone 16″ to 18″ thick, both for the floor and the sides, for the full length. The roof is semicircular and is built of pre-cast arch blocks. Cutstone lining was provided for the full length as these sluices are expected to operate for 150 days in a normal year as against six days only assumed for the low level sluices. The cross-section of the dam at the sluices has been increased in front and rear for reasons already described.

These sluices are required to discharge 25,000 cusecs under a 50 feet head, but they could discharge very nearly 48,000 cusecs in times of emergency, i.e., during abnormal flood. The channel, however, is not designed to carry such a discharge and the banks lower down the channel would be overtopped if such a discharge were permitted.

The site of the high level sluices is an excellent one. There is a fine bed of gently sloping rock for nearly 100 feet width behind the sluices. Water cascades down this rock and there is no fear of retrogression for many years to come. No water cushion is required just behind the sluices for dissipating the energy of water which emerges at velocities up to 50 feet per second. A ' fault ' in the rock at the foot of the cascade automatically serves as a natural water cushion without any probability of the bed of hard rock cutting back. The foundations of the side walls of the channel are carried deep at this point and well protected with the masonry flooring to prevent any possibility of their being undermined.

Emergency gate for high level sluices.—The emergency gate is similar to that used for the low level sluice but is much larger, the weight of the gate being nearly 20 tons. As in the case of low level sluices roller paths of smooth pre-cast concrete blocks have been built into the face from the cast iron frame to the parapet level. The emergency shutter runs between the side grooves which extend from top of parapet to the cill of the gate and cannot therefore be displaced when raising or lowering. The pressure on the roller path is very slight.

The roller path blocks were pre-cast face downwards on smooth steel plates and have a hard fine grained surface. Abrasion of the emergency shutter rollers is thus minimised.

Emergency shutter houses.—To store the emergency gates when not in use, shutter houses have been constructed at either flank of the dam. The walls of these buildings are entirely of dressed stone. The circular veranda pillars are cast in concrete and reinforced concrete lintels support the roofs which are of concrete slabs laid over steel joists. Reinforced concrete Chajjas or sunshades project all round each building which presents neat appearance. Each house consists of a central room 30′ × 20′ for storing the emergency shutter and two side rooms each 12′ × 14′ 0″. One room is available as a retiring room for visitors and has a bath room attached, while the other is used as an office room and is equipped with a telephone. The central room is fitted with a collapsible steel gate 16′ 0″ wide and 12′ 0″ high.

The shutter house at the left flank of the dam has been somewhat modified internally as the permanent tramway from the Railway station crosses over the rear part of the building, the slope of the hill at that flank being very steep.

CHAPTER XIX

The Mettur Hydro-Electric Project.

Foreword.—The Mettur Hydro-Electric Project forms part of a comprehensive scheme for the gradual electrification of the Madras Presidency and for the provision of cheap electric power facilities similar to those met with in progressive countries in other parts of the world.

The general layout of the projected Madras Grid is shown on the facing page.

This national scheme provides for the division of the Presidency into nine power areas as follows :—

Mettur.	Pykara.	Vizagapatam.
Madras.	Papanasam.	Bezwada.
Anantapur.	Periyar.	Lammasingi.

The Madras and Pykara Power areas exist, but have to be further developed; the Mettur Power area is now started by the construction of the Mettur Hydro-Electric System, while proposals are to be submitted for forming the remaining power areas, except possibly Periyar, within the next five years.

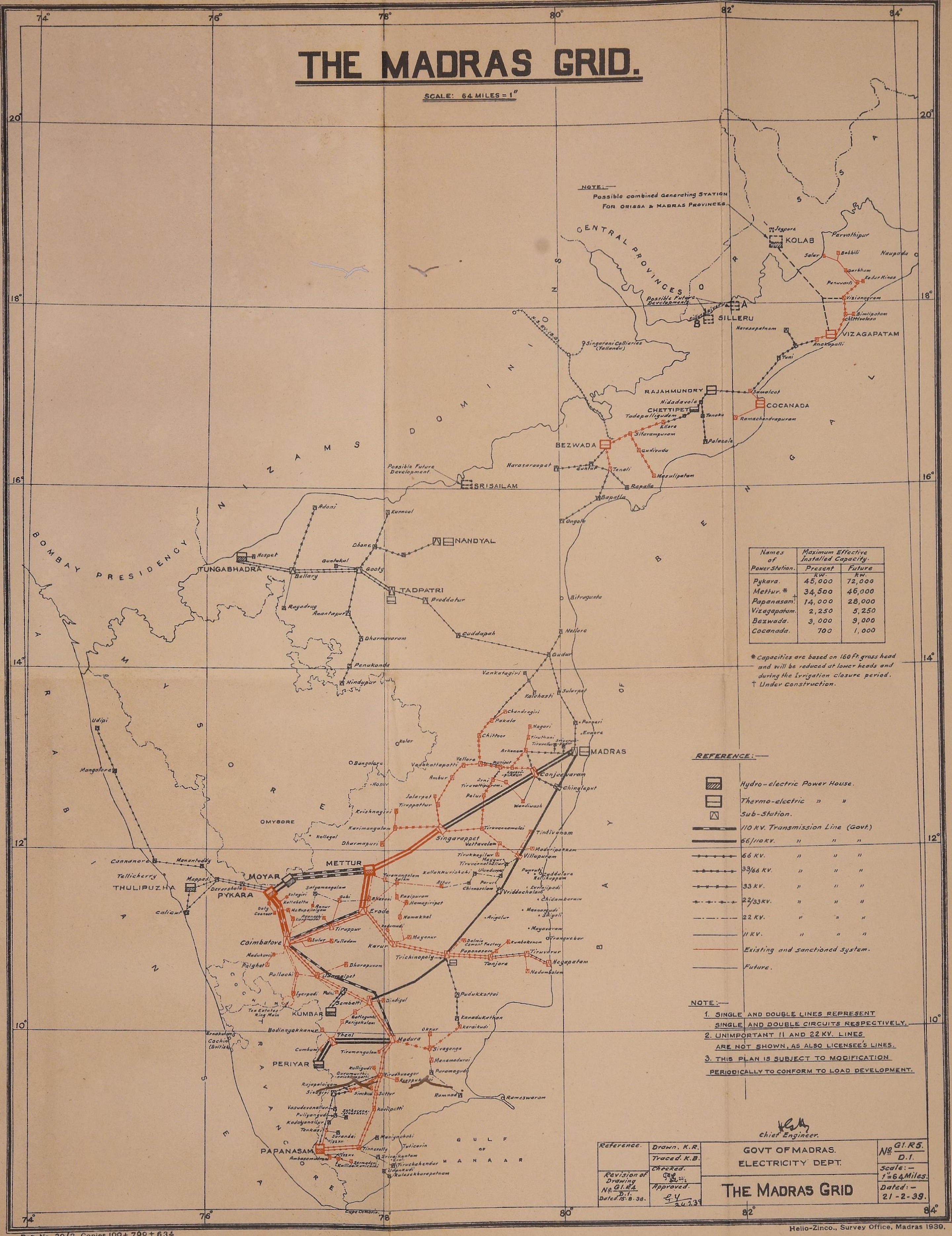
Certain of the power areas will operate together and there will be an interchange of power between stations to conform to load and water conditions, so that each generating plant may be operated to the best advantage.

This pamphlet deals with the Mettur Hydro-Electric Power Project only.

The scheme.—The Mettur Dam, one of the largest structures of its kind in the world, is 176 feet high and can impound a total of 93,500 m.c.ft. of water. This storage is primarily for irrigation purposes, but the water let down for irrigation is also to be utilized to the best advantage for the generation of hydro-electric power. During the construction of the dam, 4 pipes 8·5 feet in diameter were built into the structure and equipped with the necessary valves, gates, screens, and other fittings. The function of these pipes was for surplussing from the reservoir during the latter part of the construction period, and for power generation afterwards. The total cost of this hydraulic installation was Rs. 10,80,00C and the amount is debited to the Hydro-Electric Scheme and included in the estimates. On opposite page a photograph of the four hydraulic pipes discharging, is shown; and each represents about 16,000

THE MADRAS GRID.

SCALE: 64 MILES = 1"



Names of Power Station.	Maximum Effective Installed Capacity.	
	Present kw.	Future kw.
Pykara.	45,000	72,000
Mettur.*	34,500	46,000
Papanasam.†	14,000	28,000
Vizagapatam.	2,250	5,250
Bezwada.	3,000	9,000
Cocanada.	700	1,000

* Capacities are based on 160 ft. gross head and will be reduced at lower heads and during the Irrigation closure period.
† Under Construction.

REFERENCE:—

- Hydro-electric Power House.
- Thermo-electric " "
- Sub-Station.
- 110 KV. Transmission Line (Govt.)
- 66/110 KV. " " "
- 66 KV. " " "
- 33/66 KV. " " "
- 33 KV. " " "
- 22/33 KV. " " "
- 22 KV. " " "
- 11 KV. " " "
- Existing and sanctioned system.
- Future.

NOTE:—
1. SINGLE AND DOUBLE LINES REPRESENT SINGLE AND DOUBLE CIRCUITS RESPECTIVELY.
2. UNIMPORTANT 11 AND 22 KV. LINES ARE NOT SHOWN, AS ALSO LICENSEE'S LINES.
3. THIS PLAN IS SUBJECT TO MODIFICATION PERIODICALLY TO CONFORM TO LOAD DEVELOPMENT.

Chief Engineer.

Reference.	Drawn. K.R.	GOVT OF MADRAS. ELECTRICITY DEPT.	Nº G1.R5. D.1.
	Traced. K.B.		Scale:— 1"=64 Miles.
Revision of Drawing Nº G1.R4 D.1. Dated 15.8.38.	Checked.	THE MADRAS GRID	Dated:— 21-2-39.
	Approved.		

Reg. No. 30/2 Copies 100+ 700+ 634
Helio-Zinco., Survey Office, Madras 1939.

PLATE No. XLVIII.

HYDRO-ELECTRIC PIPES (DISCHARGING).

horse-power awaiting development. Each pipe is designed to discharge a maximum of 1,250 cusecs for power purposes.

The operating head will vary from a gross maximum head of 160 feet at full reservoir level to a minimum gross head of 60 feet. The average gross head will be 135 feet. Under such water conditions a minimum demand of 19,200 horse-power or 7,680 horse-power continuous may be met without the assistance of other plants. It is under these conditions that the commercial prospects of the scheme are judged. By operating Mettur in conjunction with Pykara or an auxiliary steam plant, higher demands for power may be met. Short-time assistance from Pykara or an auxiliary steam plant is necessitated for greater outputs by the fact that the storage is essentially for irrigation purposes and the power plant can use only the water let down for irrigation, which is an enormously varying quantity; whereas for power purposes, continuity of supply is essential. Not more than 1,000 cusecs will be available during the irrigation closure season. When the possibility of generating hydro-electric power was first considered—and pipes provided in the dam—it was the intention of the authorities responsible to change the crop season in the new area to be supplied so that among other advantages a continuous supply may be available for power purposes. This however was not finally accepted by the Government and the scheme as now designed assumes that the same seasons will be adhered to in the new as well as the old area. The following figures give an approximate idea of the maximum output under varying conditions :—

	PEAK HORSE-POWER.	BASE HORSE-POWER.
Mettur alone with no restriction in irrigation ..	19,000	7,700
Mettur alone with limited restriction in irrigation about twice in 15 years	19,000	13,000
Mettur with Pykara (present installation only). No restriction of irrigation	23,000	9,500 to 12,000
Mettur with Madras and/or an auxiliary Steam Plant	45,000	24,000

In an emergency as much as 60,000 horse-power might be generated under certain water conditions.

A normal feature of the scheme will be the availability of what is called secondary and tertiary power as contrasted to the primary power which should be available for all time. The secondary power will be restricted only in the dry years and tertiary power would be available for eight months in the year.

The restriction on irrigation is explained in the Mettur Hydro-Electric Project Report. For a comparatively small restriction of irrigation flow of a few weeks twice in 15 years, the reservoir working tables could be so modified as to increase appreciably the potential power output and the earning power of the project. The present scheme does not, however, contemplate any restriction in the irrigation flow for power purposes, but is based upon the minimum output and least favourable conditions.

Power plant.—It is proposed to install four double horizontal Francis turbo-generator sets of 16,000 horse-power each, one of which will be spare. Only three units are to be provided at first, and the fourth will be added later, when load conditions justify the additional generating capacity.

The original scheme included four single vertical units of 13,000 horse-power each but the Consulting Engineers to the Secretary of State for India preferred the arrangement outlined above and their recommendation was adopted. The plant when completed will thus be capable of a maximum output of 64,000 horse-power.

The generators will operate at 11,000 volts, 50 cycles, having a normal rating of 12,500 K.V.A. each. They will be specially designed for transmitting power eventually to Madras and be equipped with a modern quick response excitation system.

The power-house building will be about 317 feet long by 46 feet broad of simple design to harmonize with the dam structure.

The transformer station is to be of the outdoor type similar to that at Pykara and will be designed to operate at 66,000 volts initially and 110,000 volts eventually. The transformer units will be of the same capacity as the generators.

Transmission system.—Two 66/110 K.V. circuits on steel towers will be constructed to a point near Singarappet 64 miles from Mettur and form a section of the future trunk lines connecting Mettur and Madras.

From the above terminal a single circuit 66 K.V. line will be constructed to Vellore via Ambur while another line at 33 K.V., will go ultimately to Vellore via Polur and Arni, thus constituting an extensive high voltage ring main around the Javadi Hills. A 66 K.V. line is also to be constructed from the same point to Villupuram to supply the area served by the South Arcot Electricity Distribution Company which includes the towns of Cuddalore, Villupuram, Chidambaram and several important villages. It will be possible to supply from this extension, also Pondicherry which appears to have good load possibilities.

A double circuit 66/110 K.V. line between Mettur and Erode will be provided for operating in parallel with the Pykara System and for supplying the Trichinopoly and Tanjore districts.

Special arrangements are to be made at Erode Receiving Station for synchronizing the two systems together.

The Trichinopoly-Negapatam transmission system is already constructed and is now in operation. This system forms a natural part of the Mettur Scheme although till the Mettur Station is in service, the power-supply will be from Pykara. The amount of energy which can be transmitted satisfactorily to those areas from Pykara is limited, so that it is highly important for those districts to be supplied from Mettur as soon as possible.

There are two 66 K.V. circuits from Erode to Tanjore 112 miles long and a single 66 K.V. circuit of 50 miles from Tanjore to Negapatam. A 33 K.V. line 16 miles long supplies Papanasam and Kumbakonam from Tanjore. The important loads of the Negapatam Rolling Mills, the Golden Rock Workshops of the South Indian Railway, the Trichinopoly-Srirangam Electric Supply Corporation, and the East Tanjore Electric Supply Corporation, are being supplied from these lines.

This transmission system is of particular interest as power is transmitted direct at 66 K.V. from Pykara to Negapatam, a distance of about 270 miles. This is unusually long and believed to be one of the few examples on record of direct transmission of 4,000 K.V.A. at 66,000 volts. Interesting relay stability and regulation problems were involved. The stabilizing equipment is installed at Trichinopoly and consists of two 2,500 K.V.A. specially designed synchronous condensers with voltage regulators capable of adjusting the speed of exitation response.

The total cost of this complete system is around Rs. 46·5 lakhs which is to be debited to the Mettur Scheme as soon as it is transferred. This expenditure has already been included in the project estimates. As soon as Pykara is relieved of the load at Trichinopoly and Negapatam, it is proposed to transmit power to Madura in a similar manner and when the demand for power at that place reaches a certain limit the Periyar Hydro-Electric Project should be taken in hand.

The Erode-Salem System was the first Electricity Distribution Scheme started by the department. The system was constructed at a total cost of Rs. 4·3 lakhs in 1931 and until Pykara power was available, purchased electricity from the Mysore Government. It is proposed to transfer this property to the Mettur Scheme as being nearer it can be more economically supplied from Mettur than Pykara. The total cost of the system is to be debited to Mettur and has been included in the estimates for the project.

A summary of the approximate mileage of transmission and distribution lines included in the project is—

		MILES.
110,000 volts lines	double circuit	99
66,000 ,,	,,	112
66,000 ,,	single circuit	200
33,000 ,,	,,	145
22,000 ,,	,,	90
11,000 ,,	,,	150

Sub-stations.—One of the features of this scheme is the rural distribution system at 66,000 and 33,000 volts mainly in the North Arcot area. In many cases distribution is to be effected direct from the high voltage lines. For this purpose an economical and standard type of 66 K.V. transformer station has been designed, capacities ranging from 100—500 K.V.A.

The sub-stations contemplated in the scheme are as follows :—

Receiving and transforming stations at Erode, Singarappet, Trichinopoly and Negapatam, with stations of lesser importance at Tiruvarur, Tanjore, Papanasam, Karur, Villupuram, Vellore and Tiruvannamalai. Smaller transformer stations are to be located at Tiruppattur, Ambur, Vadakattapatti, etc.

Districts served.—The districts to be served are North and South Arcot, Chittoor, Salem, Trichinopoly, Tanjore and later Chingleput and Madras. Generally speaking all towns and villages in the above districts will be given an electric supply whenever the demand is sufficient to justify the investment in lines and transformers.

Demand for power.—The estimates of load and revenue are based on the actual requirements of the various licensees who have agreed to take a power-supply, on the results already achieved in the Pykara area, and the experience of the Mysore and the United Provinces Hydro-Electric Undertakings. Particular attention is to be paid to agricultural requirements for which the area to be served holds out great promise. In the Coimbatore district alone, in less than two years, over 1,000 horse-power in pumps are already connected or agreements signed, and the development of this class of load is, as yet, only in its preliminary stage. Boring for water in a systematic manner, as in the United Provinces, is being advocated for those areas where water is scarce.

In order to speed up development beyond that contemplated in the estimates, proposals for starting certain specialized industries, at or near Mettur, have been suggested in the project report.

Generally speaking the load situation is even more favourable to-day than when the estimates were prepared. There have been important enquiries for future power services from various parts of the area included in the scheme. New sugar factories are to be established and textile mills of various types are projected at Salem, Karur, Trichinopoly and Tanjore, so that taken in all the commercial outlook is promising.

Tariffs.—The rates for electricity throughout the whole area will not be higher than those prevailing in the Pykara system at present. An effort will be made to maintain similar tariffs in both power areas.

Financial.—The total expenditure on the scheme is estimated to be as follows :—

Initial.	Within ten years.	Total.
	(In Lakhs of Rupees.)	
138·648	53·952	192·600

but these figures do not represent actual cash outlay. Of the above, debit adjustments for works already constructed amount to Rs. 57·440 lakhs (Rs. 10·80 lakhs for hydraulic works), and approximately Rs. 2·00 lakhs for buildings, construction, plant and tools, etc., transferred at Mettur. This reduces the actual cash outlay for the initial works to about Rs. 81 lakhs.

The financial forecast for the tenth year of operation according to the Government formula for remunerative works results in a gross return of 11·4 per cent. If all interest deficits accumulated during the development period are capitalized and all operating expenses deducted, the net return is 7·9 per cent with a surplus of Rs. 2,88,800.

The latest estimates now submitted are in excess of those given in the Hydro-Electric Project Report by Rs. 10·60 lakhs or nearly 6 per cent. The increase is due to the higher cost of the power plant on account of the adoption of certain recommendations of the Consulting Engineers to the Secretary of State for India and an allowance, in some cases, for the higher prices of plant and machinery over those of 18 months ago, when the project estimates were prepared. The estimates are now believed to be on the conservative side, i.e., the expenditure is expected to be slightly below the estimated cost, while the revenue anticipated should be easily reached if normal business conditions continue. A safety margin is considered justified in development schemes of this nature where the greater part of the cost of production is due to fixed charges, and the risk of over-capitalization must be carefully guarded against.

The scheme is attractive being both technically and economically sound; it possesses greater revenue potentialities than can be judged by the financial forecast, since the latter is not based on the maximum power output.

The work on the foundations of the power plant and surveys of transmission lines was commenced in April 1935 and it is hoped that the whole scheme will be in commercial operation within $2\frac{1}{4}$ years.

Products of Indian origin will be used wherever possible and it is proposed to start the manufacture of certain equipment and fittings for transmission lines and sub-stations at the Mettur Workshops.

CHAPTER XX

Gauging Operations at Headworks.

In order to ascertain the discharge from the various sluices in the reservoir and over the surplus works, gauging stations were set up during the construction of the dam both in the supply channel and in the river at Nattarmangalam, a village situated about $3\frac{1}{4}$ miles below the dam and about $\frac{1}{2}$ mile below the confluence of the surplus course with the Cauvery. Though the results of the gaugings revealed slight changes from year to year they proved of much value in regulating the supplies let down the river. Some slight scouring of the bed of the supply channel may have caused some modification of the discharges at the gauge well, but since the drops above the site and the bed regulator below the site of the channel gauging station are unchanged the alteration in discharge for any gauge reading must be too small to be of any consequence.

In the case of the river gauging station at Nattarmangalam however, it is clear that the original gaugings are now entirely unreliable. The reason for this is that since the surplus course first came into operation during the flood season of 1934, an enormous quantity of material has been washed down from the bed of the natural surplus course and, since that course enters the main stream at right angles, a very large shoal has been thrown up immediately below the confluence, and is of such a size that it covers more than half the width of the original river bed. The tendency is, therefore, for the course of the main stream to be deflected towards the right bank and this will become more and more pronounced as the floods during a succession of years bring more scoured material down the surplus course and deposit it in the river bed.

The maximum flow in the original river bed above its junction with the surplus course can now only be that due to the combined discharge of the irrigation sluices and the hydro-electric pipes, and may never exceed 35 to 40 thousand cusecs, while the flow in the surplus course may be anything up to 400,000 cusecs.

The original river between the dam and the junction has thus become a minor stream, while the surplus course is the major one. The right-angle junction of that stream with the river must eventually cause the river to change its course below that point and an S bend will be created. After the gauging operations of 1934 it was observed that the shoal thrown up below the mouth of the surplus course had considerably affected the flow of the stream at the Nattarmangalam gauging site, since the normal course of the stream was thereby deflected, and gauging operations at that site were therefore discontinued, the results being too unreliable and variable to be of any value.

A description of the gauging operations as actually carried out may, nevertheless, be of interest.

The river at the Nattarmangalam site had a fairly straight course and was comparatively free from rocky obstructions, the bed being tolerably level. At no other site in the river bed near Mettur were conditions suitable for the erection of a gauging station for measuring the velocity of flow.

At this place, therefore, where the bed of the river is 1,020 feet wide, two lines of steel cable of $\frac{5}{8}''$ and $\frac{3}{8}''$ diameter respectively were stretched across the river. They were supported on either bank on steel trestles fitted with pulleys and winches so that the tension on the cables could be adjusted as required.

These two cables were utilized for marking the observation points at regular distances from one bank to the other and for securing the gauging boats carrying the measuring apparatus. About 50 feet downstream of these cables another $\frac{3}{8}''$ cable was stretched. This cable was used for steadying the boats at the observation points. On investigation it was found that the $\frac{5}{8}''$ cable intended for securing the boats was not strong enough to withstand the pull of a boat carrying the observer and coolies with a maximum stream velocity due to a flood equivalent to that of 1924. This cable was therefore replaced during August 1934 by another $1\frac{1}{8}''$ diameter. The trestles were also shifted to higher ground on either side so that the lowest point of the wire with the required sag would be well above the maximum flood level at the site.

Two gauge posts with zeros at 611·71, capable of being read up to 25 feet, were fixed 500 feet above and below the gauging station. The surface fall at the site was measured from these gauges and varied from 0·1 to 0·4 according to the intensity of the flood. As the gaugings were required only temporarily till the correct values of discharge co-efficients through the surplus sluices could be ascertained, construction of proper gauge wells and fixing of automatic gauge recorders, etc., were not deemed necessary. The discharge in the river was calibrated with reference to the average of the readings on these gauges. The discharge curves were plotted for each set of observations.

Velocities were observed by current meter at 50 feet interval across the full width of the river. Up to 15 feet in depth, discharges were calculated on actual soundings taken each day. For depths above 15 feet they were arrived at from the readings on the gauges.

Cross-sections of the river at the site were also taken at the beginning of each season. As the bed is generally of a rocky nature, very little change in bed levels was observed. Two jolly-boats fastened together and towed on the main cable across the river by a man working on a cradle suspended from the cable were used by the observer to take his meter gaugings. A Price current meter fitted with two fish weights of 17 lbs. each was suspended from the boat by a $\frac{1}{8}''$ steel flexible wire. Velocity at 0·6 depth was observed at each station. For velocities up to 2 feet per second, two observations of 90 seconds each were made, while for velocities above 2 feet, about 150 revolutions were counted. The gauging staff usually consisted of an observer, a boatman for controlling the boat, two coolies for steadying the boat on the observation line and one coolie stationed in a cradle to tow the boat on the main cable across the river, to the various stations. The daily observations generally lasted from 7-30 a.m. to 11 a.m. Observations were taken by this method for all depths up to 17·5 feet on the gauge.

This depth corresponds to a discharge of 150,000 cusecs with an average velocity of 6 feet per second. At some stations the velocity was as high as 8 feet per second. For stages above this, observations would have to be done from the cradle with rigid rod suspension for the meter. There was, however, no occasion to resort to this method in the river though necessary tackle was provided for such emergency at the gauging site. No correction for the deflection of the current meter from the vertical was made for the velocities arrived at and owing to the tendency of the meter to rise when velocities were high, it is probable that the velocities were all too high for gaugings when the depth exceeded 10 feet or so. So, as is the case of all large rapidly flowing streams, the results of gauging for the higher discharges cannot be accepted as reliable. An abstract of gauging operations conducted during the years 1929–1933 is attached :—

Period of gaugings.	Number of observations made.	Range of gauge readings at Nattarmangalam gauge.	Discharge in cusecs.	Remarks.
March–December 1929.	128	1·30 to 11·62	983 to 61,529	The maximum flood was recorded on 7th July 1927.
June–November 1930.	137	2·40 to 15·15	1,747 to 1,09,358	The maximum flood was recorded on 9th August 1930.

Period of gaugings.	Number of observations made.	Range of gauge readings at Nattarmangalam gauge.	Discharge in cusecs.	Remarks.
May–August 1931 ..	113	2·10 to 17·35	1,399 to 151,507	The maximum flood was recorded on 18th August 1931.
July–November 1932.	99	5·10 to 16·80	10,332 to 127,937	The maximum flood was recorded on 29th August 1932.
July–December 1933.	144	2·58 to 17·10	1,716 to 127,565	The maximum flood was recorded on 4th August 1933.

Usually the current was strong towards the right margin between stations 600 feet to 950 feet measured from the left margin. The maximum velocity recorded during these gaugings was 7·6 feet per second, and it may be realized, therefore, that the gauging work was frequently of a hazardous nature.

The river gaugings at this site were useful for determining the discharge through the hydro-electric pipes. Conditions, however, were never sufficiently favourable for arriving at any really satisfactory results.

Gauging of the supply channel.—The combined supply channel from the low level and high level sluices consists of channel of uniform section with bottom width 142 feet and with side slopes of 1 : 1. The bed is rocky and the sides are revetted. To ascertain the discharge co-efficient for these sluices, gaugings were conducted in the channel from 1932 onward. The supply channel was gauged from 11/32 to 1/33 at a site near the water cushion below the drop adjoining the Park Bridge.

Forty-two observations were made for depths from 1·30 to 4·75 in the channel. For these two depths the calculated discharge came to 269 and 4,182 cusecs the mean velocity being 1·43 and 6·15 feet per second respectively. As this site was found to be too near the cushion below the drop a new site opposite the gauge well, where a much steadier flow was available, was chosen and necessary cables were fixed during January 1934. Forty-eight observations were made for depths varying from 2·0 to 5·7 feet on the channel well gauge. The calculated discharge for these depths were 450 cusecs and 5,310 cusecs respectively. The maximum velocity observed was 7·0 feet per second. For greater depths it was found impossible to

GAUGING OPERATIONS IN SUPPLY CHANNEL.

take velocity observations from the boat as it was liable to sink. A cradle was fitted up to the wire rope and the meter was suspended by a cable from the cradle and observations were continued for higher stages.

It was now noticed that, due to high velocity in the channel, the deflection of the cable was so much that the meter must have been riding higher than at 0·6 d. thus registering an unduly high velocity; the calculated discharges being therefore considerably exaggerated. From further observations it was found that an error of 7·4 per cent would result on account of this deflection of the cable for a depth of 6·2 feet. Series of fresh observations were taken applying the required corrections for this cable deflection. For stages above 6·2 on the gauge the meter was suspended from the cable by a rigid rod and observations were continued up to a stage of 7·2 feet on the gauge. The discharge for this gauge reading 8,305 cusecs, the velocity being 8·20 feet per second. From observations made it was possible to obtain somewhat roughly the value of the co-efficient for discharges through the high level and low level sluices. A mean value of 0·7 is now adopted for the discharge co-efficient pending further observations.

The discharge curve for the various readings of the channel gauge was plotted and is in regular use for regulating the discharge to the delta.

CHAPTER XXI

Demarcation of Water-spread of Full Reservoir Level.

The demarcation of the water-spread of the reservoir had been carried out during the preliminary investigation of the project in order that the amount of land acquisition required could be estimated and provided for in the original project estimate.

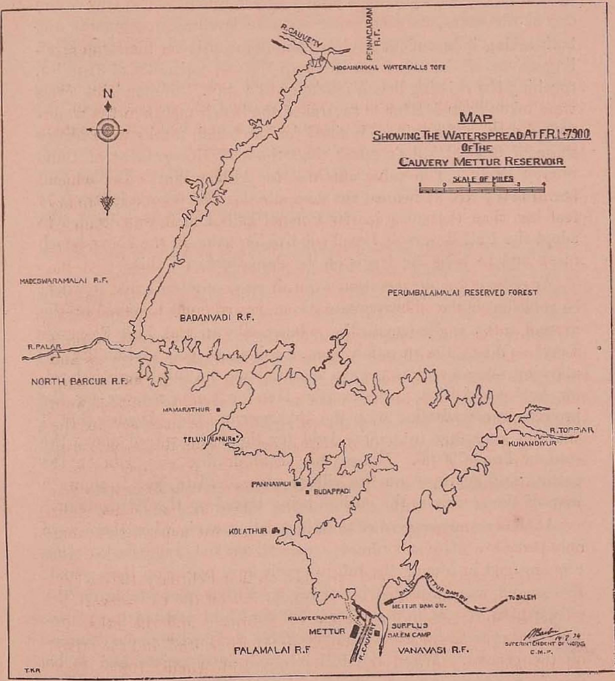
As a result of the Mysore-Madras Arbitration case which permitted a greater capacity for the reservoir, and the extraordinary floods of 1924 which led to the shifting of the site of the dam, it became necessary to raise the full reservoir level from +785 to +790. The raising of the Full Reservoir Level necessitated the fresh demarcation of the water-spread area, for determining the limits of the submersible area and the additional lands to be acquired.

Staff.—For the demarcation of the new Full Reservoir Level a special subdivision with one Assistant Engineer, four surveyors and twelve lascars was sanctioned by Government for a period of eight months. Three peons and one clerk for the Assistant Engineer were also sanctioned for the same period. To ensure accuracy in the obviously important work of demarcating the Full Reservoir Level it was represented that it would be desirable to post supervisors of the department in place of the surveyors who were to be entertained temporarily for the work. Two of the surveyors had joined duty early and in the place of the other two, two supervisors were appointed.

The subdivision came into existence on 2nd February 1927 when the Assistant Engineer assumed charge of it. Of the two surveyors, one joined duty about the middle of February and the other in April. One of the supervisors joined on 8th June 1927 and the other was available for out-door work only from 10th August 1927. Due to this delay in getting the full sanctioned strength of the establishment, the Government accorded sanction for the continuance of the subdivision for a further period of six months, thus extending the life of the subdivision up to 2nd April 1928. But all the out-door work was completed by 21st December 1927 and one supervisor and the two surveyors were dispensed with on the same day. The office work such as the preparation of the water-spread area map, etc., was completed and the subdivision was abolished from 26th January 1928, i.e., more than two months earlier.

The surveyors were passed upper subordinates of the College of Engineering and were subsequently appointed as supervisors in the Public Works Department.

PLATE No. L.



Details of work.—Detailed survey and contour of the Project Headworks was prepared at the commencement of the project by the Government of India Survey Party. The values noted in these plans for the several bench marks on granite stones fixed in concrete were found to differ considerably from those obtained by Colonel Ellis's party when the bench mark stones were fixed during the investigation of the project and recorded in the project volumes. The datum of the levels of both the parties was said to be the same, viz., G.T.S. mean sea level. It was therefore considered desirable to ascertain which set of levels was the more reliable by connecting the bench marks with levels from the nearest G.T.S. bench mark at the

Erode railway station. So, before the demarcation work was commenced, fly levels were taken jointly by the Subdivisional Officer and one of the surveyors each using separate levelling instruments and both taking independent readings simultaneously on the same levelling staves, all the way from Erode to Mettur, a distance of 37 miles, touching the existing bench marks on the way. Similar joint levels were taken from Mettur to several of the bench marks in the water-spread area. The values obtained for the bench marks were nearer those of Colonel Ellis's party than those of Government of India Survey Party. The value obtained for Public Works Department bench mark No. 27 nearest the dam site was 659·48 and it was 0·74 feet less than that recorded by Colonel Ellis and it was decided to adopt the Full Reservoir Level subdivision value of the above bench mark and to base the levels of the dam works on this.

As regards the demarcation work, it was considered that it would be sufficient if the +790 contour alone was run and surveyed on the ground so as to demarcate the submersible area at Full Reservoir Level. When the question was raised about the advisability for allowing some margin for wave action above the full reservoir level, for land acquisition purposes, the Hon'ble Commissioner for the project, in consultation with the Engineer-in-Chief, decided that it was not necessary to acquire land for the water-spread above the contour line +790·00. Hence this contour line was run on the ground and surveyed on the village plans. Plate No. L shows a map of the reservoir, the outline being traced on the 790 contour.

At the commencement of the demarcation work, when there were only three executive subordinates, they all worked as one party. One was engaged in tracing the full reservoir level points on the ground, the second was employed in surveying with a plane-table on the village plan, the points so traced and the third assisted the plane-table surveyor to trace out and recognize the field boundary stones on the ground. When the full reservoir level points had to be traced on ground sloping in more than one direction, the assistance of the third man was required by the leveller also, as the untrained coolies could not intelligently move the staff as desired by the leveller for fixing the points on such sloping ground. When the fourth subordinate joined duty, two survey parties, each consisting of one supervisor and one surveyor, were formed so as to expedite the work.

To ensure accuracy in the work, the following procedure was adopted: Temporary bench marks were fixed at short intervals at about level + 790·00 close to the probable margin of the water-spread by joint fly levels, from the Public Works Department bench mark stones which had been fixed in concrete within the water-spread area at the time of the investigation of the project and whose values were, at the commencement of the full reservoir level work, accurately determined by connecting with the G.T.S. bench mark at Erode. The full reservoir level contour points were then traced on the ground carrying the levels from the above temporary bench marks and their positions were marked by small wooden pegs with small stone cairns round them. The cairns were whitewashed to make them prominent. The contour points were then surveyed directly on the printed village plans with a plane-table using, as far as possible, the field survey stones as the station points of the survey. Blue print copies of these village plans with the new full reservoir level contour marked thereon were taken, and these were supplied to the land acquisition officers for their guidance in effecting the early acquisition of the submersible lands.

The demarcation of the full reservoir level in the difficult portions of the reserve forest, especially in the reach between Hogainakal falls and the confluence of the Palar river with the Cauvery, a distance of 14 miles along the river, would have required considerable clearance of dense jungle growth. It was considered that the demarcation of the full reservoir level in such reserve forest areas where acquisition on payment was not required was of no particular importance and so it was not done. The full reservoir level contour in such areas was marked on the plans by interpolation from the contour plans prepared during the time of investigation of the project.

A map of the entire water-spread area from the dam site to the Hogainakal falls was finally prepared to a scale of 4 inches to the mile. The area of the water-spread at full reservoir level as computed from this plan is 59·25 square miles.

Nature and locality of the work and the health of the staff.—The out-door work was of an arduous nature since it lay in remote, unhealthy and difficult country adjoining reserve forests in many places. Suitable healthy camping places were not to be found close to the workspot. There were no recognized roads or cart-tracks or even foot-paths by means of which the workspot could be approached with the usual means of conveyance for instruments. The distances from the nearest camping place to the work sites ranged from 3 to 8 miles and, usually, the whole distance had to be traversed on foot. While working in the land around the Erumanur, hamlet of Nagamarai village in the Thoppiar valley, and in the Settipatti, hamlet of Kaveripuram village, the work was particularly arduous. But the health of none of the staff was seriously impaired as the parties happily consisted only of energetic and healthy young men.

CHAPTER XXII

Social Amenities at Headworks—The Headworks Club and Co-operative Stores.

Where a very large number of people are gathered together for the execution of a large work such as this, and where there are very few facilities for getting away from the spot for a number of years it is essential that both physical and mental recreation of the workers should be provided. The old saying " All work and no play." . . is as true in this case as in any other. Accordingly, the Headworks Committee, who had the entire control of the administration of the camps, permitted public entertainments to be given at Mettur at fairly frequent intervals, and the place was visited by circuses, cinema shows and other travelling entertainment parties. But, for the daily recreation of the headworks staff, a club was necessary and, through the generosity of the Government, a club building was provided. A brief description of its activities is given in the following pages. The opening of the Headworks Co-operative Stores also proved a very popular move for it not only provided the members with necessities but was instrumental in controlling the local bazaar prices.

The Mettur township was still in the making, when a few officers and the staff then on the spot, realizing that they were in for a long spell of unrelieved upcountry life, conceived the idea of creating a social centre which would afford relaxation and recreation to the employees after the day's toil. At a public meeting held on the 15th August 1926, the formation of a club was decided upon.

It was first proposed to be called the Mettur Project Club, but at the first committee meeting was re-named the ' Mettur Project Headworks Club.'

Owing to paucity of buildings in the village, the club was housed in the first instance in a very small one-roomed thatched hut at Thukkanampatti overlooking an open and level space which served as a playing field.

It was considered that a proper club building might, with the approval of Government, be provided at the expense of the project and on 10th January 1927, the Government, recognizing that a recreation club for the use of gazetted officers at Mettur was a necessity, sanctioned a sum of Rs. 2,590 towards the cost of the construction of a suitable building for the purpose, and at the same time called for proposals to provide similar amenities but on a suitable scale for the non-gazetted staff also. Exactly six months later, i.e., on 9th July 1927 Government were pleased to sanction Rs. 5,400 for a club building for the use of the non-gazetted officers at Headworks.

At a public meeting of the gazetted officers at Mettur on 21st August 1927, under the chairmanship of Mr. C. T. Mullings, the then Engineer-in-Chief, the gazetted officers with commendable self-sacrifice and a solicitude for the welfare of the more numerous but less happily circumstanced subordinate staff, resolved that the funds allotted for the Officers' club should be diverted for the equipment of the Mettur Project Headworks Club building which was already under construction, subject only to the proviso that two tennis courts should be provided near the officers' quarters for their use. Government having approved of this arrangement, a fully equipped building with two tennis courts, furniture, fixtures, etc., was soon made available for the ' Mettur Project Headworks Club ' which entered on a newer and brighter lease of life with the occupation of its new home on 19th November 1927.

The actual expenditure incurred on the club building and all tennis courts was Rs. 9,170 against the sanction of Rs. 8,990 but Government, on the recommendation of the Engineer-in-Chief, generously passed the excess.

The club was maintained largely by subscription from members. The only other sources of income to the club were dramatic entertainments by the members themselves and donations from members. The maximum strength of the club at any one time was 165.

The first " Club Day " was celebrated on 18th June 1927. Thereafter, the Club Day was annually held during the Pongal holidays in January. The Club Day was usually marked by the holding of tournaments in various games and sports, tea or light refreshments being provided to members and their friends, and a happy day finished off with the staging of some dramas or farces by the members of the club.

The Engineer-in-Chief was the patron of the club, while the president of the club was elected annually from among the officers at Headworks.

The club proved very popular, and the relaxation which it afforded must have contributed much to the cheerfulness with which the staff carried out their arduous duties year in and year out on what was perhaps the greatest work ever undertaken by the Public Works Department. Members of other departments stationed at Mettur also took a keen and active interest in the club. Some of the more important contractors were also admitted as members.

With the starting of work on the Hydro-Electric Scheme the Headworks Club has been revived and continues to provide the recreation so necessary to those whose duties rarely permit them to leave the place for a holiday.

Co-operative Stores.

The Co-operative Stores was constituted in about October 1926 with a view to provide the ordinary requirements of the project employees at reasonable rates. Membership was open to all Government employees to whatever department or category they belonged, e.g., Postal, Police, Revenue, Excise, etc., departments and also Government employees borne on the work-charged establishment of the project. The staff of the Government of Mysore Electrical department, stationed at Mettur, were also admitted under the special exemption of Government.

Management.—The management of the stores was vested in a body consisting of ten honorary directors elected from among the members from year to year.

The executive functions of the directorate consisted of control of purchases and sales, selection of markets and fixation of selling prices. The verification of stock, internal audit and such duties were delegated to sub-committees and individual directors.

Staff.—The paid staff varied according to the extent of business transacted, but for the most part consisted of a clerk, one or two salesmen for general stores and one salesman for petrol when a petrol pump was added to the business of the stores during 1930–31. A part-time checker and two to four boy assistants for weighing and packing goods were also employed. The part-time checker was a Government servant and his duties consisted in checking from day to day the entries in day-books, personal ledgers and stock ledgers with reference to the original bills.

General working.—The chief usefulness of the stores was the means it afforded of controlling market prices and the prevention of profiteering by local shopkeepers. The articles stocked consisted of all the usual requirements such as grain, groceries, oilman's stores, piecegoods, and petrol. That the stores grew in popularity from year to year is evidenced by the figures showing the increase in sales. This increase in sales permitted a reduction in sale prices and a corresponding decrease in the levy of profit on sales. The added profit on petrol sales was also contributory to the reduction of profits on sales. Sales of petrol to the general public were made regardless of the rules relating to membership; otherwise the installation of a petrol pump would not have been commercially possible.

Instances were known where the local bazaar rates for commodities immediately rose if the co-operative stores happened to run short. In principle, the stores differed little from those on large planting estates which regulate prices for their labour by keeping a stock of grain from which their labour may purchase if the local rates go against them.

Particulars of sales, profits, etc., are given in the table below for the years 1926–1933 :—

Year.	Total sales. Petrol.	Total sales. General stores.	Percentage rate of gross profit.	Cost of establishment and contingencies.
	RS.	RS.		RS.
1926–27 (nine months only).	..	5,421		210
1927–28	..	20,554		615
1928–29	..	45,782	$6\frac{1}{4}$	1,061
1929–30	..	48,554		1,073
1930–31	* 6,261	51,420		1,590
1931–32	15,095	68,891	5	2,271
1932–33	17,691	66,378	$4\frac{1}{2}$	2,482

* Petrol sales for five months only.

CHAPTER XXIII

Mettur—Its Industrial Potentialities.

The high efficiency obtained in the generation and transmission of electricity over long distances in recent years has, no doubt, made the choice of many industrial sites almost independent of the source of power supply. Nevertheless, the availability of cheap electric power and labour is still an important factor when determining the site for modern factories. In addition to being the source of supply of ample and cheap power, Mettur offers important facilities for industrial development. Among these are: the availability of ample water for industrial purposes, the proximity to cotton and groundnut growing areas, the existence of good communication and the promise of an ample supply of labour (proved only too well during the construction of the Mettur Dam). The combination of all these favourable factors should go very far to recommend the locality of an industrial centre.

Ample up-to-date accommodation exists in an attractive and healthy township and is available for the labour and the staff of an industrial concern, while the gravelly subsoil of the area is very suitable for the construction of buildings and factories. The large waterspread of the reservoir and the increased degree of humidity of the air is expected to prove favourable to the opening up of textile industries. Enquiries regarding local conditions have already been received from companies interested in these industries.

The bamboo forests in the hills in the vicinity of the lake and facilities for cheap water transport for the conveyance of bamboos to Mettur offer scope for the development of pulp or paper manufacture at that place. The local manufacture of alkalis and other allied chemicals may also become practicable as soon as cheap electric supply becomes available, and the hydrogenation of fats as substitutes for ghee, etc., utilizing the oil seeds grown locally, would be commercially possible for the same reason. The possibility of reviving the smelting of the iron ores in the Salem district may also be mentioned. The ores have a traditional reputation for high quality but the obstacle in the way of their extraction has, in the past, been due partly to the lack of a continuous and sufficient supply of cheap fuel. The availability of cheap power may justify the re-examination of the prospects of the production of iron in the district. Besides iron, there are very extensive deposits of some of the finest magnesite in the Salem district. This magnesite, when calcined, is considered the best in the world for the manufacture of composite floorings and other products employed in the building industry. On account of restricted demands for magnesium products in this country and the prohibitive tariffs imposed on its import into foreign countries, the deposits have not hitherto been worked to any large extent. But the introduction of pure fused magnesites into the commercial markets by Swiss manufacturers revives the prospects of the successful development of this industry in India.

The Director of Industries, Madras, is in a position to furnish detailed information regarding the prospects of developing industries at Mettur to all interested in the matter, and the foregoing remarks are intended to convey to the reader only a very brief sketch of the industrial potentialities of Mettur.

CHAPTER XXIV

A Note on Cavitation in Valves and Sluices.

It is well known that all iron and steel used in connexion with irrigation works is liable to rapid deterioration through corrosion unless well protected, and frequent inspection, scraping and painting are necessary if such works are to be properly maintained.

Such protective work presents few difficulties with regard to regulators and sluices in rivers and canals whose beds, for several months of the year, are more or less dry. In the case of a large dam, however, where it may never be possible to empty the reservoir, sluices situated at low levels may never be accessible for inspections or treatment unless very special equipment is provided.

In the Mettur Dam, emergency shutters have been provided for use with all the sluices which pierce the dam and, while these shutters admit of inspection and repairs to the main gates and their guides, they do not admit of examination of or repairs to the front part of the sluice linings or roller paths on which the emergency shutters operate. For this reason heavy cast iron frames and linings have been provided, as cast iron has the reputation of resisting corrosion far better than ordinary classes of steel. We know that cast iron water mains have a very long life, while cast iron piles, as used for piers and jetties, even when in contact with sea-water, offer high resistance to corrosion. However, under certain conditions, it is found that even cast iron can be very rapidly affected, and such conditions were found to exist at Mettur. The cast iron needle valves on the hydro-electric pipes in particular were found to have undergone very serious corrosion in the course of three or four years, and a very lively debate ensued as to the causes responsible for the very severe pitting which was taking place, particularly towards the downstream noses of these valves. It was held by some that this rapid deterioration was due to the use of inferior metal by the makers, but, since the cast iron used is shown to differ in no respect from that used by them in the construction of many similar works in other parts of the world, the reasons for this extraordinary behaviour of the castings had to be looked for elsewhere.

For two seasons after the hydro-electric pipes and needle valves had been installed they did not come into operation and remained closed. Thereafter, they were operated under low heads until 1938 when the height of the spillway in the dam had been raised to a level some 100 feet above the river bed. For constructional reasons it was inexpedient to operate the hydro-electric pipes on full throttle while the dam construction was in progress and they were generally throttled down for long periods in each season, the normal stream line through the valves thereby being modified. To eliminate water-hammer, however, the air valves situated at the rear end of the valves were kept partially open and it is evident that violent agitation of the water took place in and around the down-stream nose of the needles. Therein, it is believed lay the seat of the trouble, aggravated, to some extent at least, by the presence of gases or acids in the water due to decomposition of vegetable matter which had accumulated in the bed of the reservoir immediately upstream of the dam.

In the presence of acids in the water, corrosion or cavitation due to electrolytic action may be greatly accelerated, but much research work has yet to be done in this connexion. There seems little doubt that where a smoothly flowing stream is broken up and agitated, such action occurs. Now it first became evident that something unusual was taking place at Mettur, when, on opening the hydro-electric pipes after a long period of closure, it was seen that the rocks in the river bed in rear of the pipes became stained a bright-oranged colour and that there was a strong smell similar to that of sulphuretted hydrogen emanating from the water as it emerged from the dispersers on the ends of the pipes. This was also noticeable in the case of the low level sluices, which are situated only 30 feet higher in the dam than the hydro-electric pipes. This phenomenon, however, became so pronounced in the case of the latter that one of the pipes was shut down for a thorough examination. After lowering the emergency shutter and draining off the leakage water through the drain situated near the needle valve, it became possible to enter the pipe and examine it as well as the valve. The pipes were found to be in perfect condition and showed no sign of corrosion or pitting, but, on examination of the valve, it was found that the portions of the castings near the valve seatings and the downstream ends of the webs which support the central portion of the valve were very badly pitted. The pitting was in places so deep that portions of the heavy webs had been eaten away entirely. The makers' representative, with whom the examination was made, had apparently never before experienced such an extraordinary case. The matter was referred to the makers in Scotland and towards the end of 1934, the writer, while on home leave, took the opportunity of calling at their works and discussing the matter with the designers. While there, he also saw actual laboratory tests being carried out on metals to ascertain the causes of rapid corrosion or cavitation.

Experience elsewhere points to the fact that the valves in the dam at Mettur should have shown a much slower rate of deterioration. The fact that it has been so rapid points either to the design of the valve being unsuitable for operation on part throttle which, after all, is the normal function of a needle valve, or that the presence of acids in the water during the earlier years of the work was unusually high. Another matter which may possibly have some influence on the rate of cavitation is that of temperature. The normal water temperature in the Mettur reservoir is a little above 80° F. while in most other projects, particularly those in Europe or in the hills of India, a much lower mean temperature prevails.

Whatever the causes of local corrosion, we may at least learn one lesson and consider the matter when taking up the design of sluices in future works of this nature. The less iron is used in situations where water is subject to violent agitation and aeration the better, particularly where conditions are such that the parts concerned are not easily accessible or replaceable ; that, regardless of cost, the material used for needle valves and the like should, as far as practicable, be proof against corrosion. Results elsewhere seem to indicate that for needle valves gunmetal is superior to cast iron while cast steel is better than either. It may also be assumed that unless heads and velocities obtaining in irrigation sluices are much higher than those at the Mettur Dam the use of cast iron linings for sluice vents is unnecessary and, in fact, undesirable in situations where the water passing into the vent is liable to severe agitation. A good quality of fine cut stone for sluice linings, even under severe conditions, is probably the best material that can be used as it is not liable to cavitation or any of those diseases to which practically all metals are prone and is, moreover, generally considerably cheaper.

Many interesting technical papers have been written on the subject of cavitation. Still, opinions differ so widely that it would not be expedient here to discuss the matter further. It is hoped however, that this brief note may be of some interest to those of the department who may in future be connected with works of this nature.

CHAPTER XXIV-A

Motor Launch and Causeway.

At about the time of completion of the dam construction, an order was placed at Howrah for the construction of a motor launch of suitable size and power for use of inspecting officers. It was also to be of service for securing and towing to a safe place of any large trees or floating objects which might drift down the lake during floods and be of danger to the sluices in the dam.

The great size of the lake, which covers an area of nearly 60 square miles at full reservoir level and its irregular and very long shore line measuring about 180 miles, makes it extremely difficult for officers of the Public Works Department, Revenue, Forest and Fisheries departments to inspect the foreshore by land, since there are no roads and, for the greater part, the margins are precipitous and heavily wooded. A glance at Plate L will reveal to the reader the very broken nature of the coast line. By means of the launch, however, any part of the foreshore is made easily accessible from Mettur. The return trip from the dam up to the lower end of the rocky gorge immediately below the Hogainakal falls, a distance of about 65 miles, can easily be made in about 8 hours. During 1934 and 1935 a good deal of illicit cultivation of foreshore lands which was extended into the bed of the reservoir as the water level fell, was practised by the villagers, but by means of the launch, the authorities were easily able to locate and put a stop to such cultivation.

A brief description of the motor launch may be of interest Appropriately, the launch has been christened "Cauvery." It has an over-all length of 50 feet, a beam of 10 feet and a moulded depth of 4 feet. The draft aft is approximately 2½ feet. It was specially designed to have good stability and to be able to withstand rough and squally weather, the forward sections having a good flare to render the boat dry in choppy water. The hull is divided into six compartments. These consist of (1) the fore-peak and chain locker, with accommodation for the large petrol tank, (2) the motor room, (3) first-class accommodation with cane seats and folding table, (4) a lavatory and store-room amid-ships, with passageway between, giving communication with (5) the third-class or servants' accommodation, which is fitted with wooden seats on either side, and lastly (6) the Aft Peak with door in bulkhead.

The hull is strongly constructed of steel plates and angles of British manufactory, ship-building quality, all well galvanized after fabrication. A teakwood awning carried on steel stanchions runs the whole length of the boat from the engine room to the aft end of the third-class cabin.

The steering is done by wheel located at the fore-end of the engine room. The propellor shaft runs beneath the teakwood flooring and is easily accessible. The propeller bracket is fitted with a skeg, to protect the tips of the propellor blades.

A Thorneycroft Marine Engine, of Type R.D./6, developing 75 B.H.P. propels the launch at a speed of about 11 miles per hour. A dynamo is driven direct off the engine and provides lighting throughout the launch. In addition to the usual navigation lights an electric spot light is provided. Two anchors and all the usual equipment is provided. A teakwood dinghy or tender accompanies the launch. The total cost of the launch and dinghy was Rs. 23,300. The launch crew consists of a serang or steersman, an engine driver, a cleaner and three or four lascars. This dinghy is essential for getting ashore in places where shallow water prevents the launch approaching too near. The shore line is for the most part very rocky. The dinghy is provided with a mast and a balanced lug-sail in addition to oars. Since the boat was launched at the end of 1934 various minor improvements have been made. These include a cupboard for charts and maps. The entire reservoir area has been contoured. The charts used for navigation show these contours in different colours so that, the lake level at any time being known, navigation at any stage of the water-level is comparatively safe and easy.

The water-level in the lake varies very considerably during the irrigation season, and may rise or fall as much as 80 or 90 feet, though it would not normally exceed 60 or 65 feet during a season. For this reason the construction of a causeway or landing stage was found necessary so that the launch could be brought alongside with safety at any water-level.

The causeway is situated about 200 yards above the right flank of the dam where the natural slope of the ground near the entrance to a well-protected bay was found eminently suitable for the purpose, the bay affording a safe anchorage during stormy weather. The construction of the lower end of the causeway was started while the dam was still under construction and before the water-level in the lake had risen much above the cill level of the low level sluices. At its lower end the top of the causeway is at about + 680 and a height of about 9 feet above bed is maintained throughout its length of some 1,000 feet. The normal slope of the causeway is about 1 in 10, and where it is steepest the gradient is 1 in 5. In such places the paving of the causeway is stepped. It was built on economical lines and has been found entirely satisfactory. The upstream face of the causeway is built of cement masonry in the form of a retaining wall provided with internal buttresses at 12-foot intervals. Bollards are built into the wall at frequent intervals for securing the launch or any other boats which come alongside. In rear of the wall rock spoil has been dumped and consolidated, giving a top width of 12 feet to the causeway. The rear slope is pitched with rock throughout its length. Should it be necessary at any future date to widen the causeway for industrial or other purposes, extension can be carried out without any alterations being necessary to the existing structure. The estimated cost of the causeway was Rs. 19,780, while the actual cost of construction was only Rs. 17,481.

To enable the launch to be " dry docked " for periodical painting or repairs to the hull a special trolley cradle has been constructed. This runs on tramrails secured to the top of the causeway. The line has been laid for a length of 580 feet from the upper end of the causeway from a point above maximum water level down to + 720. The launch is floated on to the cradle which is run down this slipway and is hauled up clear of the water by means of an electric winch situated at the top. Rollers set in the track prevent abrasion of the hauling cable. Electrically lit guiding lights are placed above the causeway on the hull side, these being in line with the causeway which is straight throughout its length. The approach to the causeway after dark is thus rendered safe for the launch or any other craft.

There is at present no other landing stage in the entire lake, but it is likely that ferry services by fast motor launches will be opened in the course of a few years.

Hitherto, the ferry services across the river in the area now covered by the reservoir were done by means of coracles, the peculiar craft which have already been described, but since these would be dangerous in rough open water such ferries have been closed. If the villages on either shore of the lake are to be properly served, heavier country craft or motor launches must be introduced on the reservoir.

Canals.

CHAPTER XXV

Drag-line Excavators.

Two large drag-line excavators were employed for the excavation of the Grand Anicut Canal between R.Ds. 0/53 and 15/87. In this length of nearly 30 miles the canal crosses the main South Indian Railway line between Madras and Trichinopoly at three places (opposite telegraph posts 236/5–6; 222/17–18; 220/1–2). Each of the excavators weighed 200 tons and in cutting the canal special arrangements had to be made to convey them across the railway line at R.D. 4/1418 of the canal. The railway department had to be warned in advance, the permanent way had to be protected against damage due to the weight of the excavators. Telegraph and telephone lines had also to be temporarily dismantled and diverted, so as to clear the jib arms of the machines. All this had to be done at night time when a few hours were available for the work between the passing of two successive trains. The canal lying to the north of the railway line near Tanjore between R.Ds. 12/3315 and 14/08 was not dug by the excavators since they would have had to cross and re-cross the railway line if they had worked in that reach. It happened that the soil in this reach was composed mostly of disintegrated rock, which was too hard for the excavators to tackle, and which had to be excavated by other means.

The following brief description of the excavators may be of interest :—

The machines are alike and are of the Diesel-Electric drag-line type, built by Ruston Hornsby Company, Limited, Lincoln. The prime mover in each case is a 5-cylinder Diesel type oil engine of 250 H.P. coupled to an electric generator of 120 K.W. (500 amps. at 240 volts D.C.). Power is distributed to a number of D.C. motors by means of which all operations are carried out.

The jib is adjustable in length to 70, 80 or 90 feet and is designed for use with buckets of 4, 3½ and 3 cubic yards capacity respectively.

The excavators are self-propelling and run on tracks constructed with 100 lb. rails, which are generally laid for a length of 200 feet at a time. The normal speed of travel as designed is 0·53 of a mile per hour, the travelling power being sufficient to enable them to negotiate gradients up to 1 in 10. Allowing for the laying of the track, shifting it from one position to another, etc., a speed of 80 feet per hour was obtained when the excavators were actually moved from one working position to the next.

The excavators were the largest of the Diesel-electric type manufactured by the Firm of Ruston-Hornsby and these were the first machines in which they had employed complete electric drive for the numerous operations of hoisting, slewing, digging and travelling. The electrical gear was all supplied by the British Thompson-Houston Company, Limited. It may be of interest to note that one of these excavators was actually inspected by His Majesty the King-Emperor, when Prince of Wales, before despatch from the Maker's Works at Lincoln.

The excavators were named " Cauveri " and " Bhavani " and were comparable to " Mars " and " Mercury ", two other excavators that had worked in the Sukkur Scheme. The excavator parts, shipped to Madras, were all unloaded at a small railway station on the South Indian Railway called Tiruverambur, and were trammed over a distance of six miles to a spot near the Grand Anicut. They were assembled by December 1927 and January 1928 respectively and started regular excavation work in the main canal in February 1928; they worked for four years and completed operations by the end of March 1932.

When the machines were obtained, it was anticipated that they would have to work for 4½ years and that their working expenses would be Rs. 4 per unit of 1,000 c.ft. of earthwork. The recorded expenditure was Rs. 5,43,850 and depreciation at 1 per cent per month, taking their life to be 100 months, was assumed. They were worked in three shifts of six hours each per day of 24 hours, and in each shift, half an hour was treated as an idle period to permit of oiling, etc. The number of working days in a year was taken as 250. The depreciation charges thus worked out to Rs. 13·13 per engine working hour.

The salvage value at the end of March 1932, when the excavators ceased work was taken as Rs. 1,14,450, but they have not yet been disposed of.

The following is a brief extract of the work done by the two excavators, for the 48½ months they were in use.

The total outturn was 99,333 units of earthwork or nearly 100 million cubic feet, giving an average of 1,024 units

CHAPTER XXVI

Design and Construction of Aqueducts.

The design and construction of the aqueducts on the Grand Anicut Canal do not differ greatly one from another except in size, the main differences occurring in the design of foundations. In cases where suitable hard clay foundations were not available within the depth provided for in the original design, the use of wells was adopted in certain cases. By this means good foundations were secured and very heavy pumping operations were reduced.

In view of the similarity of the various aqueducts in the system it is felt that a description of one of these, the Agniar aqueduct, will suffice to convey to the reader some idea of the design and work involved, and as this had already been described and illustrated in a departmental Circular (No. 3416/35, B.E.P., dated the 25th July 1935), the note contained in that Circular is reprinted below :—

"1. The Grand Anicut Canal is carried by means of a siphon aqueduct over the Agniar river, which is the largest of the several drainage courses crossed by the canal. At the site of the crossing which is 57 miles from the head regulator at the Grand Anicut, the river has a catchment area of 335 square miles. It runs in a sandy bed about 700 feet wide, the bed and marginal levels being +99·00 and +105·0, respectively. The normal bed width of the main canal in this reach is 63½ feet and the full supply depth, 6·2 feet, the bed level being +109·68.

2. A design for this work was approved in 1928, providing for 30 vents of 12 feet span for passing a discharge of 48,000 cusecs, with a velocity of 11·8 feet per second. This discharge was obtained by using Ryves' Formula with C = 1,000. The design provided for open foundations carried down to a level of + 92·68. Before the work was taken up the design was modified in several respects.

3. The Tank Restoration Scheme party has been adopting a coefficient of 400 in Ryves' formula for calculating the run-off in this area but the Engineer-in-Chief of the Mettur Project wanted a value of 1,000 to be adopted for the coefficient when designing the cross drainage works on the Grand Anicut Canal. Quite a large number of tanks in the canal

PLATE No. LI.

THE AGNIAR AQUEDUCT.

area are private ones not provided with proper surplus arrangements and far from acting as flood moderators, they actually intensify the flood by getting breached after any heavy rainfall. In October 1930 when work at the Agniar had just been taken up, there were very heavy floods throughout the project area, consequent on heavy rains from the 10th idem. The maximum rainfall in 24 hours was 11·68 inches at Pattukkottai and 12·5 inches at Trichinopoly (on the 23rd). Due to these rains and consequent breaches in a number of upland tanks there were heavy floods in the river. Calculations made from observed flood levels on that occasion both at the site of the work and at the railway bridge lower down showed that a value of 1,210 is to be adopted for the coefficient. The discharge to be provided for at the aqueduct had therefore to be raised from 48,000 to 58,300 cusecs. The Executive Engineer in charge therefore reported in November 1930 that a more liberal waterway had to be allowed and that the number of vents should be increased from 30 to 36. With 30 vents the ventway provided under the aqueduct was only 27 per cent of the natural waterway at the observed M.F.L. and with 36 vents it would be about 33 per cent. This proposal was accepted by the Superintending Engineer and the Engineer-in-Chief.

4. Before the work was put on hand, trial borings with boring apparatus and probings with ½ inch rods were made at close intervals for studying the conditions of soil and sub-soil. These operations revealed that the depth of sand overlying clay varied from 6 feet to 15 feet, the greater depth being only in small pockets here and there.

When the work was started in July 1930, open foundations presented great difficulties owing to the high spring water-level and the large volume of sand involved in the excavation. It was necessary to go down nearly 7 feet below spring water-level to reach the bottom of foundations and a cofferdam was required to keep out the inflow of water and sand.

5. A cofferdam with piles was first tried. Two rows of casuarina piles 7 feet to 8 feet long and 4 inches in diameter were driven at 2 feet centres, the rows being 5 feet apart. One-inch planks were laid against these piles and the space between cleared of sand and plugged with clay. It was found that this work was laborious, slow and uncertain. The cofferdam was not quite effective in keeping out water and was not sufficiently strong to resist lateral thrust due

to earth pressure. It required a large quantity of good stiff clay which was not easily and economically procurable.

6. An alternative method was then suggested and carried out. A number of wells of reinforced concrete of a mixture of sand and cement, 3 feet diameter and 3 inches shell thickness, were sunk to a depth of 6 feet below spring water-level, enclosing an area of 38 square feet each. These wells were plugged and the space between them was also cleared of sand and plugged with cement concrete. The enclosed space was then excavated to the required depth. No difficulty was experienced and the cofferdam was perfectly strong, watertight and reliable.

[Other alternatives were also thought of, such as sheet piles, etc., but were ultimately given up as the required materials and machinery were not readily available.]

7. As a result of the above experiment the original design providing open foundations was suitably altered. Rows of R.C. wells were now provided as shown in plate LII, under the drop and lift walls, abutments and every sixth pier and under the canal and river wings. This scheme divided the foundation area into six compartments which were taken up for excavation one after the other. Reinforced concrete rafts 6 inches thick with reinforcement at top and bottom were provided over the R.C. wells under the abutments, wing walls and every sixth pier, to distribute the load evenly on all the wells. The reinforcements adopted for the raft were ½-inch rods at 5½ inches centres. The original design provided arches over the vents as in the case of similar aqueducts higher up. The local bricks were however found to be of poor quality and so the arches were replaced by R.C. slabs. This incidentally gave more waterway, the bottom of R.C. slabs being +108·68 against +105·68 the level of arch springing, and permitted the floor to be raised by a foot and a half thereby reducing the siphoning of the river from 4 feet to 2½ feet.

Other deviations made in revising the designs were (1) to increase the thickness of the main floor to 3 feet 6 inches, the top 6 inches being in cement concrete, (2) to provide a roadway 8 feet wide on the left side instead of two pathways one on each side and (3) to provide revetments for the outer slopes of approach banks for a length of 150 feet on the upstream side and 100 feet on the downstream side.

8. (*a*) The total number of R.C. wells provided for the foundations was nearly 1,000. These wells in the main foundations under the drop and lift walls and abutments and

every sixth pier served in the first instance as already stated above as cofferdam wells dividing the foundations into six compartments which could be opened out for laying concrete and later as foundation wells for the wing walls, abutments, piers, drop and lift walls and as effective curtain walls in front and rear of the aprons.

(*b*) These wells were prepared *in situ* after removing the sand in the bed down to spring water-level. The thickness of shell was 3 inches and the wells were either 3 feet or $2\frac{1}{2}$ feet in internal diameter. The reinforcements consisted of hoops of $\frac{3}{8}$ inch British or 7/16 inch Continental rods, at 6 inches intervals with $\frac{1}{4}$ inch British, or 5/16 inch Continental, vertical rods at 9 inches centres. The moulds were 3 feet in length and were made of galvanized iron sheets 20 B.W.G. stiffened with iron strips $\frac{1}{4}$ inch × $1\frac{1}{2}$ inches. Each mould consisted of two outer halves with external flanges bolted together. The inner core was in one piece with a wedging arrangement which on removal permitted the withdrawal of the core. These moulds cost Rs. 50 each.

(*c*) The sites at which the wells were to be sunk were first levelled properly and small wooden blocks or thin cement concrete slabs laid to serve as a base for casting the R.C. well. The moulds were then assembled in position. Small wooden distance pieces were inserted at the bottom to keep the inner core in proper alignment. Cement mortar 1 : $3\frac{1}{2}$ was then poured in for a height of 1 inch to 2 inches to serve as bottom cover for the reinforcements. The grill previously tied and got ready was then placed inside and sand cement mix was then gradually added on and rodded properly. The mortar set sufficiently hard in two to three hours to permit the removal of the mould. No special difficulty was experienced in withdrawing the moulds. Wells of $4\frac{1}{2}$ feet, 5 feet and 6 feet height were manufactured by raising the mould and refitting it over the portion already cast. The reinforcements in such cases were in one piece. The length of well required was generally fixed by a reference to the subsoil contour map for clay. If on sinking, clay was found to be deeper, the height of well was increased by adding one foot rings. The top plugging in such cases was carried through these rings and a further 1 foot 6 inches into the main well.

(*d*) About 10 moulds were used for manufacturing all these 1,000 wells and daily 10 wells were made. All the wells were cast in a period of about six months.

(*e*) Sinking of these wells was begun a day or two after they were cast. Two men were engaged for each well. One worked inside the well removing the earth with small buckets or small scoops similar to those used locally for uprooting groundnut. The other at the top of the well was helping his comrade in throwing out the earth and water passed on to him. The rate of progress was fairly high for the first three feet where the soil was loose and springs were not heavy. The rate for sinking then ranged from 4 to 8 annas per running foot. Sinking in stiff clay was found easier than sinking in clay mixed with sand deposits as in the latter case spring water gave much trouble. Sinking after 3 feet depth was facilitated by loading the top of wells with sand bags. The cost of sinking per running foot in stiff clay was found to be very variable depending on the amount of spring water met with. It ranged from Rs. 1–8–0 to Rs. 2–8–0 in extremely difficult cases. On the whole a flat rate of Re. 1 per running foot of sinking for all depths up to 10 feet may safely be adopted for purposes of estimating.

9. (*a*) After these wells were sunk to the requisite depth they were sealed with cement concrete 1 : $3\frac{1}{2}$: 7 for 1 foot 6 inches at bottom and with surki mortar concrete for the top $1\frac{1}{2}$ feet. The intervening space was filled in with sand well rammed.

(*b*) The clear space between the wells was 9 inches before commencing sinking but after sinking the distance varied from almost nothing to $1\frac{1}{2}$ feet, the extreme values being noticed only in a few cases. This space between the wells was cleared of sand by first sinking rectangular R.C. slabs 1 foot high placed one over the other tangential to the main wells at either end. The space was then plugged with concrete which had to be laid under water by means of a big sheet metal funnel.

10. When the excavation of foundations was taken up the spring water was almost at the bed level of the river. Foundations for one compartment of six vents, i.e., about 90 feet in length and 70 feet in width were excavated at a time. A 16 H.P. Keighly pumping set of 8 inches suction and 8 inches delivery mounted on a trolley with tramway wheels was used for unwatering the foundations. The engine which was started with petrol and run on kerosene consumed about a gallon of kerosene per hour and took about three hours to clear the chamber. A 2 H.P. Crossley and a 9 H.P. Ruston sets were also used for supplementing the

main set when necessary. A Petter oil engine set of 18 H.P. was kept as a standby, and gave about the same outturn as the Keighly set.

11. All the 1,000 R.C. wells were manufactured, sunk to proper level and sealed and the main foundations involving 1,700 units of concrete were completed in the course of about 10 working months and the rapid progress that was made in concreting for the main floor was entirely due to the effectiveness of the R.C. well coffer dam adopted in the work and the sufficiency and the reliability of the pumping sets obtained for the work. These R.C. wells have several advantages over the ordinary brick wells. They are easily and rapidly manufactured and sunk with comparative ease. These wells cost Rs. 4–3–0 per running foot as per data given below :—

Data for R.C. wells 3 feet internal diameter and 3 inches thick (1 : 2½) for 1 running foot.

	RS.	A.	P.
0·6 cwt. cement including conveyance at Rs. 3–6–0 per cwt.	2	0	5
1/8 mason at Rs. 1–8–0 per day	0	3	0
1/2 man coolie at 7 annas	0	3	6
1/2 woman coolie at 4 annas	0	2	0
23 r.ft. 3/8″ rods 8·65 lb.			
14 r.ft. 1/4″ rods 2·34 lb.			
Total .. 10·99 or 11 lb. at As. 1–6 ..	1	0	6
Soft wire 1/2 lb. at As. 2–6 per lb. ..	0	1	3
Tying grills	0	5	0
Moulds, etc.	0	1	0
Sundries such as oil, mortar pans, etc. ..	0	1	4
Watering charges	0	1	0
Total ..	4	3	0

The booked expenditure for 4,335 R. feet was Rs. 18,201–5–4 which works out to Rs. 4–3–0 per running foot.

12. The R.C. raft over the wells under the piers, abutments and wing walls was first proposed to be anchored down by extending the vertical reinforcements of the wells and bending them into the R.C. slabs. This was found inconvenient during execution as the reinforcement rods if left projecting out would not permit of the loading of the wells with sand bags. So the arrangement detailed in plate LIV was adopted. Precast R.C. plugs with necessary anchor rods were incorporated in the top plugging of the wells.

13. The centering for the R.C. slab for the aqueduct was formed with the spoil earth, mostly sand excavated from the foundations of aprons. R.C. slabs of lime stone kunkar in the proportion of 1 : 2 : 4 of size 5 feet 11 inches × 1 foot 6 inches × $2\frac{1}{2}$ inches were manufactured and spread over the earth centering after thoroughly watering and consolidating it. This afforded a fairly stable and hard surface for tying and adjusting the grills. These precast R.C. slabs were removed after the laying of the floor by excavating the sand underneath and reused for other vents. All the slabs were finally utilized for the revetment work for the approach banks. For a few vents the top surface of the earth filling was merely plastered with clay and in spite of all the care taken, the surface became uneven by the time the reinforcements were assembled in position.

14. (*a*) The R.C. floor of the trough was designed as a continuous slab for resisting a bending moment equal to WL/10. The slab was 1 foot thick under waterway and 1 foot 3 inches under the side walls. The main tensile reinforcements were $\frac{1}{2}$ inch or $\frac{5}{8}$ inch rods and the distributing reinforcement of $\frac{1}{2}$ inch rods. The bottom tensile reinforcements were continuous for all the 36 vents. To localize temperature cracks, small grooves $\frac{1}{2}$ inch wide and 3 inches deep were left on the top of slabs over every sixth pier, i.e., at intervals of 90 feet giving a reduced section for the slab at these places. These grooves were filled with pitch.

(*b*) Leakage through the joint between the side walls and the R.C. floor slab was provided against by forming three ridges each 9 inches wide and 6 inches high in the slab under the side walls as shown in Plate No. LVII.* These ridges gave a good bond between the brick work and the slab and increased the length of "creep."

(*c*) After the structure was completed, cross bunds were formed at either end of the trough and water was pumped into a depth of $4\frac{1}{2}$ feet. At first there was a slight dripping through the slab and small needlelike growths of lime brought out by the water were noticed under the slab. After about a fortnight this dripping almost completely stopped and the bottom of the slab got dry. At the places where grooves had been left for taking up temperature expansions or contractions small cracks appeared in the side walls. Such cracks were anticipated and these panels had been left unplastered. Leakage through these cracks was also noticed over the 18th and 24th piers. This leakage practically disappeared after

* Facing page 412.

the panels were plastered. In the 24th pier the crack extended for some distance along the sloping cutwaters on the upstream side. A small portion of this cutwater had therefore to be dismantled and rebuilt in cement to stop the leakage. This shows clearly that there has been some movement of the slab due to temperature changes or shrinkage during setting. It would therefore be advisable to lay a reinforced or cement concrete template over the pier and form the slab over it after introducing an intervening layer of tarred paper or other suitable material which would permit an independent movement of the slab without the brickwork in the piers getting damaged by such movement. Whether it is also advisable to form the slabs discontinuous over each pier is a question on which probably there will be differences of opinion.

(*d*) The roadway slab was formed on wooden centerings supported on tram rail verticals suitably braced together: The roadway slab is designed as a simple beam. The slab was cantilevered out over the 9th, 18th and 27th piers for serving as refuge for pedestrains when there is vehicular traffic on the roadway slab. The outside edge of the slabs was flushed with the tip of the semi-circular cutwaters in the piers and R.C. templates with strong shear reinforcement were therefore cast on these semi-circular portions to obtain a uniform span for the roadway slab.

15. A footpath 2 feet wide is provided on the right side wall of the aqueduct by slightly corbelling out the brickwork. This wall is built only up to maximum water level so that it may act as a spillway when the canal tends to run at more than F.S.L.

A foot-bridge across the trough was also suggested but was not approved. For most of the days it would be possible to cross the canal by going under the end vents of the aqueduct where there is no flow except during high floods. But a small foot-bridge of R.C. slab supported on cast iron supports with suitable brackets would have cost very little and would be very useful for inspection purposes.

16. The canal wings in practically all the syphon aqueducts of this type built in this canal developed cracks near the junction with the abutments, soon after earth was filled up behind. In this aqueduct also there are traces of cracks at the indentical points in the canal wings, but they have shown no tendency to develop. The space between the canal and river wings was built up in brickwork for an

additional length of 10 feet and the section of the canal wings also increased from 4½ feet to 5½ feet. This appears to have improved matters.

17. In the project estimates a rate of Rs. 200 per unit was generally adopted for R.C. work. In this work more than 300 units of R.C. work were done and the rate as per actual execution was Rs. 170 per unit as per data below :—

(*a*) *Materials*—

	RS.	A.	P.
19 cwt. of cement at Rs. 3–6–0 per cwt.	64	2	0
80 cubic feet of granite jelly at 9 annas per cubic foot	45	0	0
Old paper, etc., at 4 annas per viss ..	0	1	7
1½ to 2 lb. of soft wire at As. 2–6 per lb.	0	4	0
500 lb. of mild steel reinforcement at As. 1–6 per lb.	46	14	0

(*b*) *Labour*—

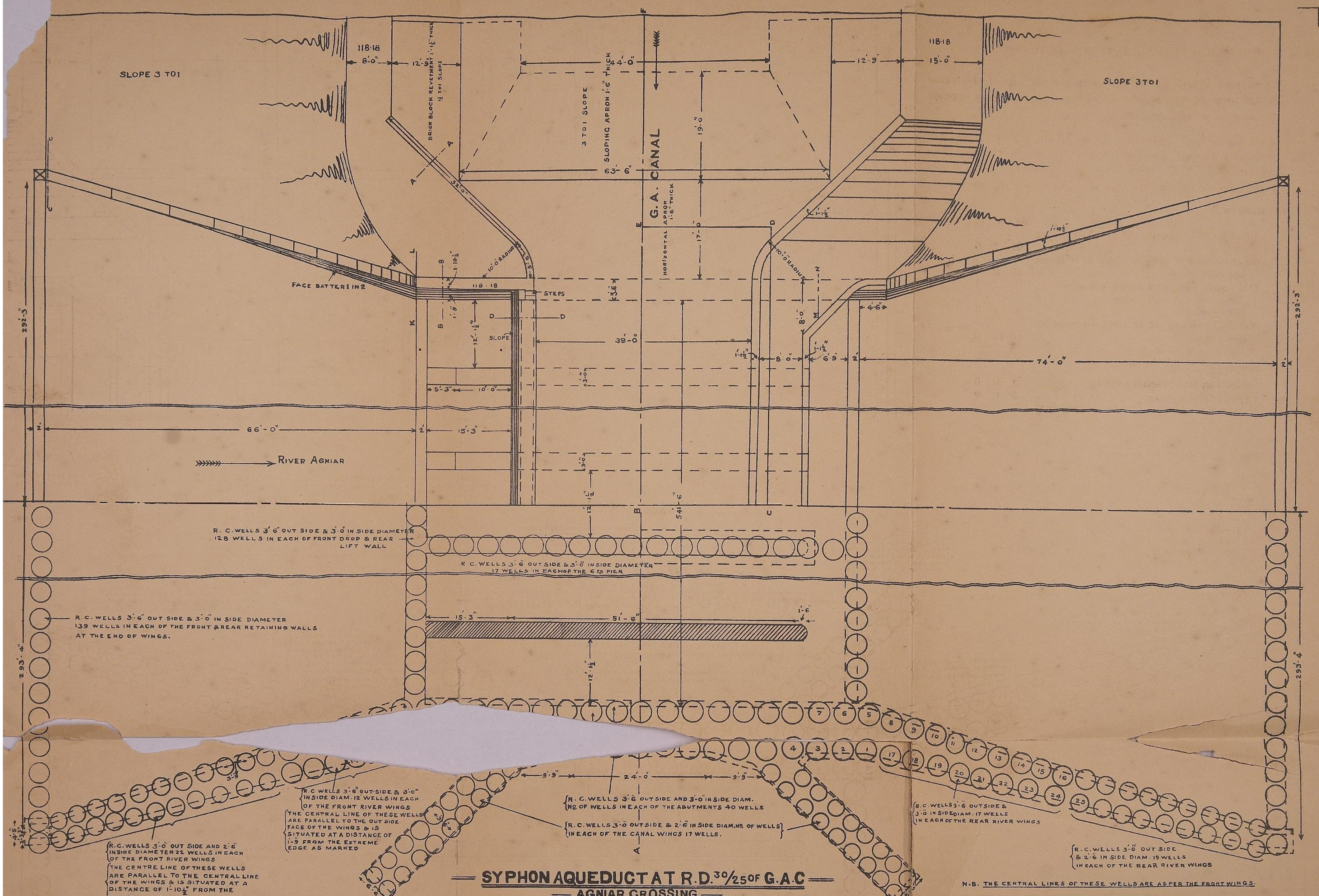
	RS.	A.	P.
Collecting and stacking sand	1	0	0
Tying grills	5	0	0
Mixing and placing concrete including washing metal and conveyance in river-bed	5	12	0
Watering charges	1	0	0
Sundries	0	14	5
Total ..	170	0	0

The aqueduct, the construction of which is described above is typical of an aqueduct with R.C. slabs. There are, however, several aqueducts of the brick arch type generally of a standardized plan. There is nothing special or unique in their design but the plans of one of these (at R.D. 23/60 Maharajasamudram aqueduct) are reproduced as Plate Nos. LIX and LX.

Syphon well drops.

Syphon well drops have been constructed on a number of small channels. These are of a somewhat unique design prepared by Col. Ellis and by their adoption considerable economies have been effected. As the name implies, they combine a drop with a syphon. A typical case is illustrated in Plate No. LXI where a channel crosses a road at approximately the same level.

PLATE LII



SYPHON AQUEDUCT AT R.D. 30/25 OF G.A.C

AGNIAR CROSSING

36 VENTS OF 12 FT. SPAN

SCALE

10 5 0 10 20 30

NOTE:- THE SPAN WILL BE 12'-1½" BEFORE PLASTERING

ALL WELLS IN THIS CANAL WING HAVE BEEN TAKEN 3' DEEPER (i.e) 85·18 & THEY HAVE BEEN JUST SEATED IN CLAY EXCEPT 2 WELL AT END WHICH ARE 1-0" IN CLAY

PARTICULARS OF DEEP WELLS

NO OF WELLS	BOTTOM LEVEL OF WELLS AFTER SINKING	NO OF WELLS	BOTTOM LEVEL OF WELLS AFTER SINKING
1	87·00	17	86·20
2	86·00	18	87·20
3	86·00	19	87·20
4	86·00	20	87·20
5	87·00	21	88·20
6	87·00	22	88·20
7	89·00	23	89·20
8	87·00	24	91·20
9	87·00	25	89·20
10	87·00		
11	87·00		
12	87·00		
13	88·00		
14	88·00		
15	89·00		
16	90·00		

WELLS 1 TO 7 HAVE GONE 0·2 TO 0·5 INTO CLAY
WELLS 8 TO 26 ARE JUST SEATED IN CLAY LEVEL

(Sd) T. S. VENKATARAMAN
EXECUTIVE ENGINEER 9-7-34
No 2 DE PATTUKKOTTAI

TRACED BY V.P.N
COMPARED BY A.K.

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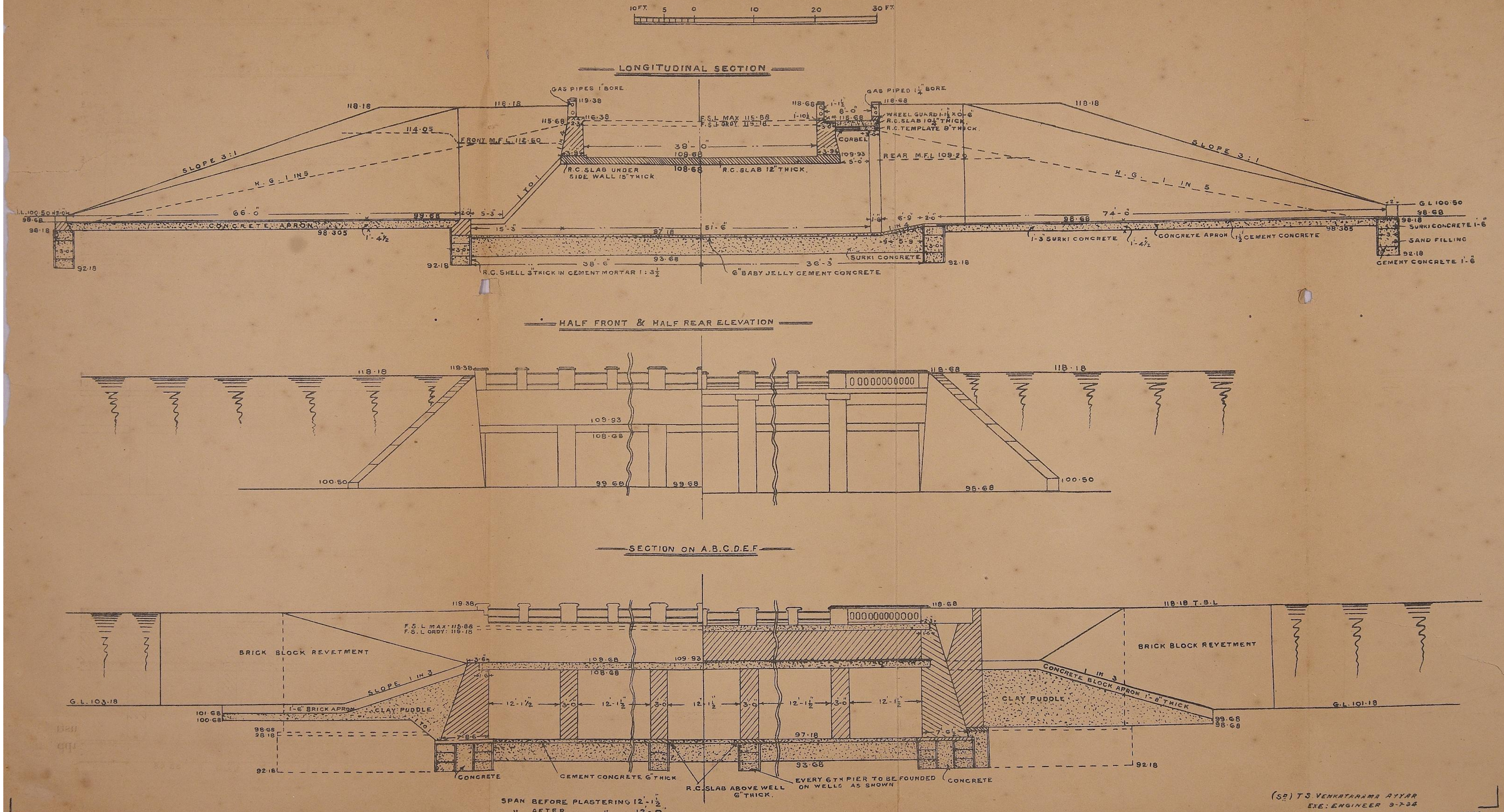
PLATE LIII

SYPHON AQUEDUCT AT R.D. 30/25 OF G.A. CANAL
AT THE CROSSING OF AGNIAR RIVER

C.S.2 No. 272-A OF 30



(Sd.) T.S. VENKATARAMA AYYAR
EXE: ENGINEER 9-7-34

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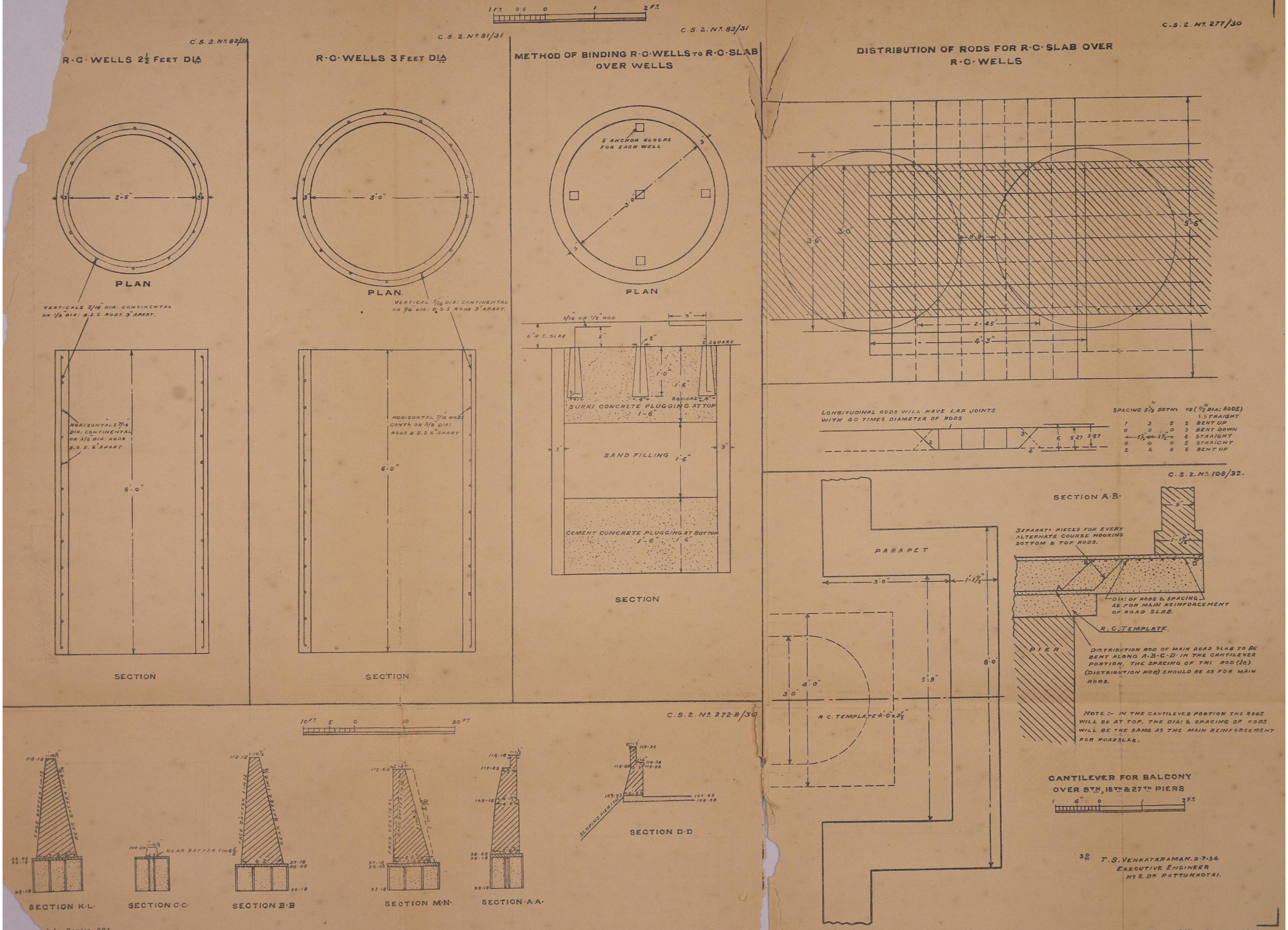
PLATE LIV


C.S.2. No. 82/31
R·C·WELLS 2½ FEET DIA.
PLAN
2'-6"
VERTICALS 5/16" DIA: CONTINENTAL OR 1/4" DIA: B.S.S. RODS 3" APART.
HORIZONTALS 7/16" DIA: CONTINENTAL OR 3/8" DIA: RODS B.S.S. 6" APART.
6'-0"
SECTION
C.S.2. No. 81/31
R·C·WELLS 3 FEET DIA.
PLAN
3'-0"
VERTICAL 5/16" DIA: CONTINENTAL OR 1/4" DIA: B.S.S. RODS 3" APART.
HORIZONTAL 7/16" RODS CONTL. OR 3/8" DIA: RODS B.S.S. 6" APART
6'-0"
SECTION
C.S.2. No. 83/31
METHOD OF BINDING R·C·WELLS TO R·C·SLAB OVER WELLS
5 ANCHOR BLOCKS FOR EACH WELL
PLAN
3/16" OR 1/2" ROD
6" R.C. SLAB
SURKI CONCRETE PLUGGING AT TOP
SAND FILLING
CEMENT CONCRETE PLUGGING AT BOTTOM
SECTION
C.S.2. No. 277/30
DISTRIBUTION OF RODS FOR R·C·SLAB OVER R·C·WELLS
5'-6"
3'-6"
3'-0"
2'-45"
4'-3"
LONGITUDINAL RODS WILL HAVE LAP JOINTS WITH 40 TIMES DIAMETER OF RODS
SPACING 5½" BOTH WS (½" DIA: RODS)
1 STRAIGHT
2 BENT UP
3 BENT DOWN
4 STRAIGHT
5 STRAIGHT
6 BENT UP
C.S.2. No. 108/32.
SECTION A·B·
SEPARATE PIECES FOR EVERY ALTERNATE COURSE HOOKING BOTTOM & TOP RODS.
PARAPET
DIA: OF RODS & SPACING AS FOR MAIN REINFORCEMENT OF ROAD SLAB.
R. C. TEMPLATE
PIER
DISTRIBUTION ROD OF MAIN ROAD SLAB TO BE BENT ALONG A-B-C-D IN THE CANTILEVER PORTION. THE SPACING OF THE ROD (Je) (DISTRIBUTION ROD) SHOULD BE AS FOR MAIN RODS.
R.C. TEMPLATE 4'-0"x3½"
NOTE :- IN THE CANTILEVER PORTION THE RODS WILL BE AT TOP. THE DIA: & SPACING OF RODS WILL BE THE SAME AS THE MAIN REINFORCEMENT FOR ROADSLAB.
CANTILEVER FOR BALCONY OVER 9TH, 18TH & 27TH PIERS
SD. T.S. VENKATARAMAN. 9-7-34
EXECUTIVE ENGINEER
No. 2 DN PATTUKKOTAI.
C.S.2. No. 272-B/30
SECTION K·L·
SECTION C·C·
SECTION B·B
SECTION M·N·
SECTION·A·A·
SECTION D·D
SLOPING PIER

SYPHON AQUEDUCT AT R.D. 30/25 OF G.A. CANAL

C. S. 2 No. 36 OF 32

PLAN SHOWING R.C. WELLS AT TOE OF REVETMENT

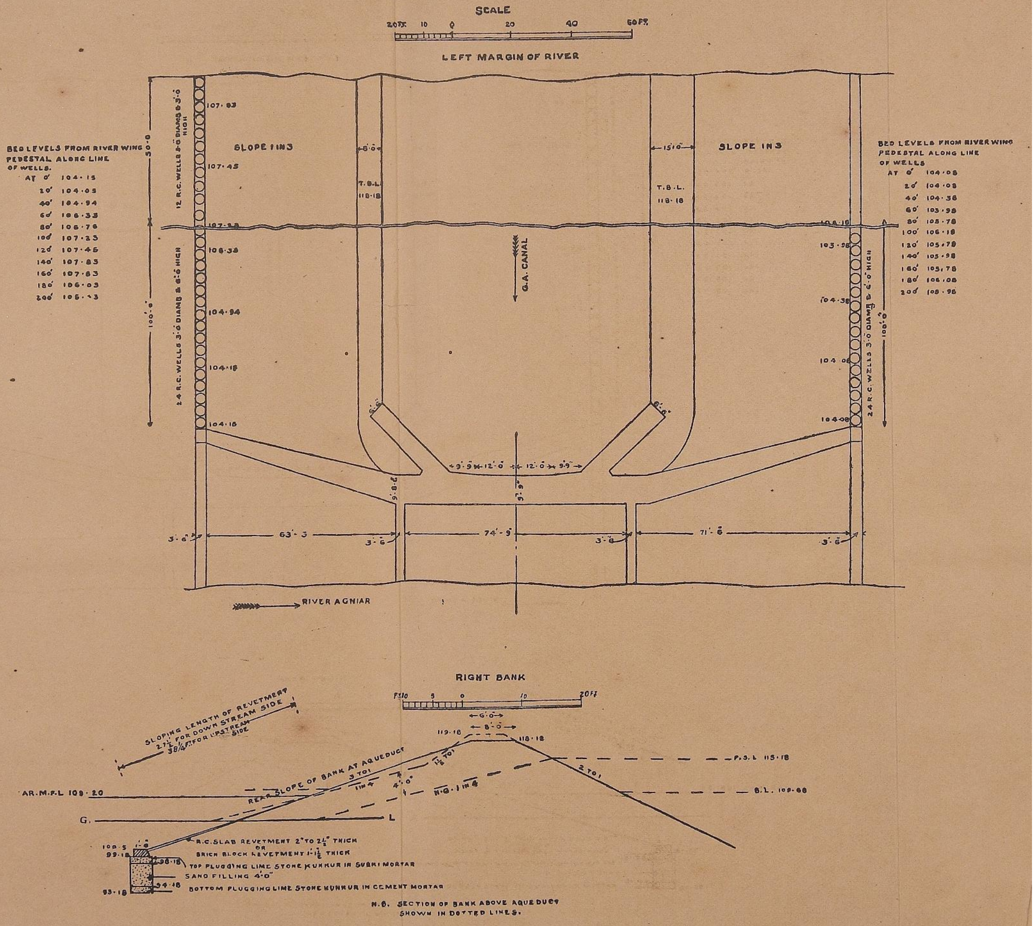
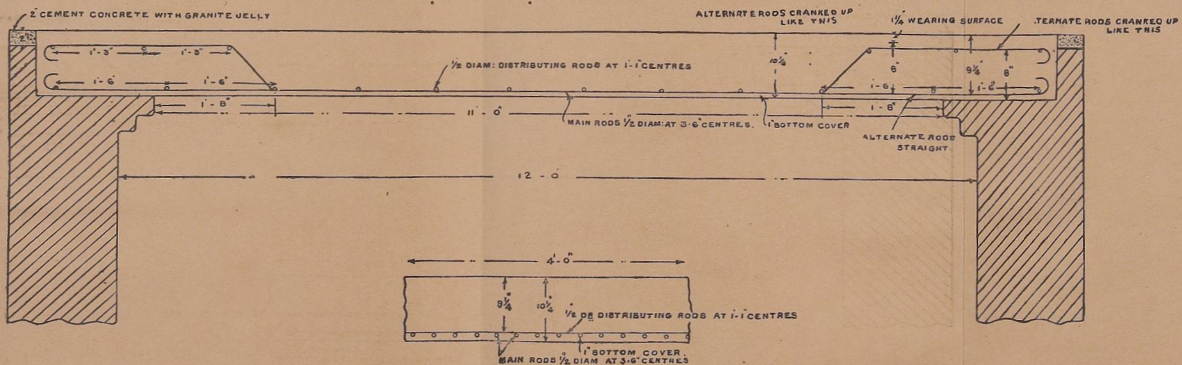


PLATE No. LVI.

C.S.2 No. 20-OF 1935.

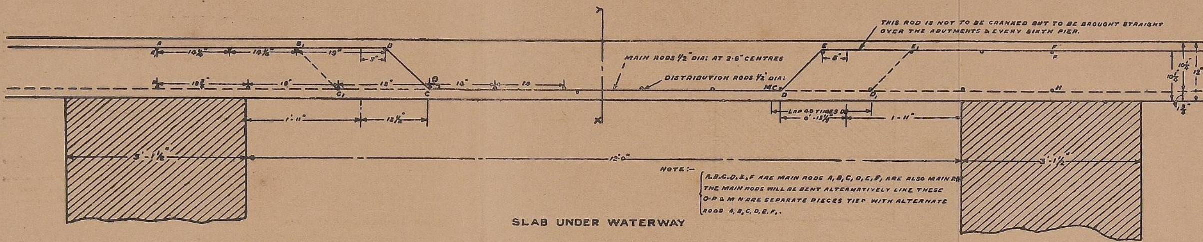
PLAN SHOWING GRILL ARRANGEMENT FOR AQUEDUCT AT R.D. 30/25
OF G.A. CANAL AGNIAR CROSSING

SLAB UNDER ROAD WAY

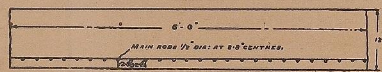


PLAN SHOWING GRILL ARRANGEMENT FOR AQUEDUCT SLAB

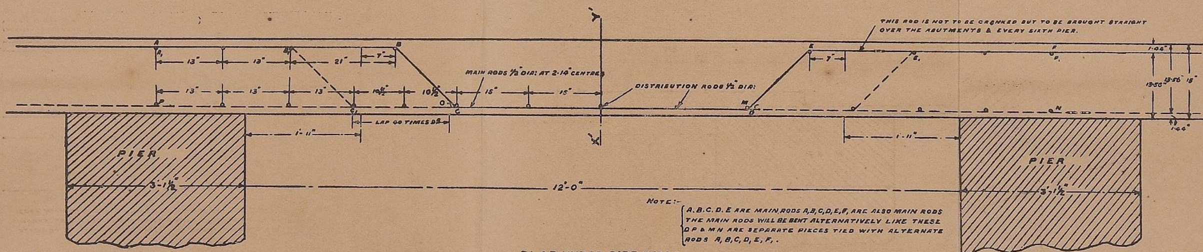
AGNIAR RIVER



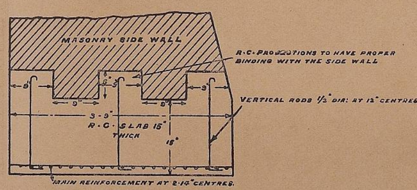
SLAB UNDER WATERWAY



SECTION X·Y·

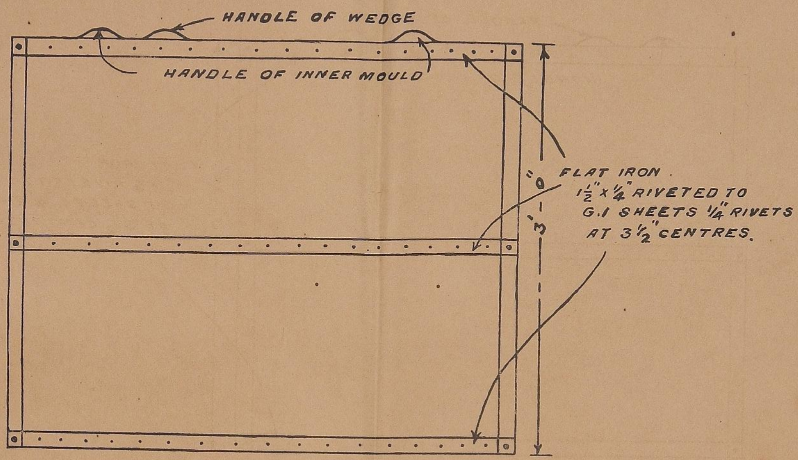


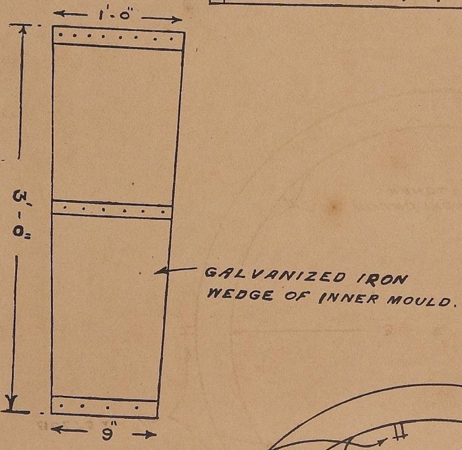
SLAB UNDER SIDE WALL

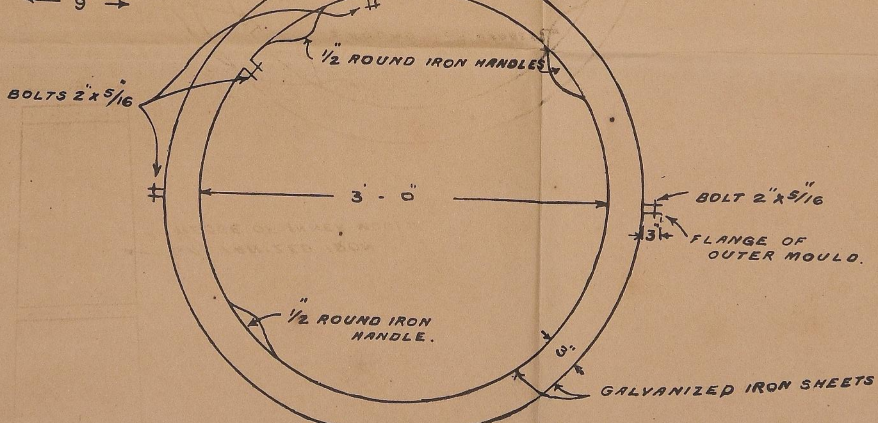


SECTION X'Y'

SKETCH OF GALVANIZED IRON MOULD FOR R.C. WELLS







SYPHON AQUEDUCT AT R.D. 23/60 OF GRAND ANICUT CANAL

SCALE FT. 10. 5 0 10 20.

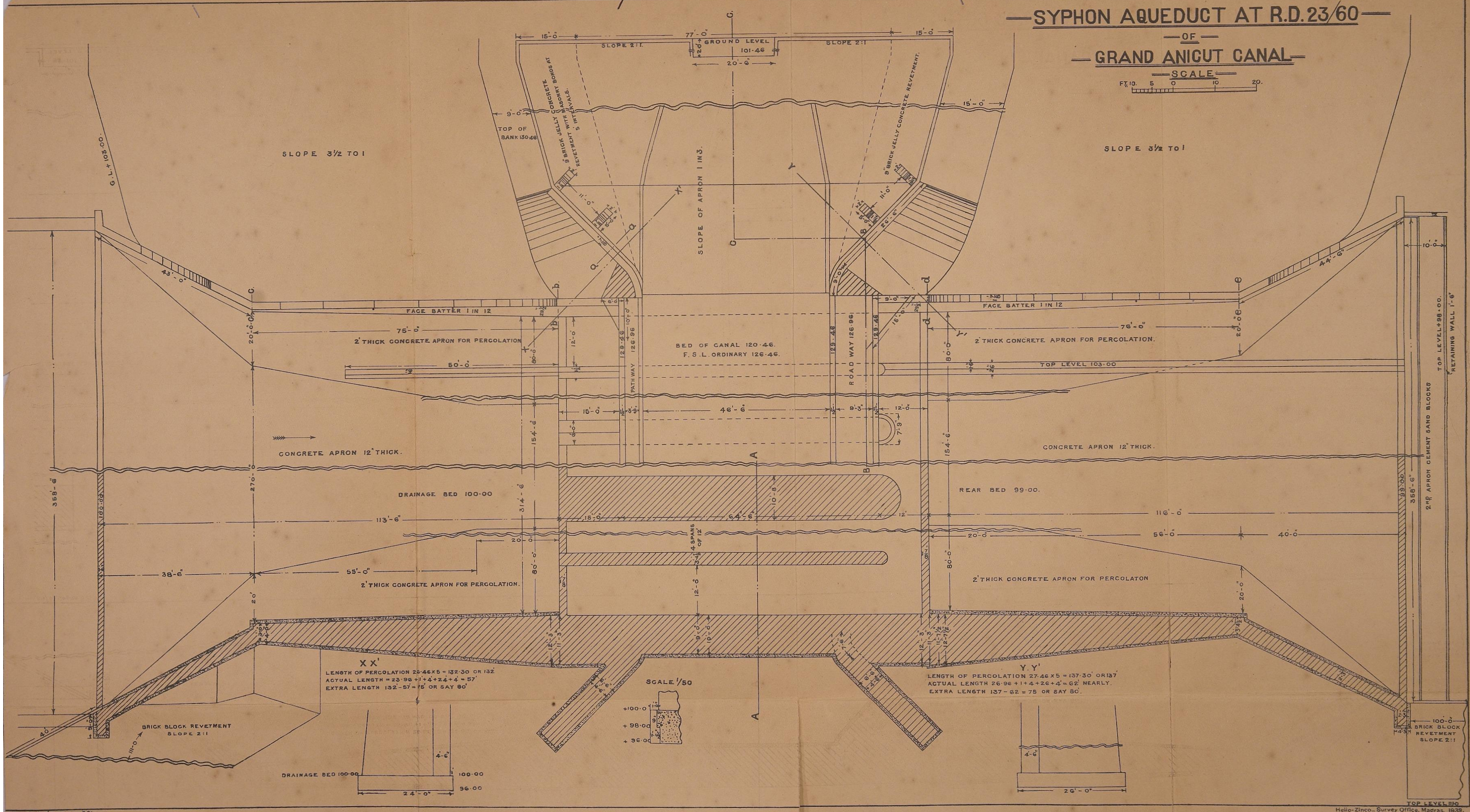


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PLATE No. LX

SYPHON AQUEDUCT AT R.D. 23/60

OF

GRAND ANICUT CANAL

20 VENTS OF 12' EACH

SCALE

FT. 10. 5. 0 10. 20.

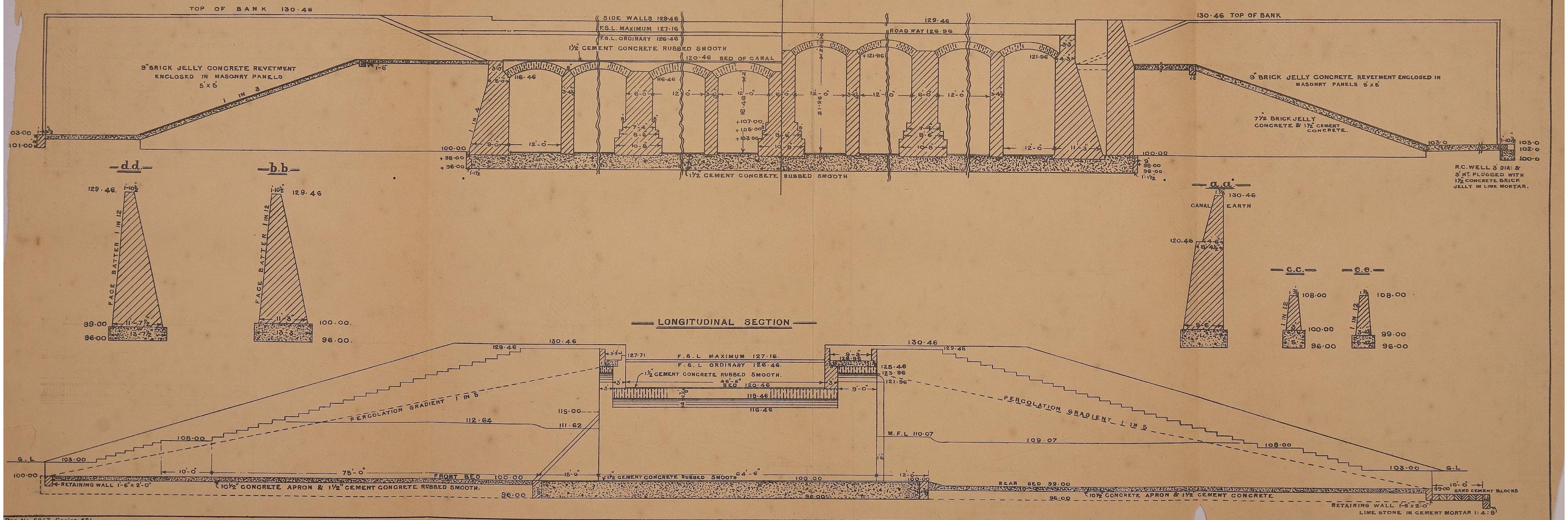

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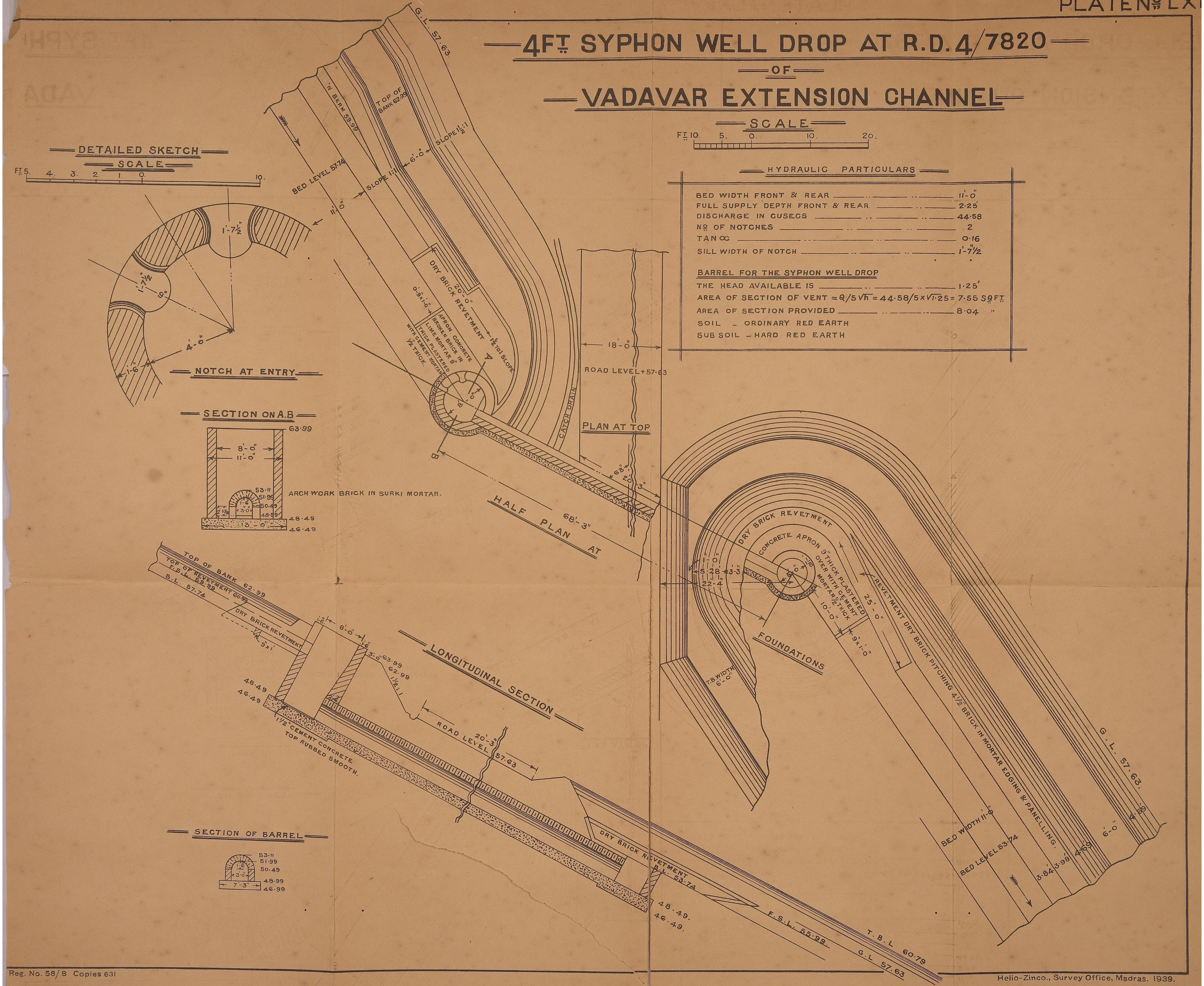
PLATE No. LXI

4 FT. SYPHON WELL DROP AT R.D. 4/7820

OF

VADAVAR EXTENSION CHANNEL



HYDRAULIC PARTICULARS

BED WIDTH FRONT & REAR	11'-0"
FULL SUPPLY DEPTH FRONT & REAR	2·25'
DISCHARGE IN CUSECS	44·58
No. OF NOTCHES	2
TAN α	0·16
SILL WIDTH OF NOTCH	1'-7½"

BARREL FOR THE SYPHON WELL DROP

THE HEAD AVAILABLE IS	1·25'
AREA OF SECTION OF VENT $= Q/5\sqrt{h} = 44{\cdot}58/5\times\sqrt{1{\cdot}25} =$	7·55 SQ FT.
AREA OF SECTION PROVIDED	8·04 "
SOIL – ORDINARY RED EARTH	
SUB SOIL – HARD RED EARTH	

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CHAPTER XXVII

Canal Embankments.

The Vettikad Embankment described.—In normal reaches of the canals and branches, the excavation of the beds and formation of the banks by manual labour presented no particular difficulties, but in the main canal, as has already been remarked, there were several localities where heavy embankment works was necessary, notably in the approaches to the aqueducts over the larger drainage courses.

These large and long embankments involved the use of selected earth with long leads and high lifts, and, in the more important cases, special means of consolidation had to be resorted to.

It will be appropriate, therefore, if a detailed description of the work involved on the construction of the Vettikad Embankment, the largest in the system, is now given. It may not be necessary here to refer to the actual aqueduct constructed over the Maharajasamudram river, since a detailed account of the Agniar Aqueduct is given in another chapter, and these aqueducts are all of very similar type.

The bottom of the valley where the Maharajasamudram Aqueduct is constructed is at about R.D. 23/60 from the head of the Grand Anicut Canal. The Vettikad Embankment commences at about R.D. 23/05, or 5,500 feet above the aqueduct and ends at about R.D. 24/1750 of 5,750 feet below it, and is thus well over two miles in length. The ground level at the aqueduct site where the heaviest embanking was involved, was +100·00, the theoretical canal bed was to be +120 while the top of the bank, with a free board of 4 feet over the F.S.L. depth of 6 feet, was +130. The soil is generally loamy, but at the embankment site pockets or veins of sand occur in conjunction with a soft clay which becomes fluid when wet, but again hardens under exposure to the sun. The red loam is somewhat pervious, while the clay referred to above is better fitted as a 'hearting' material for a bank than for use on the exposed slopes.

In order to gather some data regarding the hydraulic gradient and the pitch of the inner and outer slopes to be adopted for the embankments, an experimental tank, formed with the sandy-clay and soil obtained from adjoining burrow pits, was constructed at R.D. 23/83 to 85. The experimental tank was formed on the alignment of the Grand Anicut Canal, the left and right banks having top widths of 15 feet and 9 feet respectively, with inner slopes of $1\frac{1}{2}$ to 1 and outer slopes of 2 to 1 forming two sides of the tank while the other two sides were similarly constructed across the canal alignment. Percolation pipes were introduced in the slopes and water was pumped into the tank and the water-level readings in these pipes were regularly observed. The bed alone, which was of loose sand, was removed for a depth of 1·4 feet and this spoil was thrown on the rear slopes of the banks. The Superintending Engineer, who inspected it in March 1929, observed that the clay was plastic and should be found satisfactory for making water-tight bunds but that its suitability for the front slope was, however, doubtful and needed to be watched. In the inspection of the Superintending Engineer in August 1929, the results of observations in the experimental tank and in a small model tank nearby were summed up as follows :—

> "The observations carried out so far show that in a bund formed with the soil available at the site without proper breaking of clods and consolidation, the hydraulic gradient line is about 1 in 5·5, whereas in the small (model) tank where there is hearting of good consolidated clay, the hydraulic gradient is as steep as 1 in 1·5."

It was later decided, in consultation with the Consulting Engineer, to allow an earth cushion of 4 feet over a hydraulic gradient of 1 in 3. The experiments were, however, continued and in December 1929, when the water-level in the experimental tank was being gradually lowered, the right bank slipped suddenly without warning. The slip was inspected by the Superintending Engineer in January 1930, and though there was a difference of opinion as to the cause of the slip between the Executive Engineer and the Superintending Engineer, the latter recorded his view that the slipping was due to saturation of the clay inside the bank which was not able to yield up the water as fast as the water-level in the tank and the bank was lowered and so remained in a semi-fluid condition. The Executive Engineer thought that the failure was due to subsidence of the bund. The Consulting Engineer and Engineer-in-Chief also inspected the bund in February 1930 and it was decided that the embankments below the aqueduct should be constructed with a hearting of clay, faced with red soil on the water side.

As a result of the data obtained, the embankment above the aqueduct was made with the somewhat better clay and loam procurable in the adjoining burrow pits. An hydraulic gradient of 3 to 1 or less was observed in the experimental tank and it was considered sufficient to provide a 4-feet earth cushion over this gradient. No special consolidation except the breaking of clods and applying the earth in layers was made. The soil of the adjoining burrow pits below the Maharajasamudram aqueduct was found to be of the poor type of clay referred to above, underlying a layer of sand and it was therefore considered advisable to be guided by the results of the experimental tank observations and to construct the hearting with the better class of clay obtainable above the aqueduct, providing a front casing of the red soil available at the next cutting below (from R.D. 24/25 to 24/75 and a rear casing of the sandy soil available in the adjoining burrow pits. The hearting here was consolidated by means of two rollers of 10 and 8 tons respectively, the first worked by an internal combustion engine using crude oil and the second by steam. Earth was conveyed by tramway in trucks, 2 locomotives being used for haulage. The banks above the aqueduct were mostly constructed by manual labour with the aid of tram lines, towing of trucks being done also by coolies. Beyond the laying of the earth in layers and the preparation of top surface, no consolidation of any sort was done, except in a short length above the aqueduct for about 300 feet to 500 feet where steam rolling was done.

Some 400 feet of the Maharajasamudram river bed which had sand in it for a depth of 6 to 8 feet had to be embanked just to the south of the aqueduct. Here key trenches were carried down through the sand some 2 feet into the clayey substratum, and filled with suitable material.

The entire embankment in this reach cost nearly 6½ lakhs of rupees and the average cost of 1,000 cubic feet of earth work worked out to 23 rupees. The place was unhealthy and coolies developed hook-worm disease and malaria. Local labour was scanty and of a poor standard of physique, so a large number of ' Woddars ' had to be imported from places as far off as Salem, Coimbatore, Malabar and Karur in order to get the work done. The staff of supervisors, maistris and mechanics was provided with temporary quarters at Vettikad, and a small Government dispensary with a Sub-Assistant Surgeon in charge was maintained for about three years to afford medical aid and to attend promptly to accidents, mainly incurred in the towing of tram trucks. For some time, good well-water, available at the ridge some distance from the site of the work, was conveyed in improvised tank waggons to the work site and supplied to the coolies. The Vettikad Embankment is one of the highest constructed in South India and its behaviour under full or variable supply conditions is yet to be ascertained. The banks below the aqueduct, which were consolidated by rolling, so far show little sign of percolation except at the experimental tank site and between R. Ds. 24/10 and 24/09 on the left bank, and 23/81 to 23/84 and 24/01 to 24/09 on the right bank. The banks above the aqueduct show slight percolation from R. Ds. 23/10 to 23/25 on the left bank and 23/15 to 23/24 on the right bank. The leakage is at present about 0·04 of a cusec in a length of about 300 feet. The percolation water is clear and is observed to emerge at a level at or below that which occurs at places where banks have been formed without any special precautions having been taken.

The entire work in the Vettikad Embankment, comprising 29,000 units of earthwork, took 4 seasons or about 50 months to complete.

For the construction of this embankment 17 miles of tramways, 475 tipping waggons, 3 road rollers (the third one was obtained only in the last stages of the work), 2 locomotives and 3 portable pumping sets were employed. A smithy, where repairs to rolling stock were carried out, and also the necessary store sheds were provided.

CHAPTER XXVIII

Revenue Forecasts.

The first revenue estimated was prepared by Mr. E. H. Wallace in 1905. According to this estimate there was to be irrigation from the Cauvery-Mettur Project reservoir in the Bhavani taluk of Coimbatore district and Tiruchengodu taluk of Salem district also through west and east side channels for an extent of 45,864 acres. The estimate was revised by the same officer, Mr. Wallace, in 1910. According to this estimate, all new irrigation was confined to the areas in Tanjore district with a small extent in Pudukottah State. All new irrigation under the project was to be treated as I class irrigation. The second and third class irrigation sources in the existing delta were to be raised to I and II class respectively and the water rate on proprietary lands in the new delta was to be Rs. 6 for first crop and Rs. 4 for second crop. It was also assumed that the Government dry land would be transferred to wet and assessed at the appropriate wet assessment under I class irrigation. This gave a return of 6·93% on the outlay of Rs. 385 lakhs. A copy of this estimate as approved in G.O. No. 3347, Revenue, dated 15th October 1910, is given in Annexure I, page 442.

In 1916, consequent firstly on the construction of the Kannambadi Reservoir (later known as Krishnarajasagara) in Mysore, which involved a reduction in the area for which water could be provided by the Mettur Project, and secondly on an increase in the estimate for the construction of the latter, the revenue estimate had to be revised. In this estimate the irrigation area was reduced to 296,000 acres. The idea of transferring the Government dry land to wet and assessing it on settlement principles was abandoned; and it was decided to levy a fixed water rate of Rs. 8 for first crop and Rs. 4 for second crop on all dry lands, Government and proprietary alike. The water rate on proprietary wet was fixed at Rs. 5. This gave a return of 5·97% on the estimated outlay of Rs. 409½ lakhs. A copy of this estimate as approved in G.O. No. 2920, Revenue, dated 18th December 1916, is given in Annexure II, page 442.

The construction estimate was revised in 1921. Considerable discussion ensued as to the rates that should be charged for water. The irrigation questions with Mysore had then been settled and consequently this construction estimate also underwent a revision. The financial forecast was therefore revised in 1924, adopting water rate of Rs. 15 on all dry (Government and proprietary), Rs. 7–8–0 for proprietary wet and Rs. 7–8–0 for second crop. This gave a return of 7·43% on the sum-at-charge, viz., Rs. 627·95 lakhs. A copy of this forecast, as printed in G.O. No. 94-I, dated 31st March 1924, is given in Annexure III, page 443.

It again became necessary to revise the construction estimate owing to certain changes in design. In 1927, Mr. A. G. Leach, I.C.S., was appointed as a Special Revenue Officer to investigate the correctness and adequacy of the financial forecast and the data upon which it was based, and to revise the estimate after making personal enquiries in the area to be irrigated by the project in consultation with the local officers. The estimate was revised by him in 1928, according to which the water rate on proprietary wet was raised from Rs. 7–8–0 to Rs. 10 in the new area while retaining the rate of Rs. 15 for dry and Rs. 7–8–0 for second crop adopted in the previous estimate. The rate of Rs. 7–8–0 per acre was adopted for a second crop grown on 'single crop wet' in the existing delta. Irrigation of dry lands in the existing delta was also to be charged at Rs. 10 per acre. The irrigable area was raised from 296,000 to 299,000 acres. The new second crop area was raised from 90,000 to 154,000 acres on the basis of the rate of development which had occurred in the Periyar area in the Madura district. The collection charges were taken to be Rs. 1·5 lakhs instead of on the basis of 5% allowance. The alignment of the main canal was to be altered from about mile 39 from the head so as to avoid the Pudukottah territory. It was also assumed that the construction of the dam would be completed in June 1933, that water would be available for new irrigation in June 1932, when one quarter of the full capacity of the reservoir would be available, that the reclassification of sources in the existing delta would be given effect to in 1932–33 and that full development would be reached in 1941–42. This gave a return of 6·31% on the sum-at-charge, Rs. 879·89 lakhs. A copy of this estimate, as approved in 1928, is given as Annexure IV, page 443.

The construction of the dam could not be completed in June 1933 as originally forecast so as to confer extra benefit on the existing delta in that year. Consequently, the reclassification of irrigation sources had to be postponed to fasli 1344 and the revenue of Rs. 5,16,225 assumed for 1932–33 under this head could not be realized. In G.O. No. 1244, Revenue, dated 8th June 1931, Government published for criticism draft rules of water-cess for irrigation from Cauvery in the Tanjore district. These were based chiefly on the rates adopted in the sanctioned revenue estimates of the project. With a view to accelerate the development of irrigation, they also contemplated the grant of concessional rates of water-cess in the first few years of development. The table of growth of irrigation had to be revised so as to suit the revised date for completion of the construction of the dam. The revenue estimate was therefore revised in 1932 taking all these factors into considerations and embodying also the concessional rates. According to this estimate, irrigation in the new area was to commence and develop by sections, beginning from 1932–33 and reaching the maximum area in 1943–44. Credit was taken for the increase in water rate on inam dry lands also, both for first and second crop and for second crop revenue on Government dry lands. Second crop charge on 'proprietary wet' in the existing delta in excess of the extent entitled to free irrigation was also included. Thus, the total anticipated revenue at the end of the 12th year of irrigation was 61·63 lakhs against Rs. 60·04 lakhs arrived at in the forecast of 1928. A copy of this estimate as approved in G.O. No. 561, Revenue, dated 8th March 1932, is given in Annexures V and VI, pages 444 and 445.

The water-cess rules were also approved and issued with G.O. No. 1853, Revenue, dated 5th September 1932, as the "Tanjore District Water-cess Rules, 1932." The rates of water-cess to be levied for the irrigation of lands according to these rules are as follows :—

Description of lands.	Vadavar and grand anicut systems. First crop.	Second crop.	Dufassal.	Third crop.	Existing delta. First crop.	Second crop.	Dufassal.	Third crop.
	RS. A.	RS. A.	RS. A.	RS. A.	RS. A.	RS. A.	RS. A.	RS. A.
(a) Dry lands, ryotwari or proprietary including minor inam dry lands.	15 0	7 8	22 8	3 12	10 0	7 8	17 8	3 12
(b) Manavari lands in ryotwari or proprietary villages.	14 0	7 0	21 0	3 8	9 0	7 0	16 0	3 8
(c) Land in proprietary villages recorded as wet in a Record of Rights register prepared by the Government, or on minor inam wet lands in ryotwari or proprietary villages.	10 0	7 8	17 8	3 12	7 8	7 8	15 0	3 12

The rules further provide that—

(i) for irrigation through the Vadavar System, the rate to be charged in respect of fasli 1342, or fasli 1343, shall be one-third of the rates specified in clauses (*a*), (*b*) and (*c*) above and in respect of fasli 1344, shall be two-thirds of those rates;

(ii) for irrigation under any channel taking off from the Grand Anicut canal above 193,000 feet from the Grand Anicut Canal head sluice, the rate to be charged in respect of fasli 1343 or fasli 1344, shall be one-third of the rates specified in clauses (*a*), (*b*) and (*c*) above, and in respect of fasli 1345, shall be two-thirds of those rates; and

(iii) for irrigation under any channel taking off from the Grand Anicut canal below 193,000 feet from the Grand Anicut Canal head sluice, the rate to be charged in respect of fasli 1344 or fasli 1345, shall be one-third of the rates specified in clauses (*a*), (*b*) and (*c*) above, and in respect of fasli 1346 shall be two-thirds of those rates.

In G.O. No. 1238, Revenue, dated 14th July 1933, the Government approved the proposals for the reclassification of the irrigation sources and published a notification according to which all third-class sources connected with the Cauvery and the Vennar in the existing delta, with the exception of certain specified sources, are to be raised to Class II and all Class II sources to be raised to Class I. The classification of all non-deltaic sources in the Vadavar and Grand Anicut Canal System, irrespective of their existing classes and all delta sources of classes lower than the first included under the Vadavar System, are to be raised to Class I delta source.

The construction estimate was expected to close with a saving of about 50 lakhs. There were representations to Government that the rates of water-cess to be levied according to the rules issued with G.O. No. 1853, Revenue, dated 5th September 1932, were high. With a view to make some reduction in the rates of water-cess, if possible, it was examined how the savings on construction estimates could be diverted to the revenue estimate. At the same time, it was apprehended that cultivation in the new area would not progress at the rate assumed in the forecast and it was examined whether the statement of growth of irrigation should also be revised. It was found that the ultimate rates of water-cess should be maintained if the project should prove productive, but that concessional rates could be extended for more years than were contemplated originally, according to circumstances—G.O. No. 96, Revenue (Confidential), dated 13th January 1934.

CHAPTER XXIX

LAND ACQUISITION.

IN 1925, acquisition of lands for Headworks Camps (consisting of offices, residential quarters, store sheds, workshops, coolies huts, hospital, post office, etc.), as well as for the reservoir and for the main canals and branch channels in the canal system was taken up.

The area for acquisition at Headworks extended over two districts, viz., portions of Salem and Coimbatore on both sides of the Cauvery from Cauveripuram and Nagamarai villages on the north down to Nerinjipet on the south. There was also the acquisition of land for widening or straightening of the road from Erode Railway Station to Mettur. The total extent estimated for acquisition was about 7,409 acres in Salem district limits and 11,462 acres in Coimbatore district limits. In G.O. No. 196 I., dated 2nd May 1925, the Government appointed a Deputy Collector with necessary staff for a period of three months to deal with the acquisition of lands required urgently in Navappatti and Samballi villages at Headworks. Later, the employment of seven Deputy Collectors with field and office establishment for one year was sanctioned for this work in G.O. Ms. No. 365 I., dated 30th July 1925, and the sanction for one Special Deputy Collector, accorded previously, became merged in this. The term of office of these Special Deputy Collectors was extended from time to time according to necessity. The minimum outturn under award for each Special Deputy Collector was fixed at 2,000 acres per annum. Although it was difficult to maintain the prescribed outturn each month, owing to statutory restrictions regarding service of individual notice, etc., the Special Deputy Collectors' total award outturn for the year under both land and houses did not fall short of the minimum. With the exception of land required at the tail end of the surplus course, the acquisition at Headworks was completed in February 1930. The total extent acquired was then 18,435·84 acres and 4,146 houses. The amount spent on land compensation and expenditure on land acquisition establishment were—

	RS.
Land compensation	27,67,886
Land acquisition establishment	1,98,418 excluding pension charges.
	29,66,284

The average rate paid per acre of land was Rs. 150. The necessity for an additional area of land to be acquired to accommodate the surplus course near its junction with the river was discovered only in 1934. This, together with other minor adjustments, brought the total cost to about Rs. 30,28,000 for the head-works area alone.

In the canal system, acquisition was made for the Main Grand Anicut Canal taking off the river Cauvery at Grand Anicut down to Merpanaikkadu tank in the limits of Arantangi taluk, about 52 miles long, besides the several distributary and extension canals and channels amounting to 727 miles. There was also the acquisition of land required for tram lines and Public Works Department temporary rest-houses. With a view to restrict the work to actual ayacut requirements, and also pending settlement of the question whether irrigation from Cauvery should extend to new areas in Coimbatore, Salem and Trichinopoly districts, acquisition in the canal area proceeded by sections; work was first restricted to the area above the Agniar (R.D. 29/1246) of the Grand Anicut Canal, then it was extended to the west of the Mayavaram-Arantangi railway line below Agniar in block III, later to the east of the railway line in block III and lastly to blocks I and II also. There was also some change in the alignment of the main canal as well as some of the distributary channels necessitating extra acquisition, also for widening of the already acquired canal here and there. A staff of seven Special Deputy Collectors for a period of two years was sanctioned for this acquisition in G.O. No. 493 I., dated 25th September 1925, but the term of office of these Special Deputy Collectors was extended from time to time according to necessity. The award outturn of the Special Deputy Collectors was at first fixed at 20 miles per annum, but later, when acquisition for the main canal was nearing completion and the acquisition was more for branch channels, necessitating some increase in office and field establishment, an attempt was made to raise the outturn still further to 60 miles per annum. Acquisition of 860 miles of main canal and branches in the whole system involved an expenditure of Rs. 25,49,400 as land compensation, exclusive of the expenditure on establishment. This excludes cost of land and establishment for the portion of the Grand Anicut Canal in Tanjore town limits, to the north of the railway line between the fort ditch and railway crossing, for which lands had been acquired by the District staff about the year 1910.

In G.O. No. 1787 I., dated 19th July 1928, Government decided that lands should be acquired at the cost of Government for field channels irrigating down to 25 acres blocks. It was thought at first that out of 301,000 acres of new ayacut it would be unnecessary to provide field channels for 80,000 acres of existing wet and 20,000 dry (adjoining these wet), but in practice, field channels had to be provided both for wet and dry at an average of about 30 feet per acre in the area above blocks I and II. Acquisition for these field channels was started in November 1930, and eight Special Deputy Collectors were employed on this work. They also attended to odd cases of acquisition of land for main and branch channels in the area. In the course of acquisition for field channels, it was found that 39 miles of channels under the head "rear channel" should be provided for the irrigation of blocks of over 150 acres and the acquisition of land for these also was attended to by these Special Deputy Collectors. Excluding the length of rear channels, the total length of field channels acquired in the area above blocks I and II was 1,650 miles. The outturn of the Special Deputy Collectors was fixed at 90 miles per year as no resurvey work was involved in the acquisition. The compensation paid was roughly Rs. 4,32,550, excluding the cost of establishment.

A rather striking feature of the cost of land acquisition establishment is the surprisingly high proportion over nine-tenths —it bears to the cost of land in the case of field channels. (The corresponding proportion in the case of the main canal, branches and distributaries was only around three-tenths.) We may explain here that the term "field channels" applies to small sub-laterals conveying water to blocks of 150 acres or less, in other words, to very small channels carrying less than 2 cusecs each. It is an obvious fact that the time and trouble involved in demarcating land is a function of the length of the course as distinct from the area covered and, in the circumstances, it is quite natural to expect that the smaller the proportion of the area to the length of the course, the greater the relative expenditure on the staff. As an extreme case, we may cite the example of the acquisition of land at Headworks where an area of about 65 square miles for the reservoir-waterspread and the township-site required a demarcation over a length of only 180 miles. The cost of establishment to cost of land in this case was less than 8 per cent.

The total compensation paid for lands acquired for the entire canal system was Rs. 30,37,000 and the total cost of land acquisition establishment came to Rs. 13,20,700. The percentage of cost of land acquisition establishment to cost of land was thus 43 per cent for the canal system as a whole.

Special Controlling Officer.

Government at first sanctioned, for a period of six months G.O. No. 164 I., dated 8th April 1925), a Deputy Collector on

Rs. 1,100 per mensem to formulate proposals for the staff required for acquisition of land in Coimbatore and Salem districts for the Headworks. Later, when acquisition was started both at Headworks and Canals, they appointed a Special Officer of the rank of Collector with Headquarters at Madras to control and supervise the work of the Special Deputy Collectors, both at Headworks and Canals. This Collector was under the control of the Board of Revenue and he was to work independently of the Collectors of the districts. In G.O. No. 163, Public, dated 24th February 1927, the post of a Commissioner was created for the Project works and with effect from 1st July 1927 the post of the Special Collector was abolished and the control of the Special Deputy Collectors on land acquisition work was taken over by the Commissioner. In September 1927, the Government appointed a Special Officer for the revision of the financial forecast of the Project and abolished the post of the Commissioner. Headworks of such magnitude required on the spot an officer of the rank of Collector and District Magistrate. Therefore the Headworks, comprising 10 villages of Coimbatore district and 11 of the Salem district (21 villages in all), was constituted as a temporary District of Mettur and placed in charge of a Collector with Revenue and Magisterial jurisdiction and having a Huzur Treasury. The control of the Special Deputy Collectors on Land Acquisition work both at Headworks and Canals was transferred to this Collector who was also styled "Special Revenue Officer." The temporary District of "Mettur," and with it the post of the Collector, was abolished from 2nd July 1929, the Government having sanctioned the appointment of a Special Officer of the grade of Deputy Collector to control and supervise the work of the Special Deputy Collectors on Land Acquisition, both at Headworks and Canals. This Officer continued to function up to May 1930 when he was replaced by a liaison officer of the grade of I.C.S. employed in connexion with ayacut investigation, etc. The periods of employment of each such Special Officer, and of the office staff under him are given in the Annexure VIII. The pay of these officers and staff was debited to cost of land proportionately for Headworks and Canals, until the completion of acquisition at Headworks, when they were entirely charged to Canals.

Acquisition Procedure.

Land acquisition at Headworks differed from that in the canal area in that the former consisted of large blocks of entire fields while the latter was composed of long narrow strips of land containing portions of fields or subdivisions of small area involving heavy survey work.

Headworks.—Schedules of lands showing the survey numbers and extent of lands required in each village were prepared by the Public Works Department. The Collectors of Salem and Coimbatore prepared the notification under section 4 (1) with reference to these schedules and published it. The lands to be acquired consisted mostly of entire fields involving little or no survey work, as they were clearly detailed in the village maps. Lands in and around Mettur, which were required urgently, were acquired first. The rest of the lands were divided into compact blocks, and as each block was inspected by the Special Deputy Collectors, draft declarations under section 6 were completed and sent for publication. Along with the draft declaration, the Special Deputy Collectors sent notes on valuation, explaining in detail how the valuation was arrived at and including a sketch showing the situation of the fields contained in the draft declaration with reference to those in regard to which sale-deeds or other statistics were available. Lands were dealt with in blocks, each block comprising lands of more or less equal value. Copies of these notes were sent to the Executive Engineers concerned to enable them to offer their remarks on the rates of valuation adopted. In the case of buildings costing over Rs. 2,500, the valuation was made by the Public Works Department. The draft declarations were scrutinized by the Special Revenue Officer and submitted to the Board of Revenue or Government as the case might be. Copies of the draft declarations were also sent to the Chief Engineer but this procedure was discontinued later. The notes on valuation were scrutinized with reference to the data on which they were based, on the remarks of the Executive Engineer, and the rates adopted in the sanctioned estimate. The Special Controlling Officer also inspected lands wherever necessary. After approval of the valuation statement, the Special Deputy Collectors proceeded with the award. The Special Deputy Collectors were required to adhere to these rates, but were allowed discretion to raise the rates in the case of individual fields, if necessary, after obtaining previous approval, so as to avoid reference to the Court. Emergency provisions of the Act were applied in the case of such lands as were required urgently by the Public Works Department. But the majority of the cases were dealt with only under the ordinary provisions of the Act. Money compensation was awarded in all except one or two cases of unenfranchised religious service inams, in which cases grant of land in exchange was made with the previous sanction of Government. Certain forest blocks within the limits of the Salem district were disafforested in order to provide the ryots who were dispossessed of their lands and houses in the reservoir area with fresh lands. The Revenue Divisional Officers concerned were provided with a list of ryots thus affected by the acquisition.

Assessed wastes and poramboke lands required for the Public Works Department works were transferred to the Public Works Department free of cost (in accordance with G.O. No. 500 I., dated 28th August 1913) by the Divisional Officers concerned on application to them by the Special Deputy Collectors.

Canals—Main Canals and Branch Channels.

Acquisition here was more arduous than that at Headworks as it involved a far larger amount of survey work. The first set of notifications under section 4 (1) of the Land Acquisition Act, was prepared by the District Collector on the basis of schedules prepared by the Executive Engineer with reference to the alignment marked on the map and schedules prepared by the Public Works Department but without actual demarcation on ground. These notifications simply furnished survey numbers and the approximate extents, without noting boundaries or the names of owners. Section 2 of Chapter V, Part III, of the Land Acquisition Manual, permitted this procedure and required service of individual notices, specifying details as soon as they became known, and allowing 15 days time for preferring objections. These provisions were availed of. However, in many cases the extents notified under section 4 (1) were either greater than required or the plots themselves were found to lie outside the actual alignment according to actual demarcation done subsequently. This resulted in withdrawing, under section 48 (1) of the Act, from the acquisition of large extents of lands notified under section 4 (1). The notifications under this section which were published later, were based on actual demarcation on the ground, and in these cases the need for withdrawal under section 48 (1) did not arise except where there were changes in alignment. The Public Works Department officers demarcated the lands with 'stones' manufactured of cement concrete of the required dimensions and bearing the Government arrow mark and the letters "P.W.D." The Public Works Department furnished blue prints to the Special Deputy Collectors. A special staff of surveyors was attached to the Special Deputy Collectors to do the heavy survey work. The surveyors also prepared survey records. The Revenue Inspectors attached to the Special Deputy Collectors checked the survey and while so doing, valued the land and collected material required for the draft declaration. The survey involved in main canals and branch channels was not only the survey of portions to be acquired but also of the residual fields. The Special Deputy Collectors were personally responsible for the correctness of the measurements. They overchecked the survey, verified valuations and submitted the draft declaration with a report on valuation and a sketch, similar to that as described for the purpose at the Headworks. The lands to be acquired in certain sections of the canals were very valuable wet lands and the owners were also inclined to be litigious. The Special Deputy Collectors passed such cases with considerable care so that, taking the Canal System as a whole, the number of applications received for references under section 18 to the Civil Court was very few.

Field Channels.

Lands had to be acquired for considerable lengths over almost the entire commanded area of the Canal System. In order to minimise the labour and cost on the work, measures necessary to simplify the work were considered and it was decided to apply the urgency provisions of the Act, thereby dispensing with the enquiry under section 5-A which took a lot of time by way of service of individual notices and the hearing of objections a month after the date of publication of the notification. For valuation purposes, the detailed proceedings were dispensed with and, as acquisition was made for main canals and channels in almost every village, the class-rates paid for those acquisitions were adopted. Further, the Public Works Department did not furnish regular land plans and schedules for the field channels. They simply indicated the course of these channels on the village maps and these formed the basis of acquisition to be employed by the Special Deputy Collectors. As far as possible, the alignment of these channels followed field or subdivision boundaries. In order to avoid change of alignment, either at the instance of the Public Works Department or the Revenue Department, or at the instance of the ryots at a later stage, a joint inspection of the alignment was made by the Revenue Inspectors and Public Works Department supervisors prior to commencement of survey work. Any adjustment found necessary in the alignment was agreed upon by both these officials and approved by the Special Revenue Officer and the Executive Engineer of the Special Division.

Ordinarily, whether acquisition of land is done by the regular or special staff, the incorporation of changes in the Revenue accounts is attended to by the District staff. But consequent firstly, on the large extent of acquisition made in the Project area and secondly, on the complications due to one operation overlapping another and the survey records, prepared by the Survey Officer but not made final, forming the basis of acquisition for field channels, the District staff were unable to tackle the work without difficulty and delay. The Special Deputy Collectors were therefore authorized by Government to incorporate the changes both in the village and taluk accounts (including insertion and correction of sketches in the village and taluk copy of Field

Measurement Books), to send registration return and also to sanction subdivision and transfer of all lands at the disposal of Government required for the Project to the head "Public Works Department poramboke" independently of the Revenue Divisional Officers. Cases of transfers to be dealt with in proprietary villages were referred to the Collector. The Special Survey Party engaged on the survey of proprietary villages in the district in connexion with the Cauvery-Mettur Project was made use of and it was arranged that all changes arising out of acquisition in proprietary villages should be carried out by them in the Field Measurement Books and maps, either as pre or post-survey corrections.

Lease of acquired Lands.

Headworks.—At Headworks, lands had to be acquired about a year in advance of the requirements and this policy was followed as far as possible, but the ryots in the submersible area who were to evacuate their villages and settle down elsewhere preferred prompt acquisition. The acquisition for a greater portion of the area was therefore proceeded with so as to cause the least amount of inconvenience to the ryots. Later, however, the acquisition was slowed down by reducing the number of Special Deputy Collectors. In order to minimize hardships on the ryots and also to save interest charges, lands acquired but not immediately required for works were leased out to their former owners on an annual rental equivalent to 4 per cent of the compensation paid. The leases were for a year at a time and special lease deeds were drawn up. The leasing of lands and collection of rentals were entrusted to the acquisition Deputy Collectors first, but the work was heavy and, when a Revenue Division was formed at Mettur, this work was transferred to the Revenue Divisional Officer.

Canals.—The leasing was quite feasible at Headworks as the lands were in large and compact blocks, but the same result could not be realized in practice in the Canal zone where the lands acquired were small areas in the shape of long narrow strips. At first, the Executive Engineers themselves arranged to lease out such of the lands as were not immediately required for works, but later the leasing was arranged through the Revenue officials of the district. The same method as that adopted at Headworks was followed in the method of leasing with the difference that 6 per cent of the compensation amount was fixed as the upset rental. However, the result of the lease was very poor for, either there were no bidders at all or, even where there were bidders, the bid amounts were only nominal.

CHAPTER XXX

(1) *Ayacut Operations.*

SIMULTANEOUSLY WITH the revision of Revenue forecast of the Project in 1928, Government examined the need for carrying out certain special operations in the Canal area in connexion with the determination of the ayacut so as not to exceed the total extent of 301,000 acres fixed by the Madras–Mysore Agreement, and for the better and more convenient assessment of water-cess in proprietary areas. They finally decided upon :—

(*a*) the cadastral survey of the proprietary areas;

(*b*) the preparation of a Record of Rights;

(*c*) the reservation of land for communal purposes; and

(*d*) the determination of ayacut. A Survey Party was employed for the initial and supplemental survey of the proprietary areas in the Tanjore district. A special staff (consisting of two Deputy Collectors for some time and only one Deputy Collector later), together with the necessary field and office staff, were employed for the preparation of the Record of Rights. A Deputy Collector styled 'Reservation Officer' was employed on the investigation and determination in each village of the communal requirements for village-sites, threshing floors, cattle stands, burial and burning grounds, cart-tracks, foot-paths, drainage channels, etc. All these items formed the necessary preliminary to the determination of the ayacut in each village. A Special Executive Engineer and Special Revenue Officer (of the grade of Indian Civil Service) were appointed by Government to work together for the determination of the ayacut. The fields included in the ayacut were to be recorded in an "Ayacut Register" and, for all the included lands, permits were to be granted. Each subdivision of a field formed the permit unit and the inclusions in the ayacut register had, therefore, to be for either an entire survey number or a subdivision. The permits were to issue, without application, for each subdivision of each survey number included in the ayacut register, and with the extent and the source of supply both for first and second crops noted therein in different colours. The ryotwari wet lands were to have a written authorization. These were to be in force until fasli 1353 when there would be a revision of the ayacut register. The Executive Engineer and the Special Revenue Officer were to fix first the ayacut in each village by mutual agreement, then the Executive Engineer, exclusively, was to determine the limits of land to come under each channel, to fix sluice points, align rear channels from pipe sluices to points where they would irrigate 150 acres or slightly less, to align field channels down to points where they irrigate about 25 acres, to prepare ayacut maps and ayacut registers for each channel and to issue a permit for each subdivision included in the ayacut register. Acquisition of land for rear and field channels formed the last item of field work of the ayacut operations. The Special Revenue Officer's duties consisted in co-operating with the Special Executive Engineer in carrying out these processes, to regulate, with reference to his programme of the work of fixing ayacut and other considerations, the work of the staff engaged on the preparation of the Record of Rights and reservation, to co-ordinate the progress of the Survey Party with that of the staff engaged on the preparation of the Record of Rights and with the requirements of the Public Works Department. He had to acquire lands for rear and field channels selected by the Executive Engineer, to subdivide portions of fields or subdivisions reserved or included in the ayacut and also to acquire lands reserved for cart-track, foot-path and drainage channels in Government villages. The District Board, Tanjore, was required to construct new roads in the Project area to suit post-project developments, and it was one of the duties of the Special Revenue Officer to co-ordinate the activities of local bodies with the work of the Government Departments. The Special Revenue Officer was to work under the control of the Board of Revenue and to make his proposals and carry out his works in close consultation, wherever necessary, with the Chief Engineer and Collectors concerned. All these operations are so intertwined and complicated (some having also statutory restrictions) that it may be worthwhile mentioning the details of procedure for each of these operations.

(2) *Survey of villages.*

This was the first essential in the ayacut operations, and it formed the framework of each succeeding operation. About two-thirds of the area in the new delta was 'proprietary' and this was either unsurveyed or partly block-surveyed and partly cadastrally surveyed. In the villages which were cadastrally surveyed, the survey was not under maintenance and they had therefore to be surveyed supplementally, and fresh sets of Field Measurement Books had, of necessity, to be prepared.

The number of villages surveyed initially and supplementally was 613. The Survey Officer was supplying survey record to the Record of Rights Officer at a rate of 20 square miles per month, and maps to the Executive Engineer at 20 villages per month. The supply of record to the Record of Rights Officer and maps to the Executive Engineer for the areas above blocks I and II was completed in March 1933, and the areas in blocks I and II, comprising some 90 villages, were completed by about August 1934. The publication of section 13, notification and the preparation of triplicate copies of Field Measurement Books for these areas have since been done.

(3) *Record of rights.*

Next to the cadastral survey of the proprietary areas, a record of existing wet conditions and irrigation sources was necessary to enable the proper assessment of irrigation cess to be levied for the use of Project water on lands not entitled to free irrigation. In 1915 a special staff was employed for the localization and demarcation of mamul wet lands in the Tanjore district. This staff attended to the work in the Nannilam and Negapatam taluks and 37 villages in Pattukkottai taluk, but before the record was made final and work in other areas was taken up, the work was postponed pending sanction to the Cauvery-Mettur Project estimates. Lastly, Government ordered the preparation of a Record of Rights for the proprietary villages.

These operations were done, not only for the villages in the new area, but also for those in the existing delta. At first, it was proposed that a Record of Rights should be prepared in respect of all estates situated within the areas irrigable by the Cauvery-Mettur Project, but later (in G.O. No. 1000, Revenue, dated 28th May 1930), it was ordered that the record should be prepared for all proprietary lands which whether irrigable or unirrigable, had been cadastrally surveyed. The following note on Record of Rights was prepared by the Record of Rights Officer :—

> "The Record of Rights was found necessary because there had been no cadastral survey in respect of most of the proprietary villages and the village accounts were therefore framed on an unsatisfactory basis. They only furnished figures, whether for cultivation or irrigation, in lump for blocks sometimes extending to whole villages, which did not admit of any proper verification. It was not easy to ascertain, by reference to the village accounts, the classification of a particular field, such as 'wet,' 'dry' or

'manavari,' and whether it was or was not entitled to irrigation from any particular source. As such a system was full of complications and was pre-eminently likely to lead to disputes between the land-holder and the ryot on the one hand and between them and the Government on the other, the preparation of an authentic record of facts, as they stood prior to the introduction of project water, was the only remedy possible. The existing delta also came within the scope of these operations since the conditions there were more or less similar to those in the non-deltaic area, and the project was also designed to ensure a better regulated supply and would thus benefit the delta."

The object of the Record of Rights operations was primarily to make a record of all existing irrigation rights and practices under tanks, channels and other sources of irrigation in the above tracts, so that the record might form a basis on which Government could decide questions of rights that might accrue, or concessions that might be shown, on the advent of the project. Incidentally, the record would also furnish information to facilitate the levy and collection of water-cess. As these questions would not be confined to the "Estate villages" only, the investigation had to be extended also to inam villages which were not governed by the provisions of the Madras Estates Land Act I of 1908, but with the difference that, while in the former the record was prepared under the provisions contained in Chapter XI of Act, in the latter it was done only informally.

The Record of Rights register contains in respect of each survey number and subdivision, particulars about its corresponding old survey number (if any), its present extent, tenure, classification, source or sources from which it is irrigated (if under irrigation), the names of the inamdars, or the names of the land-holders and the ryots if the village is an "Estate" and other important facts, particularly those relating to irrigation, observed in the field. The record is prefaced by a statement of irrigation rights and practices in the form of a memoir, containing information about the capacity of each irrigation source, its nature, the amount and duration of supply together with a description of the sluices and other permanent structures connected with the irrigation. The memoir also furnished statistics of irrigation relating to a few years preceding the introduction of the project water, details regarding the nature and the number of crops grown, the then existing practice as regards the levy and collection of water-cess, improvement made to the irrigation source subsequent to the inam or the Permanent Settlement, and other matters likely to have any bearing on the question of irrigation rights.

The procedure adopted in the preparation of the records is as follows :—

The investigation begins immediately on receipt of the survey records, notices prescribed in the Act being issued in advance. The Revenue Inspector inspects each field and gathers all the particulars necessary to fill up the several columns of the Record of Rights registers. The current village accounts and other records in the Taluk office, as well as the Divisional and the Collector's offices, are also consulted. The Minor Irrigation Overseer, who is attached to the staff, similarly gathers all the details relating to irrigation and irrigation sources. These records are scrutinized by the Special Deputy Tahsildar and by the Record of Rights Officer, both in the field and by local enquiries and, in the case of " Estate villages," are then published under section 166 (1) of the Madras Estates Land Act I of 1908. Individual notices are issued to every land-holder and ryot interested in the fields, giving them three months' time to prefer any objection they may have to the draft records which include the village plan, the irrigation plan and the Field Measurement sketches, besides the Record of Rights Register and the Irrigation Memoir. In the case of villages not governed by the Act, where these formalities have been dispensed with and the record is prepared only informally, the period allowed for preferring objections is one month. After the disposal of the objections, the records are amended so as to conform to the orders passed in each case and are then put aside to await the completion of the survey operations. On the publication of the notification under section 13 of the Survey and Boundaries Act (Act VIII of 1923) by the Assistant Director of Survey, the final Record of Rights is framed for the " Estate villages " and published in the manner prescribed in the Madras Estates Land Act I of 1908. In the case of the other villages, there is no final publication and the survey notification practically marks the final stage of the operations.

Side by side with the Record of Rights register, a supplement to it is also prepared. The supplement is intended to cover all subsequent changes in the register, brought about by the reservation and ayacut operations, which could not be embodied in the Record of Rights Register without observing all the formalities prescribed in the Act.

The Record of Rights register together with the memoir and the supplement are printed for supply to all officers who are entitled to a free copy. They are also to be made available for sale to the public.

The cost of the operations has been borne by the Government in the first instance but, after completion of the work, the cost is to be apportioned between the land-holders and the ryots in such proportions as the Government may determine.

The Record of Rights work started in March 1930 with one Deputy Collector in charge of the operations. In February 1931 an additional Deputy Collector was appointed and he continued the duties till the end of March 1933, when the entire field staff was disbanded, leaving one Deputy Collector and the Ministerial staff to complete the work. Subsequently, it was decided to extend the operations in blocks I and II and a small field staff was reconstituted in January 1934 to complete the work.

The Record of Rights operations cover, on the whole, 710 villages with an aggregate area of about 675 square miles of which 400 villages, with an extent of about 533 square miles, are "Estates," the remaining villages being not governed by the provisions of the Madras Estates Land Act I of 1908. The final Record of Rights has been published for all these villages. The monthly outturn for a Deputy Tahsildar, having three Special Revenue Inspectors, was actually 7½ square miles, while that of the Record of Rights Officer, having two Special Deputy Tahsildars, was 14 square miles.

(4) *Reservation of lands.*

Reservation of lands.—The Madras-Mysore Agreement limited the extent which would be irrigated by the new canals under the Project to 301,000 acres. It was therefore necessary to fix in each village in the new area all lands which could possibly be irrigated and enter them in the ayacut register so that there might be no scope for irregular irrigation, constituting thereby breach of that Agreement. To this end, all lands required for communal purposes which might be required in each village under post-project conditions had to be determined and excluded, the rest of the lands alone being included in the ayacut register. The processes of reservation were alike both in Government and proprietary villages.

Accordingly, the Executive Engineer was required to take block-levels of each village and mark on the village maps the areas which, according to their levels, came under one or other of the three following heads*:—

(*a*) commanded area;

(*b*) uncommanded (above 1 foot) over F.S.L. of the channels; and

(*c*) lowerable (up to 1 foot over F.S.L. of channels).

The details of reservation work carried out in a Government village were as follows :—

A register called the "Reservation register" containing particulars of survey numbers and extent, grouped under the above three items (*a*), (*b*) and (*c*) according to levels, was prepared by the Revenue Inspectors with reference to village adangals which formed the frame work of the operations. The names of pattadars or occupancy ryots were also entered in these registers as they were required by the Executive Engineer to prepare permits. The Director of Public Health and Director of Town-Planning drew up certain model instructions for the guidance of the Officer employed on reservation operations. Although these instructions were kept in view in selecting fresh village sites, it was not possible to follow them rigidly. Existing compact blocks of houses comprising village-sites within the commanded area were retained and reserved, but possible future extension were located on high level ground outside the irrigable zone. Generally, the total reservations for house-sites ranged from 3 to 5 per cent of the total area of the 'village.' Existing irrigation or drainage channels from their heads down to the point where they were poramboke subdivisions were reserved subject to confirmation by the Public Works Department officer. Similarly, all existing important cart-tracks were reserved, while neglected or superfluous cart-tracks and foot-paths were abandoned and included in the ayacut. Provision was made, where necessary for new cart-tracks required to link existing roads with the proposed village-sites. Generally, there was no need to provide fresh grazing grounds. Cattle stands, threshing floors, burial and burning grounds, drinking water tanks, etc., to meet post-project requirements were reserved. Coconut topes of over three years' growth were excluded from the ayacut register, being exempt from water-cess. Sites for fresh bridges across project canals and channels were investigated, and the Public Works Department were advised regarding them. In view of the extra revenue which the District Board was likely to realize by way of land-cess from the project, it was suggested to the Board that it should take up the work of providing feeder roads, at the same time taking up the metalling of existing roads. The proposed roads were aligned on the ground and the lands required for them were reserved. The extents proposed either for reservation or exclusion, if they did not already comprise entire fields or subdivisions, were roughly estimated and entered in the reservation register. These reservations were marked on the delimitation map in red hatched lines consistently with the entries in the Reservation register, and rough sketches were prepared for all fields, portions of which have been proposed for inclusion or reservation. The Special Revenue Inspectors attached to the Reservation Office made these preliminary investigations and prepared the records. Each Revenue Inspector was required to complete about 4,000 acres each month. The Reservation Officer checked these reservations, entered his proposals in the appropriate column of the Reservation register and prepared for each village a consolidated report in the form of a "scheme report," setting out all items of his proposals under distinct paragraphs such as—

(1) Situation of the village.
(2) Irrigation and drainage facilities.
(3) Village sites.
(4) Communications.
(5) Bridges.
(6) General.

The same procedure was followed in proprietary villages, but in this case the Reservation Officer had only a tracing of the village map on a 16-inch scale, supplied by the Executive Engineer with reference to the preliminary map prepared by the Officer-in-charge. Although this map contained sufficient detail for reservation purposes, it did not contain all the topographical details found in the Government village map. The Reservation register had to be prepared with reference to the record of rights and details of irrigation sources collected from the irrigation memoir of the village.

The Reservation Officer was required to overcheck not less than 15 villages a month and to send the records complete to the Special Revenue Officer as soon as his overcheck was completed. These records were scrutinized by the Special Revenue Officer and passed on to the Executive Engineer of the Special Division who inspected any important items in the village either before or after the actual ayacut hearing. The Reservation register formed the basis of the Public Works Department ayacut register, and its accuracy was therefore of primary importance.

At a late stage, the need arose for reserving land required for the proposed railway line between Tanjore and Pattukkottai, to which reference has already been made. The proposed line passed through 22 villages in the commanded area of the Project. As reservation operations had already been completed in almost all these villages the Survey Party did the necessary survey of the railway line both in Government and proprietary villages and furnished the survey record. The lands required for them were reserved in accordance with these records, and the ayacut registers were duly corrected.

Ayacut Investigations.—On the Reservation register and village maps furnished to him, the Executive Engineer fixed the points for sluices, grouped the ayacuts under each channel and sluice, and he aligned the field channels and prepared the Public Works Department ayacut register, both channelwar and sluicewar. He confirmed reservations for drainage channels, proposed reservations of tanks as well as any fresh drainages necessary, fixed inclusion of fields, portions of which only happened to be irrigable, and returned his records to the Special Revenue Officer with sketches for subdivision cases. Then the two registers were compared and made to agree both by the Public Works Department and Revenue staff, after which notice of ayacut hearing was sent to the villages not less than seven days in advance of the date of the hearing so as to enable the village officers and interested ryots to appear before the Ayacut Officers. At these ayacut hearings representations were heard, and the proposals were explained to those present. If there were no objections the entries in the ayacut register were confirmed. The Executive Engineer and Special Revenue Officer jointly completed ayacut hearings at a rate of not less than 12 villages each month.

Field Channel Maps.—After the ayacut hearing, the Executive Engineer prepared another copy of the village map, illustrating the fields which had been included in the ayacut register and also showed the reservations and the alignment of field channels. These were then sent to the Special Revenue Officer. These maps took the places of regular land plans and schedules.

Ayacut Registers.—The map, to which we have referred above, together with sketches for subdivision cases were then sent to the Special Deputy Collectors who prepared a correction statement showing all changes in notation and areas consequent on the acquisition and subdivision, and sent them to the Special Revenue Officer. These changes were required to be incorporated in the Public Works Department ayacut register immediately, as only then the ayacut register became complete and ready for the preparation of permits. The Special Revenue Officer scrutinized these correction statements and passed them on to the Executive Engineer, Special division, who made these changes in his ayacut register and returned the correction statement to the Special Revenue Officer with his acceptance. The Special Revenue Officer then proceeded with the preparation of indexes while the Special Deputy Collectors passed award and did the post-award work. At the same time the Executive Engineer completed the channelwar ayacut register and prepared the permits for each subdivision included in the ayacut register.

District Board Roads.—The acquisition of land for the District Board roads to be formed in the Cauvery-Mettur Project area was attended to by a separate Special Deputy Collector. His work was also controlled and supervised by the Special Revenue Officer as the changes arising out of this acquisition had to be incorporated both in the Public Works Department ayacut registers and record of rights registers in the same way as other subdivision and acquisition changes in the area.

Ten roads were provided for and the length of these roads, for which lands had to be acquired, was 62 miles, of which a length of about 1½ miles lay outside the irrigable area. The District Board aligned the roads and prepared preliminary land plans and schedules, by employing its own staff, and obtained the technical approval of the Superintending Engineer concerned for the alignment. The preliminary land plans, schedules and valuation were verified by the Special Deputy Collectors employed on acquisition of channels in the Cauvery-Mettur Project area as they had acquired lands in almost every village through which the roads passed. After receipt of the land plan and schedule verified, the President of the District Board, obtained the formal sanction of the District Board for the estimate and sent regular land plan and schedule with an application for acquisition in the prescribed form. The alignment was also demarcated by the District Board. The acquisition was done under the ordinary provisions of the Act, all formalities under the Act being observed. The Special Deputy Collector was authorized to incorporate changes in the Revenue accounts and maps independently of the district staff, as in the case of the Special Deputy Collectors employed on acquisition of land for channels. In the proprietary villages situated in the commanded area, the Special Deputy Collector had no survey work beyond technical scrutiny of the sketches, measurements and areas, since the survey party has already surveyed them, following the demarcation on the ground, during the survey of the village.

As soon as the draft declaration for each road was completed, the Special Deputy Collector communicated all changes in notations and area in respect of the road fields situated in the respect of the road fields situated in the commanded area and these were embodied both in the reservation and the Public Works Department ayacut register.

This acquisition started in August 1933 and was completed by March 1935. The cost of land compensation as well as staff is met by the district board. The district board supplies funds required for compensation in advance, while in the case of establishment, the expenditure is incurred in the first instance under "22. General Administration" and then recovered from the district board.

CHAPTER XXXI.

Development of Irrigation.

The Vadavar System was opened to irrigation in fasli 1342. According to the forecast of growth of irrigation, an extent of 5,000 acres of ryotwari dry, 1,000 acres of zamin dry and 100 acres of zamin and inam wet or 6,100 acres was to have come under irrigation of the project under the Vadavar system in 1932–33. But mainly due to the prevalence of an unprecedented economic depression, the actual extent of new irrigation in that fasli fell rather short of expectations, in spite of the fact that the rates for the year were only one-third of the final proposed rates.

With a view to develop irrigation in the area, the Government, in 1933, appointed a Deputy Collector styled as " Irrigation Development Officer " for a period of six months, and entrusted to him the following specific duties :—

(1) to ascertain the causes which would tend to operate against the growth of irrigation, and to suggest ways and means to eliminate them;

(2) to explain to the ryots the advantages of irrigation, the periods during which water would be supplied and the concessions to be granted in the water cess rules for irrigation in the first few years;

(3) to grant loans to persons who were likely to take water, but who needed capital to prepare their lands for irrigation and to cultivate it;

(4) to explain to the ryots that the acquisition of land by the Government for the field channels under the Cauvery-Mettur Project had been undertaken at the cost of the Government with the express purpose of affording some relief to the ryots, and to persuade them, in return for this concession, to dig these small channels by their own joint labour;

(5) to make the ryots realise that the present economic depression is a passing phase and that if they did not take water now they would lose the benefit of the concessions in the rates of water cess and might, also, lose the chance of their lands being included in the ayacut of the Cauvery-Mettur Project;

(6) to examine the conditions in proprietary areas where the divided interests of landholders and tenants were likely to prove an obstacle to speedy development of irrigation;

(7) to ascertain the cause of disputes, if any, between the proprietors and the tenants in proprietary villages which were likely to retard the progress of irrigation in those villages, and to use his influence towards the amicable settlement of those disputes;

(8) to collaborate with the Agricultural Department in giving advice and assistance to those ryots who expressed a desire to grow crops other than paddy;

(9) to investigate the possibilities of introducing and working colonisation schemes for large blocks of both ryotwari and proprietary waste lands;

(10) to investigate, in consultation with the local officers of the Co-operative Department, the practicability of forming and working co-operative land improvement societies for large blocks of occupied land, for compact groups of ryotwari villages or for proprietary villages;

(11) to take special steps towards the encouragement of individual enterprise in bringing large areas under irrigation, by personal advice on such matters as the cultivation of remunerative crops, the suitability of the soil for such crops, the ways and means of securing capital to reclaim the land and of securing labour, etc.;

(12) to assist the Agricultural Department in the location of its farms and to disseminate among the ryots the results of the experiments conducted in the farms regarding the cultivation of different crops;

(13) to collaborate with the Public Works Department to see that no departmental obstacles were allowed to postpone the development of irrigation;

(14) to scrutinise the working of water-cess rules to see in what direction a relaxation of them was likely to be advantageous; and

(15) to take all other steps conducive to the rapid development of irrigation under the project channels and to the rapid expansion of second crop cultivation in the existing delta.

The Irrigation Development Officer toured round the important places in the new delta, started quick and effective propaganda, disabused the minds of ryots of the area who entertained wrong notions owing to an organized sedulous propaganda against the use of the Cauvery-Mettur Project water, made them cognizant of the details of the favourable rates granted by Government and induced them to start cultivation in the initial years. The Special Deputy Tahsildars attended each village and explained to the ryots the details of the project and made them conversant with the methods of irrigation. As a result of the propaganda, up to the end of January 1934, 214 villages took project water and the extent cultivated both wet and dry was 30,684 acres against the forecast of 32,870 acres. There was insistent demand that field channels should be dug by Government, but ryots were gradually persuaded to excavate them themselves. The term of office of the Development Officer which was to expire on 15th December 1933 was extended to 27th January 1934, when he was appointed as Special Revenue Officer of the Cauvery-Mettur Project and the duties of the Development Officer became merged with those of the Special Revenue Officer. The pay of this officer as well as that of the Special Deputy Tahsildars and staff was debited to ' 55. Cauvery-Mettur Project '. From February 1934, the Special Revenue Officer for the Cauvery Mettur Project was directed to do all the work that was formerly being done by the Irrigation Development Officer.

In view of the continued slump in the price of paddy and in order to encourage development of irrigation, the question of the grant of concessional rates was further examined and, at the instance of the Irrigation Development Officer, the Government, in March 1934, granted the following concessional rates for regular irrigation with Cauvery water supplied through the Vadavar and Grand Anicut Systems for faslis 1344 and 1345. This has subsequently been extended to fasli 1346 also. The question of granting any concession in the rates of water-cess to be charged after the end of fasli 1346 will be considered with reference to the circumstances that might then prevail.

——	Dry.			Manavari.			Proprietary and minor inam wet.		
	RS.	A.	P.	RS.	A.	P.	RS.	A.	P.
First crop	5	0	0	4	10	8	3	5	4
Second crop	2	8	0	2	5	4	2	8	0
Dufassal	7	8	0	7	0	0	5	13	4
Third crop	1	4	0	1	2	8	1	4	0

ANNEXURE I TO CHAPTER XXVIII.

Item.	Extent.	Amount.
	ACS.	RS.
Increase in revenue from first-crop area and assessment on waste land in the newly-commanded area ..	328,395	19,74,658
Second crop in the newly-commanded area and extension of second-crop area in the delta	145,000	5,80,000
Enhancement in first crop revenue due to the raising of the classification of irrigation in the delta, including the Lower Coleroon anicut system	681,270	5,95,204
Enhancement in second crop revenue	67,380	33,690
Interest on sale-proceeds	18,276	73,104
Total gross revenue ..		32,56,656
Deduct—		
Maintenance charges at As. 13–6 per acre on 328,395 acres ..		2,77,083
Collection and establishment at 11 per cent of the total revenue excluding interest on sale-proceeds and enhancement of land revenue from the existing delta and 5 per cent on the latter ..		3,12,457
Total deductions ..		5,89,540
Net revenue ..		26,67,116

Return on the capital outlay of 385 lakhs 6·93 per cent.

ANNEXURE II TO CHAPTER XXVIII.

	RS.
1 Dry—	
(*a*) Government lands (95,683 acres) at Rs. 8 per acre	7,65,464
(*b*) Zamindari and inam lands (119,549 acres) at Rs. 8 per acre.	9,56,392
2 Existing inam and Zamindari wet (62,770 acres) at Rs. 5 per acre ..	3,13,850
3 Government existing wet—	
Occupied 16,230 acres at Re. 1–2–0 per acre over previous rates ..	18,259
Unoccupied 1,768 acres at Rs. 6 per acre	10,608
4 Assessment on unoccupied dry lands 12,648 acres at Rs. 1–4–0 per acre	15,810
	20,80,383
Second crop in the newly-commanded area and extension of second crop in the delta (10,000 + 65,000 acres or 75,000 acres) at Rs. 4 per acre	3,00,000
Enhancement in first-crop revenue due to the raising of the classification of irrigation source	5,29,550
Enhancement in second-crop revenue	33,000
Interest on sale-proceeds	73,104
Total ..	30,16,037
Deduct—	
(i) Maintenance charges at As. 13–6 per acre on 296,000 acres ..	2,49,750
(ii) Collection and establishment charges—	
(*a*) Six per cent on gross revenue excluding share of enhanced land revenue and interest on sale-proceeds [6 per cent on (30,16,037—88,914) or 29,27,123]	1,75,627
(*b*) Five per cent on gross revenue less interest on sale-proceeds [5 per cent on (30,16,037—73,104) or 29,42,933] ..	1,47,147
Total ..	5,72,524
Net revenue ..	24,43,513

The return on an estimated capital outlay of 409½ lakhs will be 5·97 per cent.

ANNEXURE III TO CHAPTER XXVIII.

		RS.
99,474	acres of Government dry lands at Rs. 15 per acre	14,92,110
119,009	acres of zamin and inam dry lands at Rs. 15 per acre ..	17,85,135
64,349	acres of zamin and inam wet lands at Rs. 7–8–0 per acre.	4,82,618
16,400	acres of Government wet occupied at Rs. 2 per acre ..	32,800
1,768	acres of Government wet unoccupied at Rs. 6 per acre ..	10,608
301,000		
15,789	acres—assessment on unoccupied dry lands at Re. 1–4–0 per acre	19,736
90,000	acres—second-crop charge at Rs. 7–8–0 per acre	6,75,000
Enhancement of first crop revenue in existing delta		5,29,550
Enhancement of second crop revenue in the existing delta		33,000
Interest at 6 per cent on sale-proceeds of 17,557 acres at Rs. 150 per acre		1,58,010
	Gross revenue ..	52,18,567
Deduct—		
Charges both direct and indirect against Revenue Account ..		5,54,028
	Net annual revenue ..	* 46,64,539

* Represents a return of 7·43 per cent on the sum-at-charge.

ANNEXURE IV TO CHAPTER XXVIII.

		RS.
Gross direct receipts—		
Water-cess on 100,600 acres of ryotwari dry lands at Rs. 15 an acre.		15,09,000
Water-cess on 119,000 acres of zamin and inam dry lands at Rs. 15 an acre		17,85,000
Water-cess on 62,000 acres of existing zamin and inam wet lands at Rs. 10 an acre		6,20,000
Enhanced assessment on 17,400 acres of ryotwari occupied wet under non-deltaic sources at Rs. 2–8–0 an acre		43,500
Second-crop charge on 154,000 acres at Rs. 7–8–0 an acre		11,55,000
Enhancement of second crop revenue on 37,000 acres of Government wet in the existing delta (exclusive of 23,000 acres of compounded double-crop lands)		1,11,000
Enhancement of first crop revenue in the existing delta owing to reclassification of sources		5,16,225
Increased revenue due to revision of water-rate in the case of first and second crop on dry lands in the existing delta		1,00,000
	Total direct receipts ..	58,39,725
Indirect receipts—		
Land assessment on 16,840 acres of unoccupied ryotwari dry lands at As. 13 an acre		13,682
Interest at 6 per cent on sale-proceeds of 16,840 acres of waste lands at Rs. 150 an acre		1,51,560
	Total indirect receipts ..	1,65,242
	Total gross receipts ..	60,04,967
	RS.	RS.
Deduct—		
1 Maintenance charges on 301,000 acres of new irrigation at Re. 1 per acre	3,01,000	
2 Collection charges	1,50,000	
		4,51,000
	Net revenue ..	55,53,967

A return of 6·31 per cent on the same-at-charge.

ANNEXURE V TO CHAPTER XXVIII.

		RS.
Gross direct receipts—		
(*a*) Water-cess on 100,600 acres of ryotwari dry lands at Rs. 15 an acre		15,09,000
(*b*) Water-cess on 119,000 acres of zamin and inam dry lands at Rs. 15 an acre		17,85,000
(*c*) Water-cess on 62,000 acres of zamin and inam wet lands at Rs. 10 an acre		6,20,000
(*d*) Enhanced assessment on 17,400 acres of ryotwari occupied wet under non-deltaic sources at Rs. 2–8–0 an acre		43,500
(*e*) Second-crop charge on 154,000 acres at Rs. 7–8–0 an acre (70,000 old area, 84,000 acres new area)		11,55,000
(*f*) Enhancement of second crop revenue accruing on Government wet and in non-Government villages in the existing delta (exclusive of compounded double crop lands)		1,78,500
(*g*) Enhancement of first crop revenue in the existing delta owing to reclassification of sources—		
378,200 acres at Re. 1–2–0 (on difference between II and I) ..		4,25,475
132,000 acres at As. 11 (on difference between III and II)		90,750
(*h*) Increased revenue due to revision of water rate in the case of first and second crop on dry lands in the existing delta—		
Government dry—		
First crop 31,645 acres at Rs. 3–12–0		1,18,650
Second crop 3,000 acres at Rs. 4–6–0		13,125
Inam dry—		
First crop 9,600 acres at Rs. 3–12–0		36,000
Second crop 5,400 acres at Rs. 4–6–0		23,625
Inam wet-first and second crop.—Nil		..
Total ..		59,98,625
Gross indirect receipts—		
1 Land assessment on 16,840 acres of unoccupied ryotwari dry lands at As. 13 an acre		13,682
2 Interest at 6 per cent on sale-proceeds of 16,840 acres of waste lands at Rs. 150 an acre		1,51,560
		1,65,242
Total gross receipts ..		61,63,867
	RS.	RS.
Deduct—		
1 Maintenance charges on 301,000 acres of new irrigation at Re. 1 per acre	301,000	
2 Collection charges	150,000	4,51,000
	451,000	
Net return ..		57,12,867

ANNEXURE VI TO CHAPTER XXVIII

Estimate of growth of irrigation and revenue receipts and charges.

Year.		Irrigated area in the year.	Direct receipts.	Indirect receipts.	Total gross receipts.	Charges.	Net revenue including indirect receipts.	Net revenue excluding indirect receipts.
(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)
		ACS.	RS.	RS.	RS.	RS.	RS.	RS.
1932–33 ..	N1	6,100	30,333	..	30,333	..	..	..
1933–34 ..	N1	32,870	10,82,633	..	10,82,633	68,870	10,13,763	10,13,763
	D2	5,000	..	..	..	..	..	..
1934–35 ..	N1	81,170	13,76,383	..	13,76,383	1,31,170	12,45,213	12,45,213
	D2	15,000	..	..	..	..	..	..
	N2	6,000	..	..	..	..	..	..
1935–36 ..	N1	104,300	19,13,958	..	19,13,958	2,06,300	17,07,658	17,07,658
	D2	25,000	..	..	..	..	..	..
	N2	15,000	..	..	..	..	..	..
1936–37 ..	N1	120,400	26,98,791	..	26,98,791	2,66,400	24,32,391	24,32,391
	D2	35,000	..	..	..	..	..	..
	N2	25,000	..	..	..	..	..	..
1937–38 ..	N1	144,900	33,27,124	24,531	33,51,655	2,95,500	30,56,155	30,31,624
	D2	50,000	..	..	..	..	..	..
	N2	35,000	..	..	..	..	..	..
1938–39 ..	N1	170,400	38,67,124	71,140	39,38,264	3,30,000	36,08,264	35,37,124
	D2	65,000	..	..	..	..	..	..
	N2	45,000	..	..	..	..	..	..
1939–40 ..	N1	194,900	43,22,124	1,07,152	44,29,276	3,45,500	40,83,776	39,76,624
	D2	70,000	..	..	..	..	..	..
	N2	55,000	..	..	..	..	..	..
1940–41 ..	N1	219,400	47,39,624	1,53,761	48,93,385	3,70,000	45,23,385	43,69,624
	D2	70,000	..	..	..	..	..	..
	N2	65,000	..	..	..	..	..	..
1941–42 ..	N1	244,730	51,99,574	1,65,242	53,64,816	3,96,730	49,68,086	48,02,844
	D2	70,000	..	..	..	..	..	..
	N2	79,000	..	..	..	..	..	..
1942–43 ..	N1	272,030	56,21,574	1,65,242	57,86,816	4,24,030	53,62,786	51,97,544
	D2	70,000	..	..	..	..	..	..
	N2	84,000	..	..	..	..	..	..
1943–44 ..	N1	299,000	59,98,624	1,65,242	61,63,866	4,51,000	57,12,866	55,47,624
	D2	70,000	..	..	..	..	..	..
	N2	84,000	..	..	..	..	..	..

N1 denotes newly irrigated area, single or first crop. Total area equals 299,000 acres.

N2 denotes newly irrigated area second crop. Total area equals 84,000 acres.

D2 denotes extension of the second-crop area in the existing delta irrigation. Total equals 70,000 acres.

APPENDIX A

GEOLOGISTS' REPORTS.

I

Report on inspection of sites for the Mettur Dam Cauvery Reservoir by Dr. W. F. Smeeth, M.A., D.Sc., A.R.S.M.

On the invitation of the Chief Engineer for Irrigation I paid a visit to the Mettur on the 9th and 10th of March 1926.

I was met by Mr. C. T. Mullings, Chief Engineer, Mr. R. F. Stoney, Superintending Engineer, and Messrs. C. G. Barber, T. I. S. Mackay and W. P. Roberts, Executive Engineers, who accompanied me during my inspection and afforded me every assistance.

I have received a copy of papers on the Cauvery Reservoir Project, Volume I, which contains a summary by Mr. Stoney on earlier proposals for a dam across the Cauvery and a geological report on a number of proposed sites prepared by Dr. H. Walker, Superintendent of the Geological Survey of India in 1909. Dr. Walker's report is accompanied by sketch maps showing the main geological features of the area under consideration.

Site D.—I was first taken over the site marked D in Dr. Walker's report. This is the site most favoured by Dr. Walker and a detailed longitudinal section for a dam at this point has been prepared showing probable foundation levels.

From the right bank of the river, which is covered with deep alluvium, we looked across the river to the left bank which rises steeply up the site of a hill said to be composed of gneiss and charnockite. We did not cross the river at this point as it was proposed to do so after inspection of sites further north. Time, however, did not permit of this and I did not consider it necessary to make a special point of the crossing as, from what I could see from the right bank and from what I saw on crossing a little further to the north, I considered that no geological difficulties would be encountered at site D.

The abutment of the dam on the left bank of the river should give rise to no difficulty once the heavy boulders and talus have been removed. A solid foundation will be secured at a very moderate depth whether the rock be gneiss, which appears to fringe the river, or charnockite, which appears to crest the ridge on the eastern side above the gneiss. In the river-bed itself a few ridges of rock, which appear to be charnockite, rise above the water. Under the water there may be some bands of gneiss, but, whichever rock may predominate, there is no doubt about securing satisfactory foundations at a small depth below surface or below low water level, whichever is lower. One somewhat unfavourable feature is the existence of a deep channel towards the left bank of the river. This is said to be

200 feet wide and some 14 feet deeper than the average river-bed. This was examined some years ago and several wells were sunk in it with the result that, beneath a layer of sand and pebbles, solid charnockite was encountered. This means so much deeper excavation and so much more masonry at this point but no further difficulty.

The rest of the river-bed does not present any difficulty or doubtful features and, once the upstanding ridges of rock are removed, quite solid rock for foundation should be found at a few feet, say 3 to 5 feet below the low water level or below the existing rock surface whichever is lower. On the longitudinal section of the dam which has been sent to me, and which I herewith return, I notice that the excavation for foundations has been shown at 14 feet below existing surface. In his notes on the section Mr. Stoney hopes that so great a depth will not be found necessary and I agree with this. I am satisfied that a depth of some 4 feet below the existing surface or below the water level of the river will be ample to secure satisfactory foundations. This is of course an average figure and, if some highly micaceous gneisses or schists were encountered or cross veins of pegmatite with soft micaceous selvages, it might be necessary to scoup them out for a few feet deeper. Such extra scoups would make no appreciable difference to the total excavation or masonry required. On the longitudinal section of the dam I have drawn a line in green chalk which represents my idea of the average depth of foundation required.

On the right bank there is a deep layer of alluvium up to Smith's Knoll, which is an outcrop of charnockite. Dr. Walker refers to two trial pits in the alluvium, one of which, that nearer to the river, failed to reach solid rock and the other met with solid charnockite at a depth of 25 feet. He also notes the probable existence of a basic dyke which would cross the foundations in this section. A deep trench has now been dug in the centre of this alluvial patch at 1,500 feet from the eastern end of the dam. At the time of my visit this had reached to several feet below water level. Owing to water I was unable to see the character of the materials at the bottom of the trench, but it was certainly not hard rock and, most probably, was semi-consolidated alluvium or " sudda ". I am of opinion that this indicates another deep channel in an older river-bed. Even so, no difficulty need be anticipated beyond some more excavation and masonry as the rock, when encountered probably a few feet deeper, should be hard and sound. Smith's Knoll, at a chainage of about 2,000, is composed of large rounded blocks of charnockite resting on more massive charnockite. A good deal of the knoll will have to be removed owing to joints and fissures, but the foundation level will be high as indicated by the green line on the section.

To the west of this point, between Smith's Knoll and Campbell Hill is a low-lying area of gneiss covered with soil. Several pits have been sunk on this section, but none of them reaches a depth of more than 15 feet. In the pits banded granitic gneisses are exposed, but the rock at the lower points is still weathered and insufficiently fresh to provide good foundations. I am of opinion that across this gneissic section the average depth of foundation is likely to be not less than 25 feet with possible deeper pockets. At about this depth I see no reason why quite satisfactory rock for foundations should not be secured.

Campbell Hill, to the west of the above area, is another charnockite outcrop of considerable width on which good foundations should be secured at a comparatively high level once the large loose blocks and drummy slabs of the main boss have been removed.

To the west of Campbell Hill is a valley, about 500 feet in width, in which several shallow pits have been sunk. These disclose a series of banded gneisses, some of which are hornblendic and some very micaceous with veins of quartz and pegmatite. The pits have not reached really hard and sound rock for foundations, but such should be encountered at a depth of some 25 feet with allowance for pockets of micaceous material or selvages of pegmatite veins.

The remainder of the section is on a rising slope of charnockite in which good foundations should be secured at a high level and very modest depth from surface.

The section as a whole must be considered satisfactory from a geological point of view and no difficulty should be experienced in securing sound foundations at moderate depths which I have endeavoured to indicate on the longitudinal section sent to me.

To my mind the only real objection to the site lies in the convenience for surplussing large floods. Originally, it was considered that an independent saddle on the east bank of the river about half a mile north of the dam would be ample for surplussing any heavy floods. In recent years much larger floods than any previously recorded have been experienced and the Engineers consider it necessary to provide for surplussing a portion of the flood waters over the western section of the dam itself. This would not be serious if the whole of such floods could be taken over the western section, which is on charnockite, but would be more serious if the flood waters were allowed to scour the softer section of micaceous and hornblendic gneisses to the west of Campbell Hill. Considerable protective work would be necessary to prevent this section being scoured back towards the toe of the dam. Barring this objection, the site may be considered satisfactory so far as the geological features are concerned.

Site Y.—The position of this is shown on a plan prepared by Mr. Stoney which is herewith returned. In the longitudinal section which has been prepared the thickness of the alluvium and soil is shown; also the thickness of the underlying zone of soft rock and the depth at which hard rock has been reached in the trial pits. This site lies about half a mile north of site D and is in the neighbourhood of site B of Dr. Walker's report.

The left abutment of line Y is close to that of line B, but Y takes a more oblique course across the river some distance to the north of B.

Dr. Walker was not so favourably impressed with site B as he was with site D chiefly on account of a band of decomposed schistose gneiss in Pit 4 (near the road) and in view of the fact that no information was available as to the character of the river-bed nor as to the nature of the rock underlying the wide stretch of alluvium on the eastern bank.

These disabilities do not exist in regard to line Y on which a large number of pits have been sunk to hard rock. The geological formation on line Y may be described as follows with the aid of the longitudinal section referred to.

The left or eastern end of the section is in charnockite which is hard and fresh quite close to surface. From 300 feet to 1,200 there is a thick layer of alluvium with some pebble beds reaching to a depth of some 30 feet. Pits 1 to 9 have been sunk through the alluvial layer to hard rock at the depth shown on the section. There is comparatively little soft rock below the alluvium, but I consider that the comparatively hard rock reached in the pits should be excavated for a further 5 feet or so on the average to reach a harder and fresher material than has been disclosed at the bottom of some of the pits. The rock from the bottom of the pits appeared to me to be mainly charnockite, but I would not be certain without microscopic examination that some of it is not granitic or hornblendic gneiss. In either case I feel satisfied that perfectly sound foundations can be secured within a few feet of the depths reached by the trial pits.

Pits 10 and 11 contained water, but some of the pieces brought up appeared to be basic charnockite which was fairly fresh. I should judge that good sound rock would be reached within 10 feet or so of surface.

The exposures in the river bed which project above water are all charnockite so far as I could see. There may be some gneissic band under water and there are some lands of granitic gneiss a little to the north of line Y at the left margin of the river. I don't apprehend any difficulty in securing hard and sound foundations, whether in gneiss or charnockite, at a few feet (say, an average of 4 feet) below low water level or below the existing rock surface, whichever is lower. There does not appear to be any deep channel in the bed at this site such as occurs at site D.

Near the western margin of the river bed a calyx drill boring has been put down in charnockite to a depth of 25 feet from surface. The rock is hard and fairly fresh throughout with some joints and small faults which are to be expected and need not cause any anxiety. On the right bank is a layer of alluvium some 25 feet thick, but thinning out rapidly to the west Pit 13 passes through the alluvium and a little soft rock with fairly hard charnockite at a depth of 27 feet from surface and a few feet below water level. Excavation for a few feet deeper should give a good hard foundation. Pit 14 is sunk which is several feet of rather soft granite gneiss with mica. The material from the bottom of the pit is getting harder, but water level has not been reached and excavation may have to be carried 5 or 10 feet below water level to get satisfactory hard rock. A good deal depends on the character of the gneiss when opened up along the line. If more granite the depth will be less and if more micaceous or banded or traversed by quarts pegmatite veins a certain amount of scouping out and filling in will be necessary, but there is no cause for uneasiness and no reasonable doubt that good foundations can be secured at the expense of a little deeper excavation over limited patches.

It is not known how wide this gneissic band may be, as Pit 15 is some 350 feet to the west. Pits 15 to 22 have all reached fairly hard charnockite at comparatively shallow depths and I should judge that on this section good sound foundation rock should be secured at an average depth of not more than 15 feet from surface. The band of highly decomposed schistose gneiss, which Dr. Walker found in Pit 4 of his line B a little to the south of this section, has not been met with in the Pits in line Y. It may have been a denticular patch which has thinned out or it may be a comparatively narrow band which has passed between the pits. If encountered, it will harden up at a somewhat greater depth than the charnockite and require deeper excavation and I do not apprehend any real difficulty in dealing with it.

At 3,600 feet there is a knoll of charnockite covered with large loose blocks. These will have to be removed and drummy and fissured portions of the underlying mass removed. The foundation line on this knoll should rise considerably above that in the immediately adjoining sections.

From this knoll to the end of the section the alluvium and soil is shallow with a variable but moderate thickness of soft rock before hard rock is reached. The rock is all charnockite and an average excavation of a few feet below the levels reached by the pits is desirable and should give satisfactory foundations.

Comparison of site Y with site D.

I consider that the geological conditions at site Y are superior to those of site D and that relatively a large proportion of charnockite at the former is a favourable feature when contrasted with the wide and little explored areas of banded and micaceous gneisses found at site D.

Other things being equal, I should choose site Y in preference to D.

Site Y gives a dam of 5,200 feet in length compared with 6,352 feet at D, and it is possible that this may result in some saving of masonry. Ample facilities exist for disposing of all surplus water and floods without taking any of it over the dam itself. The surplusing weirs will be quite independent of the main dam and there will be no possibility of scouring action in front of the toe of the dam. I consider this to be a very important feature in favour of site Y.

Site Z.—After my inspection of site Y Mr. Mullings suggested that it would be worth while to consider the line marked Z on Mr. Stoney's plan. Z would give a dam of some 4,800 feet in length as against 5,200 feet for Y which crosses the river obliquely. Accordingly, I made an inspection of the greater portion of line Z and crossed the river to the hills on the east bank. Practically no work has been done on the line and I had to form what opinion I could from scanty surface indications. From the charnockite hills at the west end of the line to the river bank the surface levels along Z appear to be lower than for the corresponding section of Y as the ground falls northwards towards some shallow nalas. To the west of the road several patches of decomposed gneiss are exposed in these nalas. A little to the north of Z is line A of Dr. Walker's Report which he condemned on account of the great admixture of rocks, including many bands of gneiss and schist. I found one of Dr. Walker's pits to the west of the road which has been converted into a well with water at a depth of 25 feet. The site of the well showed not only an admixture of gneiss and schist but also considerable disturbance, so that some of the bands or patches of these rocks were lying nearly horizontal. The fact that the ground levels along Z are lower than along Y and that the decomposed gneisses—which exist there to some considerable extent at least—will be decomposed to a greater depth than the charnockite along line Y leads to the conclusion that the average depth to foundation level on Z west of the river would be materially greater than on the Y line. The extra amount of masonry required at this depth would very probably more than offset any advantage to be gained from the shorter length.

In the river bed the rocks exposed are mainly charnockite with some bands of gneiss and should give quite satisfactory foundations.

A basic dyke, however, some 40 feet in width cuts obliquely across the river bed from N.N.W. to S.S.E. and would cross the foundations of the proposed dam. The dyke is fresh hard rock but much jointed and fissured horizontally and vertically. This is not a favourable feature and the dyke would require considerably deeper excavation than the charnockite in which it lies in order to get away from the more superficial effects of the jointing. It is not likely to cause any further trouble beyond, possibly, an unnecessary amount of leakage.

On the east bank of the river the hill slope against which the dam would abut is covered with huge rounded blocks of gneiss underlying and around which is a considerable talus of stone and soil. These would, in my opinion, require a good deal more clearing and excavation than is the case with the abutment of the Y line where solid charnockite is found practically at surface.

There is little evidence on which to form a very decided opinion, but I am satisfied that foundations along Z would be at a lower level than along Y which means increased masonry, and that the rock variations to be dealt with are likely to prove more troublesome.

In addition, the selection of site Z would sacrifice the surplusing saddle which lies between the eastern ends of sites Y and Z. Speaking generally, I cannot see any features at Z of favourable import with the sole exception of shorter length of dam and this is favourable only if it leads to reduced quantity of masonry and lower cost. The reduction in quantity is, in my opinion, more than doubtful and might easily prove to be an increase.

Surplus weirs for site Y.—Suitable sites for these exist at the points marked C and F on Mr. Stoney's plan. A visit was paid to the saddle at C to determine the run of the basic dyke which has been referred as crossing the river bed in the neighbourhood of site Z and to ascertain whether or not it would cut across the eastern end of a dam at Y. The continuation of the dyke was located cutting across the southern end of the saddle at C. It will probably cut across the foundations of the surplus weir, but will be at least a furlong north of the foundations of the main dam. On Dr. Walker's geological sketch map the whole of the saddle is shown as charnockite, but from my inspection of the decomposed rocks near the saddle I judge that the greater portion is gneiss with some tongues or bands of charnockite. I understand that the surplusing level will be above the general ground level of the saddle and, as some of the rocks at the saddle, including the dyke, will be weathered to a considerable depth, it would be desirable to have some cross trenches excavated to ascertain at what depth good foundations can be secured as well as sufficiently firm rock to stand the scouring action of the surplus water.

The site at F is probably all in charnockite and may offer more satisfactory conditions for surplusing. In that case it might be possible to take the whole surplus, including exceptional floods, over a weir at F and merely block up saddle C to the required height.

Boreholes.—I am informed that it is under contemplation to put down a number of boreholes to a depth of 40 feet at 10 feet intervals along the line of the proposed dam with a view to testing the character of the rocks at deeper levels.

In my opinion, this work is unnecessary in the case of those deep seated charnockite and gneiss which are dipping steeply and more or less uniformly to the east and the results are not likely to afford much more satisfactory information than can be gathered from an examination of excavations down to hard rock level. In a few cases in which excavations have not been carried down to hard rock or have not disclosed sufficiently clearly the width of some of the softer patches, boreholes might give quicker information than the sinking of more trial pits, but otherwise would not, I think, prove of much service.

It is suggested also that these boreholes should be utilized for the injection of cement under pressure in order to seal up joints and cracks and stop leakage under the dam. This would no doubt be achieved to some extent, but joints and cracks will exist to a considerably greater depth than that reached by the cement sealing and leakage will continue under the dam though, doubtless, to a restricted extent. Is it worth while to try and stop or restrict this leakage?

If the dam was to be used for power purpose, or if the water was to be taken off by high level channels, in which case it would be desirable to retain as much water as possible at a high level, the expenditure on boring holes and sealing cracks might be justifiable. In the present case, I understand that the water is to be used solely for irrigation and that the supply will pass through sluices into the river bed below the dam.

The water that leaks under the dam will arrive at the same destination and it does not appear to me to be very material whether more or less water passes through the sluices or through natural cracks and other channels. The proportion passing under the dam will be relatively small and, if the foundations are carried down to sound rock, will not sensibly affect the stability of the dam.

II

Report on Excavations along the dam site of Cauvery-Mettur Project by Mr. W. D. West, Assistant Superintendent, Geological Survey of India, dated 7th October 1926.

While I was staying at Pykara, the Chief Engineer for Irrigation asked me to see some excavations which had been made along part of the dam site (Y) of the Cauvery-Mettur Project. These had been made since Dr. Smeeth reported on the site earlier in the year. Consequently I spent a few hours on the 2nd of October at Mettur, while on my way back to Calcutta.

2. My attention was particularly drawn to some shallow pits which had been excavated on the saddle on the right side of the dam site, which is to be used for the discharge of surplus water (site F); to some deep pits on the right side of the river; and to the cores obtained by boring with calyx drills along the same part.

The Saddle F.

3. The evidence provided by some shallow pits scattered about over this saddle indicated that sound solid rock should be found nearly everywhere at a depth of a few feet below the surface. The rock across this saddle varies considerably, and includes some rather soft micaceous gneiss, somewhat deeply weathered in places, and some acid (siliceous) gneiss, which might give trouble if not properly dealt with. The greater part, however, seems to be quite sound.

4. In considering the suitability of this saddle as a site for the discharge of surplus water, the point to be considered is whether the scouring action of the water will have much effect on the underlying rocks. As regards the greater part of the saddle there should be no cause for any anxiety, provided the down-stream side of the saddle be suitably terraced, so that the drop of water is never more than 10 feet. Further excavation will show if the weaker varieties of rock mentioned above are at all prominent or remain as weak in

depth. It is thought that any difficulty of this sort could be overcome by using masonry at these points to join up the zones of sound rock which probably occur over the greater part of the saddle at a small depth.

5. As this site will only be used occasionally for the discharge of water (the main discharge going over the middle to the left of the dam), any scouring action which might begin could be repaired in its early stages during the long periods when the site is not in use.

Excavations along the dam site.

6. As regards that part of the dam site on the right side of the river, there is one short section which calls for comment.

7. Owing to the fact that I have not yet received some information which I have been awaiting from Mettur, I am unable to give the precise position of this section. It is situated in the deepest pit that has so far been dug on the right side of the river, it extends for a distance of 200 feet, and into it a boring has been put down to 69 feet below the surface. This should be sufficient to locate the point.

8. The rock here is almost white in colour. It is not certain whether it represents a siliceous variety of the gneiss or is mainly pegmatitic material. In either case there is no reason to suppose that it does not continue in depth.

9. A boring was put down in the midst of this section to 69 feet below the surface of the ground. The core obtained consisted of rather small pieces of the abovementioned rock. This rock in itself seems to be quite sound; but it appears that during the boring numerous sections of a very soft rock were encountered, so soft that no cores of it were obtained, the drill suddenly descending several inches as each patch was reached. It is not quite clear to what this was due; and it is therefore suggested that either the boring be continued to see if the rock as a whole becomes sounder, or that further excavation be made in this trench as quickly as possible. The latter is the best course to adopt, as it gives more definite information; but it is very much slower.

10. Unfortunately, the foliation of the rocks throughout this part of the dam site (and no doubt throughout the whole site) is parallel to the length of the valley, i.e., at right-angles to the length of the dam. It is therefore *absolutely essential* that perfectly sound foundations be secured throughout the whole length of the site. Should a certain section be less sound, then any leakage, however slight at first, will be facilitated by the foliation of the rock, which in the more micaceous varieties is strongly marked. Under a high pressure of water this may increase rapidly, and so undermine the foundations.

The remainder of this long pit shows badly weathered micaceous gneiss or schist at the top. But it seems to be improving rapidly in depth, and no anxiety need be entertained on this score.

11. The other cores examined were all of perfectly fresh sound rock.

12. The pits further to the right showed fresh charnockite quite close to the surface of the ground; it all appeared to be quite sound.

13. Dr. Smeeth in his report considered that this site was the best available. It need only be mentioned here that as the strike of the rocks is parallel to the length of the valley, any other sites are likely to have the same zones of softer rock, and they may be more prominently developed. In addition, this site has the great advantage of suitable saddles for the discharge of the surplus water.

III

Report on the dam site at Mettur by Rao Bahadur M. Vinayaka Rao, Assistant Superintendent, Geological Survey of India, after inspection in 1928.

The present site was examined by me in company with Mr. R. F. Stoney, the Superintending Engineer (now Chief Engineer) in 1926. The dam will be about 5,200 feet in length.

The narrow valley of the Cauvery is walled in on both sides by high hills mostly of charnockites which were more developed to the west than on the eastern side of the valley. Occurring among the charnockites the narrow irregular patches of the older gneisses including hornblende gneisses, micaceous schists and pegmatites. These are found mostly on the western part of the valley. To the east are newer gneisses which probably correspond to the mottled gneiss of Mr. Middlemiss. There are irregular strips of Charnockites associated with them. In the river bed are found some dykes with a north and south direction and one branch goes north-west. These occur south of the dam and do not appear to cut across the dam-site. In fact one of them comes to an end at the toe of the dam at the site of the temporary sluices.

The difficulties the Engineer has met with are the following:—

(1) Joints in the charnockites which are quite hard.

(2) Potholes in the charnockites made by the river in its meandering course.

(3) A band of mica schist turned into clay occurring in the older gneisses in a trial trench.

(4) An "Artesian" well at the 1,705 feet of the dam.

(5) The dyke below this at the toe of the dam.

Jointing in charnockites is a common feature of these rocks and I think it is not necessary to blast perfectly sound and hard rocks to find out how deep the joints penetrate. The only thing to be done is to pass in plenty of concrete and to grout them where necessary.

2. The same applies to potholes which do not extend to any depth.

3. The decomposed rock should be removed entirely up to a certain depth—say ten feet—below solid rock and the excavated portion filled with concrete. The softer gneisses may be treated in the same way.

4. The "artesian" well occurs at the 1,705 feet length of the dam and is close to the river bed; clear sweet water has been tapped at a depth of about 26 feet; the well has a continuous flow and rises about 3 feet above the surface. I think the water has come along the joints from a long distance upstream and the flow is due to gravity. The water which is 26 feet below the dam foundation which is here on solid rock is not likely to interfere with the dam. However, it would be as well to have bores put at a distance of 20 feet to the north, south and east of this flow and find out whether water is found anywhere in these bores.

5. The dyke stops dead at the toe of the dam at about 1,705 feet length of the dam and is much broken up. It would be as well to remove all those broken parts completely and grout the cavity.

The site is a good one being mostly on solid rock and the decomposed gneiss does not extend to any great depth, it is easily removed. There is no need to blast perfectly sound hard charnockites in order to follow the joints to depth.

APPENDIX B

Calculations for the profile proposed for adoption (with toe cut off).

Calculations of Upstream thirds, Centre thirds, Downstream thirds and Maximum stresses.

Level of top of dam	810
Maximum water level	805
Specific gravity of masonry	2·35

Calculation of maximum stresses.

(1) By Bouvier—

Maximum stress—Reservoir empty $= \frac{2\,w}{L}(2 - \frac{3u}{L})$

Reservoir full $= \frac{2\,w}{L}(2 - \frac{3\,u}{L})$ sec 2 α

L = base width.
u = upstream third reservoir empty.
u = downstream third reservoir full.
w = weight of masonry (includes water load in the case of reservoir full).

tan α $\frac{\text{Water thrust}}{\text{weight of masonry reservoir full}}$

(2) Unwin's method—

Maximum stress—Reservoir empty $= \frac{2\,w}{L}(2 - \frac{3\,u}{L})$ Sec. $2\theta_1$

Reservoir full $= \frac{2\,w}{L}(2 - \frac{3\,u}{L})$ sec. $2\theta_2$

Layer 798.

Reservoir empty.	Weight.	Lever arm.	Moments.
Masonry area of rectangular portion ..	216	9	1,944
	216		1,944

Upstream third reservoir empty $= \frac{1,944}{216} = 9$ ft.

Water thrust $= \frac{7 \times 7}{2 \times 2{\cdot}35} = \frac{49}{4{\cdot}7} = 10{\cdot}4255$.

Moment of water thrust $= \frac{10{\cdot}4255 \times 7}{3} = 24{\cdot}3262$.

Centre third $= \frac{24{\cdot}3262}{216} = {\cdot}1126$.

Downstream third $= 18 - (9{\cdot}1126) = 8{\cdot}8874$.

Maximum stress—Reservoir empty.

Bouvier $= \frac{2\,w}{L}(2 - \frac{3\,u}{L})$

$= \frac{2 \times 216}{18}(2 - \frac{3 \times 9}{18})$ $\theta_1 = 0$

$= \frac{432}{18}({\cdot}5)$ Unwin = ·786

$= \frac{216}{18} = 12.$

$= 12 \times {\cdot}0655$ tons = ·786 ton per square foot.

Reservoir full—

Maximum stress $= \frac{2 \times 216}{18}(2 - \frac{3 \times 8{\cdot}8874}{18})$ sec. 2 α tan $\alpha = \frac{10{\cdot}4255}{216}$
= ·04826

(Bouvier)— $= 24 \times {\cdot}5188 \times 1{\cdot}00233$ 1 + tan. 2α = 1·00233

$= 12{\cdot}48 \times {\cdot}0655$ ton.

= ·8174 ton per square foot 1 + tan. $2\theta_2$ = 1·002

Maximum stress (Unwin) = ·817 ton per square foot.

Reservoir empty.	Weight.	Lever arm.	Moment.
Layer 790—Reservoir empty—			
Masonry above 798	216	..	1,944
Masonry between 790 and 798 rectangular portion	144	9	1,296
Masonry between 790 and 798 triangular portion	1·44	18·12	26·0928
	361·44		3266·0928

Upstream third .. .. $= \frac{3266 \cdot 0928}{361 \cdot 44} = 9 \cdot 036$ ..

Water thrust .. .. $= \frac{15 \times 15}{2 \times 2 \cdot 35} = \frac{225}{4 \cdot 7} = 47 \cdot 872$

Moment of water thrust .. .. $= \frac{47 \cdot 872 \times 15}{3} = 239 \cdot 360$

Centre third .. .. $= \frac{239 \cdot 36}{361 \cdot 44} = 0 \cdot 662$

Downstream third .. .. .. $= 18 \cdot 36 - (9 \cdot 036 + 0 \cdot 662)$.
$= 8 \cdot 662$

Maximum stress reservoir empty—

Bouvier .. .. $= \frac{2 \times 361 \cdot 44}{18 \cdot 36} \left(2 - \frac{3 \times 9 \cdot 036}{18 \cdot 36}\right)$.
$= 39 \cdot 3725 \times (2 - 1 \cdot 4764)$.
$= 39 \cdot 3725 \times 0 \cdot 5236 \times \cdot 0655$ tons.
$= 20 \cdot 6154 \times 0 \cdot 0655$ tons.
$= 1 \cdot 3503$ tons per square foot.

Maximum stress reservoir full—

Bouvier .. .. $= \frac{2 \times 361 \cdot 44}{18 \cdot 36} \left(2 - \frac{3 \times 8 \cdot 662}{18 \cdot 36}\right) \sec.^2 \alpha$.

$= 39 \cdot 3725 \times 0 \cdot 5846 \times 1 \cdot 01753$
$= 23 \cdot 0172 \times 1 \cdot 01753$

$\tan \alpha = \frac{47 \cdot 872}{361 \cdot 44} = 0 \cdot 1324$.
$1 + \tan^2 \alpha = 1 \cdot 01753$

$= 23 \cdot 4207 \times 0 \cdot 0655$ tons.
$= 1 \cdot 5341$ tons per square foot.

Unwin—

Reservoir empty maximum stress—
$1 \cdot 3503$ tons, $\theta = 0$.

Reservoir full Maximum stress .. .. $= 23 \cdot 0172 \times (1 + \tan^2 \theta_2)$ $\tan \theta_2 = 0 \cdot 146$.
$= 23 \cdot 0172 \times 1 \cdot 02132$ $1 + \tan^2 \theta_2 = 1 \cdot 02132$.
$= 23 \cdot 508 \times \cdot 0655$ tons.
$= 1 \cdot 54$ tons per square foot.

Layer 780—	Weight	Lever arm	Moment
Reservoir empty—			
Masonry above 790	361·44	..	3,266·0928
Masonry between 790 and 780 rectangular portion	183·6	9·18	1,685·448
Masonry between 790 and 780 triangular portion	7·30	18·847	137·583
	552·34		5,089·124

Upstream third .. .. .. $= \frac{5{,}089 \cdot 124}{552 \cdot 34} = 9 \cdot 214$

Water thrust .. .. .. $= \frac{25 \times 25}{2 \times 2 \cdot 35} = \frac{625}{4 \cdot 7} = 132 \cdot 979$

Moment of water thrust .. .. $= 132 \cdot 979 \times \frac{25}{3} = \frac{3{,}324 \cdot 475}{3}$
$= 1{,}108 \cdot 158$

Centre third .. .. $= \frac{1{,}108 \cdot 158}{552 \cdot 34} = 2 \cdot 006$

Downstream third .. .. .. $= 19 \cdot 82 - (9 \cdot 214 + 2 \cdot 006)$
$= 8 \cdot 600$

Reservoir empty.	Weight.	Lever arm.	Moments.

Maximum stress reservoir empty—

Bouvier .. .. $= \frac{2 \times 552{\cdot}34}{19{\cdot}82} \left(2 - \frac{3 \times 9{\cdot}214}{19{\cdot}82}\right)$

$= 55{\cdot}7356 \times {\cdot}6054$

$= 33{\cdot}7423 \times {\cdot}0655$ tons

$= 2{\cdot}210$ tons per square foot.

Reservoir full—

Maximum stress bouvier .. . $= \frac{2 \times 552{\cdot}34}{19{\cdot}82} \left(2 - \frac{3 \times 8{\cdot}6}{19{\cdot}82}\right) \sec 2\alpha$

$= 55{\cdot}7356 \times {\cdot}6983 \times 1{\cdot}05794$

$\tan 2 = \frac{132{\cdot}979}{552{\cdot}34}$

$= {\cdot}2407$

$1 + \tan^2 \alpha = 1{\cdot}05794$

$= 38{\cdot}9202 \times 1{\cdot}05794$

$= 41{\cdot}1752 \times 0{\cdot}0655$ tons

$= 2{\cdot}697$ tons per square foot.

Unwin—

Reservoir empty
Maximum stress .. .. .. $= 2{\cdot}210$ tons $\theta = 0$

Reservoir full
Maximum stress .. .. .. $= 38{\cdot}9202 \times (1 + \tan \theta_2)$

$\tan \theta_2 = {\cdot}0265$

$1 + \tan2\ 02$

$= 1{\cdot}07023$

$= 8{\cdot}9202 \times 1{\cdot}7023$

$= 41{\cdot}654 \times 0655$ tons

$= 2{\cdot}728$ tons per square foot.

Level 770—

	Weight.	Lever arm.	Moments.
Masonry above level 780	552·34	..	5089·124
Masonry between 770 and 780 rectangular portion.	198·20	9·91	1964·162
Masonry between 770 and 780 triangular portion	13·25	20·703	274·315
	763·79		7327·601

Upstream third $= \frac{7327{\cdot}601}{763{\cdot}79} = 9{\cdot}594$

Water thrust $= \frac{35 \times 35}{2 \times 2{\cdot}35} \times \frac{1225}{4{\cdot}7} = 260{\cdot}638$

Moment of water thrust $= \frac{260{\cdot}638 \times 35}{3} = \frac{9122{\cdot}330}{3} = 3040{\cdot}777$

Centre third $= \frac{3040{\cdot}777}{763{\cdot}79} = 3{\cdot}981$

Downstream third $= 22{\cdot}47 - (9{\cdot}594 + 3{\cdot}981)$

$= 8{\cdot}895$

Maximum stress reservoir empty—

Bouvier $= \frac{2 \times 763{\cdot}79}{22{\cdot}47} \left(2 - \frac{3 \times 9{\cdot}594}{22{\cdot}47}\right)$

$= 67{\cdot}983 \times (2 - 1{\cdot}2809)$

$= 67{\cdot}983 \times 7191$

$= 48{\cdot}887 \times 0{\cdot}0655$ tons.

$= 3{\cdot}202$ tons per square foot.

Maximum stress reservoir full—

Bouvier $\frac{2 \times 763{\cdot}79}{22{\cdot}47} \left(2 - \frac{3 \times 8{\cdot}895}{22{\cdot}47}\right) \text{Sec } 2\alpha$

$= 67{\cdot}983 \times {\cdot}8124 \times 1{\cdot}1164$ $\tan \alpha = \frac{260{\cdot}638}{763{\cdot}79}$

$= {\cdot}3412$

Reservoir empty. — Weight. — Lever arm. — Moments.

$= 55{\cdot}2294 \times 1{\cdot}1164$ — $1 + \tan^2\alpha = 1{\cdot}11642$

$= 61{\cdot}6581 \times {\cdot}0655$ tons

$= 4{\cdot}039$ tons per square foot.

Unwin—

Maximum stress reservoir empty $= 3{\cdot}202$ tons per square foot $\theta_1 = 0$

Reservoir full maximum stress $= 55{\cdot}2294 \times (1 + \tan^2 \theta_2)$

$= 55{\cdot}2294 \times 1{\cdot}156$ — $\tan \theta_2 = {\cdot}395$

$= 63{\cdot}845 \times {\cdot}0655$ tons. — $1 + \tan^2 \theta_2 = 1{\cdot}1560$

$= 4{\cdot}182$ tons per square foot.

Level 760—Reservoir empty—

	Weight.	Lever arm.	Moments.
Masonry above 770	763·79	..	7,327·601
Masonry between 770 and 760 Rectangular portion.	224·70	11·235	2,524·505
Masonry between 770 and 760 triangular portion.	19·75	23·787	464·393
Total ..	1,008·24		10,316·499

Upstream third $= \frac{10{,}316{\cdot}499}{1{,}008{\cdot}24} = 10{\cdot}232.$

Water thrust $= \frac{45 \times 45}{2 \times 2{\cdot}35} = \frac{2{,}025}{4{\cdot}7} = 430{\cdot}851.$

Moment of water thrust $= 430{\cdot}851 \times \frac{45}{3} = 6{,}462{\cdot}765.$

Centre third $= \frac{6{,}462{\cdot}765}{1{,}008{\cdot}24} = 6{\cdot}410.$

Downstream third $= 26{\cdot}42 - (10{\cdot}232 + 6{\cdot}410) = 9{\cdot}778.$

Maximum stress reservoir empty—

Bouvier $= \frac{2 \times 1{,}008{\cdot}24}{26{\cdot}42}\left(2 - \frac{3 \times 10{\cdot}232}{26{\cdot}42}\right).$

$= 76{\cdot}324 \times {\cdot}8382.$

$= 63{\cdot}975 \times {\cdot}0655$ tons.

$= 4{\cdot}190$ tons per square foot.

Unwin $= 4{\cdot}190$ tons per square foot $\theta_1 = 0.$

Maximum stress reservoir full—

Bouvier $= \frac{2 \times 1{,}008{\cdot}24}{26{\cdot}42}\left(2 - \frac{3 \times 9{\cdot}778}{26{\cdot}42}\right) \sec^2\alpha$

$= 76{\cdot}324 \times {\cdot}8897 \times \sec^2\alpha$

$\tan\alpha = \frac{430{\cdot}851}{1{,}008{\cdot}24}$

$= {\cdot}4273$

$1 + \tan^2\alpha = 1{\cdot}1826$

Maximum stress $= 76{\cdot}324 \times {\cdot}8897 \times 1{\cdot}1826.$

$= 67{\cdot}825 \times 1{\cdot}1826.$

$= 80{\cdot}210 \times {\cdot}0655$ tons.

$= 5{\cdot}254$ tons per square foot.

Unwin maximum stress reservoir full $= 67{\cdot}825 \times (1 + \tan^2 \theta_2).$

$\tan \theta_2 = {\cdot}545$

$1 + \tan^2 \theta_2 = 1{\cdot}2970$

$= 67{\cdot}825 \times 1{\cdot}297.$

$= 87{\cdot}969 \times {\cdot}0655$ tons.

$= 5{\cdot}762$ tons per square foot.

Level 750—Reservoir empty—

	Weight.	Lever arm.	Moments.
Masonry above 760	1,008·24	..	10,316·499
Masonry between 760 and 750 rectangular portion	264·20	13·21	3,490·082

Reservoir empty.	Weight.	Lever arm.	Moments.
Masonry between 760 and 750 triangular portion	27·25	28·237	769·458
	1,299·69		14,576·039

Upstream third $= \frac{14{,}576{\cdot}039}{1{,}299{\cdot}69} = 11{\cdot}215$

Water thrust $= \frac{55 \times 55}{2 \times 2{\cdot}35} = \frac{3{,}025}{4{\cdot}7} = 643{\cdot}617$

Moment of water thrust $= \frac{643{\cdot}617 \times 55}{3} = \frac{35{,}398{\cdot}935}{3}$

$= 11{,}799{\cdot}645.$

Centre third $= \frac{11{,}799{\cdot}645}{1{,}299{\cdot}69} = 9{\cdot}079$

Downstream third $= 31{\cdot}87 - (11{\cdot}215 + 9{\cdot}079).$

$= 11{\cdot}576$

Maximum stress—Reservoir empty—

Bouvier $= \frac{2 \times 1{,}299{\cdot}69}{31{\cdot}87}\left(2 - \frac{3 \times 11{\cdot}215}{31{\cdot}87}\right)$

$= 81{\cdot}562 \times {\cdot}9443$

$= 77{\cdot}019 \times {\cdot}0655$ tons.

Unwin— $= 5{\cdot}045$ tons per square foot.

$= 5{\cdot}045$ tons per square foot $\theta_1 = 0$

Maximum stress—Reservoir full—

Bouvier $= \frac{2 \times 1{,}299{\cdot}69}{31{\cdot}87}\left(2 - \frac{3 \times 11{\cdot}576}{31{\cdot}87}\right)\sec.^2 \alpha$

$= 81{\cdot}562 \times {\cdot}9103 \times \sec.^2 \alpha$

$\tan \theta = \frac{643{\cdot}617}{1{,}299{\cdot}69} = {\cdot}4952$

$1 + \tan^2 \theta = 1{\cdot}2452$

$= 81{\cdot}562 \times {\cdot}9103 \times 1{\cdot}2452$

$= 74{\cdot}246 \times 1{\cdot}2352$

$= 92{\cdot}451 \times {\cdot}0655$ tons

$= 6{\cdot}056$ tons per square foot.

Unwin—

$= 74{\cdot}246 \times (1 + \tan^2 \theta_2)$

Res. full

$\tan \theta_2 = {\cdot}709$

$1 + \tan^2 \theta_2 = 1{\cdot}5027$

$= 74{\cdot}246 \times 1{\cdot}5027$

$= 111{\cdot}569 \times {\cdot}0655$ tons

$= 7{\cdot}308$ tons per square foot

Level 730—Reservoir empty—			
Masonry above 750	1,299·69	..	14,576·039
Masonry between 750 and 730 ectangular portion.	637·40	15·935	10,156·969
Masonry between 750 and 730 triangular portion at the downstream side.	141·78	36·596	5,188·581
			29,921·589
Masonry between 750 and 730 triangular portion at the upstream side.	22·22	·7407	— 16·458
	2,101·09		29,905·131

Upstream third .. .. .. $\frac{29{,}905{\cdot}131}{2{,}101{\cdot}09} + 2{\cdot}222 = 16{\cdot}455$

Maximum stress—Reservoir empty—

Bouvier .. .. $\frac{2 \times 2{,}101{\cdot}09}{48{\cdot}27}\left(2 - \frac{3 \times 16{\cdot}455}{48{\cdot}27}\right)$

$= 87{\cdot}056 \times {\cdot}9773 \times {\cdot}0655$ tons.

$= 85{\cdot}080 \times {\cdot}0655$ tons.

$= 5{\cdot}573$ tons per square foot.

Reservoir empty.	Weight.	Lever arm.	Moments.
Reservoir full—			
Total masonry as above	2,101·09		29,905·131
Water load rectangular portion $= \frac{2\cdot222 \times 55}{2\cdot35}$	52·00	1·111	— 57,776
Water load triangular portion $= \frac{22\cdot222}{2\cdot35}$	9·465	1·4814	— 14·008
	2,162·55		29,833·347

Upstream third .. .. $= \frac{29,833\cdot347}{2,162\cdot55} + 2\cdot222 = 16\cdot017$

Water thrust .. .. $= \frac{75 \times 75}{2 \times 2\cdot35} = \frac{5,626}{4\cdot7} = 1,196\cdot809$

Moment of water thrust .. $= 1,196\cdot809 \times \frac{75}{3} = 29,920\cdot225$

Centre third .. .. .. $= \frac{29,920\cdot225}{2,162\cdot55} = 13\cdot836$

Downstream third .. .. $= 48\cdot27 - (13\cdot836 + 16\cdot017)$

$= 18\cdot867$

Maximum stress —Reservoir full—

Bouvier .. .. .. $= \frac{2 \times 2,162\cdot55}{48\cdot27} \left(2 - \frac{3 \times 18\cdot867}{48\cdot27}\right) \sec^2 \alpha$

$= 89\cdot602 \times \cdot8294 \times \sec^2 \alpha$

$\tan \alpha = \frac{1,196\cdot809}{2,162\cdot55}$

$= 74\cdot137 \times 1\cdot3063$ $\qquad = \cdot5534$

$= 96\cdot845 \times \cdot0655$ tons. $\qquad 1 + \tan^2 \alpha$ .. $= 1\cdot3063$

$= 6\cdot343$ tons per square foot.

Unwin maximum stress—Resevoir empty—

$\sec^2 \theta 1 = 1\cdot0123$

$= 5\cdot573 \times 1\cdot0123$

$= 5\cdot642$ tons per square foot.

Reservoir full (unwin)—

Maximum stress .. .. .. $= 74\cdot137 \times 1\cdot5027$

$= 111\cdot406 \times \cdot0655$ tons

$= 7\cdot297$ tons per square foot.

Level 710—Reservoir empty—			
Masonry above 730	2,101·09	..	29,905·131
Masonry between 730 and 710 rectangular portion right of vertical	920·96	23·024	21,204·183
Masonry between 730 and 710 traingular portion downstream side ..	141·88	50·777	7,204·241
			58,313·555
Masonry between 730 and 710 rectangular portion upstream side ..	44·44	1·111	— 49·373
Masonry between 730 and 710 triangular portion upstream side ..	22·22	2·963	— 65·838
	3,230·59		58,198·344

Upstream third $= \frac{58,198\cdot344}{3,230\cdot54} + 4\cdot444 = 22\cdot459$

Reservoir full.	Weight.	Lever arm.	Moments.
Masonry including water load above 730	2,162·55	..	29,833·347
Masonry between 710 and 730 ..	1,129·50	..	28,293·213
			58,126·560
Water load on the upstream face between 710 and 730 rectangular portion $= \frac{2 \cdot 222 \times 75}{2 \cdot 35}$	70·915	3·333	— 236·360
Water load on the upstream face between 710 and 730 triangular portion $= \frac{22 \cdot 222}{2 \cdot 35}$	9·456	3·703	— 35·016
	3,372·421		57,855·184

Reservoir empty.	Weight.	Lever arm.	Moments.

Upstream third $\frac{57,855 \cdot 184}{3,372 \cdot 421} + 4 \cdot 444 = 21 \cdot 600$

Water thrust $= \frac{95 \times 95}{2 \times 2 \cdot 35} = \frac{9,025}{4 \cdot 7} = 1,920 \cdot 213$

Moment of water thrust $= 1,920 \cdot 213 \times \frac{95}{3} = \frac{182,420 \cdot 235}{3}$

Centre third $= \frac{60,806 \cdot 745}{3,372 \cdot 421} = 18 \cdot 036 \qquad = 60,806 \cdot 745$

Downstream third $= 64 \cdot 68 - (21 \cdot 6 + 18 \cdot 036)$
$25 \cdot 044$

Maximum stress—Reservoir empty—

Bouvier $= \frac{2 \times 3230 \cdot 59}{64 \cdot 68} \left(2 - \frac{3 \times 22 \cdot 459}{64 \cdot 68}\right)$
$= 99 \cdot 894 \times \cdot 9583$
$= 91 \cdot 895 \times \cdot 0655$ tons.
$= 6 \cdot 019$ tons per square foot.

Reservoir full—

Maximum stress $\frac{2 \times 3,372 \cdot 421}{64 \cdot 68} \left(2 - \frac{3 \times 25 \cdot 044}{64 \cdot 68}\right) \sec^2 \alpha$
$= 104 \cdot 280 \times \cdot 8384 \times \sec^2 \alpha$
$= 87 \cdot 428 \times \sec^2 \alpha \qquad \tan \alpha = \frac{1,920 \cdot 213}{3,230 \cdot 50}$
$= 87 \cdot 428 \times 1 \cdot 3533$
$= 118 \cdot 316 \times \cdot 0655$ tons $\qquad = \cdot 5944$
$= 7 \cdot 750$ tons per square foot $1 + \tan^2 \alpha = 1 \cdot 3533$

Unwin maximum stress—Reservoir empty—
$= 6 \cdot 019 \quad 1 \cdot 0123 = 6 \cdot 093$ tons per square foot.

Reservoir full
$= 87 \cdot 428 \times 1 \cdot 5027$
$= 131 \cdot 378 \times \cdot 0655$ tons.
$= 8 \cdot 605$ tons per square foot.

Level 690—Reservoir empty—

Masonry above 710	3,230·59	..	58,198·344
Masonry between 710 and 690 rectangular portion right of vertical.	1,204·72	30·118	36,283·757
Masonry between 710 and 690 triangular portion.	141·77	64·962	9,209·663
			103,691·764

Reservoir full.	Weight.	Lever arm.	Moments.
Masonry between 710 and 690 rectangular portion at upstream side.	88·88	2·222	— 197·491
Masonry between 710 and 690 triangular portion.	22·23	5·185	— 115·263
	4,688·19		103,379·010

Upstream third $= \frac{1,03,379\cdot01}{4,688\cdot19} + 6\cdot667 = 28\cdot718.$

Reservoir full—

Masonry including water load above 710.	3,372·421	..	57,855·184
Masonry between 710 and 690 as above.	1,457·600	..	45,180·666
			103,035·850

Reservoir full.	Height.	Lever arm.	Moments.
Water load on the sloping face between 710 and 690 rectangular portion $= \frac{95 \times 2\cdot223}{2\cdot35}$.	89·866	5·556	— 499·295
Water load on the sloping face between 710 and 690 triangular portion $= \frac{2\cdot223 \times 10}{2\cdot35}$.	9·460	5·926	— 56·060
	4,929·347		102,480·495

Upstream third $= \frac{102,480\cdot495}{4,929\cdot347} + 6\cdot667 = 27\cdot457.$

Water thrust $= \frac{115 \times 115}{2 \times 2\cdot35} = \frac{13,225}{4\cdot7} = 2,813\cdot830.$

Moment of water thrust $= \frac{2,813\cdot830 \times 115}{3} = \frac{323,590\cdot450}{3} = 107,863\cdot483$

Centre third $= \frac{107,863\cdot483}{4929\cdot347} = 21\cdot882.$

Downstream third $= 81\cdot08 - (27\cdot457 + 21\cdot882)$
$= 31\cdot741$

Maximum stresses.

Reservoir empty (Bouvier)—

$= \frac{2 \times 4,688\cdot19}{81\cdot08}\left(2 - \frac{3 \times 28\cdot718}{81\cdot08}\right).$
$= 115\cdot644 \times \cdot9374$
$= 108\cdot405 \times \cdot0655$ tons.
$= 7\cdot101$ tons per square foot.

Reservoir full—

Bouvier $= \frac{2 \times 4,929\cdot347}{81\cdot08}\left(2 - \frac{3 \times 31\cdot741}{81\cdot08}\right)\sec^2 \alpha$
$= 121\cdot592 \times \cdot8256 \times \sec^2 \alpha$

$\tan \alpha = \frac{2,813\cdot83}{4,929\cdot347}$

$= 100\cdot386 \times \sec^2 \alpha$
$= 100\cdot386 \times 1\cdot3258$ $\qquad = \cdot5708$
$= 133\cdot092 \times \cdot0655$ tons $\qquad 1 + \tan^2 \alpha = 1\cdot3258.$
$= 8\cdot718$ tons per square foot.

Unwin maximum stress—Reservoir empty—
$= 7\cdot101 \times 1\cdot0123 = 7\cdot188$ tons per square foot.

Reservoir full.	Weight.	Lever arm.	Moments.
Reservoir full—Maximum stress— (Unwin) = 100·386 × 1·5027 = 150·850 × ·0655 tons. = 9·881 tons per square foot.			
Level 670—			
Masonry above 690	4,688·19	..	103,379·010
Masonry between 690 and 670 rectangular portion right of vertical.	1,488·26	37·207	55,373·690
Masonry between 690 and 670 triangular portion.	141·78	79·139	11,220,327
			169,973·027
Masonry between 690 and 670 rectangular portion at the upstream side.	133·34	3·334	— 444·456
Masonry between 690 and 670 triangular portion.	22·22	7·408	— 164·606
	6,473·79		169,363·965

$$\text{Upstream third} = \frac{169{,}363{\cdot}865}{6{,}473{\cdot}79} + 8{\cdot}889 = 35{\cdot}050$$

Masonry including water load above 690.	4,929·347	..	102,480·495
Masonry between 690 and 670 as above.	1,785·60	..	65,984·855
			168,465·350
Water load on the sloping face between 690 and 670 rectangular portion = $\frac{115 + 2{\cdot}222}{2{\cdot}35}$.	108.736	7·778	— 845·749
Water load on the sloping face between 690 and 670 triangular portion = $\frac{2{\cdot}222 + 10}{2{\cdot}35}$.	9·456	8·148	— 77·047
	6,833·139		167,542·554

$$\text{Upstream third} — \frac{167{,}542{\cdot}554}{6{,}833{\cdot}139} + 8{\cdot}889 = 33{\cdot}408$$

$$\text{Water thrust} — \frac{135 \times 135}{2 \times 2{\cdot}35} = \frac{18{,}225}{4{\cdot}7} = 3{,}877{\cdot}660$$

$$\text{Moment of water thrust} = 3{,}877{\cdot}660 \times \frac{135}{3} = 174{,}494{\cdot}7$$

$$\text{Centre third} = \frac{174{,}494{\cdot}7}{6{,}833{\cdot}139} = 25{\cdot}536$$

$$\text{Downstream third} = 97{\cdot}48 — (33{\cdot}408 + 25{\cdot}536) = 38{\cdot}536$$

Maximum stresses—Reservoir empty—

$$\text{Bouvier} = \frac{2 \times 6{,}473{\cdot}79}{97{\cdot}48}\left(2 — \frac{3 \times 35{\cdot}05}{97{\cdot}48}\right)$$

$$= 132{\cdot}823 \times {\cdot}9213$$
$$= 122{\cdot}370 \times {\cdot}0655 \text{ tons.}$$
$$= 8{\cdot}015 \text{ tons per square foot.}$$

Reservoir empty	Weight.	Lever arm.	Moment

Reservoir full—

$$\text{Maximum stress} = \frac{2 \times 6{,}833{\cdot}139}{97{\cdot}48}\left(2 - \frac{3 \times 38{\cdot}536}{97{\cdot}48}\right)\sec^2\alpha$$

$$= 140{\cdot}196 \times {\cdot}8140 + \sec 2\,\alpha \qquad \tan\alpha = \frac{3{,}877{\cdot}66}{6{,}833{\cdot}139} = {\cdot}5675$$

$$= 114{\cdot}120 \times \sec + 2\,\alpha$$

$$= 114{\cdot}12 \times 1{\cdot}3221 \qquad 1 + \tan^2\alpha = 1{\cdot}3221$$

$$= 150{\cdot}878 \times {\cdot}0655 \text{ tons.}$$

$$= 9{\cdot}883 \text{ tons per square foot.}$$

Unwin—Reservoir empty—

$$\tan.\ \theta\ 1{\cdot}167$$

$$\text{Maximum stress} = 8{\cdot}015 \times 1{\cdot}0279 \quad 1 + \tan.\ 2\,\theta_1 = 1{\cdot}0279$$

$$= 8{\cdot}238 \text{ tons per square foot.}$$

$$\text{Reservoir full} = 114{\cdot}12 \times 2 \times {\cdot}0655 \text{ tons soc } 2\theta 1 = 2$$

$$= 14{\cdot}95 \text{ tons per square foot.}$$

Level 650—Reservoir empty—			
Masonry above 650	6,473·79	..	169,363·865
Masonry between 670 and 650 rectangular portion right of the vertical.	1,771·82	44·296	78,484·539
Masonry between 670 and 650 triangular portion.	200·00	95·258	19,051·600
		Total ..	266,900·004
Masonry between 670 and 650 triangular portion at upstream side.	177·78	4·445	— 790·232
Masonry between 670 and 650 triangular portion.	33·33	10	— 333·300
Total ..	8,656·72		265,776·472

$$\text{Upstream third} = \frac{265{,}776{\cdot}472}{8{,}656{\cdot}72} + 12{\cdot}22 = 42{\cdot}922.$$

	Weight.	Lever arm.	Moments.
Reservoir full—			
Masonry including water load above 670.	6,833·139	..	167,542·554
Masonry above 650 and below 670 as above.	2,182·93	..	96,412,607
		Total ..	263,955·161
Water load on the sloping face at the upstream side between 670 and 650 rectangular portion $= \frac{135 \times 3{\cdot}333}{2{\cdot}35}$.	191·470	10·556	— 2,021·157
Water load on the sloping face at the upstream side between 670 and 650 rectangular portion $= \frac{3{\cdot}333 \times 10}{2{\cdot}35}$.	14·183	11·111	— 157·587
Total ..	9,221·722		261,776·417

Reservoir empty.	Weight.	Lever arm.	Moments.

Upstream third $= \frac{261,776 \cdot 417}{9,221 \cdot 722} + 12 \cdot 22 = 40 \cdot 607.$

Water thrust $= \frac{155 \times 155}{2 \times 2 \cdot 35} = \frac{24,025}{4 \cdot 07} = 5,111 \cdot 702.$

Moment of water thrust $= \frac{5,111 \cdot 702 \times 155}{3} = \frac{792,313 \cdot 810}{3}$
$= 264,104 \cdot 603$

Centre third $= \frac{264,104 \cdot 603}{9,221 \cdot 722} = 28 \cdot 639.$

Downstream third $= 120 \cdot 81 - (40 \cdot 607 + 28 \cdot 639)$
$= 51 \cdot 564$

Maximum stresses—Reservoir empty—

Bouvier $= \frac{2 \times 8,656 \cdot 72}{120 \cdot 81} \left(2 - \frac{3 \times 42 \cdot 922}{120 \cdot 81}\right)$
$= 143 \cdot 311 \times \cdot 9342.$
$= 133 \cdot 881 \times \cdot 9655$ tons.
$= 8 \cdot 769$ tons per square foot.

Reservoir full—

Bouvier $= \frac{2 \times 9,221 \cdot 722}{120 \cdot 81} \left(2 - \frac{3 \times 51 \cdot 564}{120 \cdot 81}\right) \sec^2 \alpha$
$= 152 \cdot 665 \times \cdot 7196 \times \sec^2 \alpha.$
$= 109 \cdot 858 \times 1 \cdot 3072;$ $\qquad \tan \alpha = \frac{5,111 \cdot 702}{9,221 \cdot 722}$
$= 143 \cdot 606 \times \cdot 0655$ tons
$\qquad = \cdot 5543$
$\qquad 1 + \tan^2 \alpha = 1 \cdot 3072$
$= 9 \cdot 406$ tons per square foot.

Unwin—Reservoir empty—
$= 8 \cdot 769 \times 1 \cdot 0279$ tons.
$= 9 \cdot 014$ tons per square foot.

Unwin—Reservoir full $= 109 \cdot 858 \times \cdot 131.$
$= 14 \cdot 391$ tons.'

	Weight.	Lever arm.	Moments.
Level 630—			
Masonry above 650	8656·72	..	265,776·472
Masonry between 630 and 650 rectangular portion right of the vertical	2171·80	54·295	117,917·881
Masonry between triangular portion	200·00	115·257	23,051·400
			406,745·753
Masonry between 630 and 650 triangular portion at the upstream side	244·40	6·11	— 1,493·284
Masonry between 630 and 650 rectangular portion	33·36	13·332	— 444·756
	11,306·28	..	404,807·713
Upstream third .. .. .. =	$\frac{404,807 \cdot 713}{11,306 \cdot 28}$	+ 15·556	= 51·360
Reservoir full—			
Masonry above 650 including water load	9,221·722	∴	261,776·417
Masonry between 650 and 630 as above	2,649·56	..	139,031·241
			400,807·658
Water load on the upstream face between 650 and 630 rectangular portion $= \frac{155 \times 3 \cdot 334}{2 \cdot 35}$	219·902	13·819	— 3,054.219

Reservoir empty.	Weight.	Lever arm.	Moments.
Water load on the upstream face between 650 and 630 triangular portion = $\frac{3.334 \times 10}{2.35}$	141·86	14·444	— 204,903
	12,105·370		397,548·536

Upstream third .. .. .. $= \frac{397,548.536}{12,105.37} + 15.556 = 48.397$

Water thrust .. .. $\frac{175 \times 175}{2 \times 2.35} = \frac{30,625}{4.7} = 6,515.957$

Moment of water thrust .. .. $6,515.957 \times \frac{175}{3} = \frac{1,140,292.475}{3}$

$= 380,097.492$

Centre third .. .. $= \frac{380,097.492}{12,105.37} - 31.399$

Downstream third .. .. .. $= 144.15 - (48.397 + 31.399)$
$= 64.354$

Maximum stress—Reservoir empty—

Bouvier .. .. $= \frac{2 \times 11,306.28}{144.15} \left(2 - \frac{3 \times 51.36}{144.15}\right)$
$= 156.868 \times .9311$
$= 146.060 \times .0655$ tons.
$= 9.567$ tons per square foot.

Reservoir full—

Bouvier .. .. $= \frac{2 \times 12,105.37}{144.15} \left(2 - \frac{3 \times 64.354}{144.15}\right) \sec.^2 \alpha$
$= 167.955 \times .6607 \times \sec^2 \alpha$

$\tan \alpha = \frac{6,515.957}{12,105.37}$

$= 110.968 \times 1.2898$

$= 5,383$

$= 143.127 \times .0655$ tons

$1 + \tan^2 \alpha$
$= 1.2898$

$= 9.375$ tons per square foot.

Unwin—Reservoir empty .. .. $= 9.567 \times 1.0279$
$= 9.843$ tons per square foot.

Unwin—Reservoir full .. .. $= 110.968 \times 0.131$ tons per square foot.
$= 14.537$ tons per square foot.

Level 610—Reservoir empty—

	Weight	Lever arm	Moments
Masonry above 630	11,306·28	..	404,807·713
Masonry between 630 and 610 rectangular portion right of vertical ..	2,571·88	64·297	165,364·168
Masonry between 630 and 610 triangular portion	200·00	135·261	27,052·200
			597,224·081
Masonry between 630 and 610 rectangular portion on upstream side between 630 and 610	311·12	7·778	— 2,419,891
Masonry between 630 and 610 triangular portion	33·33	16·667	555·511
	14,422·61		594,248·679

Upstream third $= \frac{594,248.679}{14,422.61} + 18.889 = 60.092.$

Reservoir empty.	Weight.	Lever arm.	Moments.
Reservoir full—			
Masonry including water load above 630	12,105·37	..	397,548·536
Masonry between 630 and 610 as above	3,116·33	..	189,440·966
			586,989·502
Water load on the sloping face at the upstream side between 630 and 610 rectangular portion $= \frac{175 \times 3·333}{2·35}$ ..	248·202	17·223	− 4,274·783
Water load on the sloping face at the upstream side between 630 and 610 triangular portion $= \frac{3·333 \times 10}{2·35}$ ..	14·183	17·778	− 252·145
	15,484·085		582,462·574

Upstream third $= \frac{582,462·574}{15,484·085} + 18·889 = 56·506.$

Water thrust $= \frac{195 \times 195}{2 \times 2·35} = \frac{38025}{4·7} = 8,090·423.$

Moment of water thrust $= \frac{8,090·423 \times 195}{3} = 525,877·495.$

Centre third $= \frac{525,877·495}{15,484·085} = 33·962.$

Downstream third $= 167·48 - (56·506 + 33·962).$
$= 77·012.$

Reservoir empty—

Maximum stresses—

Bouvier $= \frac{2 \times 14,422·61}{167·48} (2 - \frac{3 \times 60·092}{167·48}).$
$= 172·231 \times ·9236$
$= 159·073 \times ·0655$ tons.
$= 10·419$ tons per square foot.

Reservoir full—

Bouvier $= \frac{2 \times 15,484·085}{167·48} (2 - \frac{3 \times 77·012}{167·48})$ Sec. 2α.
$= 184·906 \times ·6205 \times$ Sec. ^{2}L ; tan. $\alpha = \frac{-8,090·423}{15,484·085}$
$= 114·734 \times 1·2730$ $= ·5225.$
$1 + \tan 2\alpha = 1·2730$
$= 146·056 \times ·0655$ tons.
$9·567$ tons per square foot.

Unwin Res. Empty $= 10·419 \times 1·0,279$ tons.
$= 10·71$ tons per square foot.

Unwin Res. full $= 114·734 \times ·0655$ tons.
$= 7·515$ tons per square foot.

	Weight.	Lever arm.	Moments.
Level 590—Reservoir empty.			
Masonry above 610	14,422·61	..	594,248 679
Masonry between 610 and 590 rectangular portion right of vertical..	2,971·82	74·296	220,794·339
			815,043·018
Masonry between 610 and 590 rectangular portion at the upstream side.	377·78	9·445	—3,568·132

Reservoir empty.	Weight.	Lever arm.	Moments.
Masonry between 610 and 590 triangular portion	33·33	20	— 666·600
	17,805·54		810,808·286

Upstream third $= \frac{810,808 \cdot 286}{17,805 \cdot 54} + 22 \cdot 222 = 67 \cdot 759$

Reservoir full—	Weight.	Lever arm.	Moments.
Masonry including water load above 610	15,484·085	..	582,462·574
Masonry between 610 and 590 as above	3,382·93	..	216,559·607
			799,022·181
Water load on the sloping face between 610 and 590 rectangular portion 195 × $\frac{3 \cdot 333}{2 \cdot 35}$	276·556	20·556	—5,685·091
Water load on the sloping face between 610 and 590 trangular portion 3·333 × $\frac{10}{2 \cdot 35}$	14·183	21·111	— 299·417
	19,157·764		793,037·673

Upstream third $\frac{793,037 \cdot 673}{19,157 \cdot 764} + 22 \cdot 222 = 63 \cdot 617$

Water thrust $= \frac{215 \times 215}{2 \times 2 \cdot 35} = \frac{46,225}{4 \cdot 7} = 9,835 \cdot 106$

Moment of water thrust $= \frac{9,835 \cdot 106 \times 215}{3} = \frac{21,14,547 \cdot 790}{3} = 704,849 \cdot 263$

Centre third $= \frac{704,849 \cdot 263}{19,157 \cdot 764} = 36 \cdot 792$

Downstream third $= 170 \cdot 82 - (63 \cdot 617 + 36 \cdot 792)$
$= 70 \cdot 411$

Reservoir empty.

Maximum stresses.—

Bouvier $= \frac{2 \times 17,805 \cdot 54}{170 \cdot 82} \left(2 - \frac{3 \times 67 \cdot 759}{170 \cdot 82}\right)$
$= 208 \cdot 471 \times \cdot 8100$
$= 168 \cdot 862 \times \cdot 0655$ tons.
$= 11 \cdot 060$ tons per square foot.

Reservoir full.

Bouvier $= \frac{2 \times 19,157 \cdot 764}{170 \cdot 82} \left(2 - \frac{3 \times 70 \cdot 411}{170 \cdot 82}\right) \sec^2 \alpha$
$= 224 \cdot 303 \times \cdot 7364 \times \sec^2 \alpha$
$= 165 \cdot 177 \times 1 \cdot 2636$
$= 208 \cdot 718 \times 0 \cdot 0655$ tons
$= 13 \cdot 671$ tons per square foot.

$\tan \alpha \frac{9,835 \cdot 106}{19,157 \cdot 764}$
$= \cdot 5134$
$1 + \tan^2 \alpha = 1 \cdot 2,636$

Unwin reservoir empty $= 11 \cdot 06 \times 10279$
$= 11 \cdot 369$ tons per square foot.

Unwin reservoir full $= 165 \cdot 177 \times \cdot 0655$ tons
$= 10 \cdot 819$ tons per square foot.

Reservoir empty.	Weight.	Lever arm.	Moments.
Level 570—			
Masonry above 590	17,805·54	..	810,808·286
Masonry between 590 and 570 rectangular portion right of the vertical.	2,971·82	74·296	220,794·339
			1,031,602·625
Masonry between 590 and 570 rectangular portion at the upstream side.	444·44	11·111	— 4,938·173
Masonry between 590 and 570 triangular portion.	33·33	23·333	— 777·689
	21,255·13		1,025,886·763

$$\text{Upstream third} = \frac{1{,}025{,}886{\cdot}763}{21{,}255{\cdot}13} + 25{\cdot}555 = 73{\cdot}82$$

Reservoir full.

	Weight.	Lever arm.	Moments.
Masonry including water load above 590.	19,157·764	..	793,037·673
Masonry between 590 and 570 as above	3,449·59	..	215,078·477
			1,008,116·150
Water load on the sloping face between 590 and 570 rectangular portion $= \frac{215 \times 3{\cdot}333}{2{\cdot}35}$.	304·934	23·889	— 7,284·568
Water load on the sloping face between 590 and 570 triangular portion $= \frac{3{\cdot}333 \times 10}{2{\cdot}35}$.	14·183	24·444	— 346·689
	22,926·471		1,000,484·893

$$\text{Upstream third} = \frac{1{,}000{,}484{\cdot}893}{22{,}926{\cdot}471} + 25{\cdot}555 = 69{\cdot}194$$

$$\text{Water thrust} = \frac{235 \times 235}{2 \times 2{\cdot}35} = \frac{23500}{2} = 11{,}750$$

$$\text{Moment of water thrust} = \frac{11750 \times 235}{3} = \frac{2{,}761{,}250}{3} = 920{,}416{\cdot}667$$

$$\text{Centre third} = \frac{920{,}416{\cdot}667}{22{,}926{\cdot}471} = 40{,}147.$$

$$\text{Downstream third} = 174{\cdot}15 - (69{\cdot}194 + 40{\cdot}147) = 64{\cdot}809.$$

Maximum stresses—Reservoir empty.

$$\text{Bouvier} = \frac{2 \times 21{,}255{\cdot}13}{174{\cdot}15}\left(2 - \frac{3 \times 73{\cdot}82}{174{\cdot}15}\right)$$

$= 244{\cdot}101 \times {\cdot}7283.$

$= 177\ 779 \times {\cdot}0655$ tons.

$= 11{\cdot}645$ tons per square foot.

Reservoir full.

$$\text{Bouvier} = \frac{2 \times 22926{\cdot}471}{174{\cdot}15}\left(2 - \frac{3 \times 64{\cdot}809}{174{\cdot}15}\right)\sec.^2 \alpha$$

$= 263{\cdot}296 \times {\cdot}8836 \times \sec.^2 \alpha$ $\qquad \tan. \alpha = \frac{11{,}750}{22{,}926{\cdot}471} = {\cdot}5125.$

$= 232{\cdot}648 \times 1{\cdot}2627.$ $\qquad 1 + \tan.^2 \alpha = 1{\cdot}2627.$

$= 293{\cdot}765 \times 0{\cdot}0655$ ton.

$= 19{\cdot}242$ tons per square foot.

Unwin reservoir empty $= 11{\cdot}645 \times 1{\cdot}0279$ tons.

$= 11{\cdot}97$ tons per square foot.

Reservoir full $= 232{\cdot}648 \times {\cdot}0655$ ton.

$= 15{\cdot}238$ tons per square foot.

Weight of masonry.		Reservoir empty.
Level 740—		
Weight of masonry above 750	=	1,299·69
Do. between 750 and 740	=	359·7
Weight of masonry above 740	=	1,659·39
Level 720—		
Weight of masonry above 730	=	2,101·09
Do. between 730 and 720	=	523·73
Weight of masonry above 720	=	2,624·82
Level 700—		
Weight of masonry above 710	=	3,230·59
Do. between 710 and 700	=	687·80
Weight of masonry above 700	=	3,918·39
Level 680—		
Weight of masonry above 690	=	4,688·19
Do. between 690 and 680	=	851·80
Weight of masonry above 680	=	5,539·99
Level 660—		
Weight of masonry above 670	=	6,473·79
Do. between 670 and 660	=	1,033·13
Weight of masonry above 660	=	7,506·92
Level 640—		
Weight of masonry above 650	=	8,656·72
Do. between 650 and 640	=	1,266·45
Weight of masonry above 640	=	9,923·17
Level 620—		
Weight of masonry above 630	=	11,306·28
Do. between 630 and 620	=	1,499·83
Weight of masonry above 620	=	12,806·11
Level 600—		
Weight of masonry above 610	=	14,422·61
Do. between 610 and 600	=	1,683·15
Weight of masonry above 600	=	16,105·76
Level 580—		
Weight of masonry above 590	=	17,805·54
Do. between 590 and 580	=	1,716·53
Weight of masonry above 580	=	19,522·07

Results.

Level.	Weight of dam per foot run above that level in masonry units.	Weight of dam per foot run above that level in tons.
570	21,255·13	1,417·01
580	19,522·07	1,301·47
590	17,805·54	1,187·04
600	16,105·76	1,073·72
610	14,422·61	961·51
620	12,806·11	853·74
630	11,306·28	753·75
640	9,923·17	661·54
650	8,656·72	577·11
660	7,506·92	500·46
670	6,473·79	431·59
680	5,539·99	369·33
690	4,688·19	312·56
700	3,918·39	261·23
710	3,230·59	215·37
720	2,624·82	174·99
730	2,101·09	140·07
740	1,659·39	110·63
750	1,299·69	86·65
760	1,008·24	67·20
770	763·79	50·92
780	552·34	36·82
790	361·44	24·10
798	216·00	14·40
800	180·00	12·00
805	90·00	6·00
810	..	..

15 cubic feet of masonry units = 1 ton.

APPENDIX C

Rolling-stock and Tramway Plant employed at Headworks.

Description.	Number employed
1 Sentinel locos	38
3 C.yd. side discharge wagons	331
2 C.yd. tipping wagons	561
1 C.yd. tipping wagons	1,254
Black bogies, 10-ton capacity	21
Bogie wagons 6-ton capacity	17
Bogie wagons 5-ton capacity	19
Platform trucks small (steel top plate)	32
Platform trucks small (wooden decking)	106
Box trucks	5
Box trucks with inclined sides	2
All round tipping wagons	1
Bottom discharge wagon	1
Platform wagons with wooden top and roof	3
Platform trucks for carrying timber	2
Platform trucks without decking	3
Cement bogies 10-ton capacity	17
2 feet gauge tram-track (24 lb.)	68 mile (approximately).
Switches right hand and left hand (24 lb.)	832
Turn tables	77
Hudson easy turn-outs	46
Diamond crossings	69
Right-angled crossings	30

APPENDIX D

Monthly Progress of Dam Foundations Excavation.

Month.	Quantity in cubic feet.
1927	
1 July	11,813
2 August	1,640
3 September	141,267
4 October	174,542
5 November	252,608
6 December	708,850
	1,290,720
1928	
7 January	629,861
8 February	231,141
9 March	796,314
March supplemental	916.187
10 April	266,035
11 May	572,207
12 June	598,371
13 July	801,834
14 August	906,665
15 September	1,435,904
16 October	1,234,189
17 November maximum	1,962,168
18 December	1,366,968
During 1928	11.717,844
To end of 1928	13,008,564
1929	
19 January	1,249,982
20 February	1,479,375
21 March	1,355,327
22 April	274,048
23 May	320,459
24 June	92,016
25 July	353,570
26 August	730,767
27 September	575,429
28 October	683,289
29 November	942,288
30 December	392,639
During 1929	8,449,189
To end of 1929	21,457,753
1930.	
31 January	478,727
32 February	641,203
33 March	1,079,604
34 April	119,764
35 May	716,326
36 June	379,534
37 July	498,569
38 August	228,462
39 September	288,898

Month.	Quantit in cubic feet.
1930 —*cont.*	
40 October	294,466
41 November	239,227
42 December	338,873
During 1930	5,303,653
To end of 1930	26,761,406
1931	
43 January	766,882
44 February	636,855
45 March	870,349
46 April	341,551
47 May	377,778
48 June	354,509
49 July	320,701
50 August	123,590
51 September	278,865
52 October	270.804
53 November	65,446
54 December	29,332
During 1931	4,436,662
To end of 1931	31,198,068
1932	
55 January	160,687
56 February	72,289
57 March	106,508
58 April	134,893
59 May	165,698
60 June	62,032
61 July	32,970
62 August	207,300
63 September	124,900
64 October	104,538
65 November	39,725
66 December	32,488
67 to 69 March	33,960
During 1932	1,277,988
Grand total	32,476,056

	Reach L. S.	Total.
1	0—616	7,669,800
2	616—1700	4,376,337
3	1700—5300	20,429,919
		32,476,056
	Grand total	32·476 million cubic feet.

APPENDIX E

Monthly Progress of Construction in masonry and concrete in Dam.

Month. (1)	C.D.W. cubic feet. (2)	C.D.E. cubic feet. (3)	M.H.W, cubic feet. (4)	Total. cubic feet. (5)
1928.				
June	6,475	..	..	6,475
July	33,707	..	..	33,707
August	96,513	..	..	96,513
September	150,528	..	..	150,528
October	235,277	..	..	235,277
November	185,988	..	..	185,988
December	105,867	..	..	105,867
To end of 1928 ..	814,355	..	..	814,355
1929.				
January	221,092	..	..	221,092
February	25,752	..	..	25,752
March	239,547	167,155	..	406,702
April	350,862	168,753	..	519,615
May	210,247	345,429	..	555,676
June	217,994	209,777	..	427,771
July	245,293	104,463	..	349,756
August	204,586	73,229	..	277,815
September	231,553	96,490	..	328,043
October	180,515	65,642	..	246,157
November	315,840	89,609	..	405,449
December	264,611	170,788	..	435,399
To end of 1929 ..	3,522,247	1,491,335	..	5,013,582
1930.				
January	206,172	165,319	..	371,491
February	221,236	210,108	..	431,344
March	247,620	212,107	..	459,727
April	205,134	228,258	..	433,392
May	339,266	220,710	..	559,976

Month.	C.D.W. cubic feet.	C.D.E. cubic feet.	M.H.W. cubic feet.	Total cubic feet.
(1)	(2)	(3)	(4)	(5)
1930.				
June	394,360	222,108	3,850	620,318
July	584,454	142,626	82,870	809,950
August	625,173	113,749	74,911	813,833
September	443,307	175,943	88,360	707,610
October	494,436	117,354	87,653	699,443
November	839,929	227,892	98,298	1,166,119
December	666,395	262,666	128,052	1,057,113
To end of 1930 ..	8,789,729	3,790,175	563,994	13,143,898
1931.				
January	661,042	333,590	91,566	1,086,198
February	745,183	448,608	129,950	1,323,741
March	690,419	461,173	165,275	1,316,867
April	654,721	585,699	152,534	1,392,954
May	887,166	731,834	151,939	1,770,939
June	851,249	537,253	161,255	1,549,757
July	863,021	263,473	172,409	1,298,903
August	1,084,108	351,981	162,676	1,598,765
September	1,017,325	263,007	176,606	1,456,938
October	1,068,302	340,353	197,519	1,606,174
November	935,516	344,191	212,122	1,491,829
December	902,191	364,694	199,062	1,465,947
To end of 1931 ..	19,149,972	8,816,031	2,536,907	30,502,910
1932.				
January	923,170	479,508	157,165	1,559,843
February	963,741	337,006	171,775	1,472,522
March	1,012,334	489,245	177,499	1,679,078
April	1,207,237	287,781	167,244	1,662,262
May	826,486	339,099	218,220	1,383,805
June	726,861	82,967	25,273	835,101
July	964,939	257,510	311,075	1,533,524
August	660,160	201,305	258,316	1,119,781
September	693,119	205,174	126,688	1,024,981
October	832,448	230,541	150,866	1,213,855
November	700,429	167,025	177,319	1,044,773
December	831,528	255,335	287,255	1,374,118
To end of 1932 ..	29,492,424	12,148,527	4,765,602	46,406,553

Month.	C.D.W. cubic feet.	C.D.E. cubic feet.	M.H.W. cubic feet.	Total. cubic feet.
(1)	(2)	(3)	(4)	(5)
1933.				
January	507,532	288,472	212,382	1,008,386
February	452,570	448,918	235,770	1,137,258
March	469,112	509,972	257,842	1,236,926
April	468,867	417,979	208,285	1,095,131
May	273,608	209,029	108,754	591,391
June	212,811	112,408	71,975	397,194
July	234,260	139,248	52,490	425,998
August	195,126	88,562	6,909	290,597
September	257,213	81,995	6,000	345,208
October	169,977	19,080	..	189,057
November	93,821	85,498	..	179,319
December	105,592	275,931	..	381,523
To end of 1933 ..	32,932,913	14,825,619	5,926,009	53,684,541
1934.				
January	76,096	180,167	..	256,263
February	76,952	170,200	..	247,152
March	75,790	175,797	..	251,587
April	37,906	94,921	..	132,827
May	11,886	12,242	..	24,128
June	8,620	14,596	..	23,216
July	..	336	..	336
To end of 1934 ..	33,220,163	15,473,878	5,926,009	54,620,050

APPENDIX F.

SPEECHES DELIVERED AT INAUGURATION CEREMONY (1934).

Statement read by M.R.Ry. Rao Bahadur R. Narasimha Ayyangar Avargal, B.A., B.E., *Chief Engineer for Irrigation, on the Inauguration of the Cauvery-Mettur Irrigation System by His Excellency Lieutenant-Colonel. The Right Honourable Sir George Frederick Stanley, P.C., G.C.S.I., G.C.I.E., C.M.G., Governor of Madras—21st August* 1934.

MAY IT PLEASE YOUR EXCELLENCY,

On behalf of the officers of the Public Works Department, and more particularly of those of us who have been associated with the investigation and construction of this great work, I welcome Your Excellency here this morning.

2. I wish to express the great honour we feel you have done us by so graciously consenting to perform this Inauguration Ceremony which marks the completion of what is, perhaps, the greatest engineering work ever undertaken by the Public Works Department in this Presidency.

3. Your Excellency has watched the progress of this work at Mettur with a very lively interest, and it is very appropriate, therefore, that, having inspected the work in its earlier stages, you should once more honour us with your presence to-day to celebrate its completion.

4. It is, perhaps, a curious coincidence that exactly a hundred years should have elapsed since that great Irrigation Engineer, Sir Arthur Cotton, conceived in 1834 the idea of constructing a dam across the Cauvery for the protection of irrigation in the delta by the storage of flood water thereby. During the past century many of our engineers put forward schemes with that object, but it was not until Col. W. M. Ellis, R.E., C.I.E., elaborated Mr. Moss's scheme and in 1910 submitted his report on the project that the chances of materialization of such a scheme appeared to be assured. Perhaps none but those who have been associated with this project can fully appreciate the extraordinary knowledge and infinite care that Colonel Ellis bestowed upon his great work. We are greatly indebted to him and to the officers who worked with him in his investigations for the collection of the vast information which has been so helpful to us in the actual execution of this scheme. We therefore regret that he is unable to be with us to-day to witness the completion of the work which he so ably initiated.

5. We extend to our late Engineer-in-Chief, Mr. C. T. Mullings, C.S.I., a very hearty welcome. To him we are indebted for much valuable advice. His quick conception and courage in meeting many a problem in the earlier days of the construction contributed in no small measure to the rapid progress of the work.

6. The execution of Colonel Ellis's scheme was, as Your Excellency is aware, held in abeyance for about 15 years, mainly on account of the unfortunate dispute which arose between the Mysore Darbar and the Madras Government over the rights of the two parties to the waters of the Cauvery. Thanks to the untiring efforts of Sir C. P. Ramaswami Ayyar, through whose good offices the claims of both parties were eventually settled to their mutual satisfaction, the project estimate received the sanction of the Secretary of State for India early in 1925. He continued to be in charge of the Irrigation portfolio until 1928 and it was under his fostering care and guidance that the organization of the staff for the work in its earlier stages was made.

7. Steps were taken immediately after the receipt of the Secretary of State's sanction to put the work in hand, and on the 20th July 1925, His Excellency the Right Hon'ble Viscount Goschen visited the site of the dam at Mettur and performed the Inaugural Ceremony.

8. It was, perhaps, a blessing in disguise that the execution of the work had been so long delayed, for, in July 1924 the Cauvery valley experienced the highest floods in living memory and great havoc was caused thereby. Had the dam been built prior to that date it is likely that the surplus works would have proved inadequate and the dam would have been over-topped, for it is computed that the flood at Mettur reached the stupendous figure of 456,000 cubic feet per second, or nearly double the highest discharge previously recorded.

9. In consequence of this experience the surplus works were redesigned and enlarged, and the site of the dam was shifted a mile further up-stream in order to utilize a natural saddle on the right flank as an emergency surplus. To compensate for the reduction in the capacity of the reservoir, the height of the dam was also increased. This, together with the decision to employ cement in place of lime in the construction of the dam in order to accelerate progress, also led to modifications in the design of the dam. As now designed, the maximum surplussing capacity of the reservoir is 550,000 cubic feet per second, which should ensure the safety of the work under the worst probable flood conditions in the river.

10. It was not until the new site for the dam had been thoroughly examined and proved to be entirely satisfactory that the sites for the Mettur township, the workshops, stores, offices and the many other buildings essential to a work of this size could be determined.

11. Early in 1927, however, the lay-out of the camp with its water-supply and underground drainage systems was well in hand, and their construction was completed early in the following year. Meanwhile, the excavation of the foundations for the dam had been started in the river-bed—always the most difficult and risky part of the work on account of the vagaries of the river—but I am happy to be able to record that despite unseasonal freshes in the river this difficult part of the work was carried out according to programme. The excavation of the very deep foundations on the right bank proved a much heavier task than had been anticipated.

12. The first concrete in the foundations of the dam was laid in August 1928 and the entire structure, comprising upward of 54½ million cubic feet of masonry and concrete was completed in all respects in June of this year. The actual time of construction has thus been five years and ten months. The Souvenir, of which Your Excellency has a copy, contains a table comparing the size, cost and period of construction of some of the largest dams in India and other parts of the world. From this it will be observed that the Mettur dam is by far the largest hitherto constructed. At the same time its construction has been unusually rapid, and its cost per unit of masonry laid compares favourably with any of them.

13. The rapidity of construction was in a large measure due to the substitution of Portland cement for lime, to the wide employment of modern machinery and methods for the handling of such vast quantities of materials, and to our good fortune in being able to secure the services of ample labour. Troubles in other parts of the country had little or no effect on the labour here which remained happy and contented at all times.

14. Sanitary measures and anti-malarial operations were started right from the commencement of the works under the direction of the Director of Public Health, and the labour camp was remarkably free from attacks of malaria or any epidemic disease.

15. It is to the credit of the contractors and piece-workers and their labour that the greater portion of this gigantic structure was built by their hands, and I cannot let this opportunity pass without a word of congratulation to them all for the great part they have played in bringing this work to a state of completion. In passing, I should like to recall the name of one, the late Mr. G. Srinivasa Ayyar, a very capable and popular contractor and sportsman who died as the result of an accident sustained while supervising his work. His loss was keenly felt by all. His competent partner Mr. S. Chandappa Ayyar, however, carried on his work till the end. To him was entrusted the contract work in connexion with the erection of this Memorial Pavilion.

16. In speaking of the work that has been done here, one is inclined to overlook the herculean tasks that have been carried out, often under great difficulties, in the construction of the Grand Anicut Canal. Special mention should be made here of the services of Mr. T. M. Subrahmanya Ayyar, the first large contractor who, with a very good command of outside labour, took up earthwork excavation for the canal system, and whose activities tended to keep down the rates. The other figure that stands out prominently amongst those who laboured on that great work is Mr. G. Thandavaraya Mudaliyar, a prominent contractor, who in the face of many difficulties undertook the heavy work in the Vettikkad embankment, and brought it to a satisfactory state of completion.

17. Of the European contractors whose work is outstanding we have Messrs. Glenfield and Kennedy of Kilmarnock, Scotland, to whom was entrusted the entire supply and erection of the irrigation

sluices and hydro-electric pipes in the dam as well as the imposing array of surplus gates over which Your Excellency passed a few minutes ago. The two emergency gates and the 50-ton Goliath cranes by means of which they are placed in position were also supplied by the same firm. Messrs. Hadfield supplied the heavy crusher plant, while Messrs. Stothert and Pitt supplied the two giant concreting towers, the skeletons of which still overshadow the dam. Many of the concrete mixers which figured so largely in the rapid construction of the dam, and which have given such excellent service were also the products of that firm.

18. Much time and expense in construction have been saved by the free use of pre-cast and reinforced concrete wherever it could be employed. The archwork in the irrigation sluices, the coping blocks on the dam parapets, the emergency shutter houses and this pavilion are all examples of that class of work.

19. I may now quote a few of the leading particulars of the work—

The total length of the dam is 5,300 feet, about 1,000 feet shorter than as originally designed for the lower site. On the other hand, its average height is considerably greater, being 215 feet above the deepest foundations and 176 feet above the river-bed. The maximum width at foundations is 171 feet while the cubical contents exceed 54½ million cubic feet.

The dam is 20½ feet wide at crest and carries a concrete roadway 16 feet in width between parapets.

To deal with temperature changes and for the prevention of contraction cracks forming in this mile-long dam, it is constructed in sections, generally of 126½ feet length, each closely abutting the next but not bonded into it. The contraction is thus deliberately encouraged to take place at these joints, and the percolation of water through them is arrested by the provision of expanding copper joints running vertically from below ground level to the top of the dam. Reinforced concrete staunching bars, diamond-shaped, are also provided at each joint for the same purpose.

Leakage through the face of the dam, if any, is collected in a number of drainage shafts which connect on to an inspection and drainage gallery extending for a length of some 4,000 feet in the body of the dam at about ground level. It is found that the contraction joints are functioning exactly as the designers intended they should, in consequence of which the leakage through the dam is insignificant, considering the enormous area which is exposed to high water pressure. We feel, therefore, that the many precautions which have been taken to meet the defects found in many other large dams in the world have been fully justified, and trust that those who succeed us here will ever do so with a comfortable sense of security.

The sluices in the dam are divided into three groups. The lowest of these are the four 8½ feet diameter hydro-electric pipes each regulated by a needle valve of very robust construction. These pipes pierce the dam at a level 15 feet above the original river-bed. They are, nevertheless, designed to operate under a head of over 150 feet of water.

With their cills 30 feet above these pipes is a set of five low-level sluices, fitted with electrically operated gates each $7' \times 14'$. Fifty feet above these, i.e., at 720 feet above mean sea level, is a set of high-level sluices eight in number each measuring $10\frac{1}{2}' \times 16'$.

The surplus sluices, which have their cills at plus 770 (or 50 feet above the high-level sluices) are 16 in number and are of unusually large dimensions, each gate measuring $60' \times 20'$. As is the case with the other sluices, these gates are electrically operated with simple push-button control, exactly similar to the small control box which is on the table before Your Excellency. All the sluices, hydro-electric, low-level, high-level and surplus sluices can be worked by hand as well, if necessary.

In the event of extraordinary floods the byewash which is now nearing completion on the F. Saddle near the right flank of the dam will automatically come into operation.

20. Your Excellency, there may be many other items of interest to Engineers on which I have not touched, but I realize that your time is precious and feel that you as well as our guests here this morning have heard sufficient of our work here.

21. With Your Excellency's kind permission, therefore, I will now request the Hon'ble the Revenue Member, Sir Archibald Campbell, to address you. Before retiring, I would like to voice the wishes of the project staff in expressing our appreciation of the extraordinary interest which Sir Archibald Campbell has always taken in following the progress of this work. His periodical visits to the work and the genuine pleasure he had expressed at the progress we have made have encouraged the staff to give of their best.

R. NARASIMHA AYYANGAR.

Sir Archibald Campbell's Speech.

Sir Archibald Campbell, Member for Irrigation, next spoke as follows —Inviting His Excellency to open the Pavilion and unveil the memorial tablet:—

YOUR EXCELLENCIES, LADIES AND GENTLEMEN,

I do not think I can add anything to the very interesting account which the Chief Engineer has just given us of the conception and execution of this great system. But I should like to say a word or two with reference to the results which we hope to obtain in the area affected by this system.

The great advantages of irrigation in increasing the produce of the land and in securing it against failure of rainfall in areas where the soil is suitable and the rainfall is scanty and uncertain have been recognized in India for many centuries. Innumerable wells and tanks have been in existence in Southern India for many generations. The greatest engineering work carried out in South India until comparatively recent times was the Grand Anicut across the Coleroon river, at the head of the Cauvery delta, which, according to tradition was constructed towards the close of the second century, though it may be of a much later date, and serves to prevent the water of the Cauvery from flowing down the Coleroon and forces it to irrigate a vast extent in what is now the Tanjore district. The Cauvery river divides at the western end of the Srirangam island into two rivers known as the Cauvery and the Coleroon. The Grand Anicut was constructed at the eastern or lower end of the Srirangam island. About a century ago, the main stream had begun to flow down the Coleroon on the northern side of the Srirangam island and so was diverted from the district of Tanjore which suffered in consequence. In 1836 Sir Arthur Cotton constructed the Upper Anicut across the Coleroon river near the western end of the Srirangam island and this was followed by the construction of a dam in the same neighbourhood across the Cauvery, thereby enabling the division of the waters between the Cauvery and the Coleroon by the Srirangam island to be regulated to some extent. These measures did much to restore the agricultural prosperity of the Tanjore district.

Control of distribution of water.—In dealing with proposals for the irrigation of the Godavari delta, Sir Arthur Cotton pointed out that four kinds of works were required before the resources of such tracts with their immense natural advantages could be developed in any good degree.

First.—The embankment of the rivers to secure the crops from destruction by the river floods.

Second.—Dams with channels for irrigation leading from the river to bring its waters from the level of its bed to that of the surface of the land.

Third.—Surplus channels or, as we should say now-a-days, drainage channels to lead off the floods, caused by the local rains, from flat lands to the sea.

Fourth.—Raised roads and bridges to allow of the conveyance of produce to the markets, and to the coast through a country which is otherwise, from its nature, impassable during the rains.

The fact that it is not sufficient merely to pour water on to the land has been amply illustrated in the old Tanjore delta. The main rivers are now kept within bounds by high and strong embankments. The distribution of water is kept under better control by means of the regulators at the head of the Cauvery and the Vennar rivers and in the various rivers or channels branching off from them. Measures have been adopted for the diversion of flood water from the Cauvery into the Coleroon especially at the Grand Anicut. Some very important measures in this respect have been carried out within the last three or four years by diverting some of the upland drainage which formerly flowed into the Vennar below the Vennar regulator at the Grand Anicut so that it now flows into the Cauvery above the regulator; the Cauvery and Vennar regulators and shutters have been strengthened so as to withstand a higher pressure of water; and the road dam, about 4,000 feet long on the Srirangam island just above the Grand Anicut has been lowered so that flood water may pass into the Coleroon earlier and in greater volume than in the past; the new scouring sluices at the Grand Anicut also serve the purpose of passing the flood water into the Coleroon. The provision of railways and roads has received and is receiving the constant attention both of the Government and of local bodies.

Effect of the reservoir in Tanjore.—Until quite recent years, however, there has been no reservoir for the storage of waters on the Cauvery or any of its tributaries, with the result that the flow of water in the rivers and in the canals taking off from them was liable to great fluctuations; at one time much more water flowed over the land than was required, or the excess had to be passed down to the sea, while at other times for days or weeks at a stretch the amount of water available was not sufficient. The provision of this great dam and reservoir should go far to remedy this great defect in the past irrigation in the Tanjore delta. Until it is actually full it will serve to check any flood water flowing down the river from above the reservoir and the adverse results from floods due to local rainfall below Mettur can be mitigated by the closure of the sluices in the dam. On the other hand, when the supply of water in the river is less than is really required for the crops, and there is water in the reservoir, it will be possible to send more water down the river than would otherwise flow in it. We have had an excellent example in this season of this effect of this reservoir. The monsoon this year was weak and late but in the earlier portions of the season we were able to send down more water from this reservoir than was flowing into it. From the 23rd June till the 8th July, the river came down in flood and, but for the existence of this dam, about four times as much water as was required for the delta during that period would have flowed into the sea. At the beginning of that period, the reservoir level was 56 feet; by the 12th July it had risen to 103 feet. After that date the monsoon was very weak and inflow for several days fell to about one-third of the water required in the delta but it was possible to maintain a steady outflow of water from this reservoir to meet the full requirements of all irrigation, although the reservoir was never full to within 17 feet of the full reservoir level.

The ryots of Tanjore will, I trust, realize the very great extent to which they are already indebted for this reservoir which has been completed in an abnormal year when the inflow was insufficient even by the end of July to fill the reservoir. Although the season started with a practically empty reservoir, the impounding of the June flood when the Bhavani river was almost sufficient to supply the needs of irrigation, has enabled us to maintain the full requirements of irrigation at a time when, without the reservoir, there would have been a serious shortage involving probably a loss of crop over thousands of acres. There were only 20 days out of 58 up to the 9th of August when the natural flow into the reservoir was sufficient to meet the requirements of the delta but all demands were fully met.

No danger of over-production.—It has been some times said that it is a mistake to encourage the irrigation of new areas for the cultivation of heavily irrigated crops, especially rice owing to the dangers of over production. I find however that during the 50 years 1881 to 1931 the area cultivated under irrigation rose from about $3\frac{1}{2}$ million acres to about 5 million acres or by about 43 per cent, while the area cultivated without irrigation rose by about 29 per cent and the population in the Presidency rose by about 51 per cent. Even allowing for better outturn owing to the adoption of improved methods of husbandry, it is most improbable that the irrigation of a further 300,000 acres will result in any excess of production. Enquiries which have been made all indicate that at the present moment this Presidency does not produce as much rice as it requires. The Agricultural department of the Government has for some years been endeavouring to spread the cultivation of more valuable crops than rice, especially in areas where irrigation can be provided for longer periods than six months. The ryots are generally ready to take advantage of changes in crops or methods of cultivation when they are satisfied that the change will be to their benefit. In the five years ending 1933, the area cultivated with sugar-cane has increased from 90,000 acres to 121,000 acres or by 36 per cent, the area under plantains has risen from 127,000 acres to 145,000 acres or by 14 per cent, whereas the increase in the area cultivated with paddy is only $4\frac{1}{2}$ per cent during the same period.

The Chief Engineer has mentioned the fact that large pipes have been inserted in the dam to serve the purpose of a hydro-electric installation which may be constructed in the future. Should that scheme be carried out, a certain amount of water will have to be passed down the river throughout the year. I trust that that water will be used for perennial irrigation of such valuable crops as betel or plantain and will not be allowed to pass unused, to the sea.

Rates of water cess.—I will deal very briefly with one other criticism which is made against the scheme and that is that the rates of water cess to be charged on the new area, which are based upon the rate of Rs. 15 for a single crop and Rs. 7–8–0 for a second crop or third crop, are too high. These rates were provided in the financial forcasts in the estimates which were approved by the Madras Legislative Council with the support of the representatives from Tanjore and were sanctioned by the Secretary of State. Since they were so approved and sanctioned, there has been a fall of prices and, partially on this account and partially in recognition of the fact that the ryot has to spend a certain sum of money in the preparation of his land for irrigation for the first time, we have reduced the rates very considerably during this year and next year. But we do not anticipate that the prices will always remain at their present level; looking back over the centuries, one is impressed by the fact that although prices fluctuate from time to time, there is in the long run a tendency for prices to rise. Ryots themselves can, however, very materially reduce, by the rapid development of the project, the amount which should be recovered annually from the irrigated area in order to cover the expenses and interest for the more rapid the development the less will be the interest which will have to be added to the capital until the system pays its way. I would, however, like to point out that the rates of water cess proposed in the estimates are not high compared to those in force in other parts of India. In connexion with the Thungabadra Project we deputed recently an Engineer to make enquiries regarding certain canal systems in the Bombay Presidency. It may be of interest to know that the standard water rates under the major canal system include a rate of Rs. 45 an acre for sugar-cane and Rs. 66 for betel gardens. The Government are ready to do all they can to co-operate with the ryots in the development of the project in a manner which may bring the greatest profit to the ryots and I should like to appeal to the mirasdars and others concerned to co-operate in their turn with the Government and to do all in their power to see that this project is developed as quickly as possible. In the long run, this will be to their greatest advantage and I am confident that they will find that the construction of this reservoir and the connected works will bring increased prosperity to the old delta as well as to the 301,000 acres to be newly irrigated.

The Chief Engineer has very rightly drawn attention to the most important part played by Sir C. P. Ramaswami Ayyar in the negotiations with the Mysore Government and the inception of the project. It is a matter of great regret to us all that owing to an important conference with the Diwan of Cochin at Trivandrum, which it was not possible to postpone, he is unable to be present and witness the formal completion of the work for which he is so largely responsible. I should like to endorse most heartily the remarks made by the Chief Engineer regarding the valuable services rendered by the officers and contractors engaged on this project. I share his great regret that Colonel Ellis was not able to be with us to-day. To initiate and bring to a successful conclusion such a work as the construction of this great dam, a man must be not only a great engineer but also a great organizer; the Madras Government were fortunate in having at their immediate disposal a man so eminently fitted and qualified for this purpose as Mr. Mullings. When to our great regret the rules of his service compelled his retirement, his place was worthily filled by Mr. Hart.

Your Excellencies have taken a deep interest in the progress of this great work and we are all delighted that Your Excellency has agreed that this dam and this reservoir should in future be known as the Stanley dam and the Stanley reservoir while the park below it in the lay out of which Her Excellency took a great personal interest, will bear Her Excellency's name. I will now request Your Excellency to be good enough to inaugurate the Cauvery-Mettur System.

The Governor's Speech.

His Excellency the Governor then replied and inaugurated the Cauvery-Mettur Irrigation system. In doing so His Excellency said:—

Sir Archibald Campbell, Rao Bahadur Narasimha Ayyangar, Ladies and Gentlemen, I have received messages from the Secretary of State, the Viceroy and Lord Goschen which they have sent to me for this occasion and I will commence my speech by reading them out to you.

Secretary of State's Message.—From the Secretary of State—"The opening of the Cauvery-Mettur Irrigation system brings to a successful conclusion many years of strenuous and skilful work. I hope that those of all ranks to whom the credit for this work is due will realize how proud we are of their achievement. This project takes its place among the greatest works of the kind that have ever been conceived and constructed, and it will add to the wealth of the large area which it serves. I send my congratulations and best wishes to all concerned."

The Viceroy's appreciation.—From His Excellency Lord Willingdon—"On the occasion of the opening of the Cauvery-Mettur Irrigation system, much of the preliminary work of which was carried out while I was Governor of the Presidency, I should be very glad if you would express to those responsible for the construction of the project the great admiration I feel for their splendid achievement which will, I feel sure, be a great contribution not only to the welfare of the Madras Presidency but also that of India as a whole. Will you also be good enough to convey to Sir Clement Mullings my sincere congratulations on the well deserved honour which he has received as a result of his great work on this remarkable project."

Lord Goschen's Tribute.

From Lord Goschen—"I hear that you are opening the Cauvery-Mettur Project on August 21st.

"As I inaugurated this scheme in July 1925, may I, through you, send a message of warm congratulation to all who have been concerned in the work on its completion? To the engineers who have devised it and supervised its progress; to the workmen who have laboured on it; to the civilians and doctors who have watched over the welfare of the toiling labourers, and to all who have contributed to its fulfilment. I earnestly hope that it will bring increased prosperity to the districts which it will serve."

Continuing His Excellency said:

I am sure you will all wish to join me in thanking them for their kindness in sending these messages. At one time I hoped that it would be possible for Lord Willingdon to come and open the project, but in the midst of so many engagements and so soon after his return from leave he was unable to accept. It would have been most appropriate had he been able to come, as it was during his period as Governor of Madras that the negotiations with the Mysore Government regarding the distribution of the Cauvery waters were successfully terminated and the estimates for the project forwarded to the Secretary of State for sanction. Lord Goschen performed the foundation ceremony and his time as Governor. We are very grateful to him for his message took a keen personal interest in the work in its initial stages during

It is a great pleasure to us to have here to-day, Sir Clement Mullings who as Engineer-in-Chief for the project overcame the initial difficulties and, and when he retired, left it established on the way to a successful completion. We were fortunate in having Mr. Hart to take over the work from Sir Clement Mullings and great credit is due to him for the rapidity with which it has been finished and for the very considerable savings—about 60 lakhs—effected. We regret the absence of Colonel Ellis who was responsible for the original design of the project and especially of Sir C. P. Ramaswami Ayyar, who was prevented at the last minute from attending. He was indefatigable in his labours for the successful conclusion of the agreement with Mysore and as the Irrigation Member was intimately connected with the work during its first years of progress.

Gentlemen, it is very greatly to the credit of the Public Works Department that a work of this magnitude, the greatest of its kind in the world, should have been constructed by the officers of that department, who, however high their technical qualifications, can have had no experience during the course of their service of an enterprise on so colossal a scale. The department can be justifiably proud of their achievement and in future if they are twitted—as I believe they sometimes are—with their inability to design and build satisfactory bungalows they have only to point to Mettur to silence all critics of the shortcomings of the department.

Irrigation scheme.—Rao Bahadur Narasimha Ayyangar has dealt with the technical story of the construction and Sir Archibald Campbell with the revenue aspect. I hope that critics of the scheme will pay particular attention to his remarks regarding the very considerable benefit which it has conferred in the effective regulation of irrigation during the present year when the monsoon has been weak. Sir Archibald has also dealt with the question of the rates and has shown how for the present very considerable concessions have been made in them. In many other ways the Government are endeavouring to speed up the irrigation in the area served by the scheme and of these I may mention the acquisition at Government cost of field channels, cart-tracks and footpaths, the provision of more bridges across canals for facility of transport, the adoption of the same irrigation season in both the old and new deltas, the opening of an agricultural farm in the project area to demonstrate the feasibility of introducing commercial and garden crops and the grant of a loan to the Tanjore District Board for the construction of roads in the area. In order to facilitate the grant of loans to persons who are likely to take water but need capital to prepare their land for irrigation and cultivate it, the Special Revenue Officer, Cauvery-Mettur Project, has been empowered to grant Takkavi loans.

Claims of other districts.—There has been some agitation from landholders of Salem, Coimbatore and Trichinopoly districts for a share of the benefits of the Mettur reservoir for extension of irrigation in their districts, but it was found on detailed investigation that it was not possible on engineering grounds to take water from the reservoir to these districts or only at prohibitive rates of water-cess. The question of pumping water from the reservoir for the irrigation of lands in the Omalur taluk, Salem district, is however, being investigated afresh and the question of supplying drinking water to Salem town from the reservoir is also under consideration.

During the construction, pipes and gates were inserted in the dam so that the water can be used for hydro-electric purposes and the Government have submitted estimates for the hydro-electric scheme to the Secretary of State for his sanction. This scheme, when completed, will complete another stage of the grid of hydro-electric power with which the southern part of the Presidency is being covered.

I join with the Chief Engineer and Sir Archibald in congratulating and thanking the engineers, and contractors for their labours in bringing this monumental work to completion, and I am delighted that I was able to announce that His Majesty, the King Emperor has been pleased to confer on Sir Clement Mullings the honour of Knighthood.

It only remains for me to express our grateful thanks for the signal honour done to Lady Beatrix Stanley and myself in having our names associated with the Cauvery-Mettur system and to say what a pleasant memory it will be to us in England that we have been perpetuated in this magnificent enterprise. It is given to few Governors to have been associated with two such schemes of progress as the Cauvery-Mettur system and the Pykara Hydro-Electric works, and I am very happy to think that they were both completed in my time.

I now have much pleasure in inaugurating the Cauvery-Mettur system of irrigation."

APPENDIX G (i).

ESTABLISHMENT AT HEADWORKS.

Yearwar Statement of Staff employed in Headworks, Cauvery-Mettur Project, against that sanctioned from 1st *April* 1925 *to* 1st *April* 1934.

Serial number and posts.	* 1st April 1925.		* 1st April 1926.		* 1st April 1927.		1st April 1928.		1st April 1929.		1st April 1930.		1st April 1931.		1st April 1932.		1st April 1933.		1st April 1934.	
	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.
1 Consulting Chief Engineer	..	..	..	..	..	..	..	..	..	..	1	1	..	..	..	..	..	..	..	..
2 Engineer-in-Chief	..	..	..	..	..	..	1	1	1	1	1	1	1	1	1	1	1	1	..	..
3 Personal Assistant to Engineer-in-Chief.	..	..	..	..	..	..	..	..	..	..	..	..	1	1	1	1	1	1	..	..
4 Superintendent of Works	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	1
5 Personal Assistant to Superintendent of Works.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	1
6 Superintending Engineers	1	1	..	..	..	..	1	..	1	1	1	1	..	..	..	..	..	..	..	..
7 Executive Engineers	1	1	3	3	4	4	6	6	6	6	6	5	4	4	4	3	4	3	2	
8 Electrical Engineer	..	..	..	..	..	..	1	..	1	1	1	1	1	1	1	1	1	1	1	1
9 Assistant Engineers	1	1	3	2	10	10	15	12	14	12	14	13	12	11	12	11	13	10	6	6
10 Quarry Superintendents	..	..	..	..	..	..	..	..	1	..	1	1	2	2	2	1	2	..	..	..
11 Supervisors	5	3	8	8	19	19	47	33	47	40	47	41	45	39	45	38	44	33	20	20
12 Forwarding Agent or Transport Officer.	..	..	..	..	1	1	1	1	1	1	1	1	1	1	1	1	1	1	..	..
13 Overseers	..	..	6	2	8	5	12	5	12		12	1	12	..	12	..	12	..	..	..
14 Surveyors	..	..	..	..	2		..	..	..	..	..	..	..	..	..	..	..	..	..	..
15 Workshop Foreman	..	..	..	..	1	1	1	1	1	..	1	..	1	..	1	..	1	..	..	..
16 Accountants	..	..	2	2	4	4	5	5	6	6	7	7	5	4	5	4	5	3	2	2

Yearwar Statement of Staff employed in Headworks, Cauvery-Mettur Project, against that sanctioned from 1st *April* 1925 *to* 1st *April* 1934—cont.

Serial number and posts.	* 1st April 1925.		* 1st April 1926.		* 1st April 1927.		1st April 1928.		1st April 1929.		1st April 1930.		1st April 1931.		1st April 1932.		1st April 1933.		1st April 1934.	
	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.
17 Manager (150—10—200)	..	..	..	..	..	..	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18 Clerks (80—4—120)	..	..	1	1	3	2	6	6	6	6	6	6	6	6	7	7	6	5	4	4
19 Do. (60—4—80)	..	..	3	..	2	4	16	10	16	10	16	14	16	13	16	12	16	10	6	5
20 Do. (35—60)	3	2	10	10	30	35	58	39	58	46	58	48	58	49	58	47	56	45	34	33
21 Typist (35—60)	1	1	2	2	4	4	10	8	10	7	10	8	10	7	10	5	10	5	5	5
22 Head Draughtsman (150—10—200)	..	..	1	1	1	2	2	1	2	1	2	1	2	1	2	1	2	1	1	1
23 Draughtsman II Grade	4	1	3	2	3	5	5	4	5	2	5	1	5	1	5	1	5	1	1	1
24 Do. III Grade	..	..	5	1	1	3	15	11	15	4	15	6	15	2	15	1	15	1	1	1
25 Electrical Draughtsman	..	..	..	..	..	..	1	..	1	..	1	..	1	..	1	..	1	..	..	..
26 Mechanical Draughtsman	..	..	..	..	..	..	3	1	3	1	3	1	3	2	3	3	3	2	2	2
27 Tracers	..	..	2	1	3	3	6	6	6	2	6	1	5	2	5	2	6	2	2	2
28 Storekeepers	..	..	..	..	1	1	2	1	2	2	2	2	2	2	2	2	2	2	2	1
29 Assistant Storekeepers	..	..	..	..	1	1	1	1	1	1	1	1	1	1	11	1	1	1	1	1
30 Stationery Assistant	..	..	..	..	..	..	1	1	1	1	1	1	1	1	1	1	1	1	1	1
31 Daffadar	..	..	..	..	..	..	1	1	1	1	1	1	1	1	1	1	1	1	..	..
32 Peons	10	8	25	22	58	70	136	86	136	98	136	102	128	90	127	85	115	74	49	49
33 Forester	..	..	..	..	1	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..
34 Sub-Assistant Su	..	..	..	..	1	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..
35 Compounder	..	..	..	..	1	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..
36 Midwife	..	..	..	..	1	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..
37 Ward boys	..	..	..	..	2	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..

* Figures not available.

APPENDIX G (ii)

ESTABLISHMENT IN CANALS.

40 *Yearwar Statement of Staff employed in Canal Circle, Cauvery-Mettur Project, against that sanctioned from 1st April 1925 to 1st April 1934.*

Serial number and posts.	* 1st April 1925.		* 1st April 1926.		* 1st April 1927.		* 1st April 1928.		1st April 1929.		1st April 1930.		1st April 1931.		1st April 1932.		1st April 1933.		1st April 1934.	
	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.
1 Superintending Engineer	..	..	..	..	..	..	..	..	1	1	1	1	1	1	1	..	..	..	..	..
2 Executive Engineers	..	..	..	..	..	..	..	..	3	3	3	3	4	4	3	3	2	2	2	2
3 Assistant Engineers	..	..	..	..	..	..	..	..	..	..	..	..	7	7	6	6	5	5	4	4
4 Supervisors	..	..	..	..	..	..	..	..	47	35	47	33	44	43	43	30	31	24	31	22
5 Manager	..	..	..	..	..	..	..	..	..	..	..	..	1	1	1	..	..	..	..	..
6 Head Clerk (Superintending Engineer's office).	..	..	..	..	..	..	..	..	..	..	..	..	1	1	1	..	..	..	..	..
7 Accountants	..	..	..	..	..	..	..	..	..	..	..	..	3	3	3	2	1	1	1	1
8 Storekeeper (80—4—120)	..	..	..	..	..	..	..	..	1	1	1	1	1	1	1	Nil	1	Nil	..	..
9 Head Clerk, Division Offices	..	..	..	..	..	..	..	..	3	3	3	3	3	3	3	2	1	1	1	1
10 Clerks (60—4—80)	..	..	..	..	..	..	..	..	8	6	8	5	8	5	8	3	3	2	3	3
11 Do. (35—60)	..	..	..	..	..	..	..	..	30	28	30	26	28	23	28	18	14	13	14	13
12 Typists	..	..	..	..	..	..	..	..	5	4	5	4	5	5	3	3	2	2	2	3

Yearwar Statement of Staff employed in Headworks, Cauvery-Mettur Project, against that sanctioned from 1st April 1925 to 1st April 1934.

Serial number and posts	* 1st April 1925.		* 1st April 1926.		* 1st April 1927.		1st April 1928.		1st April 1929.		1st April 1930.		1st April 1931.		1st April 1932.		1st April 1933.		1st April 1934.	
	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.	Number sanctioned.	Number employed.
13 Head Draughtsman	..	..	..	..	..	..	..	..	..	..	..	..	1	1	1	..	..	..	..	..
14 Second Grade Draughtsman	..	..	..	..	..	..	..	..	4	4	4	4	4	4	4	2	1	1	1	1
15 Third Grade Draftsman	..	..	..	..	..	..	..	..	14	9	14	8	14	7	14	5	6	6	6	6
16 Tracers	..	..	..	..	..	..	..	..	5	5	5	4	6	6	5	4	3	3	3	3
17 Attender (20—35)	..	..	..	..	..	..	..	..	..	..	..	..	1	1	1	..	..	..	..	..
18 Peons	..	..	..	..	..	..	..	..	91	79	91	77	92	92	84	63	57	45	56	45
19 Copyists	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20	4	20	20
20 Sub-Assistant Surgeon	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	1	..	..
21 Compounder	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	1	..	..
22 Nursing Orderly	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	1	..	..

* Figures not available.

APPENDIX H

List of Officers who served in the Project.

Consulting Chief Engineer to the Project—

(Sir) C. T. Mullings (*Kt.*, C.I.E.).

Engineers-in-Chief—

(1) (Sir) C. T. Mullings (*Kt.*, C.I.E.).
(2) Mr. V. Hart (C.S.I.), A.M.I.C.E.
(3) ,, F. M. Dowley, M.I.C.E.

Superintending Engineers—

(1) Mr. R. F. Stoney.
(2) M.R.Ry. S. Bhaskara Ayyar (Rao Bahadur), B.A.
(3) ,, N. Swaminatha Ayyar (Diwan Bahadur), B.A., B.E.
(4) Mr. V. Hart (C.S.I.), A.M.I.C.E.
(5) M.R.Ry. R. Narasimha Ayyangar (Diwan Bahadur), B.A., B.E.
(6) ,, G. Ramaswami Ayyar (Rao Bahadur), B.A., B.E.
(7) Mr. W. P. Roberts, M.I.MECH.E., M.I.E. (Ind.).

Superintendent of Works—

Mr. C. G. Barber (C.I.E.), M.B.E., A.C.G.I.

Executive Engineers—

(1) M.R.Ry. R. Narasimha Ayyangar (Diwan Bahadur), B.A., B.E.
(2) Mr. W. P. Roberts, M.I.MECH.E., M.I.E.(Ind.).
(3) ,, F. M. Dowley, M.I.C.E.
(4) ,, A. Vipan, A.C.G.I.
(5) M.R.Ry. N. Parameswaram Pillai (Rao Bahadur), B.A., B.E.
(6) Mr. C. G. Barber (C.I.E.), M.B.E., A.C.G.I.
(7) ,, D. W. Gollan, A.M.I.C.E.
(8) ,, T. I. S. Mackay, B.SC., A.M.I.C.E., M.I. STRUCT. E.
(9) M.R.Ry. L. Venkatakrishna Ayyar (Rao Bahadur), B.A., B.E.
(10) ,, N. Keshava Rao, B.A., B.E.
(11) ,, N. Govindaraja Ayyangar (Rao Bahadur), B.A., B.E.
(12) Mr. H. G. Jackson, B.SC., A.M.I.C.E.
(13) ,, J. Mathai.
(14) M.R.Ry. A. R. Venkata Acharya (Rao Sahib), B.E.
(15) Mr. W. H. Turner, B.SC., A.M.I. MECH.E.

Executive Engineers—cont.

(16) M.R.Ry. R. Mahadeva Ayyar, B.A., B.E.
(17) ,, M. S. Tirumalai Ayyangar, B.E.
(18) ,, T. S. Venkatarama Ayyar, B.E.
(19) ,, N. Padmanabha Ayyar, B.E.
(20) ,, R. S. Rajangam Ayyar, B.A., B.E.
(21) ,, S. V. Kanakasabai Pillai (Rao Sahib).
(22) Mr. L. Henshaw, A.M.I. MECH.E., A.M.I.E.E., A.M.I., STRUCT.E., A.M.I.E.(Ind.).
(23) ,, H. A. Irwin, M.C.
(24) ,, A. H. S. Campbell.
(25) ,, F. T. Learmonth.

Assistant Engineers—

(1) M.R.Ry. M. S. Tirumalai Ayyangar, B.E.
(2) ,, T. S. Venkatarama Ayyar, B.E.
(3) ,, U. S. Ramasundaram, B.E.
(4) ,, T. R. Narasimha Acharya, B.A., B.E.
(5) ,, R. Rajagopala Acharya, B.A., B.E.
(6) ,, S. V. Kanakasabai Pillai (Rao Sahib).
(7) ,, M. B. Krishnaswami Ayyangar.
(8) ,, G. G. Krishna Ayyar.
(9) ,, P. S. Viswanatha Ayyar (Rao Sahib).
(10) ,, S. Ramanuja Acharya, B.A.
(11) ,, Y. Harinarayana.
(12) ,, M. V. Ramaswami Ayyar.
(13) ,, R. Vaidyanatha Ayyar.
(14) ,, N. Sundarasiva Rao.
(15) ,, M. S. Bhaskara Ayyar.
(16) ,, M. S. Srinivasa Rao.
(17) ,, A. Subrahmanya Ayyar.
(18) ,, C. S. Sivarama Ayyar.
(19) ,, K. Venkata Acharlu.
(20) ,, C. Krishna Ayyar.
(21) ,, S. Panchapakesa Ayyar.
(22) ,, P. Srinivasa Ayyar.
(23) Mr. M. Muhammad Sikander Saheb.
(24) M.R.Ry. T. V. Sundaresa Ayyar.
(25) ,, V. Sekhara Menon.
(26) ,, K. S. Nallaperumal Pillai.
(27) ,, T. V. Sesha Ayyar.

Assistant Engineers—cont.

(28) M.R.Ry. G. V. Lakshminarayanayya.
(29) ,, S. Vaidyanatha Ayyar.
(30) ,, S. V. Balasubrahmanya Ayyar.
(31) ,, M. Satyanarayanamurthi.
(32) ,, A. Chidambaram Pillai (Rao Sahib).
(33) ,, P. Ayyaswami Ayyar.
(34) ,, N. Raghunatha Rao.
(35) ,, N. S. Subrahmanya Ayyar.
(36) ,, G. Krishnaswami Ayyar, B.A., B.E.
(37) ,, D. Purnayya, B.A., B.E.
(38) ,, S. R. Gopalan.
(39) ,, M. N. Venkateswaran, B.E.
(40) ,, P. Subrahmanyam.
(41) ,, S. R. Narasimham.
(42) ,, S. Narasimha Kamath (Rao Sahib).
(43) ,, Mr. C. T. D'Silva.
(44) M.R.Ry. V. Radhakrishna Ayyar.
(45) ,, K. S. Viswanatha Ayyar.
(46) ,, V. Setu Sarma.
(47) ,, L. M. Sundaresa Ayyar.
(48) ,, N. Thanikachala Mudaliyar, B.E.
(49) ,, M. N. Kamath.
(50) ,, N. Ramaswami Ayyar.
(51) ,, N. Achuta Menon.
(52) ,, B. R. Somayajulu.

APPENDIX J

SUMMARY OF THE CAPITAL ASPECT OF THE SCHEME AS IT STOOD ON 30 TH SEPTEMBER 1934.

	Provision in the estimate sanctioned in 1928.	Total outlay.			Differences.	
		Expenditure to end of 30th September 1934.	Probable further outlay.	Total.	Excess.	Savings
		RS.	RS.	RS.	RS.	RS
Direct charges Headworks—						
Works alone	3,91,88,000	3,54,38,695	4,20,028	3,58,58,723	..	33,29,277
Special Tools and Plant ..	66,75,000	84,93,195	56,805	85,50,000	9,25,000	..
Receipts by sale of special Tools and Plant.	..	—2,30,013	—7,19,987	—9,50,000		
Losses on stock	..	5,864	2,44,136	2,50,000	2,50,000	
Total, Headworks—" Works "	4,58,63,000	4,37,07,741	982	4,37,08,723	..	21,54,277
Establishment	48,71,500	34,80,992	1,96,464	36,77,456	..	11,94,094
Tools and Plant—Ordinary.	3,44,000	1,97,399	14,417	2,11,816	..	1,32,184
Suspense	75,000	4,33,380	— 4,33,380	..	..	75,000
Receipts and Recoveries on Capital account.	—10,00,000	—9,67,415	— 7,45,380	—17,12,995	..	7,12,995
Total, Direct Charges—Headworks.	5,01,53,500	4,68,52,097	—9,67,097	4,58,85,000	..	42,68,500
Direct Charges—Canals—						
Works alone	1,76,60,100	1,43,00,263	17,79,308	1,60,79,561	..	15,80,539
Special Tools and Plant ..	16,28,000	12,20,530	14,620	12,35,151	..	3,92,849
Receipts by sale of special tools and plant.	..	—1,45,754	—45,106	—1,90,860	..	1,90,860
Losses on stock	..	34	1,105	1,139	1,139	..
Total works—Canals ..	1,92,88,100	1,53,75,073	17,49,927	1,71,25,000	..	21,63,100
Establishment	25,55,400	21,43,019	5,02,609	26,45,608	90,228	..
Tools and plant—Ordinary.	3,47,000	97,458	35,901	1,33,359	..	2,13,641
Suspense	67,000	— 2,167	2,167	..	..	67,000
Receipts and recoveries on capital account.	—1,00,000	—71,267	—69,720	1,40,987	..	40,897
Total, Direct Charges—Canals.	2,21,57,500	1,75,42,116	22,20,804	97,63,000	..	23,94,500
Grand total, Direct Charges.	7,23,11,000	6,43,94,213	12,53,787	6,56,48,000	..	66,63,000
Indirect charges—						
(1) Capitalisation of abatement of land revenue.	8,13,028	4,42,747	6,547	4,49,294	..	3,63,734
(2) Audit and accounts ..	5,66,000	5,61,929	25,160	5,87,089	21,089	..
(3) Leave and pensionary allowances.	17,972	23,617	..	23,617	5,645	..
Total, Indirect charges ..	13,97,000	10,28,293	31,707	10,60,000	..	3,37,000
Grand total, Cauvery-Mettur Project.	7,37,08,000	6,54,22,506	12,85,494	6,67,08,000	..	70,00,000

This statement has since been revised in the final completion report.

APPENDIX K

Statistics relating to the Cost of Anti-malarial and Conservancy Operations.

I. Cost of anti-malarial operations.

Year.	Population.	Staff.	Cost.
			RS.
1927–28 ..	Roughly 10,000	6 Sanitary Inspectors, 5 maistris and 60 coolies.	12,129
1928–29 ..	,, 15,000	Do.	13,222
1929–30 ..	,, 15,000	6 Sanitary Inspectors, 5 maistris and 30 coolies.	13,579
1930–31 ..	15,851	Do.	15,291
1931–32 ..	18,387	6 Sanitary Inspectors, 3 maistris and 30 coolies.	13,125
1932–33 ..	19,136	5 Sanitary Inspectors, 3 maistris and 30 coolies.	12,000
1933 34 ..	15,170	Do.	11,000

II. Conservancy.

Year.	Population.	Staff. Provincial.	Staff. Work-charged.	Cost of staff.	Cost of tools and plant and other expenditure.	Total cost.	Average cost per head per year.
				RS. A. P.	RS. A. P.	RS. A. P.	RS. A. P.
1926	2,900	3 Sanitary Inspectors	3 Sanitary maistris 32 Scavengers	2,532 9 0	2,800 0 0	5,332 9 0	1 14 5
1927	12,000	Do.	6 Maistris 85 Scavengers	12,766 6 0	6,500 0 0	19,266 6 0	1 14 0
1928	15,000	Do.	10 Maistris 100 Scavengers	17,134 13 0	4,353 3 0	21,488 0 0	1 6 11
1929	15,000	Do.	10 Maistris 115 Scavengers	18,756 0 0	4,434 5 6	23,190 5 6	1 8 8
1930	15,851	Do.	10 Maistris 123 Scavengers	20,360 0 0	3,600 0 0	23,960 0 0	1 8 2
1931	18,387	Do.	10 Maistris 123 Scavengers	21,723 0 0	1,028 2 0	22,751 2 0	1 3 6
1932	19,136	Do.	8 Maistris 120 Scavengers	21,175 14 0	1,693 13 0	22,869 11 0	1 3 1
1933	15,170	2 Sanitary Inspectors	8 Maistris 100 Scavengers	18,870 12 0	1,321 3 0	20,191 15 0	1 5 3
1934	12 000	Do.	7 Maistris 100 Scavengers	17,236 12 0 (approximate)	300 0 0 (approximate)	18,536 12 0	1 8 4

III. Anti-malarial measures.

Year.	Population.	Staff. Provincial.	Staff. Work-charged.	Cost of staff.	Cost of larvicides and other expenditure.	Total cost.	Average cost per head per year.
1926	2,900	1 Sanitary Inspector	3 Maistris 32 Coolies	2,563 15 0	6,418 12 0	8,982 11 0	3 1 7
1927	12,000	3 Sanitary Inspectors	6 Maistris 60 Coolies	11,167 5 0	6,521 5 0	17,688 10 0	1 7 7

1928	15,000	Do.	Do.	10,195 15 0	6,440 0 0	16,635 15 0	1 1 9
1929	15,000	Do.	6 Maistries 30 coolies 30 Non-oiling coolies	11,232 0 0	5,344 1 0	16,586 1 0	1 1 9
1930	15,851	Do.	5 Maistris 30 Coolies	8,685 10 0	7,360 0 0	16,045 10 0	1 0 2
1931	18,387	Do.	Do.	6,703 9 0	8,863 0 0	15,566 9 0	0 13 0
1932	19,136	2 Sanitary Inspectors	Do.	6,778 12 0	7,819 15 0	14,598 11 0	0 12 3
1933	15,170	1 Sanitary Inspector	3 Maistris 30 Coolies	6,238 5 0	5,120 0 0	14,358 11 0	0 12 0
1934	12,000	Do.	Do.	6,034 7 0	4,777 8 0	10,811 15 0	0 14 5

IV. Office establishment and small-pox prevention.

Year.	Staff.	Cost of staff. RS.	A.	P.	Cost of equipment. RS.	A.	P.	Total cost. RS.	A.	P.
1926	1 Health officer 1 Vaccinator 1 Clerk 1 Laboratory attendant 2 Peons	4,000	2	0	1,049	11	0	5,049	13	0
1927	1 Health Officer 2 Vaccinators 2 Clerks 1 Laboratory attendant 2 Peons	6,850	0	0	2,412	8	5	6,732	8	5
1928	Do.	6,913	0	0	320	13	0	7,234	7	0
1929	Do.	9,604	0	0	4,792	7	0	14,396	7	0
1930	Do.	7,926	0	0	840	0	0	8,766	0	0
1931	1 Health Officer 2 Vaccinators 1 Clerk 1 Laboratory attendant 2 Peons	8,980	0	0	1,344	3	0	10,324	3	0
1932	Do.	7,690	0	0	1,033	11	0	8,723	11	0
1933	Do.	6,480	0	0	1,431	5	0	7,911	5	0
1934	Do.	4,040 (approximate)	0	0	700	0	0	4,740	0	0

APPENDIX L

List showing the Numbers, Type and Costs of Building in Headworks Camps.

Number of quarters in Mettur Camp.

Mettur Camp.

Engineer-in-Chief's quarters	1
Superintending Engineer's quarters	1
Collector's quarters	1
European Executive Engineer's quarters	5
Indian Executive Engineer's quarters	2
Health Officer's quarters	1
Subdivisional Officer's quarters	16*
Supervisor's quarters	44
Higher Grade Clerk's quarters	66
Lower Grade Clerk's quarters	88
Higher Grade Mechanic's quarters	36
Lower Grade Mechanic's quarters	74
Maistry's quarters	40
Peon's quarters	180
Fitter-mate's quarters	90
Cooly huts	1,000
Scavenger's quarters	40
Additional Foremen's quarters	4
Indian Erector's quarters	2
European Erector's quarters	4
Assistant Surgeon's quarters	1
Senior Sub-Assistant Surgeon's quarters	1
Junior Sub-Assistant Surgeon's quarters	1
Compounder's quarters	3
Midwife's quarters	1
Female Attendant's quarters	3
Male Attendant's quarters	6
Watermen's quarters	2
Thotties' quarters	3

Salem Camp.

Subdivisional Officer's quarters	1
Supervisor's quarters	4
Lower Grade Clerk's quarters	6
Lower Grade Mechanic's quarters	18
Maistry's quarters	24
Peon's quarters	8
Transport Officer's quarters	1
Cooly huts	800
Scavenger's huts	24

* Subdivisional officer's type	8
Foremen's type	4
and Independent supervisor's quarters type	4

STATEMENT SHOWING THE AVERAGE COST OF EACH TYPE OF QUARTERS.

Serial No.	Type of quarters.	Cost.	
		RS.	
	Mettur Camp.		
1	Engineer-in-Chief's quarters	25,141	
2	Collector's quarters	18,926	Average Rs. 19,219
3	Superintending Engineer's quarters	19,512	
4	Executive Engineer's (European type) quarters.	16,122	
5	Executive Engineer's (Indian type) quarters ..	15,960	
6	Subdivisional Officer's quarters	5,426	
7	Foremen's quarters	3,482	
8	Additional Foreman's quarters	3,342	
9	European Erector's quarters	5,004	
10	Indian Erector's quarters	4,058	
11	Health Officer's quarters	6,028	
12	Assistant Surgeon's quarters	5,657	
13	Supervisor's Independent type quarters ..	2,840	
14	Supervisor's Block type quarters	2,519	
15	Higher Grade Clerk's Block type quarters ..	1,599	
16	Higher Grade Clerk's Independent type quarters.	1,538	
17	Sub-Assistant Surgeon's Senior quarters ..	2,522	
18	Sub-Assistant Surgeon's Junior quarters ..	1,727	
19	Sub-Inspector of Police quarters	1,757	
20	Lower Grade Clerk's quarters	1,234	
21	Higher Grade Mechanic's quarters	1,228	
22	Lower Grade Mechanic's quarters	1,151	
23	Maistry's quarters	795	
24	Fitter-mate's quarters	336	
25	Peon's quarters	323	
26	Cooly huts	170	
27	Scavenger's quarters	185	
28	Police constable's quarters	325	
	Combined office buildings.		
1	Combined office—Engineer-in-Chief and Audit Office	59,795	
2	Combined office—3 divisions	16,034	
3	Treasury and Magistrate's Court	8,523	
4	Police Station	3,048	
5	Post Office, quarters for Postmaster, Postmen and mail peon	5,161	
	Hospital buildings	59,870	
	Salem Camp.		
1	Dam Superintendent's quarters	5,895	
2	Erector's (Rest-house) quarters	3,963	
3	Supervisor's quarters	2,569	
4	Lower Grade Clerk's quarters	1,330	
5	Lower Grade Mechanic's quarters	1,821	
6	Transport Officer's quarters	3,939	
7	Maistry's quarters	899	
8	Peon's quarters	348	
9	Cooly huts	202	
10	Scavenger's quarters	208	

APPENDIX M

Glossary of Vernacular and other Irrigation Terms.

Adangal:

The most important of the village accounts containing the accounts of the whole village.

Anicut:

Weir.

—Ar:

Termination or suffix meaning river.

Ayacut:

Area irrigable from the source of supply.

Bothie:

A very small channel conveying water direct to fields.

Canal:

An artificial channel constructed to convey appreciable quantities of water (arbitrary minimum capacity 300 cusecs).

Main (*Canal*).—The principal channel of a canal system offtaking from a river or other sources of supply.

Branch (*Canal*).—A large channel (carrying more than 300 cusecs) taking its supply from a parent canal and supplying water to distributaries.

Cauvery:

The name of the big river in Southern India. Very often this term is used elsewhere as a suffix meaning river (e.g., Narasinga Cauvery).

Crop:

Double (*crop*).—The raising of two successive crops on the same field in one irrigation season (in Tanjore, June to January)—Applied generally in connexion with paddy irrigation. The crop that is first cut is called the " first crop " and the crop harvested later in the season is called " second crop." The term " second-crop lands " is sometimes used loosely instead of " double crop lands."

Dufassal (*crop*).—A crop that takes water for more than six months in the year (sufficient for raising two rice crops).

Long (*crop*).—The term is used generally to denote a crop that takes more than four months to mature. As a relative term, it denotes the longer of the two crops on a double-cropped land, the other crop being called " short crop."

Single (*crop*).—Raising of only one irrigated wet crop in one season. This practice is, of necessity, predominant in the lower reaches of the irrigation systems.

CUSEC:

An abbreviation meaning a flow of one cubic foot of water per second—This is the unit of measurement adopted in India.

CYCLOPEAN MASONRY:

Masonry built with very large stones or boulders embedded in a matrix of lime or cement concrete (ordinarily masonry consists of moderate sized stones set in mortar only).

DISTRIBUTARY:

A channel carrying less than 300 cusecs and supplying water to "minor distributaries" and outlets.

Major (Distributary) or a "Major".—Carrying more than 25 cusecs.

Minor (Distributary) or a "Minor".—Carrying less than 25 cusecs.

DRY CROP:

A crop which is raised entirely with the help of rainfall.

DOUBLE CROP:

Vide "Crop."

DUFASSAL CROP:

Vide "Crop."

DUTY:

Area irrigated by a given quantity of water flowing for a given time (or base). In India the unit of measurement is one cusec and the base period 15 days. (A duty of 73 implies that 73 acres could be irrigated in the particular conditions obtaining in the tract, if a discharge of 1 cusec is maintained for 15 days).

Improvement of (duty).—Increasing the area irrigated—Without increasing the draw-off at the headsluice—by remodelling or otherwise improving the system or by the removal of defects in distribution. The increase in the area effected by the improvements is termed "Extension by improvement of duty."

ERI:

A shallow storage reservoir.

FASLI:

The "revenue year" of the Indian Administration extending from 1st July to 30th June of the next year. (The year of the fasli era is the year of the Christian era less 590).

FIELD CHANNEL:

A channel conveying water to fields. This generally carries less than two cusecs (see also 'bothie').

GOVERNMENT LAND:

Lands for which the revenues are paid to Government direct by the ryots or cultivators. (This term is used to distinguish it from lands held by inamdars or proprietors).

IMPROVEMENT OF DUTY:

See "Duty."

INAM:

A grant of land for religious or charitable purposes—sometimes granted free and sometimes with light quit-rent. This right is transferable.

Major (*inam*).—An inam grant of a whole village or more than one village.

Minor (*inam*).—An inam grant of less than a whole village.

INAMDAR:

The holder of the inam grant.

INAM LAND:

The land granted as inam.

INUNDATION CANAL:

A canal with or without some form of head regulator, and dependent upon the surface level of the water in the main or parent river for its supplies. It follows that such canals will run dry during part of the year.

ITTERI:

A natural drainage course or foot-path in hilly country.

LASCAR:

A member of a gang or crew employed for the operation of regulators or maintenance of canal works.

LONG CROP:

See "Crop."

MAJOR DISTRIBUTARY:

See "Distributary."

MAMUL:

Practice, custom.

MAISTRI:

A member of the inferior establishment who supervises the work of a gang of workers.

MINOR DISTRIBUTARY:

See " istributary."

PADUGAI:

The raised flat margin between a flood bank and the river bed. A padugai is usually submerged only at times of high floods and is often intensively cultivated. Such land is much valued on account of its fertility.

PATTADAR:

An occupancy ryot.

PORAMBOKE:

Land usually adjoining a village site, tank, river margins and the like set aside for public purposes.

RED CEMENT:

Local name for a mixture of four parts portland cement to one part surki (see also surki).

RED CEMENT MORTAR:

A mortar prepared with red cement and sand (vide also Chapter XV, Part II).

RYOT:

Cultivator or worker on the land.

RYOTWARI LAND:

Land held by the ryot paying kist direct to Government.

SECOND CROP:

See 'Crop'.

SINGLE CROP:

See 'Crop'.

SHORT CROP:

See 'Crop'.

SURKI:

Pulverised burnt clay. (Vide also Chapter XV, Part II.)

SURKI MORTAR:

A mortar consisting of surki lime and sand ground together in a mill.

SYPHON:

An inverted syphon in a channel constructed for passing water beneath an obstruction and returning it to approximately the level at which it entered on the other side.

SYPHON AQUEDUCT:

A channel crossing a stream, the latter being syphoned in an aqueduct.

SYRANG OR SERANG:

The headman of a gang of mechanics.

TALUK.

The subdivision of a district for purposes of revenue administration

TANK.

Same as eri, a shallow reservoir.

THATTY:

A screen of split and woven bamboo.

VARI:

A small stream or drainage course, generally dry except during rains.

WATER COURSES:

An irrigation channel taking its supply from a Government channel, from which fields are irrigated directly.

WET CROP:

A crop which depends on irrigation for its growth.

WODDARS:

A migratory tribe of tank-diggers and quarry-labourers. Some distinguished as "cull-woddars" are stone masons. The woddars dwell in small huts made of reeds or leaves and move to any place where they can find employment.

ZAMINDAR:

An officer, who under the Moghuls was charged with the financial superintendence of the lands of a district—since made hereditary and independent.

ZAMINDARI:

The office or jurisdiction of a Zamindar.

List of contractions.

C.S.—Cross section.

H.F.L.—High flood level.

F.R.L.—Full reservoir level.

F.S.L.—Full supply level (or depth) of a canal.

H.S.L.—Half supply level.

L.S.—Chainage along longitudinal section.

M.S.L.—Mean sea level.

M.W.L.—Maximum water level.

R.D.—Reduced distances (unit of 10,000 feet).