Sukkur Barrage Project 1919
Appendices to Report on Proposed Barrage on the Indus at Sukkur Sind

Vol. I

(1920)

Government Document

SUKKUR BARRAGE PROJECT 1919.

PLAN OF BARRAGE

SHOWING

COFFERDAMS AND WORK TO BE DONE IN EACH SEASON

AND

OTHER DETAILS.

EXECUTIVE ENGINEER

SUKKUR BARRAGE PROJECT DISTRICT

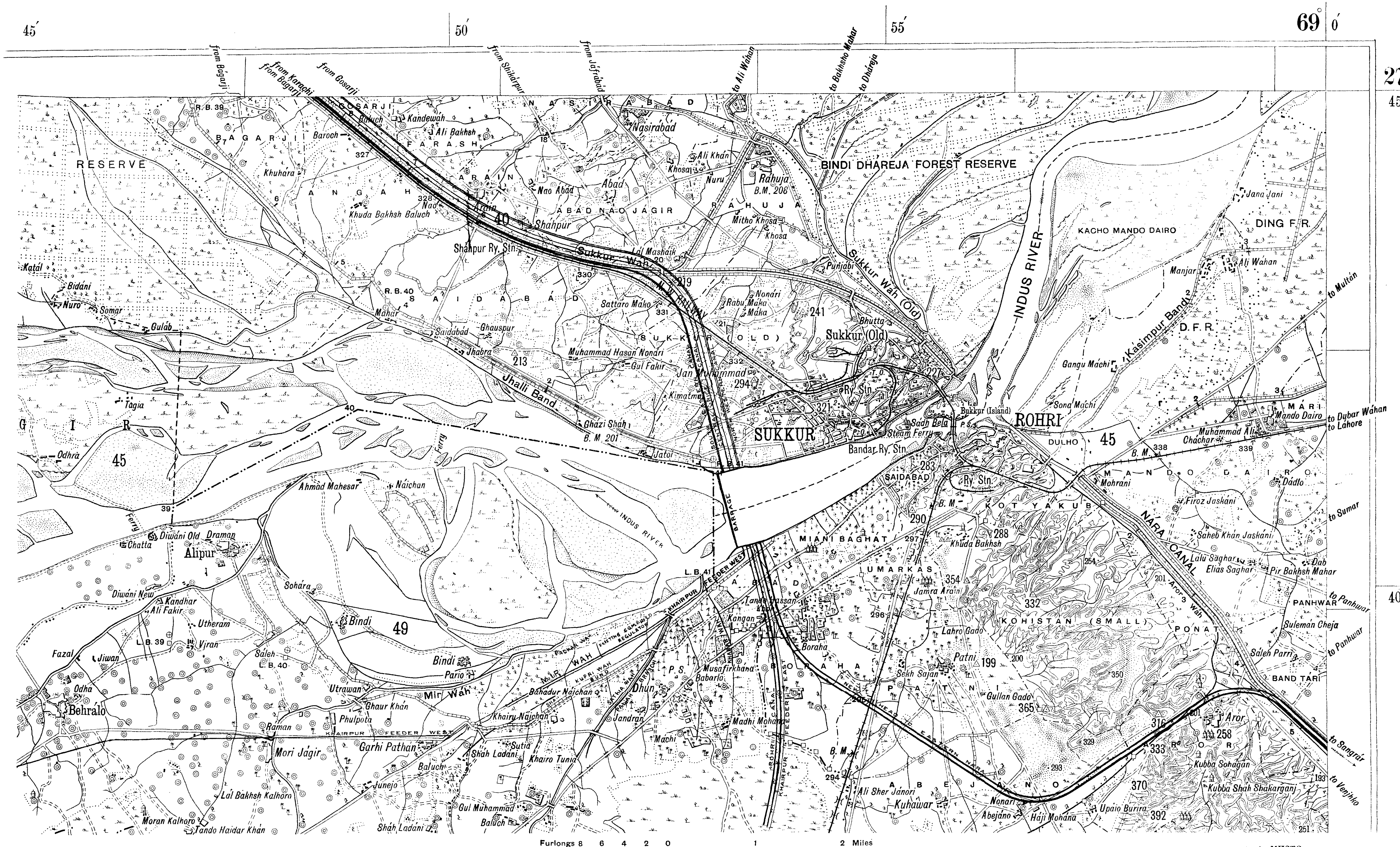
No. 1263/350

SUKKUR BARRAGE PROJECT 1919.

INDEX SHEET

SHOWING

BARRAGE AND HEADS OF PROPOSED CANALS.



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A. A. MUSTO,
Executive Engineer,
Sukkur Barrage Project.
18th October, 1919.

Helio zincographed at Photo-Mechl. and Litho Dept. Thomason College, Roorkee

June, 1920 - No. 350-S 50.

SUKKUR BARRAGE PROJECT
1919.

VOLUME I.

REPORT

ON

PROPOSED BARRAGE ON THE INDUS AT SUKKUR, SIND.

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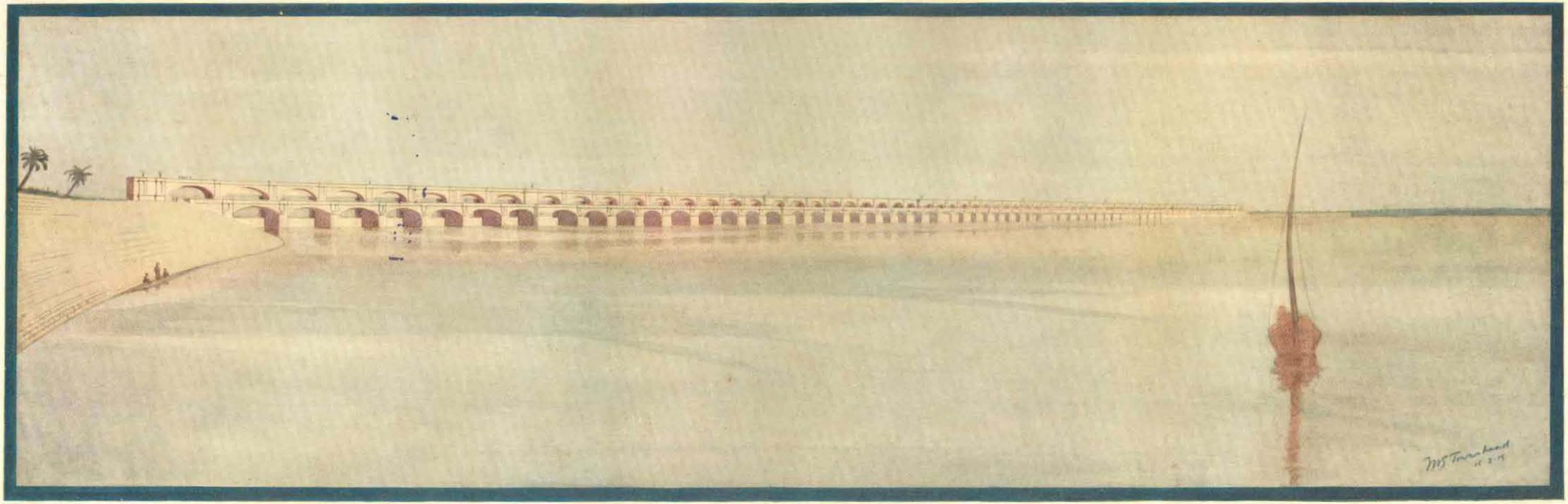

Original Water-Colour Drawing by Captain F. H. E. Townshend, O.B.E., M.C., R.E.

COMBINED RIVER BARRAGE AND ROAD BRIDGE ACROSS THE RIVER INDUS 3 MILES BELOW SUKKUR, SIND, INDIA.

To feed seven new canals for supplying irrigation water to over seven million acres of land in the Province of Sind.

Estimated cost of Barrage, £4,000,000. Cost of whole project, £16,000,000.

Designed by Mr. A. A. Musto, Executive Engineer, Public Works Department, Bombay,
1918-19.

No. 1430 OF 1919.

FROM

A. A. MUSTO, ESQUIRE,

EXECUTIVE ENGINEER,

SUKKUR BARRAGE PROJECT DISTRICT.

TO

THE CHIEF ENGINEER IN SIND,

Office of the Executive Engineer,
Sukkur Barrage Project District,
Karachi, 18*th October* 1919.

SIR,

I have the honour to submit herewith my Report, Plans and Estimates for the Sukkur Barrage Project.

2. The total estimated cost of the work amounts to Rs. 3,41,95,076. Out of this sum Rs. 17,93,343 represents the cost of the Head Regulators of the Canals on the Right Bank, and Rs. 18,53,279, the cost of those for the British Canals on Left Bank, while Rs. 4,49,903 is the cost of the Head Regulators of the Khairpur State Canals. These amounts will eventually be charged directly against their respective canals. A sum of Rs. 19,36,326 represents the cost of the Road-bridge portion of the structure above floor level which may fairly be charged to Provincial, Funds. Deducting all these sums from the total cost of the Project leaves Rs. 2,81,62,224 as the cost of the Barrage, (and buildings, plant, establishment, etc.), to be divided among all the canals in proportion to the areas commanded by each.

3. For comparison I give below corresponding figures of principal heads of the present project and of those of Mr. Beale's 1909 and 1910 (revised) projects.

	Mr. Beale's 1909 project.	Mr. Beale's 1910 (revised) project.	Mr. Musto's 1919 project.
	Rs.	Rs.	Rs.
Total estimated cost	3,23,66,733	2,19,34,767	3,41,95,076
Barrage Proper and Guide Banks Permanent Works	1,28,49,413	1,06,85,256	1,30,99,758
Left Bank Regulators, British	13,70,384	10,71,377	18,53,279
Left Bank Regulators, Khairpur State	....	....	4,49,903
Right Bank Regulators, British	7,02,010	42,740	17,93,343
Plant	45,43,259	32,33,354	55,98,506
Establishment and pension allowance	50,34,459	25,84,047	43,82,176
Service Works	50,56,259	35,73,666	47,46,298
Buildings	1,56,500	1,56,500	10,99,584
Land	1,37,800	76,735	2,96,885

4. The Report is fully indexed, paged and paragraphed for easy reference, and I hope that I have succeeded in making all reasoning and methods clear and easily traceable.

5. The Appendices contain matter for reference with the Report, but are not directly necessary in it. References to the Appendix concerned are made in the body of the Report wherever necessary.

6. The estimates are fully indexed and each estimate contains references to the pages on which its details can be found.

7. The whole of the present project has been prepared at a cost of Rs. 75,000 including all establishment, tools and plant, etc., or for 0·22 per cent. of the estimated cost of the work. This also includes a lot of work and survey for the new canals.

8. In writing my report, and in preparing the project, I have endeavoured to foresee, explain, and provide for, all contingencies in the execution of the work. I have tried to show clearly how every provision is arrived at, and to give sufficient particulars and details, to enable Government to check my estimates and to vary them where considered necessary.

9. The London Committee complained that in the 1910 project, the methods of construction had not been sufficiently investigated, nor had sufficient provision been made for pumping, pile driving, etc. I have gone into all these points fully, and in fact, have worked out many details not mentioned in the Report, which is already unavoidably lengthy.

10. The present project was started by me in October 1915, and from that date till July 1916, when I went on 6 weeks' privilege leave, I was entirely unassisted by any subordinates. During that period my rough outline proposals for the Barrage and Canals were prepared and submitted to Government. On the 1st September, after return from leave, I opened the newly formed Sukkur Barrage Project District and 2 days later handed over charge to Mr. Nazareth, on my transfer to Military duty.

11. Mr. Nazareth held charge of the District from September 1916 to January 1918. During this period practically no progress could be made with the project, as my rough proposals were under the consideration of Government and no orders had been issued until December 1918.

Mr. Nazareth however prepared some rough estimates based on my outline proposals, and also did a good deal of surveying and levelling for an alternative alignment of the Right Bank Canals, which he suggested, but which proved to be unsuitable.

12. In January 1918 I was recalled from Military Duty to complete the Barrage Project. I took up the project in exactly the same state as I left it in 1916.

Mr. Nazareth had obtained the assistance of Mr. Rochiram, Overseer, and of two temporary overseers, one of whom is now in charge of the River gauge reading work.

13. Mr. Rochiram was the only subordinate available to me for field work from January 1918 to December 1918. During this period he carried out a very creditable piece of accurate survey of the river, above and below the gorge, on both banks, besides levelling longitudinal sections and taking many cross sections of both banks of the river for the preparation of the guide bank estimates. From January to May 1919 he was engaged on surveying and levelling for the new heads of the Rohri and Right Bank Canals, and did very useful work. From June 1919 to date he has been employed in my office, assisting in the preparation of the plans and estimates for guide banks, etc. He has done very good work and has been of great assistance to me.

14. In January 1919 after repeated applications for further staff I obtained the services of Mr. Khushaldas, W. S., Supervisor, to complete the survey work for the new canal heads, etc. He was in charge of all surveys from January to May and did very excellent work. Since June he has been attached to my office at Karachi, assisting in the preparation and checking of plans and estimates, on which he has also done good work.

15. Mr. Atmaram, Overseer, has been attached to the District since March 1919 and has assisted Mr. Khushaldas in survey and office work. His work has been satisfactory.

16. On 15th January 1919 Mr. T. S. Mirchandani, Assistant Engineer, joined this district, and was attached for 3 months, until transferred in April to act as Executive Engineer, Nasrat Canals. During that 3 months he gave me great assistance with the canal project but had nothing to do with the Barrage project.

17. In July 1919 Mr. Gokhale, Executive Engineer, joined the district in place of Mr. Mirchandani, and for the past four months has been engaged entirely on the Barrage work. He has checked, and where necessary revised, all my estimates for the work, and has prepared, in consultation with me, the estimates for the annual expenditure. He has prepared, entirely alone, the design and estimates for the reinforced concrete counterweights, and besides checking all my designs, plans, stability diagrams and calculations has prepared several additional diagrams (all those which are signed by him). He has also checked the whole of my Report with Appendices. Mr. Gokhale's very capable and keen work, and his loyal co-operation in pushing through the project, have been invaluable to me.

18. Mr. N. N. Mirchandani, Temporary Engineer, also joined the district in July last and has done very good work in assisting Mr. Gokhale and myself.

19. The tracings have been made by the following subordinates :—

(1) Mr. Atmaram B. M., Temporary Overseer,

(2) ,, Shivram R., Tracer,

(3) ,, Tarachand P., Tracer,

(4) ,, Durga Prasad K., Assistant Draftsman,

(5) ,, Motilal K., Assistant Draftsman,

all of whom have done good work.

20. The following subordinates have been lent by the Chief Engineer in Sind from the Indus River Commission staff and have been employed in preparing, checking and fair copying, estimates for earthwork, etc., and statements of River discharges, etc. :—

(1) Mr. Prabhu D. B., Overseer, since June 1919.

(2) „ Naraindas B. M., Surveyor, since June 1919.

(3) „ Hirasing C. A., Surveyor, since July 1919.

(4) „ Vassumal A., Surveyor, since June 1919.

They have done useful work.

21. The original typing of the report and appendices was very well done by Mr. Kishinchand K. M., typist of my office, and the final copies have been made partly by him and partly by the assistance of—

Mr. Lekhraj M. T., typist of Chief Engineer in Sind's Office,

„ Chetanram A., typist of Superintending Engineer, Indus Left Bank's office,

„ Motumal H. M., typist of Superintending Engineer, Indus Right Bank's office,

who were kindly lent for a few days. They have all worked very hard and well.

22. The total time I have been engaged on these projects amounts to 30 months (October 1915 to July 1916—9 months and January 1918 to October 1919 21 months).

Of this period at least one-third of the time has been spent on the Canal projects, leaving 20 months as the period for preparation of the Barrage Project. Considering the very small staff I have had until the last 4 months, I trust the time is not excessive. I have worked on an average 8 to 9 hours per day including most holidays throughout this period, and have done my utmost to expedite the work. I regret that the submission of the project is three weeks later than I promised it.

23. I might mention that the last project was prepared by a Superintending Engineer with two Assistant Engineers and two permanent subordinates, besides draftsmen and tracers, and was over 2 years in preparation, while the canal projects employed one Superintending Engineer, two Executive Engineers, four Assistant Engineers and twenty-two upper subordinates for an average of 2½ years.

I have the honour to be,

Sir,

Your most obedient servant,

(Signed.) A. A. MUSTO,

Executive Engineer,

Sukkur Barrage Project District.

REPORT

ON

SUKKUR BARRAGE PROJECT, 1919.

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GENERAL OUTLINE OF BARRAGE.

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PART I.

GENERAL OUTLINE.

SECTION I.

Introduction.

1. The full history of these combined projects, forming as they do, one complete project for providing irrigation to an area of about 8,000,000 acres of land in Sind and Khairpur State, is given in Appendix A.

2. It will be sufficient ~~here~~ to deal with the points which affect the present project.

3. Many alternatives have been suggested for almost every portion of the combined projects, at different times in the long period during which previous projects were under consideration.

4. Although many of the suggestions and ideas which were made and elaborated, sometimes at great expenditure of time and trouble, have been abandoned, and the serious defects of some of them are now very apparent, yet the project in its present form, has benefited greatly by the investigations made in connection with these previous proposals, and if the present project should be found to contain less errors than previous ones, it is largely due to the very valuable and thorough investigations embodied in the earlier projects.

5. The Executive Engineer preparing this project wishes to acknowledge with gratitude the immense assistance he has received from the work of his predecessors on these projects, more especially to the very thorough and detailed investigations of Dr. Summers, Mr. Beale and Mr. Hill.

6. Although the writer is sometimes unable to agree with the proposals and deductions of these officers, the difference is in many cases due to lines of thought suggested by these officers themselves, to the advantage the writer has experienced of having their efforts to guide him, and to further data made available since their investigations were made.

7. As Assistant to Mr. Beale on the preparation of the 1909 project for the barrage, the writer obtained an invaluable insight into the details of the scheme, and an interest in its development which he maintained while on other works, until he was finally put in charge of the preparation of the present revised project, after a lapse of 6 years, at the end of 1915. The war caused an unfortunate break in the preparation of the scheme, as the writer was on military service for 16 months, and practically nothing was done during his absence, while owing to the famine and war, until the last few months, it has been very difficult to obtain technical establishment for the work.

SECTION II.

Reasons for preparing this Project.

8. The 1909-10 projects were referred by the Secretary of State for India, to an Advisory Committee of Engineers in London in 1913.

Their report is attached herewith as Appendix B. It will be seen from a perusal of the report, and from its paragraph 29, that the Committee was of opinion that any such project was not justified, as a protective work for Sind, and that it was not shown to be a productive work, *i.e.*, it was not a profitable investment for Government. But in paragraph 33 they recommend that a revised project should be prepared on lines suggested in the report, and be kept in readiness in case it should be found necessary to protect Sind from injury, which might occur due to the withdrawal of water in the Punjab and the North-West Frontier Provinces.

9. Acting on this advice the Secretary of State declined to sanction the execution of the 1909-10 projects.

10. The Government of Bombay discussed the report of the London Committee and the subsequent correspondence of the Government of India, in their letter No. W. I. 10515, Public Works Department, dated Bombay, 23rd September 1915, attached herewith as Appendix C. They showed that although it was difficult to prove any direct effect of the Punjab withdrawals, on the river at Sukkur, there was reason to believe that these might have prejudicial effect at the beginning and end of the kharif irrigation season, and that there was good reason to say that Sind ought to be protected from such a chance by the construction of a barrage.

11. They showed, furthermore, that the canal systems on the Right Bank had equal claims with those on the Left Bank to such protection, and that whereas it might be possible to ensure a supply without a barrage to the comparatively low-lying lands on the Left Bank, it was quite impossible to do this for the higher lands on the Right Bank, and that this fact effectually disposed of any proposal to construct one or both large canals *without* a barrage.

12. Further, the Left Bank canal alone would deprive the Right Bank canals of their fair supply, unless a barrage were constructed at once to give to both banks an assured level both in the kharif and rabi seasons.

13. The Government of Bombay was strongly of opinion that no distinction should be made between the relative importance of securing a good perennial supply to the lands on both the Right Bank and the Left Bank of the Indus.

14. The Governor in Council was convinced that the present conditions of cultivation and irrigation were not suited to the special circumstances of the country, and Sind was crying loudly for the improvements and benefits which the Punjab and the United Provinces had long enjoyed. To regard Sind as an inundation country pure and simple would be to adopt a policy of stagnation, which in these days of enlightenment and awakening prosperity, the Governor in Council was unable to adopt.

15. Government drew attention to the severe rules of the Public Works Department for the classification of a productive work, based solely on the revenue derived from the sale of water. They showed that the true value of irrigation water was invariably much higher than the rate Government deemed advisable to charge for it. They further showed that the proposed rates in Sind, for giving a water supply to a rainless and waterless country, were much lower than those being gladly paid in the Deccan, where some sort of crop can usually be obtained on rainfall alone, and they thought that this comparison suggested the probability of enhanced rates being obtainable in the future in Sind.

16. They emphasized the enormous indirect benefits which would accrue to Sind from an assured supply of water throughout the year, and for every year, on an area of about 5 million acres of culturable land. These benefits would include the increase of agricultural activity, rapid expansion of population and farmyard stock, a vast growth of trade giving rise to new railway lines, and still greater activity at the busy port of Karachi. These were all of such incalculable importance that the Governor in Council was unable to accept the view of the London Committee that perennial irrigation schemes for Sind could only be accepted as desirable, but unessential improvements, which should not be contemplated unless they could be shown to produce at least 4 per cent. net profit from the sale of water alone.

17. The Government of Bombay put forward a rough outline of a revised scheme with the following changes from the one previously submitted, *viz.*:—

(*a*) The inclusion of the Right Bank Canal.

(*b*) A new site for the barrage below the gorge.

(*c*) Possibly a new head to the Eastern Nara Supply Channel from the barrage.

18. They put forward a very rough forecast of the cost of the scheme as Rs. 1,120 lakhs and the revenue as Rs. 63·5 lakhs, with a net return of approximately 5·7 per cent. on the capital cost, and they asked for the sanction of the Government of India to prepare detailed plans and estimates for a scheme on these lines.

19. The letter was accompanied by six notes written by Mr. Beale, Chief Engineer for Irrigation, Bombay, explaining the various proposals and arguments.

20. In reply to this communication the Government of India in their letter, Public Works Department, No. 273-I., dated 10th March 1916, conveyed their sanction to the preparation of detailed plans and estimates for a complete project, including a barrage below the Sukkur Gorge with large canals taking off on the Right Bank and Left Bank of the Indus to provide perennial irrigation for the areas now served by numerous inundation canals.

21. The Government of Bombay accordingly issued orders in their Public Works Department No. E-6085, dated 13th June 1916, for the formation of a temporary executive district in Sind for the preparation of the project. The district was to be styled the Sukkur Barrage Project District with head-quarters at Karachi, and Mr. A. A. Musto, Executive Engineer, was appointed to hold charge of the district. He was already attached to the Chief Engineer in Sind on special duty for this work since October 1915.

22. In January 1918, Mr. Baker, I.C.S., Collector, and Mr. Lane, Executive Engineer, Public Works Department, were placed on special duty with a large staff of Revenue subordinates, to investigate the nature of the lands commanded, and to make recommendations as to the intensities of cultivation, nature of crops, and duties to be adopted in designing the canals. Their report was submitted to Government on the 15th March 1919.

Detailed classified statements of areas commanded were supplied by them to the Executive Engineer, Sukkur Barrage, on the following dates :—

For the Right Bank Canals on 20th February 1919.

For the Rohri Canal on 17th April 1919.

The deh maps showing the location of these areas by survey numbers were supplied by Mr. Lane on 20th July 1919. The deh maps of the Right Bank area are being prepared in this manner ; no special inspection has been made by these officers of the areas coming under the Eastern Nara Project.

23. In the meantime the writer had submitted to Government in June 1916, for approval, a rough outline for the combined project showing how each canal system could be given the necessary water levels and supply and giving a proposed design for the barrage.

24. On my return from Military Duty in January 1918 these proposals were returned to me, with the comments of the Chief Engineer for Irrigation, Bombay, and of the Inspector-General for Irrigation, and with instructions to draw up the detailed plans and estimates for the barrage on the lines suggested.

25. These detailed plans and estimates accompany this report and form the project for the proposed Sukkur Barrage. As will be seen, they embody a very large amount of work, which was done in the original, single handed by the writer, as the only subordinates then available were employed on survey in the field. Recently further staff has been placed at my disposal, and this has been fully

occupied for some months in checking and fair copying these plans and estimates, and in working on the canal projects.

26. The disastrous low inundation of 1918 has provided a most striking proof of the necessity for the barrage, and the zamindars on both banks of the Indus are now said to be most anxious for its construction, in order to protect them from a possible repetition of the losses, famine and hardships, that resulted from the failure of the inundation canals last season.

27. A most instructive note has been written by the Hon'ble Mr. Lawrence, C.S.I., I.C.S., Commissioner in Sind, dealing with this matter, and is attached herewith as Appendix D. Mr. Lawrence shows the immense advantage which would have accrued to Sind and to India in 1918 had the barrage and new canals been in operation. He shows that the benefits in that year alone would have amounted to about £10 millions, a figure which approaches the whole probable cost of the combined projects, so that one or two such years would pay for the whole cost of the scheme.

28. Additional reasons for the project are that with the revised proposals, it is found that—

(*a*) an additional area of over 400,000 acres can be commanded on the Right Bank, much of which has, at present, practically no water supply, and is all first class soil ;

(*b*) it will now be possible to give guaranteed full supply level to the Khairpur Canals. This was not available in the 1909 project ;

(*c*) a great saving can be effected in the cost of the upper portion of the Rohri Canal as compared with the 1909 project ; and

(*d*) it will be possible to give an assured full supply to the Eastern Nara System at all times of the year. This was not provided by the 1909 barrage.

29. All the above points will be fully explained in the projects dealing with each work separately, which combine to form the complete scheme now proposed. They will also be referred to later in this project, when describing the design of the Barrage. (See Section VII, paragraphs 48 to 68.)

SECTION III.

Scope of the Combined Projects.

30. The present combined projects, of which the barrage project now submitted forms only one part, comprise the following works :—

(*a*) The barrage across the Indus.

(*b*) A system of large canals on the Right Bank of the river to irrigate the whole area it is possible to command. Some of these canals will be perennial and others will flow in the kharif season only.

(*c*) Two separate canals on the Left Bank of the river to irrigate the lands of Khairpur State.

(d) The Rohri Canal on the Left Bank to extend, and substitute for the present inundation canals system, a modern perennial system with an assured supply.

(e) A new head to the supply channel to the Eastern Nara River feeding the Jamrao Canal and the Eastern Nara Canals system. This will ensure a perennial full supply for the Jamrao Canal and for the eventual development of the other canals of the Eastern Nara system requiring perennial water, and an increased and assured supply in the kharif season to other tracts of the Eastern Nara system which do not require rabi water.

SECTION IV.

Works included in this Report.

31. I. *The Barrage proper.*—This consists of a wide masonry floor, with top at R. L. 176·0 founded on the sand of the river bed, and protected by aprons of concrete blocks and stone pitching, and by curtains of steel sheet piling driven below the floor and embedded in its under side. On this masonry floor will be stout masonry piers at clear spans of 60′ supporting, side by side, two separate masonry arched bridges. The upstream bridge will be at a high level, and will consist of two separate arches, one 8′ wide and the other 5′ wide, with a gap of 16′ between them in which the gates and counterweights will hang. It will carry the supporting pulleys and the operating machinery for Stoney gates of 60′ clear span, which lowered, will close the openings between the piers, and head up the river to the required level. These gates will be balanced by counterweights. The height of the gates being 18·5′ it will be possible to head up water to R. L. 194·5 at all times, and this will give the required depth of water in the canals. The downstream bridge will consist of a masonry arch, 25′ wide, springing at high flood level, and carrying a 16′ roadway, and footpaths for ordinary traffic crossing the river.

II. *Canal Head Regulators.*—See Drawing Nos. 60 and 4.

(a) *On the Left Bank* there will be canal head regulators for the following canals, counting upstream from the barrage, *viz.* :—

(1) Khairpur feeder west, 2 spans of 25′ clear.

(2) Rohri Canal, 10 „ 25′ „

(3) Khairpur feeder east, 2 „ 25′ „

(4) Eastern Nara Supply Channel, 12 spans of 25′ clear.

(5) These regulators will be connected to each other and to the barrage by masonry river walls joining their abutments and supporting the earthen banks of the canals behind.

(6) At the upstream end of the Eastern Nara Regulator will be a masonry wing wall, forming a terminal retaining wall for the end of stone-pitched upstream guide bank, which commences at the abutment of this regulator.

(*b*) *On the Right Bank* there will be canal head regulators for the following canals, counting upstream from the barrage, *viz.* :—

(1) South-Eastern Canal, 4 spans of 25′ clear.

(2) Central Rice Canal, 10 „ 25′ „

(3) North-Western Canal, 5 „ 25′ „

(4) As on the Left Bank there will be masonry connecting walls between these regulators, and between the South-Eastern Canal and the barrage.

(5) There will also be a masonry wing wall at the upstream end of the North-Western Canal at the connection with the stone-pitched upstream guide bank.

III. *Guide Banks*—

(*a*) *On the Left Bank* there is a guide bank upstream of the canal regulators. This consists of an earthen bank with 25′ top width, and slopes of 2 to 1 and 1½ to 1 on the land and river sides respectively. The top of bank is to be made 2′ above the estimated highest flood level or about 5′ above the highest recorded flood, except near the regulators where it slopes up to meet the roadway over regulators. The top of bank will be used as a main road for access between barrage and Rohri. The river-side slope is protected with stone-pitching down to low-water level, and from this point an apron of loose stone, 50′wide, is laid on the river bed or at low-water level. The contents of this will fall as scour occurs and will thus form a pitched slope below water.

This bank will continue upstream for a length of about 9,100′ at which point the river bank is already protected with stone-pitching. From here upstream for another 5,400′ the bank will be continued along the edge of river bank but without stone apron. The bank here is merely needed for retaining highest estimated flood, not for protection against scour, as the river bed here is rock.

(*b*) *On the Right Bank* there is a protected guide bank upstream of the regulators similar to that on the Left Bank. This runs for about 4,540′ until it meets the existing masonry bunder wall. The latter will be raised in height an average of about 3 feet for a distance of 8,400′ nearly up to the railway bridge, beyond which point it is already high enough to exclude the highest estimated flood.

(*c*) On the downstream side of barrage there are curved splayed guide banks on each bank, 1,000′ long, curving out to meet the natural river banks. These guide banks are each protected on the riverside slope with stone-pitching and with an apron of loose stone 50′ wide.

Section V.

The new site for the Barrage.

32. In accordance with the suggestions made in paragraphs 34 to 37 of the London Committee's report (see Appendix B.) the course of the river below the Sukkur gorges has been carefully examined to find a suitable site for the barrage.

33. After careful consideration a site about 3 miles below the Landsdowne Bridge has been selected and approved by the Government of Bombay.

34. The reasons leading to the selection of this site were as follows :—

(*a*) The stretch of river between the site and the Bukkur gorges has maintained its banks, practically unaltered for as many years as surveys are available. A survey made in 1876 shows the banks of the river in this section to be practically the same as at present.

(*b*) The width of the river at the site selected is sufficient to enable the requisite waterway to be given through the barrage, without having to go to an excessive depth for the floor.

(*c*) A barrage at this site will have no tendency to obstruct or alter the natural conditions of the river above the gorges during floods, and hence introduces no danger of an avulsion above the gorge.

(*d*) At any point higher upstream the width is insufficient for the barrage, and below the site the river begins to swing from side to side through less clearly defined banks and would necessitate much heavier training works.

(*e*) The position of the Right and Left Bank Canal heads at this site is about 3 miles nearer their commanded areas and the new heads for Rohri and Khairpur Canals avoid the heavy rock cutting through Rohri.

Similarly the new head for the Eastern Nara Supply Channel, although longer by 4 miles than the existing head, will be entirely through soil, and will avoid the difficult and expensive widening through the rocky portion up to the 4th mile of the existing head, where the new head will meet it. The existing supply channel below this junction point is all in soil, and there will be no rock cutting in the widening.

(*f*) The site is sufficiently far from the gorges for the river water to have settled to a steady flow, while the velocity is comparatively low, so that surface water will not be surcharged with an abnormal quantity of silt.

(*g*) No rock is met with anywhere on the site for a great depth, so that the barrage and regulators can be designed throughout to be founded on sand (or silt) on principles well understood, and eliminating the uncertainty of foundations in doubtful rock.

(*h*) The barrage can have a straight alignment normal to the centre line of the river, which flows to it on a gentle curve for a distance of 2½ miles.

35. At the site selected, gauges have been fixed on either bank and the cross section of the river on this line is now measured weekly, on the same day that a cross section and discharge observation is taken at the Outfall Section about 6,100′ above.

Plans Nos. 3 and 40 show the position of the proposed Barrage Section and the Outfall Section. The cross sections at barrage site are plotted on plans Nos. 34 to 38. On each section is shown the actual area of the waterway on that date, and also the clear waterway available through the barrage at the same water level.

SECTION VI.

Effect on the River of the Works.

36. This matter has been very carefully investigated in " A Note on the Surface and Bed Levels of the River Indus at Sukkur during great floods, and the estimated afflux due to barrage " attached to this report as Appendix E.

37. The highest water level ever recorded at Sukkur on the Bukkur gauge gave a gauge reading of 17·9 on 28th and 29th August 1897 equivalent to water surface R. L. 202·34 (zero of Bukkur gauge being R. L. 184·44), but the discharge of the river on that date is not known as discharge observations were not commenced till March 1901.

Since the latter date the highest river recorded was on August 3 and 4, 1914, when Bukkur read 17·4, equivalent to water level R. L. 201·84.

The greatest discharge ever recorded at Sukkur Outfall Section was 949,000 cusecs on 1st August 1914 when Bukkur read 17·0, or water surface R. L. 201·44.

38. It has been decided (see paragraph 1 of Appendix E) to assume for the design of the barrage that a flood of 1,500,000 cusecs might occur, passing Bukkur at a level of R. L. 205·0, or 2·66′ higher than the highest recorded flood.

39. Paragraphs 3 to 28, Appendix E, explain how the water level and bed level at Outfall and Barrage Sections for this assumed flood of 1,500,000 cusecs have been deduced.

40. Paragraphs 29 to 31 of Appendix E show the effect of introducing into the tapered river channel, the barrage floor and the parallel throat formed by the canal regulators on either side.

41. Paragraph 32 of the Appendix E gives the calculations for afflux due to the barrage piers, and paragraph 33 shows the total effect of the barrage works.

These are found to give an afflux of 0·99, or say 1 foot at the barrage for the assumed flood of 1,500,000 cusecs. The backwater effect of this afflux would be very slight at the Outfall Section and probably would not raise the water level there more than 4 or 5 inches, and the effect would probably disappear altogether at Bukkur.

42. The barrage would therefore have little or no effect even in the greatest floods on the level of the river above the gorge.

43. Plan No. 39 shows the following cross sections at barrage site, being maxima and minima sections during the period of observations, *viz.*, 1917, 1918, 1919:—

(*a*) Maximum section below datum, *i.e.*, the sections with lowest average bed level in the hot and cold seasons respectively.

(*b*) Maximum waterway sections in hot and cold weathers respectively.

(*c*) Minimum sections below datum, *i.e.*, sections with highest average bed levels in hot and cold weathers respectively.

(*d*) Minimum waterway sections in hot and cold weathers respectively.

On each section is shown the proposed barrage floor at R. L. 176 and the clear waterway available through the barrage with the water level shown on the section.

44. It will be seen from these sections that the proposed floor level is considerably lower than the lowest average bed level recorded, so that there seems no reason why the barrage should interfere in any way with the flow through the gorge, and through the river below. The deep channels usually scoured in the river downstream of the gorge, in the flood season, gradually spread out into a more or less even section long before they reach the barrage site, and it is only in the cold weather, when the discharge is low, that defined deep channels are made on either bank at the barrage site. As the floods rise, the bed in the centre of the river is scoured out, and the side channels fill up, probably with silt waves rolled from the gorge. The barrage floor gives a lower average bed right across the stream, than naturally forms, so that it should not interfere in any way with the scouring out of the gorge. On the contrary, at the beginning of the floods the water will have an easier channel at the barrage site, and by manipulating the gates at any point desired in the width of the stream, it will be possible to induce scour at that point, and to train the river streams accordingly.

45. Since the present river banks have remained practically unchanged for, at least, the 40 years for which records are available, and the barrage will have no tendency to make its action less steady, on the contrary will tend to steady it by giving a constant level bed throughout the floods, there is no reason why the banks between Bukkur and the barrage should tend to change, or need to do so.

The river has evidently cut for itself a channel which acts as a permanent diverging mouthpiece, or Venturi neck, for distributing the confined streams issuing from the gorges and between the rocky bluffs below the gorge.

46. It is proposed therefore to dress these banks to the regular curves to which they now approximate and to protect them from erosion with stone pitched slopes, and with an apron of loose stone laid along the toe of the slope, which apron will settle down into any channel that may be scoured along the bank and thus extend the pitched slope down to the lowest point scoured.

We shall thus obtain a permanently protected channel of the same form as the river has made for itself, and found to meet its needs for so many years.

47. It is only when the discharge of the river has been much reduced, and the level is lower than that needed for irrigation, that the barrage will alter the natural conditions of the river. As soon as this condition is reached some or all of the gates (usually all of them) will be partially closed so as to head up the river to the required level. As the natural river level falls, the gates will be more and more closed, so as to always maintain the level required for the canals. This level will be about 193·5 for the greater part of the year and during the hot months the Eastern Nara may require water to be held up to the top of the gates, *viz.*, R. L. 194·5. Whenever there is a large surplus river discharge to pass the barrage, it will be possible by raising all the gates by an equal amount to head up water still higher, but this will probably not be required. This point will be dealt with more fully in a later paragraph.

SECTION VII.

Canal Supply.

48. The barrage enables water to be headed up in the river to a sufficient level at all times of the year to give the required levels in the canals.

49. The average monthly river discharge will always be greater than the final requirements of all canals combined, after full estimated development of cultivation has been attained (see statement No. I, Appendix M).

50. On a few days during many years recorded, the discharge of the river has fallen below the total requirements of the canals, but these very low discharges occur very seldom, at long intervals, and never remain at these low figures for more than a few days at a time. Even if there were no compensating features nor any reservoir capacity on which to draw, the effect of these occasional days on the canals would be negligible. The deficiency is so small that it would make a very small difference in the level of the river with all barrage gates closed, and only a small reduction in discharge in all canals fully open ; but if necessary it would always be possible to close one or more canals in rotation, for one or two days, and thereby give full level and supply to the others. This is never likely to be necessary for the following reasons.

51. These occasional days of deficiency occur only in the rabi season, when the level required by the canals is not more than 193·5 in the river. Arrangements will be made to measure the river discharge, say twice a week, as at present at a convenient point above the barrage. As soon as there is any sign of the discharge falling very low, the barrage gates would be fully closed and water headed up to the top of them, *viz.*, R. L. 194·5, thus giving one foot depth of water in the river greater than required for the canals. At such a stage of the river the backwater effect of the barrage will reach about 30 miles upstream. The average width of the water surface may be taken as at least 4,000′ including backwaters so that a reservoir capacity of $4{,}000 \times 30 \times 5{,}280 = 633{,}600{,}000$ cubic feet is available to draw from, to make good the deficiency, before the level required for the canals is affected at all. If the deficiency of river discharge amounted to 3,000 cusecs, this could be met from the reservoir capacity for 2½ days, or a deficiency of 2,000 cusecs could be met for 3¾ days, or a deficiency of 1,000 cusecs for 7½ days.

In the worst year on record (out of 18 years) the deficiency was less than 3,000 cusecs for 2 days and about 600 cusecs for a further 5 days, so that the reservoir could almost have met this deficiency, without the canals suffering in any way.

52. Moreover, if experience shows that any real deficiency may occur to the canals, there is a further reservoir area which could always be utilised. The maximum rabi demand of all canals combined, includes that for the fully developed Eastern Nara System. This development of the Eastern Nara System includes the provision of containing banks on either side of the Nara River and the prevention of the present huge outflow of water from it, during the inundation season, into the numerous large "Sangs" which adjoin it. If necessary these sangs could be filled up through sluice heads, during the months of October and November, when there is always a large surplus of discharge in the river, and the water thus impounded could be let back into the Nara in days of deficient supply in the river, and thus save part, or the whole, of the discharge for this system, from the river, during such days. The final requirements of the Eastern Nara System in October when fully developed will be over 5,000 cusecs less than the full kharif supply, so all this quantity could be passed down to fill up the reservoir area in the "Sangs."

53. It is evident however that in months of smallest discharge these canals will extract the major portion of the river supply and there will be only a small surplus to pass below the barrage. This may affect the discharge and level of the river at Kotri, and of the Fuleli Canal, but it is almost impossible to say to what extent.

54. The length of the river between Sukkur and Kotri is about 300 miles so that its channel, with all the backwaters, forms an immense reservoir draining towards Kotri.

55. It is seen from the records (see statement No. III, Appendix M) that the discharge at Kotri, during the cold weather months, is almost invariably greater than at Sukkur, and this can only be due to water flowing back into the main stream from the backwaters, as the river level falls, and perhaps slightly assisted by seepage. In months when the surplus discharge passing the barrage is fairly large, some of these backwaters would be filled up, and when the surplus is much reduced, they would return their contents to the main stream.

As the periods of very small surplus never last for long, it may be assumed that in most years these backwaters would be re-filled at short intervals and would thus maintain a fairly good supply to Kotri. But in years of unusually small discharge at Sukkur, such as 1903 and 1917 there can be no doubt that the large withdrawals at Sukkur will affect the discharge at Kotri.

56. The Fuleli Canal is the only one below Sukkur which now gets any supply during the cold weather. The discharge in the river under the worst conditions possible after the construction of the Sukkur Barrage would be far more than the present cold weather supply of the Fuleli (usually less than 2,000 cusecs), but the level of the water in the river and in the canal (and therewith its discharge) might be prejudicially affected.

57. But an inspection of the past records of gauge readings and discharges at Kotri for low discharges in the cold weather, shows an even more marked lack of connection between river levels and river discharges than at Sukkur (see statement No. II, Appendix M).

58. Thus (a) on 29th March 1902 with a discharge of 24,882 cusecs the gauge read only 2·9, while on 17th March 1903 with a discharge of only 19,772 cusecs the gauge was 3·7, or ·8 feet higher.

(b) Again, on 13th March 1900 with discharge of 31,313 cusecs the gauge was only 3·8′ while on 8th February 1906 with practically the same discharge—31,557—the gauge was 6·0, or 2·2′ higher.

(c) Again, comparing the discharges on 10th April 1917 (the minimum discharge ever recorded at Kotri) with that on 29th March 1902 (the minimum gauge reading recorded at Kotri) we see that on the latter date a discharge of 24,882 cusecs passed with a gauge reading of 2·9, while on the former date a discharge of only 17,353 cusecs, or 7,500 cusecs less, passed with the gauge reading 4·5, or 1·6′ higher.

59. Similar, but less marked, variations are found in any one season.

Thus on 30th January 1902 with gauge reading 4·4 the discharge was only 26,405 while on 8th March 1902 (five weeks later) the discharge was 32,108 with gauge reading only 3·5, *i.e.*, ·9 feet lower.

60. Thus it appears that the surface level of the river does not depend very much on the discharge, but more probably on the shape and length of the river in the vicinity of Kotri at the time.

61. The records show, moreover, that the river level at Kotri for similar discharges is steadily rising, so that small discharges are now passed at the same level as much larger discharges were passed years ago. This is probably due to the gradual raising of the river bed due to the extension of the delta and thereby the flattening of the hydraulic gradient of the stream, and to the retention of silt in the river channel, caused by the construction of river bunds.

62. Hence although the proposed withdrawals at Sukkur in the cold weather, in years of small discharge, would probably reduce the discharge at Kotri considerably, yet they may not have much effect on the level of the river at Kotri, and if they do not, then they will not affect adversely the discharge of the Fuleli Canal. Experience alone will show how far these assumptions may be true. If they are not approximately correct, then it must be conceded that any scheme of perennial canals taking off at Sukkur might prejudicially affect the Fuleli rabi supply, and that to protect this another barrage below it might be necessary. Such action has not been seriously considered hitherto, and it appears unnecessary to do so until some definite proofs of the effect of the barrage are available. This can only be after construction of the latter. As it will be a good many years before the full rabi development and water demand is reached, there will be sufficient time to study the matter after construction of the barrage.

63. Statement IV, Appendix M, shows the cold weather discharge of the Fuleli and the Kotri discharges and gauge readings for the past 16 years, from

which it will be seen that in some years the Fuleli ceases to flow altogether, and is usually less than 2,000 cusecs during these months.

64. Returning now to the supply for the proposed new canals, these may be dealt with seriatim.

65. *Rohri Canal.*—It is proposed to fix the F. S. L. of this canal at R. L. 193·0 requiring R. L. 193·5 in the river. This river level can be maintained by the barrage at any time throughout the year, as it is one foot lower than the top of the gates. The proposed F. S. L. is higher than necessary for supplying the lands originally included in the command of this canal, but the raised level has the following great advantages :—

(*a*) It reduces the very heavy cutting by about 3½ feet from the head to mile 16 of the canal, at which point, a fall will be given to bring the F. S. L. down to the same level as proposed in 1909.

(*b*) It reduces the height of the regulator gates, as these have to reach above H. F. L. of the river, whatever may be the F. S. L. of the canal, while the cill level can be raised with the raised bed of canal.

(*c*) It is required for supplying a small branch proposed to be made to replace the existing tail of the Arorwah commanding about 40,000 acres of good land, the supply of which will be cut off by the new head to the Eastern Nara Supply Channel, the level in which will be lower in the rabi season than that of the Rohri Canal.

66. *Khairpur Feeders, East and West.*—It is proposed to fix the F. S. L. of these two canals at R. L. 193·5 requiring 194·0 in the river. This river level can be maintained by the barrage at any time throughout the year.

The proposed F. S. L. gives to the existing systems of canals a guaranteed level which at present they can only obtain when Bukkur reads 11·5′, a level which frequently is only attained by the river for a few days in the year.

In the 1909 Projects, Dr. Summers allowed them a F. S. L. equivalent to 10·3 on the Bukkur Gauge, and this too, dependent on a *natural* river of that height, since the 1909 Barrage only headed up water to 7·56 on Bukkur (R. L. 192).

Hence the 1909 Barrage afforded no protection to the Khairpur Canals and in the critical months at the beginning and end of the kharif season, the river is often much below the required level of 10·3 on Bukkur.

Thus the proposed guaranteed F. S. L. is nearly 4 feet higher than could have been guaranteed by the 1909 Barrage, and is 2·2 feet higher than the designed F. S. L. in 1909 and which could not be guaranteed.

It is found from the gauge readings on the existing combined head Regulator of the State Canals that they usually begin to cut off water when the downstream gauge thereon reads 12·5′ = R. L. 193·1.

The proposed F. S. L. will give a level of R. L. 193·0 at this point, showing that it is just what is needed. In the case of the East Feeder there is a slight further gain of head to the point where it joins the Mirwah at Khairpur, owing to the shorter length and better gradient of the new channel as compared with the existing canal.

The present proposals give a guaranteed F. S. L. whenever required. A perennial supply is not provided for these canals, as it was not desired by the State Authorities in 1909, and the State at present has no rabi supply. There is in fact no surplus rabi water available in bad years, but heavy bosi waterings could be given in the month of October or November and for rice crops early waterings could be given in April and May. At present their canals are never opened till June. The State therefore benefits greatly by the present proposals as compared with those of 1909.

Statement No. V, Appendix M, shows the recorded measured discharges of the State Canals from 1905-06 to 1918 ; these have been measured through the courtesy of His Highness the Mir of Khairpur, to provide the necessary data for design of the new canals.

67. *The Eastern Nara System with the Jamrao.*

(*a*) The supply to this system presents a somewhat difficult problem chiefly owing to the very little information available about the state of the Nara river, which is used in a length of about 135 miles as a supply channel for the canals of this system.

(*b*) It is necessary first to explain the proposals made for this system in the 1909 project.

It was proposed to make containing banks on either side of the Nara River throughout this 135 miles of its length so as to prevent its discharge from being wasted at high levels into the numerous " Sangs " past which it flows. In other words it was to be roughly canalized. These proposals remain unaltered in the present project.

(*c*) At present the discharge admitted at the head of the Eastern Nara Supply Channel is sometimes in the kharif season as great as 27,000 cusecs, but out of this quantity not more than about 8,000 to 9,000 cusecs is ever utilized in the canals, the remainder running to waste, in the sangs, or down the Nara River to the Puran Dhoro and eventually to the sea, but most of it goes into the sangs.

(*d*) The 1909 project further provided for remodelling the Mithrao Canal, for the construction of a new Khipro Canal and for several smaller works. The combined discharge required for all these works, including evaporation and absorption losses, was estimated to be 13,500 cusecs.

(*e*) It was calculated and deduced from measured discharges of the existing channel, that this discharge was passed with a gauge reading 18·5, *i.e.*, R. L. 195·3 on the regulator near the head of the Nara Supply Channel (paragraph 11, Volume 7, 1909 Projects). This level is obtained at the regulator when the Bukkur gauge reads about 11 feet=R. L. 195·44 (paragraph 12, Volume 7, 1909 Projects) and it was stated that this level could usually be expected in the river from the 15th June to the end of September, but this is not so (see later).

The top of the barrage gates as designed in the 1909 projects being at R. L. 192 only, this barrage could not have given the level required for the Nara, so that the latter remained an unprotected canal, dependent on a natural river of not less than 11 feet on Bukkur.

(*f*) If the tables of gauge readings at Bukkur (Appendix F) are examined it will be seen that in the past 20 years,1899 to 1918,there were only 28 months during which the river was maintained at, or about, 11′ on most days during the month. In the remaining 52 months of the kharif season during those years, the river fell below 11′, often to a very considerable extent, for a large number of days in each month. In 1918 the river only reached 11′ on Bukkur for 11 days in the whole season (15th June to 30th September) 9 of those days being at the very beginning of the season, while the average monthly gauge readings were as follows :—

	Average gauge reading.	Average deficiency for 1909 project.
June (15th to 30th)	10·84	0·16
July	8·64	2·36
August	9·10	1·90
September	7·90	3·10

and the 1909 barrage gave only the equivalent of 7·56 on Bukkur so it would have given no assistance. Thus the 1909 project cannot be considered to have provided a satisfactory supply for the Nara System.

(*g*) A proposal to widen the Nara Supply Channel to 218′ bed width (present width about 140′) was discussed briefly in paragraph 11, Volume 7 of the 1909 Project, but was ruled out by the Chief Engineer for Irrigation (Mr. Hill) as unnecessary. No details of the proposed changes in F. S. L. due to this widening are given in the report, but in the project drawings, the F. S. L. both without widening and with widening are drawn on the longitudinal sections, though no figures are given for the latter case.

(*h*) It is seen from these sections that *without* widening, the proposed F. S. L. and surface gradient was practically the same throughout the supply channel and the Nara River, as the actual observed water levels for a similar discharge. This appears quite correct. But when the supply channel, *i.e.*, a length of 12 miles out of a total of 105 miles to Jamrao, was to be widened to 218, the surface level for the same discharge was lowered 5 feet at the head, and the hydraulic gradient flattened throughout, so as to give the same surface level as before at the 60th mile from the head.

(i) At the 12th mile, where widening ceased, this gave a water level 4·4′ lower than the observed actual water level for such a discharge, this difference gradually dying out to nothing at the 60th mile. Hence it is obvious that some alteration, either widening or deepening, was needed in the Nára River up to the 60th mile.

(j) No mention is made anywhere in the project of such deepening or improvement beyond the 12th mile. It seems to have been assumed that all that was necessary was to widen and deepen the first 12 miles (the Supply Channel) and that as the required supply could then be passed through that portion with 5′ less depth at head, this discharge would find its way down the Nara River at the lower level. Such an assumption does not appear to be justified, and deepening throughout the first 60 miles would seem to have been necessary.

(k) If, however, it is considered that this was *not* necessary, the problem of supply is very much simplified as will be seen later.

(l) Returning now to the present proposals, the method of fixing the required F, S. L. may be explained.—

Gauge readings have been recorded in the 12th mile of the Eastern Nara Supply Channel and on the head regulator since 1872 while discharges at the head of the Nara have been measured since 1905. These show that similar discharges are passed at the 12th mile with very different gauge readings, and the tendency is for a higher level to be necessary at the 12th mile in recent years, to pass a given discharge, as compared with earlier years. This may be due to two causes, *viz.*, side groyning of stone in the supply channel, and deposition of silt in the Eastern Nara and the supply Channel caused by the heading up of water when large Ghotki floods entered the channel in past years.

(m) For purposes of estimating the level required at 12th mile to pass a given discharge, the lowest levels hitherto recorded for such a discharge are adopted, it being assumed that if the channel has at one time taken the given discharge at such a level, it can do so again, or if not, that only light repairs or improvements will be required to bring the channel back to its original state.

(n) The total estimated discharge which will be required after full development of irrigation on all canals of the system (to be described in the separate canal project for this system) is 12,000 cusecs including losses *en route*.

(o) Now in 1914 a discharge of 12,000 cusecs could be passed at the 12th mile with water level 189·3.—

The distance of the 12th mile gauge from the new head at the barrage is 80,250′. The new head and the widened supply channel will be given a gradient of 1 in 16,400 (bed width 350′). Hence the water level required at the new head of the channel is 194·2. Allowing for ·3 loss of head in the regulator (designed accordingly) we require R. L. 194·5 in the river, which can just be given at any time by the barrage, the top of whose gates is at this level.

(*p*) As there is a fall of 85′ in the 93 miles of the Nara River from 12th mile to Jamrao head, or an average slope of 1 in 5,800 only, and the section is in most places very wide, there can be no doubt that it is possible to carry the required supply to the Jamrao by removal of bars if necessary.

(*q*) The conditions assumed in this report for the new supply to this channel, with F. S. L. 194·2 at the head, give a resulting supply below the 12th mile, at exactly the same level as has actually occurred with such a discharge, and hence with these conditions no alterations or improvements to the channel should be needed below the 12th mile. These conditions represent the worst possible case and as has been shown, the barrage is able to meet this case.

(*r*) Considering however the great fall which is available below the 12th mile it seems probable that it will be more economical to make some improvements in the Nara River below the 12th mile, probably by removal of bars across the bed, and by this means to lower the water level at the 12th mile. Any reduction in this level will enable a steeper gradient, and narrower (and therefore cheaper) channel to be used for the new head and existing channel up to the present 12th mile. This matter will be carefully gone into in the detailed project for this system. The proposals outlined in this report represent the worst case as regards water level required and size of channel, and these are merely tentative suggestions to show that it is possible to give the required supply from the barrage as now designed.

(*s*) For this reason, and similar reasons in the case of other canals, I should have preferred to submit this report after the complete projects for all canals had been elaborated, so that final proposals could be discussed, but, as I am pressed to submit this part of the project immediately, I have to make tentative proposals to meet the worst possible case.

68. *Right Bank Canals.*—

(*a*) There will be three separate systems of canals on the Right Bank, as follows :—

(i) The South-Eastern Perennial Canal.

(ii) The Central Kharif (Rice) Canal.

(iii) The North-Western Perennial Canal.

(*b*) The two perennial canals will eventually require a nearly constant discharge all the year round, and for command purposes the F. S. L. should be constant all the year round. Hence it must be fixed at a level which can be guaranteed (with a margin) by the barrage at all times.

(*c*) The F. S. L. of both canals is therefore taken as R. L. 193·0 at the head, requiring 193·5 in the river. The barrage can give this level with a margin of one foot all the year round. This F. S. L. enables flow water to be given to practically the whole of the areas commanded and extends the command to large additional areas of valuable land not commanded by the 1909 projects. The proposed F. S. L. is about 4′ higher than that in the 1909 project, and results in a very great saving in the cost of excavating the deep cuttings in the upper reaches of the canals.

(*d*) The Central Kharif (Rice) Canal will only flow in the months of April to September inclusive, and it will not require full discharge until June. The estimated monthly discharges required after full development are as follows :—

	Cusecs.
In April	3,696
In May	8,849
In June	11,689
In July	11,689
In August	11,689
In September	11,689

Closed from October to March.

(*e*) From June to September there is always a large surplus discharge to pass the barrage, so that there will be no difficulty in heading up the river to the top of the barrage gates, *i.e.*, to R. L. 194·5, in fact this level could also be maintained in April and May if required. Hence the F. S. L. of this canal may be taken as R. L. 194·0 (allowing ·5 loss of head in the head regulator).

If it is not convenient to hold up water above 193·5 in April and May, the level would still give the required discharge in the canal, and as no water will be utilized in the first 50 miles of the canal, there will be no difficulty in heading up to F. S. L. at the first point of offtake. The highest level possible is desirable to reduce the deep cutting in the upper reaches of the canal, and to give the head required for two syphons in the first branch (Begari Branch) of the Canal. When the commanded area falls rapidly, fall regulators will be built as required in the canal to give the proper levels.

Section VIII.

Navigation on the River.

69. In the 1909 project for the barrage provision was made for a Ships' Lock for the passage of vessels through the barrage.

The necessity for this lock was questioned by the Inspector-General of Irrigation and accordingly a census was taken of boats passing Sukkur in either direction. This census was maintained from June to October 1917 (the busiest season) and during that period not a single boat was observed to have passed *through* Sukkur in either direction, though hundreds came down to Sukkur from the Punjab, and returned, while a fair number came from below Sukkur and returned.

70. All country boat traffic from the Punjab to Sind, of which there is a considerable amount, and also timber raft traffic from the Punjab, invariably ties up and unloads at the Sukkur Bunder. Sukkur is in fact a great river port and for various reasons has become the river terminus for boat traffic in either direction, and there is no through traffic.

71. Boats from the Punjab bring down principally munj rope, wheat, barley, oil seeds and various salts. Much of this freight is probably produced in lands adjacent to the Indus and Punjab rivers, and is therefore conveniently carried to the boats; but in any case, as these boats can drift and sail downstream heavily laden, river freight is cheaper than railway freight.

The reasons for their stopping at Sukkur will be shown later.

72. On the return journey to the Punjab these boats have to travel against stream and for much of the distance have to be towed by men on the banks. They are therefore not anxious for heavy loads, and many go back practically empty. The principal freights carried in this direction are kerosine oil and spices.

73. There is very little boat traffic in either direction below Sukkur.

Rice, wheat and fuel grown in the Karachi District is to some extent carried up to Kotri by boat, for distribution locally, or by train thence to Karachi. A certain amount of fuel may also go upstream from the forests below Kotri to Sukkur. Between Kotri and Sukkur there is a certain amount of boat traffic up and down stream and across the river for distributing the produce of one place to another, and especially transferring rice from the Larkana District over to the Left Bank districts of central Sind. But none of this traffic goes beyond Sukkur.

74. The reasons for this are as follows:—

(*a*) In the first place, Sukkur has become a port in preference to any other place in its vicinity because it is built on rock, and the river channel never deserts it. An excellent stone bunder has been built in a length of nearly 2 miles, against which boats can lie at any season of the year. At no other place in Sind, except at Jerruck, 300 miles below, are such facilities available. Everywhere else the river banks are liable to great changes and no facilities for a port can be obtained.

(*b*) Secondly, Sukkur has become a great depot and distributing centre for the produce brought to it. A very large proportion of this produce is distributed in Upper Sind and Baluchistan for which Sukkur is a most convenient centre. The balance, especially of the grain, probably comes to Karachi for overseas export. All the Karachi large exporters have depôts at Sukkur, hold large stocks there, and distribute to the surrounding country, or bring from there to Karachi by train.

75. The only other traffic on the river consists of—

(*i*) The vessels of inspecting officers in Sind, *viz.*, the Commissioner in Sind and the Chief Engineer in Sind, each of whom has a steamer.

(*ii*) A few small steam launches owned by the Indus River Commission. These are occasionally needed above Sukkur for survey work, but are mostly used below Sukkur.

(*iii*) There are a few large steamers on the Punjab rivers used for ferry duties. These steamers used to come down to Kotri occasionally at long intervals to be overhauled in the floating dock which was formerly kept there by the Indus River Commission, but since this dock was lost at sea, on its way to Mesopotamia in 1915, these steamers have not come down, and their repairs are done in the Punjab.

76. Thus it will be seen that there is practically no through traffic at Sukkur and Government has accordingly decided to omit the provision of a ship's lock.

The cost of making such a lock would be very great, besides introducing complications in the design of the barrage, and it would be difficult to construct. The cost would probably be in the neighbourhood of Rs. 15 or Rs. 20 lakhs, while maintenance expenses would be high.

77. If it is considered necessary to have inspection steamers for Sind officials, and survey launches, above Sukkur as well as below, it would be far cheaper to build separate vessels above the barrage and keep them there permanently. The steamers in the Punjab do not need to come downstream for repairs which can be arranged for locally, and new steamers required could easily be erected in the Punjab.

78. As regards facility for boat traffic between the Punjab and Sukkur, this will be much improved by the construction of the Barrage as there will be always good deep water for 20 or 30 miles above Sukkur, while beyond that point the natural river is not affected.

At the Sukkur Bunder there will be always deep water alongside, so that boats can lie alongside the wall, and the lift for unloading will be reduced.

79. For boat traffic below the barrage, the discharge in the river will be greatly reduced in the cold season by the offtake of the canals, but it is probable that the smaller discharge then passing downstream will confine itself to two narrow channels, one at either bank commencing opposite the scouring sluices, and that these channels will scour fairly deep and thus maintain a navigable section. If not, then this boat traffic may suffer. But it is an axiom of irrigation engineering, and an obvious fact, that a limited quantity of water cannot be made available both for irrigation on the land, and for navigation in the river. There can be no

question in this case as to where the water would confer the greater benefits on the people, and if necessary, it must be accepted that the comparatively small amount of navigation on the Indus must suffer.

80. The above facts constitute a further argument against the construction of a lock, since even if made, there might possibly be insufficient water in the river below the barrage to enable the larger vessels to approach the lock or use the river.

81. It may be pointed out also, that as soon as the natural river level reads 12′ on the Bukkur gauge, the barrage gates will be fully open, and there will then be 14′ of head room, between water surface and bottom of gates, which is ample for country boats with masts lowered, or for small launches, so that these could pass through the barrage at such seasons.

Section IX.

Communications.

82. Both the 1909 and the present barrage projects, include the provision of a road-bridge across the barrage for vehicular and foot traffic.

In the present project the road-bridge is provided solely for that purpose and is not required for communication or manipulation of the river works, as a separate high level bridge is provided for this purpose.

83. At the present time the only means of communication between the large towns of Rohri and Sukkur and the country districts and towns behind them is by—

(*a*) boat ferrying across the Indus,

(*b*) by railway across the Landsdowne Bridge,

(*c*) by road across the Landsdowne Bridge when trains are not running. The provision for vehicular and foot traffic is thus very poor, as the railway bridge is frequently closed for the passing of goods and passenger trains. The railway also levies a toll on all vehicles crossing the bridge.

84. The provision of a new bridge, always open for traffic, has been considered a desirable feature of both the barrage schemes, especially as by combination with the barrage, the bridge can be made much more cheaply than it could be built as an independent structure.

85. In this connection the following extract from 'Notes by the Chief Engineer for Irrigation, Bombay (Mr. Beale) on Mr. Musto's preliminary report on Barrage," dated September 1916, is given:—

" I think a roadway of good size, 20 feet clear, apart from footway 5′, should be built on reinforced concrete arch ribs, and that this, or at least 15/25 of this, should be paid for by Provincial funds. In the latter case, 10/25 may be assumed to be the necessary share debitable to the barrage, to allow of a craneway for the removal of gates, etc., for repairs, etc. The Irrigation Department would then have a right to maintain a craneway along one side of this road."

86. As no part of the road-bridge is now needed for the barrage it may be considered fairly that Provincial funds (Rs. 19,36,326—for details, see Appendix P,) should bear the whole cost of the road-bridge, and such part of the piers as are necessary to carry it, and not otherwise needed for the barrage. It is not proposed to debit any part of the cost of foundations to the road-bridge, as these are needed in any case for the barrage.

87. The present project provides a bridge 25′ feet wide, carrying a 16′ road way and two foot-paths each 3½′ wide, or alternatively an 18′ roadway and one footpath 5′ wide. The roadway with the same dimensions is continued with a right angle turn on either bank, over bridges across the head regulators of the canals, and thence upstream along the top of the guide banks by the river edge, to Sukkur and Rohri respectively.

88. On the Right Bank the roadway across the barrage also continues in a direct line along the top of the canal bank, until it meets the existing Jhali Bund where it joins the existing road to the south-east, which runs along the toe of the bund.

On the Left Bank the roadway over the barrage will be continued along the canal bank to join the main Rohri road which crosses the canals about half a mile from the barrage. The details of these inland roads will be elaborated in the canal projects.

PART II.

DETAILED DESCRIPTION OF BARRAGE.

THE BARRAGE PROPER.

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PART II.

DETAILED DESCRIPTION.

THE BARRAGE PROPER.

SECTION I.

Plan, Length and number of openings—*See drawings Nos.* 3 *&* 4.

89. In plan, the barrage is built on a straight line, normal to the centre line of the river above it. Owing to the tapered plan of the river banks, and to the long parallel flanks formed by the regulators, the upstream ends of which must meet the river banks, the abutments of the barrage will be made in the river bed about 400′ from the high banks on either side.

The downstream guide banks will eventually close the space between the barrage abutments and the present river banks, but before these banks are completed it is probable that this space will have silted up to cold weather water level. The dividing banks between the canals in this portion, *i.e.*, from regulator to river bank, will be formed from the excavation further down.

90. The full length of the Barrage between regulator faces (river-side noses of regulator piers) is 4,725′, while the overall length of the high level barrage bridge, which has a land span and terminal tower at either end, will be 4,925′. The bar-

rage comprises 66 sluices, each 60′ clear span and is divided into 3 sections by means of two divide walls, built on the river bed, parallel to the regulator faces and to one another.

91. The three sections of the Barrage are as follows :—

(*a*) Left Bank scouring sluices.

(*b*) Central section of ordinary barrage sluices.

(*c*) Right Bank scouring sluices.

92. The Left Bank scouring sluices consist of 7 spans of 60 feet each clear width of opening with floor at R. L. 176·0. The width of the approach channel to these sluices, *i.e.*, between regulator face and divide wall is 487 feet at floor level, the aggregate clear width of opening being 420 feet. The piers between these spans are 10′ thick each. At the divide wall there is a 25′ thick abutment pier.

93. The Central Section of the barrage consists of 6 bays, each containing 9 spans of 60 feet each clear width of opening, with floor at R. L. 176·0. At the end of each bay is a 25 feet thick abutment pier, while the intermediate piers of the bays are each 10 feet thick. The width of the river channel approaching these bays, *i.e.*, between the left and right divide walls is 3,850 feet at floor level, the aggregate clear width of openings being 3,240 feet.

94. The Right Bank scouring sluices consist of 5 spans of 60 feet each clear opening with floor at R. L. 176·0. The width of the approach channel to these sluices, *i.e.*, between the divide wall and the regulator face is 347 feet at floor level, the aggregate clear width of opening being 300 feet, and the piers each 10 feet thick.

95. The scouring sluices and the ordinary barrage sluices are identical in every respect except in the length of protection provided on the river bed, upstream and downstream of the masonry floor.

Section II.

The Floor and Foundations.

(*See drawing No.* 42.)

96. The floor and foundations of the barrage have to be designed with two main objectives,—

(*a*) To prevent the flow of water below it, through the sand, or to reduce this flow to such proportion and velocity that it is unable to disturb the sand.

(*b*) To withstand the upward pressure on the floor, when there is the full difference of head, between the upstream and downstream sides, which the barrage is designed to create.

(*c*) To provide a solid bearing for carrying and distributing the weight of the superstructure to the sand below.

97. In the present design the provision for (*a*) and (*b*) gives an ample provision for (*c*) also. This will be shown later in connection with the piers, and it will here be shown how conditions (*a*) and (*b*) have been met.

98. The method of design elaborated by Bligh in his book " The Practical Design of Irrigation Works " has been followed, but his co-efficients and rules have sometimes been varied. The first point to be decided is the " length of creep " which must be provided for safety against " piping ". This can be expressed in the terms of the total " head " on the floor. Bligh represents this relation by the factor " C ", with which he multiples the head in order to find the required "length of creep ". He gives the following values of " C " for various sands :—

Class I.—River beds of light silt and mud, as the Nile .. C=18.

Class II.—Fine micaceous sand, as in Himalayan Rivers, etc. .. C=15.

Class III.—Coarse grained sands, as in the Central and South India C=12.

99. The actual value of " C " for the Esna Barrage on the Nile has been worked out (see plan No. 41 and Appendix G) and is found to be C=14·2 for actual conditions of working. This is for a work founded on light silt and sand for which Bligh takes C=18. As the Esna Barrage has given no trouble with " piping " it would appear that this value of " C " might safely be used for Sukkur, but as it is extremely difficult to compare the conditions at such distant and differing sites, the Chief Engineer for Irrigation (Mr. Beale) decided that a higher value of " C " should be used, and as the Jamrao is weir founded on similar material to that at Sukkur, and this weir has given no trouble, it was decided to adopt the same value of " C " for the barrage as actually obtains at the Jamrao weir. This is found to be C=17 which Bligh considers somewhat excessive. (He takes 15 as the suitable value for the Jamrao.)

The present design for the barrage floor (see plan No. 42) is therefore based on a ratio of 17 times the head for the length of creep required.

100. The next point to be decided was where this length should be arranged. A certain minimum length of impervious solid masonry is necessary on the downstream side of the gates, to withstand the swirl and scour of the water rushing through. There will be considerable swirl and eddying at the downstream easewaters of the piers, and for some little distance beyond, and it is advisable to provide solid masonry for such a length. This is a comparatively short distance though difficult to calculate.

101. Bligh gives an empirical rule for the length of downstream impervious pavement, based on the principle that this length must be provided to withstand *scour*.

I contend however that provided the masonry extends for a short distance, say 40 or 50 feet from the end of the ease-waters, so as to include the worst of the swirling, then *scour* beyond this point can be provided for by a *pervious* flooring of concrete blocks sufficiently heavy not to be movable by the rushing water.

102. Bligh's empirical rule for the length of impervious masonry downstream of undersluice gates is as follows :—

$$L = 8\,C\sqrt{\frac{H_a}{13}}$$

where C is the co-efficient for the sand (or the hydraulic gradient ratio) and H_a is the total head at the gates.

103. In the case of the Esna Barrage this gives a length as follows :—

$$L = 8 \times 14 \cdot 2 \times \sqrt{\frac{15}{13}}$$

$= 113 \cdot 6 \times 1 \cdot 07$
$= 122'$ (or 8·13 times the head).

Whereas actually only 65 feet has been given to the barrage, or 4·3 times the head, (and only 32 feet of this extends beyond the piers), and since 1910, when fairly heavy concrete blocks (1 cubic metre each) were laid beyond the impervious floor, no trouble has been experienced, showing that scour can be satisfactorily met by such construction.

104. The total length of creep to be provided remains unaltered whatever length is given to the downstream paving, but it is a great advantage to make the latter as short as possible consistent with safety, since the longer this portion is made, the greater becomes the upward pressure on the floor at any point downstream of the gates, and the whole floor below this point has to be made heavier to withstand it.

105. In my tentative proposals submitted to Government in 1916, I designed the floor more or less on the rules deduced from the Esna Barrage, but allowed for an impervious floor for a distance below the gates equal to 6 times the head, as against only 4·3 times the head at Esna. The Chief Engineer for Irrigation however considered this was somewhat too little, and in the present design I have lengthened it to 120 feet or 6·5 times the head, giving 75 feet clear length beyond the easewaters of piers.

Section III.

Design and Stability of Floor.

106. The following is the method of design adopted (see plan No. 42) :—

Assumptions—

Hydraulic gradient to be 1 in 17, *i.e.*—
Co-efficient " C " of sand=17.
Weight of masonry in air=140 lbs. per cubic foot.
∴ weight of masonry in air=2·25 times the weight of water.
Ditto submerged=1·25 times weight of water.

The weight of the floor at any point must be not less than $\frac{4}{3}$ times the upward pressure of water at that point, *i.e.*, 33 per cent. factor of safety is allowed.

Maximum head on floor=18·5 feet, when water upstream is at top of gates, *viz.*, R. L. 194·5, and tail water is level with the floor, *i.e.*, at R. L. 176·0.

107. Since hydraulic gradient is 17 and head 18·5 feet the total length of creep required is $17 \times 18{\cdot}5' = 315'$.

If paving downstream of gates is to extend 120′ (see paragraph 105) the balance to be provided is 315—120=195′. This must be made up of the length of pavement upstream of the gates, *plus* the travel round sheet piling below the floor.

108. The cutwaters of the piers extend about 26 feet upstream of the gates and the central paving on which they stand will project 4 feet beyond them, *i.e.* to 30 feet above the gates. If the upstream masonry apron is made 40 feet wide, this gives a total width of 70 feet above the gates, leaving 195′—70′=125′ of creep to be made up of vertical travel round sheet piling curtains below the floors.

109. If the upstream and downstream curtains are each made 12 feet deep below floor, these give $2 \times 2 \times 12' = 48'$ of creep, leaving 125′—48′=77′ of creep to be provided by intermediate curtains of piling.

110. The upstream central curtain will be driven 20 feet below the floor and the downstream central curtain 12 feet below the floor giving altogether $2 \times 20' + 2 \times 12' = 64'$ of creep, and leaving 77′—64′=13′ to be provided by vertical steps in the masonry. The upstream apron is 4 feet thick, giving a vertical creep of 4 feet at its upstream end. The central block of masonry is 11 feet thick giving a step of 5 feet at its junction with downstream floor, and there is a vertical step of 4 feet at the end of the latter. Hence total creep along masonry steps=4′+5′+4′=13′ as required.

111. *Stability against upward pressure.*—(See plan No. 42—Stability diagram.)

(*a*) On the upstream side of the gate, the floor must always be safe, since the downward pressure of the water is always greater than the upward pressure due to itself, *minus* frictional losses.

(*b*) *At point* (*a*) *immediately under the gates*—

Length of creep to gate—

Upstream paving	42+4=46′	creep.
„ piling	2×12=24′	„
Centre floor to gate	30′=30′	„
Upstream central piling	2×20=40′	„
Total creep to (*a*) ..	=140′	„
∴ Loss of head	$=\frac{140}{70}=8{\cdot}24'$	„
Balance of upward pressure at (*a*)	=18·5 —8·24. =10·26 feet of water.	
Add —33⅓ per cent. for safety ..	= 3·42	
Total downward pressure required ..	13·68 feet of water.	

The masonry here is 11 feet thick with specific gravity (submerged) $1 \cdot 25$. Hence its effective weight is $1 \cdot 25 \times 11 = 13 \cdot 75$ feet of water, which is sufficient for requirements.

(*c*) *At point* (*b*) *junction of downstream and central paving*—

Creep up to (*a*) brought down	$=140'$	creep.
Centre floor downstream of gate	$= 50'$	„
Downstream central piling .. .. .. $2' \times 12' =$	$24'$	„
Step in masonry .. .. $5' =$	$5'$	„
Total creep to (*b*)	$=219'$	

$\therefore$ Loss of head to this point .. $= \dfrac{219}{17} = 12 \cdot 88$

$\therefore$ Balance of upward pressure at (*b*) .. $= 18 \cdot 5 - 12 \cdot 88$

$= 5 \cdot 62$ feet of water.

Add—$33\frac{1}{3}$ per cent. for safety .. $= 1 \cdot 87$

Total downward pressure required .. $= 7 \cdot 49$ feet of water

Masonry is 6 feet thick. Hence its weight submerged is $1 \cdot 25 \times 6 = 7 \cdot 5$ feet of water, which is sufficient.

(*d*) *At point* (*c*) *upstream side of downstream piling*—

Creep up to (*b*) brought down	$=219'$	creep.
Downstream paving to (*b*)	$= 65'$	„
Total to (*c*) ..	$=284'$	„

$\therefore$ Loss of head to this point .. .. $= \dfrac{284}{17} = 16 \cdot 7$.

Balance of upward pressure at (*c*) .. .. $= 18 \cdot 5 - 16 \cdot 7$.

$= 1 \cdot 8$ feet of water.

Add—$33\frac{1}{3}$ per cent. for safety $= \cdot 6$

Total downward pressure required .. .. $2 \cdot 4$.

Hence 2 feet of masonry would be sufficient here for safety against upward pressure but 4 feet is about the minimum thickness which could be laid to be safe against cracking and settlement on the sand, and to withstand the blows of tree trunk and debris bumping through the barrage. Four feet thickness has therefore been adopted as a minimum for both upstream and downstream pavings, but if considered desirable this could be reduced to 3 feet.

112. *Loss of head to end of floor*—

Total creep to point (*c*) brought down	$=284'$
Downstream piling $2 \times 12'$	$= 24'$
Paving beyond piling	$= 5'$
Step up to pavement surface	$= 4'$
Total creep to end of floor	$=317'$

$\therefore$ Loss of head to end of floor .. .. .. $= \dfrac{317}{17} = 18 \cdot 6$

113. Thus all pressure has been absorbed in frictional resistance by the time the water reaches the end of floor, and the required length of creep for sand with co-efficient C=17 has been provided.

SECTION IV.

The Protection of River Bed and Floor of Barrage from scour.

114. This matter has been already touched upon in paragraphs 100 to 103 *ante*, and is further dealt with in Appendix G. The design for protection now submitted is based on the Esna Barrage design (as repaired), but allowing somewhat greater ratios between length of protection and working head of pressure than at Esna.

115. In the first place it has been considered desirable to provide more protection downstream and upstream of the scouring sluices, than in the case of the ordinary barrage spans. This is necessary because the former will be in operation much more frequently (almost, or quite, all the year round), and they only will be used (generally) under the full head, since that full head is only obtained when the surplus discharge of the river has fallen to a very low figure, giving practically no depth over the downstream pavement; and at such times this small surplus would be passed by the scouring sluices in order to keep the approach channels to the canal regulators clear of silt. For greater discharges, necessitating the use of the ordinary barrage spans, there will be a greater depth of water downstream, and less working head, so that scouring effect would be less severe, and the period will be much shorter.

116. The following analysis shows the results of the design as compared with Esna :—

(*a*) *Protection for ordinary barrage sluices*—

There is first 120′ of solid masonry below the gates, or 6·5 times the head (18·5′) as against 4·33 times the head (15′) allowed at Esna.

Beyond this point there will be 83′ of large concrete blocks (10′×5′×3′) laid on 3′ of stone pitching, making total 203′ from gates or 11 times the head (18·5′) as against 10 times the head (15′) at Esna.

Beyond this again will be an apron of large loose stone pitching for a width of 100′, making 303′ from the gates, or 16·5 times the head (18·5′) as against 12·8 times the head (15′) allowed at Esna originally (and found too little owing to small size of stone used) and as against 20 times the head allowed at Esna to fill up the scoured bed. (So much would not have been necessary if laid in the first place.)

On the upstream side there will be 70′ of solid masonry above the gates and beyond that an apron of loose stone pitching 60′ wide making altogether 130′ of protection or 7 times the head (18·5′) as against 6 times the head (15′) originally allowed at Esna, and 7 times the head allowed after repairs. Moreover, the apron at Sukkur will be much thicker than at Esna and properly designed to fall into any scour that may occur, and thus prevent further action.

(*b*) *The protection for scouring sluices*—

On the upstream side there will be 70′ of solid masonry and beyond this a heavy apron (6′ thick) of stone pitching to take the local swirls due to the suction of the scouring sluices. Beyond this point the whole area of river bed between the divide wall and the Canal Regulators will be covered with 3′ of stone pitching for a distance of over 1,200′ from the gates, so that no scour is possible here.

On the downstream side there will be first 120′ of solid masonry below the gates, or 6·5 times the head (18·5′) as against 4·33 times the head (15′) allowed at Esna.

Beyond this point there will be 105′ of large concrete blocks (10′×5′×3′) laid on 3′ of stone pitching, making total 225′ from gates, or 12 times the head (18·5′); as against 203′ at the ordinary sluices, and as against 10 times the head (15′) allowed at Esna after repairs.

Beyond this point there will be loose stone pitching for a further 155′, making total protection of 380′ from the gates or 20·5 times the head (18·5′), as against 303′ at the ordinary spans, and as against 20 times the head allowed at Esna after repairs.

117. It is possible that these dimensions may be considered somewhat excessive, but if so, any reductions will give savings on the estimates, which may be taken to show the maximum protection desirable.

SECTION V.

Superstructure.

118. The 1909 design for the barrage superstructure shows masonry piers 10′ thick and 86′ high above cill level, standing entirely separate, without any ties or connections between them. The lower 38′ of these piers was solid for the full length (45′) of the pier, but the upper 48′ consisted of two masonry pillars 10′×9½′ each, 16′ apart, connected to each other with a masonry arch and spandrills.

At the tops of these pillars or piers were great castings overhanging the piers on either side, and carrying the great weight of the gates and counterweights (about 50 tons each) over the extreme outside edges of the piers. This arrangement would have set up enormous stresses in the masonry pillars over the piers and would certainly not have been safe. The weights thus suspended when one gate alone was raised would have tended to overturn the piers inwards, *i.e.*, to pull them together at the top. Nor could these masonry pillars have carried these eccentric loads even had they been transmitted through horizontal girders spanning the piers and resting on their tops, as the eccentricity of the load on the pillars, when only one gate was being raised would have caused excessive intensity of pressure on the inside toe of the base of the pillar and tension on the outer toe, *i.e.*, the line of resultant pressure would have fallen outside the middle third of the base.

119. As the loads of the gate and counterweight must in any case be eccentric to the centre line of the piers, in fact they will actually be suspended clear of the side of piers, it is essential to bridge the span between the piers in some way, to give bearing points for the suspension pulleys, and to provide piers of sufficient strength and area to carry the loads transmitted. There must also be seatings for intermediate bearings of the cross shaft of operating gears.

120. This could be done in several ways, *e.g.* :—

(1) By building above the piers, steel towers with short double cantilever arms overhanging the span, and connected together by a light lattice girder across the span, to carry the bearings and gearing, and to provide a footbridge for access from pier to pier.

(2) By spanning the piers with self-contained steel arched-girders, to carry all the loads, and transmitting these vertically to the piers at the seatings of the girders.

(3) By carrying masonry arches across the span from pier to pier, so that part of the load of gate and counterweight may be carried by the arch. Such arches would form a continuous bridge, providing access from pier to pier and ample room for fixing gearing, bearings, etc.

121. We also have to provide a road-bridge for vehicular and foot traffic. In the 1909 designs this was given by a steel girder bridge resting on the piers between the upper masonry pillars.

122. The arrangements for lifting the gates must be at a high level to give the required lift, while the road-bridge must be kept as low as possible to avoid high approach banks. Hence the same bridge cannot serve both purposes.

The high level bridge to carry the gate lifting mechanism will be referred to as "The Gate Bridge," and the low level bridge as the "Road-bridge."

123. There would be no difficulty in providing for both the gate bridge and the road-bridge by separate steel structures, but there are several disadvantages to such structures, *viz.* :—

(*a*) Initial cost is high. Detailed estimates have been prepared for a masonry bridge and a steel tower superstructure, see Appendix N, each to provide the same accommodation and conveniences for suspending gates and foot-bridge. In the latter case the steel work has been estimated by the Superintendent of the Amritsar Workshops, at pre-war rates, and in the former the masonry bridge has been fully estimated at rates about 20 per cent. above pre-war rates. The result shows the masonry structure to be slightly cheaper than the steel work in initial cost. But if the price of steel work in the near future is to be about 50 per cent. in excess of pre-war rates, as seems likely, then the saving in favour of masonry is increased by about 50 per cent. since the cost of the latter will not increase much, if any, more than the 20 per cent. allowed in the comparative estimates.

(*b*) The cost of maintenance of steel work is very high, and its life is an uncertain factor, but for light lattice work is certainly not more than 80 to 100 years, if so much.

The estimated cost of painting the steel structure referred to in (*a*), if capitalized, would add Rs. 4,50,000 or about 18 per cent. to the cost of the superstructure.

(*c*) The slightest neglect or oversight in the regular painting and cleaning of every part of the structure would lead to rapid deterioration, and possibly to disastrous results.

(*d*) The appearance of a great number of fairly small spans (60′) of light lattice steel work would be most unsightly at the one beautiful spot on the river in Sind.

(*e*) The steel superstructure for gate bridge is only suitable for carrying a light load over the span between piers, while to carry a heavy travelling crane such as is needed for lifting trees and other debris from the front of the gates, it would be necessary to build a far heavier structure, the cost of which would probably be double or treble that estimated, whereas the masonry bridge needs very little increase in size or strength to carry such a crane.

124. An arched steel bridge would be still more expensive and has all the other disadvantages of the tower and girder structure.

125. The masonry bridge at Sukkur has the following advantages :—

(*a*) There is an unlimited quantity of splendid building stone available within a radius of 5 miles of the site.

(*b*) The local labour is accustomed to using this stone, which is easily worked, so that imported labour would have no difficulty in using it.

(*c*) Structures well-built of this stone would be practically everlasting as it hardens by exposure, and does not weather at all in the climate of Sukkur, while it hardens also in water, and stands the wear of water very well indeed. The Eastern Nara Head Regulator is built of it throughout and is in excellent preservation and the noses of the piers of Lansdowne Bridge are also made of it and show no signs of wear, although the velocity rises to 15 feet a second in floods.

(*d*) Maintenance charges would be very low. If well pointed with hydraulic lime or cement, it would need practically no repairs except to road surface, parapets, etc.

(*e*) Its initial cost would be lower than for steel structure even at pre-war prices, while at the present prohibitive rates for steel, the masonry will be far cheaper.

(*f*) Its appearance would be very fine and would harmonize with the surroundings instead of being an eyesore.

126. The designs and estimates now submitted have been prepared accordingly for a masonry structure. The only metal work in the structure will be in the gates, the machinery for working them, and the main cross girders to carry them between the arch ribs. The counterweights as shown and estimated, also consist of steel tanks filled with sand, as designed by the Superintendent, Amritsar Workshops, but it is suggested to substitute for these counterweights of reinforced concrete. These would have the following advantages :—

(*a*) They will be everlasting.

(*b*) They will need no painting or repairs.

(*c*) They will cost about Rs. 4,00,000 less than the steel tanks estimated for. (See Appendix O.)

(*d*) They can be made 3 feet narrower than the steel tanks, thereby reducing the length of all piers by 3′ and saving about Rs. 1,00,000 in pier masonry.

I am indebted to Mr. Pierce, Executive Engineer, North-Western Railway, for this valuable suggestion.

The Gate Bridge or High Level Bridge. (See Drawings Nos. 43, 44 and 45.)

127. This has been designed for the following work :—

a) To carry the gates and counterweights and the shafting connecting the machinery for lifting them. This machinery will be fixed on the tops of the piers.

(*b*) To carry a rail track for a travelling crane (electric or steam, to lift 5 tons 16′ radius, or 3 tons at 25′ radius), for lifting trees and debris from the face of the gates.

(*c*) To provide a foot-bridge for the passage of work people and maintenance establishment.

(*d*) To carry a rail track for travelling trollies (electric or petrol). These trollies will be very useful for rapid inspection and communication on the barrage, and each will be provided with a low speed gearing driving a sprocket wheel, which will connect by a link chain to a similar wheel on the fixed gearing of each set of gate lifting machinery. A simple arrangement of hinged stops will be fitted over each pier for holding trolly in position for this work, and all that will be necessary will be to run the trolly, carrying its crew, to the gate to be operated, lift and lock the hinged stops, put on the link chain, and lift or lower the gate.

Thus 6 trolleys (one spare) will be able to operate all the 66 gates, as well as to provide rapid communication along the bridge. We shall thus save 60 motors on the gates, and all our power units will be interchangeable for any gate.

128. This gate-bridge consists of two series of separate stone-masonry elliptical arches, each 60′ span by 15′ rise, springing at R. L. 219·0. The upstream arch is 8′ wide 3′ deep at crown, and 4′-6″ deep at springings. The top of spandrils is at R. L. 238·5 and this arch carries the track for the travelling cranes.

The downstream arch is 5′ wide, 2′-6″ deep at crown and 4′ deep at springings. There is a gap of 16′ between the two arches (can be reduced to 13′ if reinforced concrete counterweights are adopted) in which hang the gates and counterweights. These are supported over pulleys, carried by a pair of deep steel girders at each end of the gate span, near the piers, and spanning the gap between the arches. This gap will be covered with a decking of reinforced concrete slabs (removeable or otherwise as considered desirable) carried on reinforced concrete beams spanning the 16′ gap between the arches, and resting on them. A parapet wall $3\frac{1}{2}$′ high is built on the outer edges of each arch, leaving a clear bridge width of 27′ between parapets.

129. **The Road-bridge.**—This consists of a series of single elliptical stone masonry arches 25′-3″ wide, each 60′ span by 10′ rise, springing at R. L. 201·0, depth at crown 2′-9″, and at springing 4′-6″.

The roadway is at R. L. 215·0 and is 16′ wide, the two footpaths are each 3′-6″ wide with curbs 8″ deep.

The parapet walls on either side are 3′-6″ high with small recesses over each ordinary pier, and at the abutment piers recesses 6′ deep and 19′ long are provided with stone seats.

129A. Elliptical arches were selected as most suitable for the following reasons :—

In the case of the road-bridge it was necessary to keep the road-level as low as possible, while springing of arches has to be kept above highest estimated flood level.

129B. During great floods the river carries down with it many great trees which it has eroded on the way. These trees usually float with part of their roots out of water, sometimes as much as 5 or 6 feet above water, and as the branches below water touch the bed or are caught by eddies, the whole tree swings around and bobs up and down in the water. Some of these trees are probably 50′ or 60′ long over all, and they will have to pass through the barrage in a depth of only 24′ of water, so that they may bob up out of the water considerably.

It is desirable therefore to allow as much headroom as possible for these floating trees.

129C. The bottom of the counterweights and gates when latter are fully raised is R. L. 208, or 8′ above highest flood level, or allowing for the drop in water surface between the piers, about 12′ above water level. If a segmental arch, of the same rise, span and springing, as the elliptical arch were adopted, only the centre 34′ of the span would be above R. L. 208, and for 13′ on each side, the arch haunches slope down gradually to R. L. 201.

In the elliptical arches, a central width of 42′ is above R. L. 208 and the haunches of arch, only 9′ on each side, are much flatter than the segmental arch until they have almost reached the piers, when they turn through a sharp curve to the vertical.

129D. The elliptical arch therefore provides much better headroom above H. F. L. Moreover a tree root which floated 8′ out of water would probably be at least 16′ diameter. (They usually float with about half the root exposed), so that the centre of the root would be about 8′ from the pier and at this point would clear the arch altogether. At the worst, it would touch close to the abutment, where a blow would have little or no effect on the bridge.

129E. In the case of the gate-bridge, not only was it desirable to adopt the same shape of arch as for the road-bridge, for the sake of appearance—both arches being seen together—but the form of the haunches of an elliptical arch is very suitable for carrying a heavy vertical load close to the pier, such as the load provided by the gates, etc.

129F. Finally the appearance of an elliptical arch is much finer than that of a segmental arch.

130. The bridges will be lighted with electric light (or Kitson oil-lights) standards. There will be one standard over every pier on the downstream parapet of the high level bridge. If electric power is used for the operation of the gates, these lamp standards will be specially designed to carry the overhead wire for power transmission. They will give light at each set of machinery on the gate-bridge, and will also light the road-bridge below.

In addition there will be a similar or more powerful light standard over each third pier on the downstream parapet of the road-bridge. The road-bridge will thus be lighted by lamps at 70′ intervals on one side, about 36′ above road level, and on the other side by lamps at 210′ intervals and about 15′ above road level.

131. The abutments of the road-bridge will be in line with the faces of the canal regulators on either bank of the river, while the gate bridge will continue for one span inland, (See drawings 44 and 45) on each bank, and will terminate in a massive abutment tower in which will be provided an electric or hydraulic platform lift, which will be capable of raising 20 tons from ground level to the level of the gate-bridge decking. These lifts will be very useful both during construction, and afterwards in maintenance, for raising or lowering, to or from, the bridge, any machinery, tools, cranes, or trollies, etc., which require removal for repairs, or for first placing in position. Staircases will also be provided at the ends of the towers for access of workpeople, etc., to the bridge floor.

132. The ordinary piers on which these bridges rest will be 10′ thick by about 73′ long overall, the gate-bridge and road-bridge arches resting side by side on these piers, but the gate-bridge at a higher level than the road-bridge.

Cut waters and ease waters of 10′ radius will be provided on all piers.

133. At the end of each scouring sluice bay there will be an abutment pier 25′ thick by about 97′ long overall, and a similar pier at every 9th span of the ordinary barrage sluices. These piers are provided with cut waters and ease waters of 25′ radius. There are seven of them in all.

Section Va.

Architectural Features.

134. The external design of the bridges has been made as simple and economical as possible, while endeavouring to use shadow effects to the best advantage to secure a massive and quiet but pleasing result. The general motif of the design follows that adopted by Rennie in his noble bridges over the Thames, the London and Waterloo Bridges.

All cornices, string courses, parapets and pilasters are perfectly plain and square, combining the greatest shadow values with economy and ease of construction.

135. The stone to be used is mottled creamy-white in colour and is something like marble in appearance. Its general effect is most suitable in this country of white rocks, glaring sand, and vivid colours, and is in harmony with the building traditions of the people, who usually cover their local temples and mosques with pure white plaster.

136. It is hoped that the design provides a structure of massive but graceful proportions which will be pleasing alike to the Western and Eastern eye, and will form a fitting background to the noble and beautiful reach of this mighty river, seen from the great Sukkur bridge. At the same time the whole structure is entirely utilitarian, and nothing has been wasted in useless adornment.

136A. The coloured lithograph forming the frontispiece to the portfolio of plans, and the frontispiece to this report, are reproductions from a very beautiful water-colour drawing kindly made for me by Captain F. H. E. Townshend, O.B.E., M.C., R.E., Executive Engineer, while attached to this district.

The drawing is in accurate perspective and scale, projected from my working plans and elevations. It gives an excellent idea of what will be the general appearance of the work.

136B. The full size lithograph reproductions have been made by Mr. A. W. Audy, Manager, at the Government Photo-zinco Office, Poona, to whom I am much indebted for the great care and trouble he has taken with the work. The small coloured reproductions were made in London by the Abbey Press, Ltd., who have produced a very fine print.

137. *The classes of masonry proposed—*

(a) All exterior work of piers, arch spandrils, etc., will be coursed rubble masonry first sort, with fine chisel dressing to face of stones. The interior of piers and spandrils will be uncoursed rubble masonry, in hydraulic lime mortar.

(b) All string courses, parapet copings, pilasters will be fine dressed cut stone, set in hydraulic lime mortar.

(c) The arches will be made of single voussoir the full depth of arching and rough chisel dressed to template on all faces. They will be set in cement mortar with the thinnest possible joints. The faces of voussoirs exposed to view will be fine chisel dressed.

(*d*) The ower portions of the masonry floor and pavements of Barrage will be of uncoursed rubble masonry in hydraulic lime mortar, or if it is found more economical to hurry the setting, and save in pumping, cement mortar may be used.

(*e*) The upstream pavement, as far as the cut waters of piers, will in any case be cement pointed for a depth of 3 inches from the surface.

(*f*) From the cut waters to the downstream end of the masonry floor, the upper surface will be formed of special hard stone masonry (stones set on end vertically) about 15″ deep, set in rich cement mortar with wide joints.

(*g*) The downstream protection will be formed of concrete blocks $10' \times 5' \times 3'$ each.

These do not require to have strength, except for carrying their own weight when lifted, and it is proposed to make the lower 2′-6″ of them of hydraulic lime mortar and stone concrete, and the upper 6″ of cement concrete, to give them a good wearing surface to withstand the scour.

(*h*) The stone pitching under the concrete blocks will be graded from quarry chips at the bottom to large stone immediately below the blocks, so as to form an inverted filter to prevent sand being washed away.

(*i*) The stone pitching for the downstream and upstream aprons and for the guide bank aprons will be of the largest stone which can be conveniently handled by a single man.

(*j*) The pitching on side slopes of guide banks will be graded with small chips next the earth, and the largest possible stones on the exposed face, all roughly handpacked.

SECTION VI.

The Material used in the Structure.

I.—STONE.

138. Local stones will be used for every part of the structure. The hardest and best stone is found in the hills at Aror and Kalka about 6 miles from the Barrage site, and stone of very slightly inferior quality and hardness at Rohri. The latter deposits are extensively quarried and in constant demand for local buildings, etc. The North Western Railway has existing sidings running right into the quarries. The deposits at Aror and Kalka are scarcely touched owing to the greater distance from the Railway, and from the towns of Rohri and Sukkur from which much of the demand comes.

139. In Appendix H is given a report by Captain Townshend, R.E., Executive Engineer, who was attached to this district for a short time, and was asked to inspect the stone supplies. To his notes I would add the following remarks :—

(*a*) Some of the hills consist almost entirely of the stratified rock which he classifies as "A" group, while other hills are almost entirely of the monolithic structure which he classifies as "B" group.

(b) The " A " group stone is not only stratified horizontally but also vertically, in two planes approximately at right angles to one another, so that in fact this formation is like a stack of separate blocks. Stones larger than a 15″ cube cannot be obtained in any number from this formation, and about 12″×12″×15″ would be the largest ruling size for great quantities of blocks. If therefore this stone were used for the arches, it would be necessary to build the latter in two or more courses.

(c) It is an extremely hard and close grained limestone, milk white in colour and almost like marble in appearance except that it is non-crystalline. It will take a fair polish. It is free of faults within the blocks (formed by the bedding and cleavage lines) and is almost without markings of any kind, except for a very occasional flint.

Of the three sites examined, *viz.*, Kalka, Aror and Rohri, the former produces the best, *i.e.*, hardest and closest grained stone, Aror the next best, and Rohri last, but even the last is a very fine stone, suitable for the most severe loads, and capable of resisting the roughest wear of weather and water. It is comparatively easy to work and dress, but not so easy as the "B" group (monolithic) stone.

(d) The "B" group stone, *i.e.*, the monolithic mass is creamy in colour with small mottlings of milk white at close intervals. These white mottlings appear to consist of small portions of stone of the same quality as the "A" group stone already described, and these are surrounded with a matrix of the cream coloured stone which is of coarse and softer texture. The whole seems to have been formed under great pressure, as there is no suspicion of cleavage between any of the components, the mass being absolutely homogeneous.

(e) It is a most excellent building stone, easy to work, available in any size, and hardens by exposure in air or water. It is undoubtedly an eminently suitable material for all parts of the barrage structure, except for the paving of the floor, where the hardest available stone should be used to stand the abrasive effect of sand scouring through sluices. Similarly the extreme noses of the cut waters might be made of the hardest stone available, to stand the blow of trees and other debris coming against them.

(f) In Appendix I is given the result of the crushing tests of these stones.

It will be seen that the average crushing strength of Aror " A " stone is about 6,500 lbs./in.^{2} and of Aror " B " stone about 4,800 lbs./in.^{2} The maximum designed intensity of pressure in any of the arches is 316 lbs./in.^{2} (see Section IX, pages 73 to 80, paragraphs 182 to 194), giving factors of safety of about 20 and 15 respectively with " A " and " B " group stones.

The latter stone however is so very regular in quality, is available in such large blocks, enabling single stones to be used for voussoirs, and is so easily worked, that it is considered quite suitable for the arches, and preferable to using the harder stone in small courses with more joints.

(*g*) In addition to the "A" group and "B" stone, there is an unlimited quantity of loose top hamper yielding stones up to about 12″ × 6″ × 6″ (described hereafter as "C" stone). This stone is still harder than the "A" group stone. It has a considerable number of clear flints embedded in it and the limestone is almost as hard as a quartz. It can scarcely be scratched with a knife. This stone is eminently suitable for the hard stone paving of the barrage under sluice floors.

The less hard "A" group stone was used for paving the Jamrao weir, and has proved thoroughly satisfactorily. In my opinion the "C" stone is superior to Deccan trap rock for resisting the abrasive action of water, since it is non-crystalline and finer grained. It is proposed to pave the floors with these stones, stood on end, about 12″ to 15″ deep, and about 6″ square in plan, set in cement with wide joints which can be easily and thoroughly rammed. The surface of the joints would be left about ½″ below the suface of the stone, making a rough paving and preventing the jointing cement being broken by debris hitting it.

(*h*) I quote below remarks made by Mr. A. Hill, Chief Engineer for Irrigation, Bombay, in the 1910 Report on the Sukkur Barrage (paragraph 12, pages 5 and 6, volume 4):

"The quantity of stone is vastly more than is required on the Rohri side, the limestone hills extend for 15 miles, and the Nara Supply Channel has been cut at the foot of them for 11 miles and provides a convenient life of transport to the works by means of boats, the stone being carted a short distance from the hill to the boat, so that there is no doubt of the volume of stone required being readily obtained."

The Inspector-General in his notes has described the rocks he saw, but there are two other kinds of excellent stone available one a soft stone in large masses which can be wedged out to special sizes required. This stone is honeycombed *in appearance* and hardens in the air. It is useful for ashlar facings or copings.

Apparently Mr. Hill refers to the inferior "B" stone of Rohri. The good stone is not honeycombed.

The other stone is an exceedingly hard lime stone, so hard that the fracture is 'Conchoidal', the term used by geologists for the fractures of these very hard rocks. It is obtained in bands of a useful thickness, 9″ being readily obtained at quarries at Aror, close to the Nara Supply Channel. I do not think any better stone is required for the ashlar crest of the weir; it certainly will resist wear better than most trap rocks and much better than sand stones, and it is

This is apparently "A" group stone as it was obtained in *slabs* about 9″ thick for ashlar. The very hardest top hamper cannot be obtained in slabs.
A. A. M

doubtful whether the difference in the durability of this stone in the proposed position of the crest of the barrage wall exposed to scour of sand and water, and of the durability of granite or basalt is so great as to justify the great expense of procuring granite or basalt for the crest of the weir.

To procure any other stone will be to get a worse one than the Aror stone. It is certainly harder than marble and more closely grained.

The stone was used for the Ashlar for the scouring sluice floor at the Jamrao weir.

The ordinary very hard stone, but not obtainable in slabs like the Aror stone, is abundant and most suitable for rubble masonry."

II.—SAND.

140. In the 1910 Project it was proposed to use the river sand for making mortar and concrete, but this sand is extremely fine and contains much mica. It is a very poor building sand.

141. A much better sand is available, however, in the sand " bits " or hills which stretch for miles near the foot of the limestone hills of Aror at Patni. This is a sharp sand of fair sized grains, and is generally used for important local and river works. There is an unlimited quantity of it, and it is said to be perfectly clean a few feet below the surface of the hills, and does not need even washing. It could be easily brought to the barrage site by the barrage railway from the Aror quarries.

142. If a sufficiently good sand can be found in the river bed, it would of course be more convenient and cheaper, but at the worst a good sand is available in unlimited quantity within 3 or 4 miles of the work.

III.—LIME.

143. Mr. Hill writes as follows in the 1910 Project Report, paragraph 11, page 5, volume 4) :—

" The Inspector-General has made special reference to stone.

The stone at Sukkur and Rohri is a rich limestone, and when burnt, slakes freely and violently into a very white lime. When this is mixed with clay obtained on the banks of the Indus or anywhere in Sind and burned again, a good hydraulic lime is obtained suitable for use in the mass of a work and which sets well under water if allowed 24 to 48 hours to set before being submerged.

The Karachi breakwater and the Jamrao weir are examples of works built of this lime.

Lime is therefore abundant.

As the site of the work is on the railway, coal is readily obtained for burning lime and the lime can be provided."

144. To this I may add that coal mines are now in operation near Quetta so that the lead is comparatively short for coal. The coal produced is believed to be very poor in quality, but is probably amply good enough for burning lime.

145. Suitable stone for lime burning can be obtained from any of the local hills at either Sukkur, Rohri or Aror, so that this stone can be quarried at different sites to give the shortest and most convenient leads to the works on either bank.

IV.—CEMENT.

146. The quantity of cement to be used, as per the present designs and estimates, is comparatively small. Indian cement would almost certainly be used, and it is understood that the North-Western Railway are contemplating making cement at either Sukkur or Quetta. If so, this would be most convenient and possibly if the rate were low it would be worth while substituting cement for lime in the foundation mortar. This might enable work to be carried out more quickly and thus lessen pumping in the cofferdams—a very expensive, indefinite, and possibly risky item of the work which it is desirable to reduce as far as possible.

147. There are cement works at present at Bundi—about 920 miles by rail to Sukkur; at Katni—about 1,300 miles by rail from Sukkur; and at Porbander—about 300 miles by sea to Karachi and thence 290 miles by rail to Sukkur.

V.—IRON AND STEEL WORK.

148. There will be required an enormous quantity of steel sheet piling, both as part of the permanent structures, and for use during construction (cofferdams). The simplest and strongest form of piling is the "Universal" piling which consists of ordinary steel I beams and separate steel locking sections. Messrs. Tata and Company have entered into an arrangement for rolling these sections in India at their Sakchi Works, so all such material could be obtained in India, provided Messrs. Tata are able to meet the demand. This style of piling has the great advantage that salvage value is high, as the ordinary I beams can be used for buildings, structural works, etc., whereas special piles such as Lackawana, etc., are of little use for ordinary purposes.

149. There will also be a very large amount of structural steel work in the gates and counterweights. The material for these might either come from Messrs. Tata or from England, according as rates and supplies are more favourable at one or the other. They could be constructed either at the Public Works Department Workshops at Amritsar, or it might be worth while to erect shops at Sukkur and build the whole of this work there. Possibly the North-Western Railway could be approached to take over the shops for boiler and other construction afterwards. This is merely a suggestion. The rates shown in the estimate are for work built at Amritsar and carried to Sukkur. Similarly the gearing for the gates could be made at Amritsar or in England or elsewhere in India.

150. The large quantity of steel centering for arches could be made in Amritsar, Bombay or Karachi.

151. The great quantity of machinery, etc., required for construction plant should be purchased in England, where specialists in each kind of machinery can

be found. It is not within practical politics at present to purchase or make such plant in India.

SECTION VII.

The Gate and Counterweights.

152. The design for these has been provided by Mr. John Ashford, Superintendent, Public Works Department Workshops, Amritsar, at the request of the Bombay Government.

The clear span of the gates has been made 60′ as suggested by me, and this has been found to be the most economical size. Larger gates of 100′ span could be made, but would be much more expensive per unit area (about 13 per cent. more) and would have several rather serious disadvantages.

It is not necessary to enumerate these, as the Chief Engineer for Irrigation and the Inspector-General of Irrigation have accepted the 60′ gate as suitable.

153. The design for gates shown in plan No. 55 is for gates 21′ high. Actually they will be only 18·5′ high, and the final design will be modified accordingly. Mr. Ashford's estimates have been reduced in the ratio of these heights.

154. The gates are provided with antifriction rolling paths, working in cast iron grooves, built into the masonry piers. They will be suspended on wire ropes passing over pulleys at the top of the bridge, and thence round the pulleys of the counterweights to an anchorage on the bridge. Thus the counterweight hangs in a bight of the rope, and travels one half the distance of the gate, thereby enabling the superstructure to be kept much lower than if the travel of counterweight were the same as that of the gate. The counterweights must therefore be double the weight of the gates.

155. The counterweights as designed by Mr. Ashford consist of mild steel casings or tanks 58′×8′×6′ and weighing about 25 tons empty, divided by partitions into several compartments, which will be loaded with sand to give about twice the weight of the gates.

156. On plan No. 47 is shown an alternative design for these counterweights, made in reinforced concrete, and this is recommended in preference to the steel tanks, as being far cheaper, more durable, and of more convenient dimensions, enabling the cost of the piers to be reduced (*vide* paragraph 126 *ante*). See also Appendix O.

157. Each gate and counterweight is provided with a set of operating machinery which will be fixed on the top of the pier at one end of the gate. This machinery gears direct to the suspending pulley or drum at the end adjacent to it, and also, through a shaft, spanning the gate, it gears with the suspending drum on the far side. The machinery consists of a worm and wheel gearing, connecting to a train of gearing. The worm gearing of each gate is fitted with a pair of cranked handles for working by hand and two or four men will be able to operate any gate by hand, in emergency.

158. For ordinary operation it is proposed to work the gearings by power, either electric or petrol motors being used. This could be done in two ways :—

(a) By fixing an electric or petrol motor to each set of gearing, or between two gates, with clutches for working either. This method would require 33 sets of motors and clutch gearing, or 66 separate motors.

(b) By using a travelling, electric or petrol, motor trolley which can move itself quickly to any gate and be connected by a sprocket chain to the special driving wheel on the gearing of each gate (*vide* paragraph 127 (*d*) *ante*).

159. By this method (*b*) with 6 such trolleys (one spare) the whole of the barrage gates could be fully opened in 7 hours. The most rapid rise of the river at the barrage site, hitherto recorded is 3·2′ in 24 hours (April 11th-12th, 1914). To pass this increased flood, it would have been necessary to open only 20 gates in the 24 hours, whereas the 5 trolleys could easily have opened these 20 gates in 2 or 3 hours.

160. The 6 travelling, electric or petrol, trolleys are therefore strongly recommended for this work, as they not only would save 66 motors, or 33 motors and clutch gears, but in addition, they provide a means of rapid and easy communication across the mile-long bridge; and as regards lifting the gates, any one traveller is interchangeable with every gate, so that there is no possibility of the breakdown of power for any gate.

SECTION VII-A.

Method of operating Gates.

161. Regulation will be made by allowing surplus river discharge to pass below the gates, the latter being raised sufficiently to pass the required discharge. Whenever the natural level of the river is as high as, or higher than, that required for the canals, all gates will be fully raised clear of the water, and the only obstruction to the river then will be the piers.

162. As soon as the river begins to fall below the required level, some or all gates (usually all), will be lowered sufficiently to head up the river to required level upstream. Throughout the period during which the river is thus headed up, the scouring sluice gates will be manipulated in the manner which is found to be most suitable, so as to reduce the velocity of the river water in the approach channels to such a point, as will keep the surface water, for admission to the canals, at a lower velocity than that in the canals, or at least, to reduce the velocity to such a point, that the heavier silt is either deposited in the approach channel, or confined to the lower levels of the water, where it can be drawn under the scouring sluices, leaving the surface water, for the canals, free of the heavier silt.

It is *probable* that this result will be best effected by keeping very slightly open, one or more scouring sluice gates, adjacent to the regulators, and thus keeping a steady draw on the heavy silt-laden water, below the level of the canal sills.

163. It is possible that a similar reduction of velocity, in the approach channels, could be effected in the floodseason, by completely, or almost completely,

closing all the under sluice gates, and creating afflux in the river, to pass the river discharge through the ordinary barrage sluices, which would be fully open. Under these conditions, a small discharge would flow over the top of the scouring sluice gates, but this volume, added to the total discharge of the canals, would give a lower velocity in the approach channels, than the natural velocity of the river; and would give more favourable conditions for the supply of the canals. Such action, if adopted, would cause the deposit of heavy silt in the approach channels, and this could be scoured out as often as necessary by temporarily raising the scouring sluice gates.

164. It would be possible to continue such procedure until the afflux created in the river gave a level upstream as high as the highest flood level for which the works and guide banks are designed. It is only in the very highest floods that such action could not be taken.

165. This is merely a rough suggestion, put forward to meet a possible difficulty of taking too much silt into the canals, when the natural level of the river is higher than that to be held by the barrage, at which times, the natural velocity of the river is much higher than that of the canals.

166. Statements will be worked out later showing the effect of such regulation on river levels at different stages. The point hitherto has not been considered, but it has been assumed that the canals can be worked satisfactorily, when taking only surface water of the high floods, at the natural river velocity. The suggestion therefore embodies a possible improvement, not hitherto considered essential.

Section VIII.

The Approach Channels and Divide Walls in River.

(*See Drawings Nos.* 4 *and* 64.)

167. These walls are required to confine the streams of river water flowing to, and past, the canal head regulators. It is necessary to separate these streams, on either bank, from the central portion of the river, in order that the effect of the barrage scouring sluices may be concentrated along the whole length of the face of the regulators. Without such walls, the draw of the scouring sluices would be dissipated, at a short distance above the gates, over the whole, or the greater part of the width of the river.

The number of spans of scouring sluices to be provided, and consequently the width of the approach channels, is a point of considerable importance.

168. When the main portion of a weir consists of falling shutters, which normally are opened only in the flood season and closed with difficulty, it is necessary to be able to pass the ordinary cold weather discharge, through the under sluices, but when the whole barrage and the scouring sluices consist of similar sluices which all can be operated with equal ease, the cold weather discharge can be passed through any portion with equal ease and there need be no relation between the discharge of the scouring sluice portions, and the cold weather discharge of the river.

Even in the Punjab, where falling shutter weirs are adopted, there appears to have been no theory connecting the river discharge and the capacity of the undersluices.

169. In this connection I might quote Mr. Schonemann, Superintending Engineer, Punjab Irrigation, in his " Design of Canal Head Works." He states: " The function of undersluices is to scour the river bed in front of the canal head, to keep the river bed low, and to prevent shoaling. This function is not best served by great width of water-way, but by afflux, or head of pressure." Again he says: " The width of water-way given to the under sluices (Khanki) was 240,' exactly the same as in the case of the existing head works at Rupar and Madhopur; and apparently designed without any other principle than that of imitation." And again, " In the design of undersluices it should be borne in mind that what is wanted is high velocity and great erosive power, rather than great water-way and discharging capacity. Sluices should therefore be relatively narrow and deep in water-way, relying for their draught and velocity on the afflux set up by the weir; and their discharging capacity need not be very much greater than the full capacity of the canal at the low stages of the river."

170. I think, however, that in formulating this rule he has overlooked one important point. The undersluices must be separated from the weir by a divide wall extending to opposite the end of the regulator. Hence a separate channel is formed through which the whole discharge of the canal has to pass to the regulator.

If this channel be made very narrow, then the velocity in it will be very high and this would nullify its effect as a silt collecting basin.

171. It seems therefore that the scouring sluices should be made of such width that the velocity in their approach channel is kept low. Perhaps Schonemann assumed this.

172. Accordingly, on the left bank, 7 spans of scouring sluices are provided giving an approach channel about 487′ wide. This channel at its entrance has to carry the whole discharge of the left bank canals, which totals about 25,000 cusecs from June to September. The depth at entrance to the channel is 20·5′, so that the mean velocity with all scouring sluices closed would be about 2·5 feet/sec. as against about 3 feet/sec. in the canals.

173. But in addition to the canal discharge this channel has to carry the surplus discharge to be allowed to pass through the scouring sluices for scouring purposes. Thus if a mean velocity of 3 feet/sec., or a little higher, say 3·25 feet/sec. is allowed in the approach channel, this would pass about 32,500 cusecs giving about 7,500 cusecs surplus to pass under the scouring sluices.

174. In the cold season, the combined discharge of the canals is less, so that either the discharge of the scouring sluices may be increased, or the velocity in the approach channel will fall. This is entirely advantageous, as the lower the velocity, the less silt will enter the canals, and the more be deposited in the approach channel below canal cill level. It can be scoured out from here, at intervals, by opening the scouring sluices, or the latter, if kept very slightly open, will continually draw it through the barrage.

If more silt is required in the canal water, this can always be obtained by closing some of the openings of the regulators and taking lower water through others. The trouble, in most canals, is to exclude surplus silt.

175. Similarly on the Right Bank, five scouring sluices are provided, giving an approach channel about 347′ wide, for a canal discharge of about 19,500 cusecs, or a velocity (without surplus discharge through scouring sluices) of about 2·75 feet/sec.

176. A second point to notice is that, as the stream in the approach channel passes the regulator openings, and approaches the barrage, it is constantly decreased in volume. Hence to maintain a constant velocity in the channel, it would be necessary to reduce its area, in the same ratio as the decrease of volume passing along it. It is not possible to vary the width of the channel in plan, as this would mask the openings of the barrage; but in the present design, the depth of the channel is increased by 3′ at the river end (see plan No. 60) where the discharge is greatest, and this depth is gradually reduced as it comes to the barrage. This partially allows for the reduction in the volume of the water flowing along the channel.

177. The velocity still will be lower at the barrage end, so that more silt will be deposited, or tend to be deposited, at this end; and this is convenient as it is adjacent to the scouring sluices. At the same time, the drop in the bed level, at the upstream end, where the velocity is highest, gives a deeper pocket below canal cill level, in which silt can be deposited, or the lower silt-laden water can pass, without affecting the surface water entering the canal.

The Divide Walls (See Drawing No. 64).

178. These walls do not require to be water-tight, and as they have to be built in the river, for a long distance, where it would be difficult, and very expensive, to make a rigid foundation, the walls have to be designed to stand settlement, and to be constructed without masonry foundations.

179. The bed of the river will be dredged (if necessary) to 3 feet below the required bed level of the approach channels. On this dredged surface loose pitching of large stone will be deposited under water to a depth of 3 feet over the whole area of approach channels, and extending about 32 feet to the river-side of the base of divide wall.

180. On this pitching will be deposited large concrete blocks, each 10′×5′×3′, stacked in courses to break joint with one another in plan and elevation as shown in drawing No. 64.

These will be built, as shown, to form a wall 20′ wide at base, 5′ wide at top and 27′ high, terminating at 0′ to 3′ above highest estimated flood level.

181. As this wall will be built in the low water season, only the lower three courses will be under water. These will he placed by floating cranes, and guided into position by divers, or by special arrangements for the purpose. The remaining 6 courses will be above water level in the cold season. The wall will be protected from scour, on the river-side and upstream end, by an apron of stone pitch-

ing, 50′ wide and of average thickness $5\frac{1}{2}$ feet, designed to fall into any scour that may occur.

SECTION IX.

The Loads and Stresses allowed on masonry.

182. In designing the bridges severe loads have been assumed to allow for future developments of traffic, and for possible military traffic.

183. *For the road-bridge* a live load of 100 lbs. per square foot over the full area of footpaths and roadway has been assumed. To this is added 13 per cent. to allow for its " live " effect. This is the allowance given by Farr for a span of 60′. To this load has been *added* (without any deductions) the weight of a steam roller or traction engine weighing 15 tons, having 9 tons on the rear axle at the centre of the bridge, and 6 tons on front axle 11′ from the centre of bridge. These loads are assumed to be distributed over the full 25′ width of the bridge.

184. The weight of a 60 pounder B. L. gun is 4 tons 12 cwt. on one axle, or 5 tons 8 cwt. on two axles, and of a 5″ B. L. gun 3 tons 13 cwt. on one axle and 4 tons 6 cwt. on two axles. These loads are therefore much less severe than that of the steam roller allowed for. Military motor lorries fully loaded would also be much less severe, and light electric or motor trams, if ever required, would also be a less severe load.

185. It may be mentioned that the system of loads adopted gives identically the same pressures as an evenly distributed load of 200 lbs. per square foot *plus* the weight of roadway, parapet, etc., over the full area of roadway and footpaths, which shows the severity of the loading adopted.

186. With this assumed loading the maximum stresses in the masonry arches are designed to be below 320 lbs./in.^{2}. This is a somewhat higher figure than has been often adopted in the past, but after careful enquiry and examination of records and published works on the subject, this pressure is recommended as a perfectly safe limit. See paragraphs 187 to 194.

186A. For the *Gate Bridge* the following loads have been allowed for, in addition to the full weight of the arches, spandrils and parapets :—

There will be only light foot traffic of work-people, etc., on this bridge, but a uniformly distributed live load of 45 lbs. per square foot has been allowed for over the full width of bridge floor between parapets.

186B. Part of this floor is carried by girders spanning the 16′ gap between the upstream and downstream arches. For calculating the load of these girders Farr's allowance, 22 per cent., has been added to the live load, giving an equivalent dead load of 55 lbs. per square foot and this load is conveyed to the arches as a point load at the end of each girder.

186C. To the distributed live load on the top of the 60′ span arches themselves has been added 13 per cent. giving an equivalent dead load of 50 lbs. per square foot over the whole surface of spandrils.

186D. In addition to the above loads, each arch has to carry the reactions due to the weight of the girders and the $3\frac{1}{2}''$ reinforced concrete decking they support.

Near each end of the span come the heavy girders carrying the gates and counterweights. The reactions at each end of these girders are shown in the diagram and calculations, and are carried by the corresponding arches as point loads.

186E. In further addition to the above loads, the upstream arch carries the full weight of the travelling 3-ton crane. The weight of this crane, with its 3-ton load suspended, is 15 tons. Farr says that for a 60′ span it is necessary to add only 13 per cent. to the live load, for its equivalent dead load, giving 17 tons as the equivalent dead weight.

But as the crane may give partial shocks due to the sudden lifting of its load, a further 3 tons is added, making the total equivalent dead load of 20 tons due to the crane. This is divided equally between two axles 5·3′ apart, or 10 tons per axle, and the calculations have been made with one axle just over the centre of crown, *i.e.*, with the whole load just on one side of the centre of arch. This is the worst position possible.

186F. Under this combined system of loading the maximum intensity of pressure in either arch is 316 lbs. per square inch (see also paragraph 271) or below the designed limit of 320 lbs. per square inch.

187. One of the most thorough writers on masonry construction is Ira. O. Baker. The following extracts are quoted from his "Treatise on Masonry Construction," 10th Edition, pages 293-296. (The italics are mine.) See also pages 611 to 613.

188. "581. Strength of Stone Masonry. The results obtained by testing small specimens of stone are useful in determining the relative strength of different kinds of stone, but are of no value in determining the ultimate strength of the same stone when built into a masonry structure. The strength of a mass of masonry depends upon the strength of the stone, the sizes of the blocks, the accuracy of the dressing, the proportion of headers to stretchers, and the strength of the mortar. A variation in any one of these items may greatly change the strength of the masonry. The importance of the mortar as affecting the strength of masonry to resist direct compression is generally overlooked. The mortar acts as a cushion between the blocks of stone, and if it has not sufficient strength it may squeeze out laterally and produce a tensile stress in the stone. It is certain that, usually, weak mortar causes the stone to fail either by direct tension or by tension due to the flexure rather than by compression."

"No experiments have ever been made upon the strength of stone masonry under the conditions actually occurring in masonry structures, owing to the lack of a testing machine of sufficient strength. Experiments made upon brick piers 12 inches square and from 2 to 10 feet high, laid in mortar composed of 1 volume portland cement and 2 sand, show that the strength per square inch of the masonry is only about one-sixth of the strength of the brick. An increase of 50 per cent.

in the strength of the brick produces no appreciable effect on the strength of the masonry; but the substitution of cement mortar (1 portland and 2 sand) for lime mortar (1 lime and 3 sand) increases the strength of the masonry 70 per cent. The method of failure of these piers indicates that the mortar squeezed out of the joints and caused the brick to fail by tension. *Since the mortar is the weakest element, the less mortar used the stronger the wall; therefore the thinner the joints and the larger the blocks, the stronger the masonry, provided the surfaces of the stones do not come in contact.*"

"It is generally stated that the working strain on stone masonry should not exceed one-twentieth to one-tenth of the strength of the stone; but it is clear, from the experiments on the brick piers referred to above, that the strength of the masonry depends upon the strength of the stone only in a remote degree. In a general way it may be said that the results obtained by testing small cubes may vary 50 per cent. from each other (or say 25 per cent. from the mean) owing to undetected difference in the material, the cutting, and the manner of applying the pressure. Experiments also show that stones crack at about half of their ultimate crushing strength. Hence, when the greatest care possible is exercised in selecting and bedding the stone, the safe working strength of the stone alone should not be regarded as more than three-eighths of the ultimate strength. A further allowance, depending upon the kind of structure, the quality of mortar, the closeness of the joints, etc., should be made to ensure safety. Experiments upon even comparatively large monoliths give but little indication of the strength of masonry. *The only practicable way of determining the actual strength of masonry is to note the loads carried by existing structures. However, this method of investigation will give only the load which does not crush the masonry, since probably no structure ever failed owing to the crushing of the masonry.* After an extensive correspondence and a thorough search through engineering literature, the following list is given as showing the maximum pressure to which the several classes of masonry have been subjected.

"582. Pressure allowed. Early builders used much more massive masonry, proportional to the load to be carried, than is customary at present. Experience and experiments have shown that such great strength is unnecessary. *The stone arch bridge of* 140 *feet* span at Ponty-Prydd, over the Taff, in Wales, erected in 1750, is supposed to have a pressure of 72 tons per square foot (1,000 *lbs. per square inch*) on *hard limestone rubble masonry laid in lime mortar.* Rennie subjected good hard limestone *rubble* in *columns* 4 *feet square* to 22 tons per *square foot* (300 *lbs. per square inch.*)"

"In the Washington Monument, Washington, D.C., the normal pressure on the lower joint of the walls of the shaft is 20·2 tons per square foot (280 *lbs. per square inch*), and the maximum pressure brought upon any joint under the action of the wind is 25·4 tons per square foot (350 *lbs. per square inch*)."

"The pressure on the *limestone piers* of the St. Louis Bridge was, before completion, 38 tons per square foot (527 *lbs. per square inch*); and after completion the pressure was 19 tons per square foot (273 *lbs. per square inch*) *on the piers* and 15 tons per square foot (198 lbs. per square inch) on the abutments."

"The limestone masonry in the towers of the Niagara Suspension Bridge *failed under* 36 *tons per square foot,* and were taken down—*however, the masonry was not well executed and was subjected to flexure.*"

"At the South Street Bridge, Philadelphia, the pressure on the limestone *rubble* masonry in the pneumatic piles is 15·7 tons per square foot (220 *lb. per square inch*) at the bottom and 12 tons per square foot at the top. 'This is unusually heavy, but there are no signs of weakness.'"

"583. Safe Pressure. In the light of the preceding examples it may be assumed that the safe load for the different classes of masonry is about as follows, provided each is the best of its class :—

Rubble	10 to 15 tons per square foot	=140 to 200 lb. per square inch.
Squared stone	15 to 20 ,, ,, ,, ,,	=200 to 280 ,, ,, ,, ,,
Limestone *Ashlar*	20 to 25 ,, ,, ,, ,,	=280 to 350 ,, ,, ,, ,,
Granite Ashlar	25 to 30 ,, ,, ,, ,,	=350 to 400 ,, ,, ,, ,,
Concrete (see S. 403)	30 to 40 ,, ,, ,, ,,	=400 to 550 ,, ,, ,, ,,

"584. A large committee composed of the leading architects and engineers of Chicago recently recommended the following values for the building laws of that city :—

Kind of masonry.	Lbs. per square inch.
Rubble uncoursed in lime mortar	60
,, ,, in portland cement mortar	100
,, coursed, in lime mortar	120
,, ,, in portland cement mortar	200
Ashlar *limestone in portland cement mortar*	400
,, granite in portland cement mortar	600
Concrete, portland cement, 1 : 2 : 4, hand mixed	350
,, ,, ,, ,, machine mixed.. ..	400
,, ,, ,, 1 : 2½ : 5, hand mixed	300
,, ,, ,, ,, machine mixed ..	350
,, ,, ,, 1 : 3 : 6, hand mixed	250
,, ,, ,, ,, machine mixed.. ..	300
,, natural cement, 1 : 2 : 5	150."

189. It will be seen that for limestone ashlar Baker recommends a limiting pressure of 280 to 350 lbs./in.², while the Chicago Committee recommends 400 lbs. in.². My calculated maximum limit of 320 lbs./in.² is therefore below their average.

190. The various examples of limestone masonry, quoted from actual practice, show that this pressure has been considerably exceeded at times, as for example in the St. Louis Bridge and the Ponty-Prydd Bridge, though usually somewhat lower pressures are adopted. But as Baker very rightly points out, the many cases of existing structures with low pressures are of little value in deciding what is the safe limit of pressure. The only case of failure he quotes, is that of the Niagara Suspension Bridge, where the limestone towers failed under a pressure of 500 *lbs./in.²*, but he states that the masonry was not well executed and was subjected to flexure, so this is not a good test.

191. The St. Louis Bridge on the other hand stood a pressure, during construction, *of* 527 *lbs./in.*² without damage. But the most striking example of the strength of such masonry is the Pont-y-Prydd Bridge in South Wales. This has stood a *pressure of* 1,000 *lbs./in.*² for 160 *years*, and is still in excellent condition. The following further details of this bridge are taken from Trautwine, pages 615-616 :—

Span.	Rise.	Radius.	Depth at Crown.	Engineer.
140′	35′	87·5	1·5	Edwards."

" Pont-y-Prydd, in Wales, is a common road bridge of very rude construction with a dangerously steep roadway. It was built *entirely of rubble, in mortar, by a common country mason, in* 1750 ; *and is still in perfect condition.* Only the outer, or showing arch-stones, are 2·5′ deep ; and that depth is made up of two stones. The inner arch stones are but 1·5 feet deep ; but from 6 to 9 inches thick. The stone quarried with tolerably fair natural beds ; and received little or no dressing in addition. The bridge is a fine example of that ignorance which often passes for boldness."

192. The last statement is less than generous, and scarcely justified by facts, especially if the history of this bridge, and of its capable "common country mason" builder and designer is studied.

The bridge is perhaps the most valuable work existing, to show what loads can actually be carried by good limestone masonry.

193. As Baker shows, the strength of masonry is only partly and slightly dependent on the strength of the stone, while that of the mortar has a very large effect on the strength of ordinary masonry.

194. In view of his conclusion that, " the thinner the joints, and the larger the blocks, the stronger the masonry, provided the surfaces of the stones do not come in contact ; " and that in our arches it is proposed to use thin joints of strong cement mortar, and very large blocks of carefully dressed stone for the voussoirs, I consider that we might with perfect safety adopt a much higher pressure than that now recommended. A very high rate is allowed in the estimates for the easily obtained and easily worked stone, so that the very best work can be done. I am allowing a factor of safety of about 15 on the crushing strength of the stone.

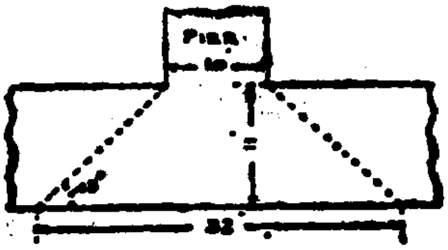
It is only in the arch masonry, which will be ashlar of the very best quality set in cement mortar, that this high pressure will be met. The maximum pressure on any parts of the piers or superstructure is far lower—under 100lbs./in.² and is unquestionably safe.

Section X.

Pressure on Sand below Foundations.

195. The only points at which there is any considerable pressure on the sand are below the piers. The piers stand on a continuous slab of solid masonry 11 feet thick, and it is probable that the whole weight of the superstructure and piers is distributed almost evenly over the whole area of this slab. But for cal-

culation it has been assumed that this would not be so, but that only so much of the slab masonry transmits the pressure, as is included in a 45° slope from the base of the piers thus :—



196. The worst case will be at the abutment piers during construction, or in the event of failure of the arches on one side of them. The maximum intensity of pressure on the sand, under these conditions (see plan No. 49) is only 2·78 tons per square foot, while the average intensity of pressure over the base width is 1·74 tons per square foot.

197. The sand on which the barrage is founded is extremely fine and compact, and provided it is prevented from spreading will probably bear almost any load.

In this connection I again quote from Baker's "Treatise on Masonry Construction," pages 339 to 342.

198. "663. Sand. The sandy soils vary from coarse gravel to fine sand. The former when of sufficient thickness forms one of the firmest and best foundations; and the latter when saturated with water is practically a liquid. *Sand when dry, or wet sand when prevented from spreading laterally, forms one of the best beds for a foundation.* Porous, sandy soils are, as a rule, unaffected by stagnant water, but are easily removed by running water; in the former case they present no difficulty, but in the latter they require extreme care at the hands of the constructor, as will be considered later."

"664. Compact gravel or *clean sand, in beds of considerable thickness, protected from being carried away by water, may be loaded with* 8 *to* 10 *tons per square foot with safety. In an experiment in France, clean river-sand compacted in a trench supported* 100 *tons per square foot. Fine sand well cemented with clay and compacted, if protected from water, will safely carry* 4 *to* 6 *tons per square foot.*"

"The New York pier of the Brooklyn Suspension Bridge is founded 44 feet below the bed of the river, upon a *layer of sand* 2 *feet thick* resting upon bed-rock the maximum pressure being about 6¾ tons per square foot."

"At Chicago sand and gravel about 15 feet below the surface are successfully loaded with 2 to 2½ tons per square foot. The Washington Monument, Washington, D.C., rests upon a *very fine sand two feet thick underlying a bed of gravel and boulders, the ordinary pressure on certain parts of the foundation being not far from* 11 *tons per square foot, which the wind may increase to nearly* 14 *tons per square foot.*"

"Corthell cites *ten examples* of structures that give pressure on *fine sand* ranging from 2·25 *to* 5·8 tons per square foot, *the average being* 4·5 *tons—all without settlement.* The same author gives *three* examples in which pressures of 1·8 to 7·0 tons per square foot (*average* 5·2) on *fine sand gave notable settlement.*"

"Corthell gives *seven examples* of structures founded *on aleuvium and silt in which the pressure ranged from* 1·5 *to* 6·2 *tons per square foot, the average being* 2·9 *tons in which there was no settlement*; and two examples in which there was notable settlement under pressures varying from 1·60 to 7·60 *tons per square foot.*"

199. Now the sand below the barrage is prevented from spreading, or from being removed by water, by the four curtains of steel sheet piling driven below the foundations, and embedded at their top ends in the masonry.

The sand is therefore compacted and protected in three great trenches; and the central slab of foundation masonry, which carries the weight of the superstructure, rests on the sand of the centre of these three trenches. Moreover, as the steel sheet piling is embedded in the foundation slab, this piling also will help to support the weight, *but no allowance has been made for this in the calculations for pressure on the sand.*

It is considered therefore that the extreme maximum pressure allowed, *viz.*, 2·78 tons per square foot and the normal maximum of 2·48 tons per square foot are low and very safe figures. At Khanki, the pressure on the sand below the downstream toe of the canal head regulator is 3 tons per square foot, with no wells or piling to prevent lateral spread.

PART III.

THE CANAL HEAD REGULATORS.

INDEX.

PART III.

THE CANAL HEAD REGULATORS.

Section I.

General.

A.—FLOORS.

200. The principles on which the floors of these regulators have been designed are similar to those followed for the design of the barrage floors.

B.—WATERWAY.

201. The width of opening provided for each canal has been designed to give a permanent cill not less than 6 feet above the floor of the approach channel when the canals are getting designed full supply, with a drop of 6 inches through the regulators.

202. The mean velocity through the regulators under these conditions will be about 3·6 feet per second, while the mean velocity in the various canals varies from about 3·0 feet/sec. to 3·27 feet/sec. (except in the case of the Eastern Nara—see later).

203. When the river level is higher than that required for the canals, *i. e.*, when the drop through the regulators is more than 6 inches, then the velocity of

intake, through the regulators, will be higher; but at the same time owing to the smaller area of discharge required, the rising cills and gates will come into operation, and the water will be withdrawn only from the higher (and less silt-laden) levels of the river.

204. In any case, the velocity through the regulators is not of great importance, provided—

(*a*) The low level water of the river is not admitted, and

(*b*) still more important, that the velocity of the water in the approach channels is kept low, if possible, lower than that in the canals. This point has been dealt with already in paragraphs 170 to 177 *ante*.

C.—REFERENCE TO PLANS.

205. Plans Nos. 3 and 4 show the general lay out in plan of all regulators. Plan No. 60 shows the general elevation of all regulators. Plans Nos. 9 and 10 show the sectional elevation through the regulators and guide banks.

Plans Nos. 62 and 63 show the detailed design of the regulator superstructure.

Plan No. 61 shows the detailed design and stability diagram for the floor of regulators.

DETAILED DESCRIPTION OF REGULATORS.

SECTION II.

Design and Stability of Regulator Floors.

206. The general principles of the design of the floor are the same as for the barrage floor, and are fully explained in section (ii), paragraphs 96 to 105 *ante*.

The same hydraulic gradient, 1 in 17 has been adopted, the same unit weight for masonry, and the same factor of safety against upward pressure, as in paragraph 106 *ante*.

207. The regulators have to be designed to be capable of complete closure at any stage of the river. The estimated highest flood level is R. L. 200·5 and the bed level of the canals is shown as R. L. 180·5, giving a total head of 20′, with canal empty.

208. Several of the canals will actually have their beds at a higher level than that shown, but as these cannot be finally decided until the detailed designs of the canals are settled, I have adopted the worst condition for design, and have estimated all at this level. When the final designs of the canals are worked out, the designs of their head regulators will be modified accordingly. All such modifications will result in savings of some magnitude.

209. Referring now to the general design submitted (Plan No. 61) it will be seen that a masonry apron 4′ thick by 55′ wide has been provided on the river side of the regulator floor. This upstream floor or apron never has a net upward pressure on it, so that theoretically it can be made very thin. Any increase in

the width of this apron results in a net saving in the total masonry of the regulator floor, as the portions downstream of the gates, necessary to provide the balance of length of creep, have to be made more heavy to withstand upward pressure.

210. In view of the fact that this upstream apron is permanently submerged in the open approach channel from the river, and that inspection is therefore never possible, and repairs would be very difficult, it has been considered advisable to restrict the width to that shown, *viz.*, 55′. For the same reasons the thickness has been made 4 feet to provide a really solid block of masonry, not liable to crack or settle. Any cracks in this apron, of course, would increase the upward pressure on the rest of the floor, at once.

211. At the riverside edge, the apron is protected and supported by the curtain of steel sheet piling, driven below it, and embedded in it, while, at the regulator side, it will be built homogeneous with the heavy central floor. It is protected from scour on the river side, by heavy stone pitching, 3 feet thick, which will extend over the full width, and full length, of the river approach channel.

212. Immediately behind the permanent masonry cill of the regulator, the surface level of the floor has to be kept low enough to allow the steel rising-cill to be lowered, until its top is flush with that of the masonry cill. This gives R. L. 177·5 as the floor level at this point.

The bed level of the canal being at R. L. 180·5, the floor is sloped upwards at 1 in 10 for a length of 30 feet until it attains bed level.

213. A minimum thickness of about 10′ is considered desirable for this central slab of flooring which has to distribute the weight of the piers and superstructure. The curtains of steel sheet piling have been made of such depth as to utilize the weight of the floor economically for resisting the balance of upward pressure at each point.

214. The bottom of the floor has been made horizontal, with vertical steps, to reduce the thickness at intervals to that required for safety. The total length of this central block is 60′. It is 2′-6″ thick behind the cill, and 10′ thick at the downstream side.

215. The downstream floor is 70′ long and requires a thickness of 6′ for safety at its junction with the central floor. The thickness is reduced to 3′ at the downstream side.

216. The four curtains of steel sheet piling are driven respectively 15′, 20′, 20′ and 11′ below the bottom of the floor, and are all embedded, at their top ends, in the masonry. The upward water pressure is reduced to *nil* by the time it reaches the end of the downstream floor, after travelling direct from the river edge of upstream floor, along the underside of the floor and round the curtains of steel sheet piling to the downstream toe.

217. If, however, no provision were made to prevent it doing so, water under pressure could find its way through the soil round the outsides of the abutment and thus outflank the floor. To prevent this a curtain of steel sheet piling is

driven, on the line of the canals, under each abutment, and closing the spaces between the cross curtains of piling below the floor.

218. Further, the curtain of piling below the upstream side of the central floor is made continuous (see drawing No. 4) starting at the upstream end of the regulator river wingwall, and running without a break under all regulators and connecting walls, under the river abutment of the barrage, and under the downstream wing wall of the barrage, meeting finally the curtain of piling under the downstream floor of the barrage.

219. The upstream masonry apron of the regulators also is made continuous, starting from the upstream end of the river wing wall of regulators, and running unbroken to meet the upstream masonry floor of the barrage. The curtain of piling under the river side of this apron is also continued throughout its full length. This apron and the two rows of piling effectually prevent outflanking of the regulator and barrage floors in all directions, and, moreover, add greatly to the protection and stability of the whole work.

220. As regards protection against scour on the canal side of regulators, we have a length of 117′ of solid masonry floor, downstream of the gates, or 5·85 times the maximum head 20′. Beyond this there will be 85′ of large concrete blocks $5' \times 3' \times 1\frac{1}{2}'$ laid on $1\frac{1}{2}'$ of stone pitching, giving a length of 202′ from the gates or 10 times the head 20′. Beyond this point again will be a talus of loose stone pitching 2′ thick, for a further length of 200′, making a total protection of 402′ from gates, or 20 times the head.

221. The 1 to 1 side slopes of the canal will be protected with stone pitching $1\frac{1}{2}'$ thick from bed to berm level, as far as the end of the bed protection.

222. This bed and side protection for the canals is rather longer, in proportion to the head, than has been allowed for the barrage (*vide* paragraph 116), but in the latter there is provision for a falling apron at the end, and scour of the river bed beyond would not matter, whereas in the canal we wish to protect the bed and sides against all scouring action (due to eddying from the regulators) until the canal has settled down to a steady flow, when it has a non-scouring and non-silting velocity.

223. It is most improbable that the canal would be ever opened with a head of 20′. This could only occur with maximum flood level in the river and an empty canal. Even if the head regulator were completely closed for several days during the highest flood, it is doubtful whether the canal could drain itself dry in that time, or that the regulator would be reopened under such extreme conditions. The whole structure, however, is designed for such conditions as ordered by Government. The full investigation of the stability of the floor is given in Part IV, pages 97 to 100, and in Appendix L.

SECTION III.

Superstructure.

(See Drawings Nos. 62 and 63.)

224. As in the barrage design, all regulators are provided with two separate bridges carried side by side on the same piers. The upstream bridge is at a high

level for suspending and operating the regulator gates, while the downstream bridge is at a lower level and provides a road bridge for vehicular and foot traffic, giving connection between the roads along the guide banks, upstream and downstream, and with the road-bridge across the barrage.

The high level bridges will be referred to as the " Regulator Gate Bridges " and the low level bridges as the " Regulator Road Bridges."

225. All regulator openings are of 25′ clear span, with piers 5′ thick. Where there are more than 6 spans in a regulator, an abutment pier 10′ thick is provided at the centre, dividing the regulator into two bays. This will economise in arch centering, and increase the safety of the structures.

226. On the upstream side, no cut waters are provided, but the edges of the piers are just slightly rounded. This is found to give better results, for openings taking off at right angles to the supply stream, than sharp nosed piers. The permanent masonry cills are carried out flush with the face of the piers, so that the scouring sluices can scour right along the face of these cills.

227. On the downstream side of the regulators, the piers are provided with ease-waters of 5′ radius to reduce eddying effects.

SECTION IV.

The Regulator Gate Bridges.

228. These are similar in all regulators. They consist of two separate semicircular arches of 25′ span each springing at R. L. 202·0, *i.e.*, 2 feet above estimated highest flood levels. The upstream arch is 4′-3″ wide, and the downstream arch 4′ wide. There is a gap of 12′-6″ between the two arches, and in this gap will be suspended the gates and counterweights. Both arches are 1′-6″ deep at crown and 2′-0″ deep at springing. The top of the spandrils is at R. L. 219·0.

229. The gap between the arches is spanned at intervals of 5′-3″ by reinforced concrete beams, carrying slabs of reinforced concrete paving (removable, or otherwise, as considered desirable), for the decking of the bridge.

Near each end of the span will be a steel girder, in place of a reinforced concrete beam, to carry one end-frame of the lifting machinery. The other end-frame will be fixed on solid masonry above the piers.

230. The decking of these bridges will have to carry only a light load consisting of the work-people and their tools, etc., all heavy machinery being carried over the masonry piers and the steel girders mentioned above.

The system of loading is identical to that adopted for the Barrage Gate Bridge, with necessary changes in the weights and spans. See paragraph 186-A to 186-D *ante*.

This is more severe than is ever likely to occur, but it allows for heavy repair machinery being loaded on the bridge at any time, and for shocks and jars from same. Even with this heavy loading the stresses in the masonry have been kept very low—less than 160 lb. per square inch in the arches, and much less in the remainder of the structure. Details will be given later under " Stability."

231. A parapet wall 3′ high will be built on the upstream or river side of the bridge, but no parapet is provided at the ends or at the downstream side, as the bridge level here is only a few feet above the roadway and platforms alongside. Access to the bridges will be given by stairways at either end of each regulator Gate Bridge, these stairways starting at the platforms, formed at Road-level, between the regulators.

SECTION V.

The Regulator Road Bridges.

232. In all regulators the road-bridge is carried on elliptical masonry arches of 25′ span, 8·33′ rise, and full width of 25′-3″. It will be seen from the longitudinal section plans Nos. 9 and 10 that the roadway at the Barrage end of regulators is at R. L. 215·0, while at the upstream end of the regulators, where these join the guide banks, the roadway is at R. L. 212. This necessitates making the roadway over the regulators on a gentle gradient. On the Right Bank this gradient will be 1 in 400 and on the Left Bank 1 in 433.

The springing level of all arches in any one regulator has been kept the same, but this level is varied in each Regulator.

233. The top of the parapet wall on the canal side of bridges is also kept level for the sake of appearance while the road surface is on the gradient. This makes the height of parapet wall, above the footpath, greater at the upstream than at the downstream end, but as the longest regulator is only 360 feet, and the gradient 1 in 433, the difference in height is only 10 inches, so that at the downstream end that height above footpath will be 2′-7″ and at the upstream end 3′-5″ both of which are unobjectionable. The string courses at the base of parapet walls, on the outer face of the bridge will be level, and parallel to the top of parapet wall.

234. These parapet walls end at the abutments of each regulator, and between each two regulators will be the ends of canal banks, so that it will not be unsightly to start the next regulator parapet at a different level.

235. On the river side of the road-bridge, there is no parapet wall, as the high-level bridge, running side by side with the road-bridge, serves the purpose. Where the intrados of the high-level bridge arches is above the level of the footpath of road-bridge, the latter will be corbelled out under the high level arch and a small guard wall or curb built along this. The gap is never more than 2½ high, and merely gives a glimpse of the gates, and the river beyond.

236. The metalled roadway over the regulator bridges will be 16′ wide, as on the barrage road-bridge, with raised footpaths, 4′ wide, on either side. The combined abutments for both bridges in all regulators are 10′ thick above R. L. 202·0 (springing level of upper bridge) with a back slope of 1 in 4, below that point, to foundation level.

SECTION VI.

Architectural Features.

237. The general design of these regulators is in the same style as that of the barrage on which they depend, so that the motif is unbroken throughout. The frieze and parapets are supported on piers of square pilasters, springing from bases, carried on the cutwaters of the piers.

238. On the river front, the gate bridge superstructure of each regulator stands well above the parapet level of the river wall, each forming a massive structure of tower-like appearance, and defining at a glance the purpose and magnitude of each work.

While it is hoped that the structures have a fine and pleasing appearance the whole is purely utilitarian.

SECTION VII.

The Regulator Gates.

239. The discharge of water through the regulators will invariably be taken from the river over the top of the gates of the regulators.

In each span of a regulator there are three of such gates, each working in separate cast iron grooves, one behind the other.

240. All gates consist of steel girder frames, enclosed in steel plating.

241. Every gate will be fitted with Ashford's roller boxes with roller bearings which will convey the pressure to the cast iron grooves.

These are stated to have been found thoroughly satisfactory in actual use on gates of 25 feet clear span.

242. Stoney's system of free roller trains is not suitable for three tier gates owing to the space required, and the difficulty of making a water-tight joint between the gates in adjacent grooves. The roller boxes, on the other hand, can easily be made of no greater, or less, width than the gates, so that the latter in tiers can be set just to clear one another, with a staunching arrangement between the two gates.

243. The lowest gate will work in a groove just behind the permanent masonry cill and will be capable of being lowered entirely behind the latter when not required, or at any position above this, to give cut-off. This gate is described as a "rising cill". Its height will be 4'-6", and it will be operated by a screw gearing, capable of lifting its weight, or pushing it down, even if obstructed by silt behind the masonry cill. The gearing is so arranged that, when the river water level is at the normal level to be held by the barrage, and the canal requires a fully opened regulator, this gate can be raised clear of the water surface, for inspection and cleaning.

The gearing for working the gate will be fixed on the deck of the gate bridge and will be capable of being worked either by hand or by power.

244. The middle gate will be 8′-6″ high working in a cast iron groove immediately behind the rising cill. It can be lowered till its top is level with the top of the rising cill, at the highest regulating position of the latter, so that when the rising cill is unable to provide sufficient cut-off, the middle gate is lowered behind it and set sufficiently high to give the required cut-off.

When the middle gate is not required for regulation it can be raised clear of the water, and will then be open to inspection and cleaning.

245. The middle gate is suspended by wire ropes, which pass over geared drums fixed on the bridge deck and thence round the pulleys of the counterweight to an anchorage on the bridge. The counterweight thus hangs in a bight of the cable, and having only half the travel of the gate, must be of double its weight.

246. The top gate will be 8 feet high and will come into operation only when the middle gate is unable to give sufficient cut off. It can be lowered completely behind the middle gate, or set at any higher position, to provide the required cut off. It is supported and counterbalanced in the same manner as the middle gate. When not in use it can be raised clear of the water for inspection and cleaning.

247. When all three gates are set in their highest working positions, *i.e.*, each overlapping one another by 3 inches, the top of the top gate will be at R. L 202·25 or 2 feet above the highest estimated flood level. In this position the canal would be completely closed.

248. The height of the superstructure has been so arranged, that at any stage of the river at which any gate will not be needed for regulation, it will be possible to raise the gate clear of the then water level, while its counterweight will also be clear of the water, so that the gate can be inspected and cleaned.

249. In the case of the lowest gate, or rising cill, which will be most frequently in use, it will be possible to raise this clear of the water at any stage up to R. L. 195 (higher than the top of the barrage gates) by lowering the middle gate to rest on the pavement, and adjusting the supply, if necessary, at the other openings.

250. The design and estimate for these gates, *vide* Plan No. 68, has been kindly provided by Mr. Ashford, at my request, and arranged according to my suggestions.

251. Mr. Ashford, however, has designed them with a steel superstructure which I have replaced by masonry, with a resulting great saving, and with added permanence, decreased maintenance, and, it is hoped, improved appearance.

Mr. Ashford has also by mistake designed for a somewhat higher flood level requiring higher gates, but his estimates have been reduced in the ratio of the actual, to assumed, heights.

252. The counterweights designed by Mr. Ashford are steel casings to be filled with sand. These have been adopted in my design, but I would propose to substitute, for these, reinforced concrete weights, which will result in a great saving, (*Vide* also paragraph 126 *ante*, and Plan No. 47).

SECTION VIII.

Lifting Arrangements.

253. The machinery for operating the gates will all be fixed on the deck of the gate bridge.

There are separate winches and gearings for each of the three gates, in each span, and all are provided with means of operating them by hand.

254. As none of the regulators are of great length, there is no necessity to have travelling inspection trolleys, and as each regulator gate bridge is separate from its neighbour, with a drop between them, it would not be possible to travel on such a trolley from one to another. The maximum number of spans in any regulator is 12, and there would be little saving in using a travelling power-unit to operate these.

255. It is proposed, therefore, to fit sprocket wheels on opposite ends of the gears of adjacent spans, and to fix one motor over the pier between two such spans. The motor would be geared to a lay shaft, provided with two driving sprocket wheels, one for each set of gates. Each driving-sprocket wheel would slide on a feather shaft, so that it could be set opposite either of the three driven-sprocket-wheels on the three sets of gearing for the gates of one span.

Three link chains of different lengths would be provided, suitable for the drive of each gear respectively.

256. When desiring to lift any one gate the driving wheel would be slid along its shaft opposite the wheel to be driven, the link chain put on the wheels and the open link connected, and the motor would then operate this gate.

In this manner, one motor could operate six gates, *i.e.*, two spans of a regulator.

257. As in the case of all such fixed power units, it would be desirable to have all units interchangeable, and to keep a few spare units in case of breakdowns.

SECTION IX.

Connecting River Walls between Regulators.

258. Between the abutments of each two canals, a masonry wall is built to serve the double purpose of a retaining wall to support the earth filling between abutments, and to provide a protected face against the river in the approach channels. The river-side face of the walls has a batter of 1 in 12, and the back of the wall a batter of 1 in 4, with a top width of 3½ feet.

259. The top level varies from R. L. 215 for the wall joining the barrage and first regulator, to about R. L. 213·0 for the wall joining the two canals furthest upstream. This follows the fall in the road level over the regulator bridges. A parapet wall 3′ high will be built along the river-side edge of this wall.

260. The walls are founded on a masonry base 22′ wide by 5′ deep, the top of which will be at the level of the floor of the approach channel. The curtain wall

of steel sheet piling, mentioned in paragraph 218 above, is driven below this wall and embedded in the foundation masonry, providing extra support for the wall.

261. The foundations are further protected from the scour, due to the draw of the barrage scouring sluices, and to the intake of the canals, by the masonry apron 55′ wide and 4′ thick which is bonded into the foundation masonry. This apron also has a curtain of piling at its river-side edge, as described in paragraph 219 above.

262. The toe of the river walls, at bed level, is kept in the same line as the face of the regulator piers and cills, so that the whole face is unobstructed, and can be effectively scoured by the barrage.

Section X.

Upstream Wing Walls.

263. At the upstream end of the line of regulators on either bank will be a masonry wing wall, abutting on the back of the last regulator abutment. In plan the face of these walls will be in line with the toe of the guide banks, and the walls will be of sufficient height at all points to support the $1\frac{1}{2}$ to 1 slope of the guide bank where it meets the regulator.

264. The top width of the walls, at their junction with the abutment is 6′, and at the upstream end, where they drop down almost to bed level, is 2′ only. The face batter is 1 in 8 and the back batter 1 in 4. This gives a cross section at all points with a mean width of one third the height.

PART IV.

CALCULATIONS AND STABILITY DIAGRAMS.

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PART IV.

CALCULATIONS AND STABILITY DIAGRAMS.

SECTION I.

Calculations for stability.

265. The sets of calculations attached in Appendix I show details of loads and resulting intensities of pressures, on all the principal parts of the masonry structures. Calculations are also given for certain girders and other steel work.

266. Mr. Ashford has not supplied the calculations for the gates, counterweights and steel superstructures, but it is believed these have been designed in detail, with the exception of the Lattice Girder Road-bridge Estimate. The latter has not been designed at all by Mr. Ashford, but he merely gives an approximate estimate for it, based on estimates for smaller span and narrower bridges.

267. I believe this approximate estimate is much too low, and that the actual weight of the bridges and consequently the cost, would be at least 40 per cent. higher.

However, as this steel road-bridge is not recommended, it has not been considered necessary to take out a detailed design and estimate for it. Mr. Ashford's estimate is merely quoted for comparison with the estimate for a masonry structure. The believed error in the former, if corrected, would only make the comparison, already in favour of a masonry superstructure, still more favourable.

SECTION II.

The Stability Diagrams.

268. The graphic method of finding the resultant pressures and the lines of forces has been adopted throughout, and the diagrams have been drawn with great care and accuracy.

SECTION III.

Weight of Masonry.

269. The unit weight of masonry has been varied for the different classes of work, and the variation in each case gives the least favourable conditions for working.

270. The weight of the stone Aror " B " is about 150 lbs. per cubic foot.

The weight of the Kalka " A " stone is about 160 lbs./c. ft.

271. To obtain the worst conditions as regards loading of arches, it was assumed that the heavier stone might have to be used (this is not actually necessary or recommended) and the weight of the masonry of arches and spandrils was taken as 160 lbs. 1 c.ft. Actually, if the Aror " B " stone be used, as recommended, the weight of the arches and spandrils will not be more than 15 lbs./c.ft. which will give lower pressures in the arches, than the general calculations show. (See Case II, Set No. VI.)

272. For the pier masonry in which the " B " stone would certainly be used the weight of masonry has been taken as 150 lbs. per cubic foot, which is probably slightly higher than the actual weight will be, but gives the worst possible conditions for load on foundations.

273. For the masonry of the floors, in which the weight is required to resist the upward pressure of water, and which will be made of uncoursed rubble masonry with a higher proportion of (lime) mortar, the low weight of 140 lbs. per cubic foot has been assumed. Details of the external live and dead loads have already been given in section IX *ante*, and are clearly shown on the diagrams.

SECTION IV.

Intensity of Pressures on sections eccentrically loaded.

274. The formula used for calculating these stresses is $S=\frac{Q}{A}(1 \pm \frac{Ey}{K^2})$.

It is similar to that given by Baker on page 611, *viz.*—

$$P=\frac{w}{e}+\frac{6\ wd}{e^2}$$

but my formula gives a more general result, *viz.*, for any desired point in the section ; and the two values, obtained from the solution, give the stresses at equal distances " y " on either side of the centroid, a negative value indicating tension and positive values compression, so that if y is taken half the length of the section, the equation gives the stresses on both edges.

275. In the equation $S=\frac{Q}{A}(1 \pm \frac{E\,y}{K^2})$ (see diagram below).

S=The stress at the points considered, *i.e.*, at each extremity of the section.

Q=Total normal pressure on the section.

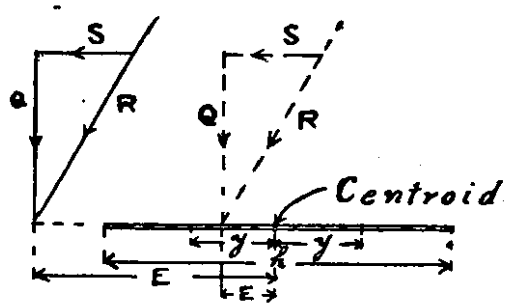
A=Area of the section=bh

E=The eccentricity of the load point, *i.e.*, the distance from the latter to the centroid of the section.

Y=The distance of the points considered from the centroid of the section.

K^2=(Radius of Gyration)^2 of the section.

$$=\frac{\text{Moment of Inertia of section}}{\text{Area of section}}=\frac{\frac{bh^3}{12}}{bh}=\frac{h^2}{12}$$



276. When the resultant pressure falls on either of the middle third points, *i.e.*, one-sixth of the length of section, from its centroid and "y" is half the length of the section, the equation simplifies to

$$S=\frac{2\,Q}{A}$$

and S=O

showing that there is no pressure at one edge of the section, and that at the other edge, the pressure is double the average pressure over the whole section.

SECTION V.

List of Calculations.

277. The following sets of calculations are contained in Appendix L :—

Stability Calculations for

A.—BARRAGE.

			Drawing No.
Set	I	Floor of ordinary and scouring sluices	42
„	II	Ordinary piers longitudinally	48
„	III	Abutment piers, in cross section	49
„	IV	Abutment of Road Bridge	50
„	V	Land Abutments of Gate Bridge	51
„	VI	Road Bridge Arch	52
„	VII	Gate Bridge Upstream Arch	53
„	VIII	Gate Bridge Downstream Arch	54
„	IX	Reinforced concrete flooring slabs, for Gate Bridge	*Nil*
„	X	Reinforced concrete beams to carry floor, for Gate Bridge ..	*Nil*
„	XI	Compound steel beam to carry gates, etc., for Gate Bridge ..	46

B.—REGULATORS.

			Drawing No.
Set	XII	Floor of Regulators	61
,,	XIII	Ordinary Piers longitudinally	65
,,	XIV	Abutment Piers in cross section	66
,,	XV	Land Abutments	66
,,	XVI	Road Bridge Arch	67
,,	XVII	Gate Bridge Arches	67
,,	XVIII	Reinforced concrete flooring slabs for Gate Bridge	*Nil*
,,	XIX	Reinforced concrete beams to carry floor for Gate Bridge ..	*Nil*
,,	XX	Steel beams to carry gates, etc., for Gate Bridge	*Nil*
,,	XXI	Connecting wall	51

PART V.

THE GUIDE BANKS.

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PART V.

THE GUIDE BANKS.

SECTION I.

Downstream Banks.

278. As the abutments of the barrage are made about 400′ from the present river banks, out in the river, it is necessary to provide curved guide banks downstream, to join to the existing banks and to train the stream issuing from barrage openings, to the full section of the river below.

279. These banks are designed and estimated to be constructed on the present river bed at their sites, but as soon as the cofferdam for constructing the first spans of the barrage has been made, silting will commence at its downstream side, and it is probable that by the time the guide banks are commenced, the river bed at their site will have silted up to low-water level, or nearly so. This would effect a large saving in earthwork.

280. The banks are designed of sand or earth with a top width of 40′ and with side slopes of $1\frac{1}{2}$ to 1 on river side, and 2 to 1 on land side. The river-side slope will be protected from scour, as follows. See Drawings Nos. 4 and 60.

281. Starting from the barrage road-bridge abutment will be a masonry wing wall with top at R. L. 210. This wall is 80′ long and at its downstream end its top is at R. L. 177′ or 2′ above pavement level. Behind this wall the earthen bank with $1\frac{1}{2}$ to 1 slope is protected by concrete blocks $5' \times 3' \times 1\frac{1}{2}'$ laid on $1\frac{1}{2}'$ of stone pitching up to R. L. 204·0. The remainder of slope to top of banks will be covered with 2′ of stone pitching only.

282. Beyond the end of the wing wall, as far as the downstream end of the concrete-block flooring of barrage, the whole river side slope of the guide bank from R. L. 204 down to pavement level will be similarly covered with concrete blocks, laid on $1\frac{1}{2}'$ of stone pitching, and above R. L. 204, the remainder of the slope will have 2′ of stone pitching only.

283. Beyond the downstream end of the concrete block slope, the whole river-side slope of the guide bank, as far as its junction with the river bank, will be protected with a 3′ covering of hand-packed stone pitching of large size.

284. At the toe of bank will be laid an apron of large stone, 50′ wide, 3′ thick at the toe of bank, and 5′-8″ thick at outer edge. This apron is designed to fall on a slope of 1½ to 1 as the bed scours at its edge, and has sufficient contents to pitch a 1½ to 1 slope, with an average thickness of 3′, to a depth of 40′ below the oe of the guide bank.

285. The tops of the guide banks slope down from R. L. 215 at the barrage to R. L. 203 where they meet the river bank.

SECTION II.

The Upstream Guide Banks.

286. The reasons for making guide banks, upstream of the Barrage, are threefold.

First.—To conserve the present regular channel for the river approaching the barrage.

Secondly.—To provide for this channel remaining of the same form, with a higher flood level than ever hitherto recorded, *i.e.*, to contain the highest estimated flood in the same river channel, leading on to the barrage.

Thirdly.—To prevent such a high flood from flowing over the natural river banks, flooding the country and possibly damaging and breaching the banks of the new canals, and perhaps thereby outflanking the Barrage abutments.

287. As regards the first reason, it has already been explained in paragraphs 45 and 46 *ante*, that the present channel is a most suitable one, and should be conserved.

For the same reasons it is desirable to raise the banks so as to contain the highest estimated flood in the same channel.

288. The necessity of the third reason is obvious. Apart from the danger of outflanking, it would be most undesirable to allow the land between the towns of Sukkur and Rohri, and the canals, to become flooded. This would not only menace the health of the towns, and the large railway communities on both banks, but it is proposed to utilize much of this land, for the residences of the large staff of officers and subordinates to be engaged on the construction. The bungalows will be permanent buildings and will be used for district and canal officials after the works are completed, so that these areas must be protected against the highest estimated flood.

289. It would be difficult, and as expensive, to protect these areas, without protecting the towns of Sukkur and Rohri, as by the proposed arrangements, which provide for the complete protection, on the river front, of both towns.

290. Since the highest estimated flood will be a natural flood, not caused by the barrage, (except an afflux of about one foot) the project is not responsible

for any flooding which might occur in the towns, and is therefore not really liable for providing protection. Government might be justified, therefore, in asking the Municipalities to contribute to the cost of such parts of the work, as provide protection for the towns, but as pointed out, such works also serve the purpose of the project.

SECTION III.

The General Design of the Guide Banks.

291. The guide banks have been aligned on regular curves or straight lines conforming to the general line of the present river banks.

They are kept at such distance from the present river edge, that the forming of the regular curves (or straight line as the case may be) will necessitate in most places a little excavation, or dressing of the existing river-bank slopes, and in some places a little filling, to form the slopes of the new banks down to the low water level.

292. These river side-slopes of the new banks will be continuous from low water level to the top of the banks, *i.e.*, no berm is left on the river side. This not only gives a regular section to the river at all stages, but it economises in the land required for the banks, and in stone pitching, since, if berms were provided, it would be necessary to pitch these also, and they would be source of weakness with a rapid flood passing over them.

293. The trimming of the river banks to form the side slopes (and the excavation for the apron at toe—see later) will generally provide almost sufficient earth for the formation of the guide bank portion above natural ground level. In places where there is a deficiency of earth from this excavation, it will be necessary to obtain the balance from borrow pits, if possible, from the river side, or the whole bank can be set-back slightly more from the river edge, to give the required quantity of cutting.

294. The whole of the river-side slope of the banks will be protected with 2′-3″ of hand-packed stone pitching, of which 2′ thickness will be large stone laid on 3 inches of quarry chips next the earth.

295. At the toe of the bank will be laid, at low water level, an apron of large size loose stone, 50′ wide, and 2½′ thick at toe of bank, and 6·4 feet thick at the river-side edge. The contents of this apron are sufficient when undercut, to fall on a 1½ to 1 slope, and pitch it to a thickness of 3′ for a depth of 40 feet below low water level (assumed at R. L. 186—a level to which the river may be expected to fall every year), *i.e.*, to R. L. 146.

296. The cross section of the river bed has been measured thrice weekly at the outfall section for the past 16 years, and weekly at the barrage section for the past 3 years, soundings being taken at intervals of 100′ right across the stream.

From these records it is found that the deepest scour at the outfall section was to R. L. 148·0 on 12th August 1914 with average bed level at R. L. 167; and at the barrage section was to R. L. 163 on 26th November 1917, with average bed at R. L. 179. On the latter date the deepest scour at outfall was to R. L.

159 only, or 11′ higher than on the previous date. If we assume the same difference in scour at barrage on the earlier date (observations were not taken then) it would give scour to R. L. 163—11=R. L. 152.

297. But these were the conditions with the *natural* river. When the masonry floor of the barrage is constructed, forming an inerodable bar across the river, such deep scour could not occur near the barrage, even with greater floods. On the other hand, at the outfall section, the greater floods estimated for, might cause considerably deeper scour than that recorded.

298. Actually on 12th August 1914 the deepest scour at outfall was 19′ lower than the average bed level on that date. The estimated average bed level at outfall for the assumed greatest flood is R. L. 154·35 (see Appendix E), and if we assume that deepest scour might be 20′ below average bed level it gives us scour to R L. 134·0 so that the provision made by the falling apron for scour down to R. L. 146 is insufficient at this point.

299. On the other hand, the estimated average *natural* bed level at the upstream end of the regulators, for greatest assumed flood, is R. L. 169 and owing to the effect of the barrage and the protection at the approach channel this must remain fairly regular across the stream. If we allow for local scour 10′ below the average bed level, it gives us R. L. 159, so that the apron provision for scour to R. L. 146 is excessive.

300. For simplicity in estimating, a constant apron width has been assumed, but in construction, this width would be varied as further investigations show to be desirable, the width being greater than 50′ at the upstream ends of guide bank where the river is narrower and deeper, and less than 50′near the barrage where the stream is wider and shallower. The constant width of apron adopted in the estimates is considered to give ample contents to provide for such suitable variation in the actual width to be laid.

301. The top of the guide banks has been kept at 2′ above the *estimated* highest flood level, or from 4′ to 5′ above the highest *recorded* flood level. The Indus River Commission Rule for height of river bunds is to allow 4′ free board above the highest recorded flood level.

302. The width of the top of the banks is made 25′ to allow for a double track roadway along it, and for security.

The back slope of the banks will be made 2 to 1.

A strip of land about 50′ wide will be reserved behind the banks to provide stacking ground for a reserve of stone, if considered necessary.

303. It is considered that all these provisions allow for the maximum expenditure likely to be required, and it is possible in view of the stable nature of the present river banks, that it may be considered safe and desirable to provide less protection than that now recommended and estimated for.

SECTION IV.

Details of Left Guide Banks.

304. Starting from the upstream end of the regulators, the guide bank is made of the design described above, and runs upstream, in a straight line for a distance of 3,600′. From this point the bank is curved in plan to a radius of 20,000′ for a further length of 5,500′.

305. At this point and for some distance upstream, the river bank is already protected with stone pitching, laid many years ago by the Railway authorities, to protect the landing places of their ferry steamers. This existing pitching has a slope of 1½ to 1 and is in excellent order. It extends in bands, at intervals, for several hundreds of feet, and at all points above this, although the water is very broken, there is no sign of erosion to the river banks, while at several places there are outcrops of high rock. It appears, therefore, that the river bed or the lower levels of the banks are in rock, and it is not proposed to provide a falling apron in these lengths, nor to pitch the river banks below natural ground level.

306. From the end of the 20,000′ curve mentioned above, the guide bank will be set back from the river edge leaving a berm of varying width along the river. The centre of the bank will be about 40′ from the edge of the high bank of the river, and for the remainder of its length will be quite a low bank, built above the natural ground to serve as a retaining bank for the estimated highest flood.

307. It will have a top width of 25′ and slopes of 1½ to 1 and 2 to 1 on the river and land sides respectively.

The river-side slope will be protected from wave wash by stone pitching 1½ feet thick from its top to ground level.

308. The following are details of this portion of the bank from the end of 20,000′ curve to the upstream end :—

				Feet.
(*a*)	A curve of	9,000′	radius for a length of	1,600
(*b*)	„	1,500′	„	400
(*c*)	„	1,000′	„	1,000
(*d*)	„	500′	„	250
(*e*)	„	100′	„	150
(*f*)	„	1,200′	„	550

At this point the bank joins the high rocky bluff of Satyun-jo-Astan, which forms a natural barrier far above the highest floods.

(*g*) A curve of 600′ radius for a length of 700 feet.

This is the last length of the bank, and it closes the gap between the Satyun-jo-Astan hill and the similar hill on which the abutment of the Rohri Cantilever Bridge is founded, and beyond which, the whole of the town of Rohri is built on high rock far above flood level.

309. The construction of this bank will completely protect all land between the town of Rohri and the proposed new head to the Eastern Nara, which would otherwise be flooded by the estimated highest flood level.

SECTION V.

Details of Right Guide Bank and Bunder Wall.

310. Starting from the upstream end of the regulators, this bank runs upstream, on a curve of 12,000′ radius, for a distance of 4,650 feet, at which point it meets the end of the existing masonry Bunder wall. The design of this bank, throughout its length, is as described above in paragraphs 291 to 303.

311. Behind the existing Bunder wall is the main bunder or roadway which is level with the door-cills of the houses built along it. These houses extend right to the end of the existing Bunder so that it is not possible to raise the level of the roadway.

312. The Bunder wall itself, however, can be conveniently heightened with a heavy masonry parapet, and the top of this parapet will be kept in line with the top of the guide bank, *i.e.*, 2 feet above the highest estimated flood level.

At this point the top of the parapet wall will be R. L. 202·7, while the present roadway is about R. L. 199.

313. To give connection between the roadways on the Bunder and on the guide bank, it is proposed to extend the Bunder wall about 100′ downstream curved inwards to meet the top of the guide bank, and built up to the full height of the latter at the point of junction. Inside the new piece of wall the roadway will be formed with a gradient of about 1 in 30 sloping down from the top of guide bank to meet the existing road along the Bunder wall.

This will give a through road connection between the town of Sukkur and the barrage, and across the latter, to Rohri, Khairpur and the surrounding country.

314. The proposed flood protection for the town of Sukkur consists of a heavy masonry parapet wall, with top 2′ above the highest flood level, built along the river edge of the existing Bunder wall.

315. This parapet will have an average height of about 3 feet, and a top width of 2′-6″, with a stepped back battering 1 in 4, and a vertical face to the river. The top of the wall will be sloped off 4 inches towards the river side, and the top edges on both sides well rounded to prevent cutting the ropes of boats tied up alongside.

316. This parapet wall will be continuous for a distance of about 8,400′ until it meets the existing high level parapet, well above flood level, about 600′ downstream of the Lansdowne Bridge.

317. Where there are existing river-side steps, or slopes for access to the water, gaps will be left in the parapet wall. At these gaps will be provided stout masonry abutment pillars for the parapet, on either side, and in each abutment

pillar will be left a groove, to take removable timber baulks for closing the gaps at times of high flood.

The baulks when not in use will be kept in similar grooves formed in the back of the parapet wall, so that they are always available when needed.

318. This parapet wall, with the guide bank, provides complete protection against the highest estimated floods, to the whole town of Sukkur and to the suburb of Adamshah, as well as to all land between the town and the new canals, which will include the site of the construction staff quarters and all works yards.

PART VI.

METHODS OF CONSTRUCTION.

INDEX.

PART VI.

METHODS OF CONSTRUCTION.

A.—The Floor and Underwater portions of Barrage and Regulators.

Section I.

GENERAL.

The Season's Work.

319. As explained in detail, in the following sections, the barrage and regulator floors will be constructed in the dry, inside large cofferdams.

As large an area will be undertaken each year, as can be completed during the working season.

Plan No. 71 shows the disposition of the various cofferdams for each season's work.

320. The heaviest year's work will be in the second season, and this will absorb all the labour which is estimated to be readily available. It will be seen that work in the barrage is confined to one cofferdam, near the Right Bank, in this year.

Even if it were possible to obtain more labour, and if extra plant were provided, still it would not be possible to make another similar cofferdam, near the Left Bank, in that year, as the unobstructed waterway between the cofferdams and through the completed portion of the barrage floor, would be insufficient to pass the possible river discharge at a reasonable velocity. With such a restricted waterway the velocity might rise to as much as 8 or 9 feet per second which would cause dangerous scour in the river bed at the ends of the cofferdams.

321. It is assumed that the completed cofferdams may be in site from the 15th October to 15th April (after the latter date they will be in course of removal) and during that period the river discharge sometimes rises as high as 313,000 cusecs with water surface at R. L. 192. With the arrangements of cofferdams shown, such a discharge could always be passed through the available waterway with a velocity not exceeding 6 feet per second and without scouring the natural bed between the cofferdams below R. L. 170·0. Protection of loose stone pitching will be thrown on the river bed outside the end of the cofferdam, to prevent scour along it and to form a falling apron which will pitch the sand slope down to the scoured bed level. It will be noticed also that in the second year, the regulator floors on each bank will be completed, as well as that year's portion of the barrage, *i.e.*, there are three cofferdams that year.

322. Some saving in plant could be effected by completing the regulators on one bank only in that year and doing those on the other bank in the following year, but it appears to be desirable to complete these regulators as early as possible, so that guide banks can be completed, and the abutments of the barrage can be fully protected, and also in order to keep the working arrangements on each bank continuously employed.

323. The quantity of temporary 40′ piling used in the cofferdams walls is a maximum in the second year's work, and all this has to be purchased for this purpose only. It will of course have a good salvage value when done with.

324. The other temporary piling is that required for the pumping trenches. Sufficient special piling is provided to make these trenches in the fourth year's cofferdam, which is fairly small. This quantity will be available for use in the previous seasons, but in those seasons a much larger quantity is required. The balance required in first, second and third years is available from the permanent piling to be used in the second, third and fourth years, respectively.

325. Hence the only temporary piling to be purchased is—

(*a*) Sufficient to make the walls of the cofferdams in the second year's work.

(*b*) Sufficient to make one side of the pumping trench in the fourth season's work.

(*c*) Sufficient to construct the wharves.

Much of this piling will be of the greatest value for use as temporary girders, staging, etc., during the flood season and after completion of the whole floor, when the work on superstructure is in progress.

SECTION II.

Construction of Cofferdams.

326. The cofferdams in which the construction of the barrage and regulators foundations will be made will consist of a single line of interlocking steel

piling 40′ long and driven about 27′ into the river bed, leaving 13′ above bed level. The maximum water level at which pumping will be necessary is R. L. 190 or about 8′ above the bed level.

327. The steel piling will completely enclose a great area of river bed and will be supported on the inside by a slope of sand resting against the piling up to water level. To sufficiently reduce the pressure of seepage water flowing into the pumping trenches in the interior of the cofferdams it is necessary to keep the walls of the cofferdam not less than 165′ from the pumping trench. This 165′ leaves room for a 50′ berm and a bank of sand with a slope of 1 in 8, inside the cofferdam walls. It is proposed to form this bank by the discharge of a dredger which will excavate the sand and silt, at the centre of cofferdam, down to the required foundation level. It is proposed to keep the outlet of the discharge pipe just below the surface of the water and to baffle the issuing water and sand in a cup-shaped baffle plate suspended below the outlet.

328. The shape of this baffle cup will be such that water will issue over its lip horizontally or slightly upwards and the perimeter of its lip will be such that the velocity of discharge over it will be quite low. Thus the sand and water will flow out gently on all sides just below the water surface in the cofferdams; and at a short distance from the outlet the sand will have lost its horizontal velocity and be free to settle vertically by gravity.

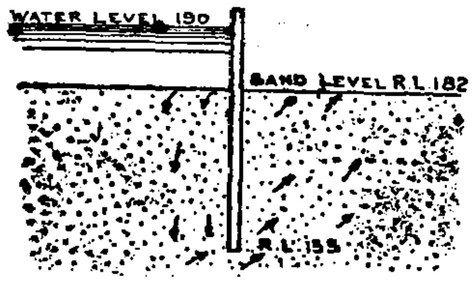
329. It is expected that by this arrangement the sand, which will be discharged, as described, all along the inside of the wall of cofferdam, will settle down to form a sloping bank having the natural angle of slope of this sand in water; or as there will be some disturbance of the water it may take a somewhat flatter slope.

Small experiments have been made by pouring samples of the various kinds of sand and silt, found at the site, into a tank of still water. It is found that these settle down to slopes varying from 1 in 3 to 1 in 6 when the water is agitated, and that the water can be roughly withdrawn without the flatter slope being exceeded. There seems no reason to doubt, therefore, that the slope of 1 in 8, the steepest allowed for in the cofferdams can be easily attained by the method proposed.

330. The proposed method of excavating in the cofferdams, and forming the sand slopes, by means of a dredger, is the only practicable method of performing these operations. Dredging and bank formation can start as soon as a fair length of the cofferdam piling has been driven and this will continue simultaneously with the pile driving, thereby lessening the time taken before the completed cofferdam is ready for laying masonry.

The piling walls of the cofferdam depend for support, above bed level, on this sand slope, so that it would not be possible to pump out the cofferdam until the slopes are made. Hence they must be deposited in the water and as the whole river bed outside and inside the cofferdam is under several feet of water, the sand for slopes must either be obtained by dredging or brought by boat from the shore. The latter method is impossible owing to the enormous quantities required.

331. Assuming for the moment that it would be possible to safely unwater the inside of cofferdam, before the sand slopes were made, the conditions would be as shown below.



There would be a head of 8′ of water to pass down the outside and up the inside of piling. Assuming loss of head in travel through sand as 1 foot of head for every 10 feet of travel; then as water has to travel from R. L. 182 to 155 and back to 182 (along the piling) the oss of head would be $\frac{2 \times 27}{10} = 5{\cdot}4'$ and the balance of head on the inside of piling would be 2·6′ of free head. This would create a great velocity and would certainly blow out the sand, but even if it did not do so, the discharge would be so great that the cost of pumping would be enormous. Hence excavation and formation of banks by dredger is the only method to adopt.

332. All pile drivers will be mounted on pontoons and will be electrically operated. The pile-driver will consist of an electric "hammer" in which the weight of the driving mechanism rests on the pile itself, after the latter is pitched, and the striking weight will be lifted and dropped automatically by electric power, giving a high frequency of blows, as in the case of steam piling hammers. Such an apparatus gives better results in driving through sand, than the slow heavy monkeys, raised by winches, of the older type of pile-driver. Even if winch-lifted monkeys were used, it would be cheaper and more convenient to use electric winches than steam.

The great advantage of the high speed hammer type appears to be that the blows are so frequent that they keep the sand in a state of vibration during which it is far easier to drive a pile through it than when the sand is at rest.

333. All pile drivers of whatever type used should be fitted with driving frames and leads for lifting and pitching the piles and for guiding them during driving. Each frame will be fitted with an electric winch for lifting and pitching the piles. It is possible that two or more pile drivers may be fitted at intervals on the same pontoon, spaced so that the distance between their piles will be exactly filled by a certain number of piles and interlocking pieces, but details will have to be very carefully elaborated to make such an arrangement successful. It would have the great advantage of enabling the speed of work on any given line of piles to be double or treble what it would otherwise be with only one pile driver working on the line and speed is essential on this work. The attached five sketches of a cofferdam explain the proposed method of operation. See also Drawing No. 71.

THE FIRST STAGE OF OPERATIONS.

334. Driving of the two outer lines of piling, *i e.*, the walls of the cofferdam will be started. As soon as these have progressed some distance—say 300′—the dredger will go out into the river, well out of the way of the pile drivers, and will commence dredging at any convenient place in the river bed. She will discharge the dredged material astern through her floating pipe line and deposit it against the inside of the sheetpiling, first at the end, then at one side and then at the other to form the sand slopes in this first portion of the cofferdam. In the meantime pile driving has proceeded.

THE SECOND STAGE OF OPERATIONS.

335. When the banks have been formed for a length of 200 feet to 300′ on either side, the dredger will come into the cofferdam and start dredging the foundation bed in a width of about 200′ and to about R. L. 173 at the outer edges of cut to R. L. 170 at centre of cut. She will deposit the spoil from this excavation, astern, to one side or the other, to continue the formation of the sand slopes inside the cofferdam walls.

THE THIRD STAGE OF OPERATIONS.

336. As soon as the dredger has dredged the foundation trench for a length of 100′ or so, further floating pile drivers will be brought into the cofferdam, and will commence driving the rows of permanent sheet piling and the temporary sheet piling for the pumping trench. There will be six lines of this piling right along the barrage.

The lengths of these piles are as follows :—

(1) and (6) Outer walls of pumping trench (temporary piling) 20′ long.
(2) and (5) Inner walls of pumping trench (permanent piling under masonry aprons upstream and downstream) 14′ long.
(3) Upstream line of piling under central floor (permanent) length 22′.
(4) Downstream line of piling under central floor (permanent) length 14′.

337. The dredged bed of cofferdam is now at R. L. 173 and the water level (to take the worst case) may be about R. L. 190, *i.e.*, there is 17′ of water over the bed. Three of the lines of piling are only 14′ long, so that these will have to be pitched and driven under water.

When starting these lines, a long pile and locking section say 40′ long will first be driven about 12′ into the bed to act as a guide. If necessary further temporary piles (to be afterwards withdrawn) can be driven at intervals and walings bolted to them by divers near bed level to act as further guides for pitching and driving the permanent piles.

338. With these interlocking piles, however, each pile driven acts as a guide for the next one and in consistent sand there should be no difficulty in pitching and driving piles to true alignment. Driving in such sand is very easy, especially with fast light blows, and when the short pile has been correctly pitched with its locking piece, a length of ordinary pile and locking piece, rivetted together and stiffened with angles rivetted to the web, will be stood on the pile to be driven, and used as a driving piece. The lower end of this driving section will be fitted with a cast steel driving head, about a foot deep, which will fit over the top of the pile to be driven, in such a way that the driving piece must remain central with the pile to be driven, but will not come in the way of the piles already driven when the pile to be driven has reached its final position. The driving piece can then be simply lifted off the driven pile and put on the next pile to be driven.

339. In the unlikely event of the driving piece jumping off the pile to be driven (it would have to jump about a foot to get clear) it would have to be replaced by a diver. But for this cofferdam work, divers will be constantly needed, and will be comparatively inexpensive. For work a few feet below the surface it is probable that local labour will become quite proficient without diving apparatus but the latter is in any case provided.

340. It is essential to get this piling driven in the water to save both time and expense. If it were left until the cofferdam was closed, there would be a long delay before masonry could be started and the cost of pumping, while the piling was being driven, would be very great. By the method suggested above all piling can be completed without any pumping, and at the same time that the construction of the cofferdam is in progress. Moreover it enables the dredging of the deep central trench to be carried out also, under water, *i.e.*, without pumping. The piling is necessary to support the sides of the trench, which would otherwise fall in and be removed by the dredger.

THE FOURTH STAGE OF OPERATIONS.

341. The dredger has completed the excavation of the foundation trench to a width of 200 feet down to R. L. 173 and has at the same time formed the side slopes nearly to the end of the cofferdam. The outside pile drivers have completed the side of the cofferdam, and driving the end piling, while the interior pile drivers have driven the greater part of the permanent lines of piling and the pumping trench piling. At this stage the dredger returns to the beginning of the cofferdam and dredges between the two centre rows of permanent piling down to about R. L. 166 in a width of 70 feet. This is for the foundation of the central block of barrage floor (founded at R. L. 165). About 1 foot of excavation will be left to be done by hand, after unwatering in order to dress the bed level, as the dredger will leave it irregular. The spoil from this dredging will be discharged either into the river, or inside the cofferdam to continue the sand slopes at the far end. While this is in progress the pile drivers will be completing the work inside the cofferdam, and the end wall of the cofferdam will be almost completed, leaving only a gap sufficient for removing the dredger and the pile driving plant, and for taking in the floating units of pumping plant.

FINAL STAGE OF OPERATIONS.

342. When all interior pile driving has been completed and the dredger has finished the central trench, the dredger will come out into the river, most of the floating pile drivers will be withdrawn, the floating pumping plants will be taken inside the cofferdam, and the end of the latter will then be closed.

The dredger will complete the end sand slope by pumping spoil, from the river bed, over the top of the cofferdam.

343. All pumps can then start work on unwatering the cofferdam. As the water level falls the levels of tops of all interior piling will be checked, and if necessary any of these can be further driven in the shallower water by the floating pile drivers left in the cofferdam. The two central lines of piling will need some further driving to their correct levels. As soon as all are satisfactory, the pile drivers will be shifted to one side out of the way and their pontoons allowed to settle on to the sand as the water is pumped out.

At the same time the level of the sand can be checked in the trenches and if large quantities of excavation are necessary at places, one of the pumping plant could probably be used to dredge this out (or a special pumping set might be taken in for this purpose).

The floating pumping plants have in the meantime been moored in their final positions and will similarly settle on the sand beside the sumps leading from pumping trenches.

344. As soon as the bed is exposed, labour will be put in to deepen the pumping trenches and to cover the sand therein with ballast to prevent it blowing.

Pumping will then be continued to lower the water down to R. L. 165, the whole foundation area will be dressed by hand and masonry work started. At least two shifts of 8 hours each should be worked, and if possible day and night work be done, until all work in cofferdams is completed. Pumping must of course continue day and night in any case.

Section III.

Excavation in Cofferdams.

345. Owing to the continual changes which take place in the bed of the river it is impossible to say with any accuracy what the bed level will be at the site of any particular cofferdam, for constructing a portion of the barrage, at the time the cofferdam will be made.

The best approximate method of estimating the excavation would appear to be to take the average bed level of the river at the period of the year when the cofferdams will be closed, and to assume this level in every cofferdam. Where this errs, what is lost in one cofferdam will be gained in another. The construction of the cofferdams is assumed to start in mid September and to be completed about mid October. We shall therefore take the average bed level during October of past years, to represent the surface of the sand in each cofferdam, when excavation starts.

346. Observations for bed levels in October at barrage are available for 1917 and 1918 and they show that in that month the average bed level was R. L. 181·68 (see statement below). R. L. 182·0 has therefore been adopted as the average level below which excavation has to be made in each cofferdam.

347. The areas enclosed by cofferdams of different years will overlap partly, but full excavation in each is estimated for, as silting to average bed level may occur over the end of previous year's work. The quantity of excavated sand will be far more than sufficient to form the interior sand slopes in the cofferdams and any surplus will be deposited outside the cofferdam, where it will assist in supporting the piling and in reducing the seepage below the piling. The method of excavation and of forming the interior slopes of sand is described in Section II *ante*.

For details of cost of dredging, see Part VIII, Section XIV.

348. *Statement showing average bed level of river at Barrage site in October.*

——	Area below datum.	Length of waterway.	Average depth.	Average bed level = 200 ; average depth.	Average for October.
2nd October 1917	100,958	5,600	18·03	181·97	181·56
9th " "	105,644	5,600	18·86	181·14	
9th " 1918	100,449	5,600	17·94	182·06	181·81
16th " "	102,445	5,600	18·29	181·71	
26th " "	102,757	5,600	18·34	181·66	

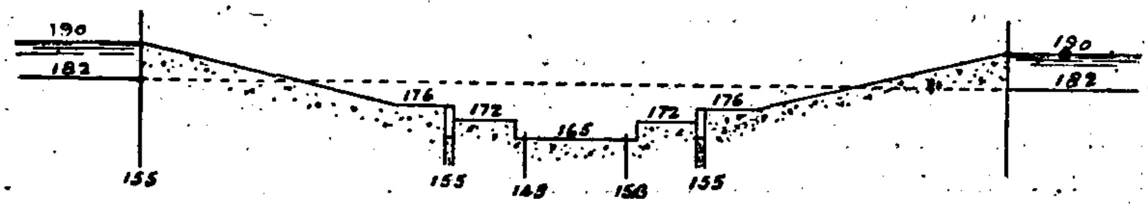
Therefore average bed level for October 1917 .. .. 181·56
" " " " " " 1918 .. .. 181·81

Therefore average bed level for October = 181·685

SECTION IV.

Pumping in Cofferdams.

349. It is proposed to collect the bulk of the seepage water flowing into cofferdams in a pumping trench to be formed by sheet piling all round the outside of the area to be covered by masonry. See Drawing No. 71. The object and effect of this trench is explained below. The sketch below shows a typical cross section of a river cofferdam. The pumping trench will be continued round the ends also.



350. It is assumed that pile driving commences on 15th September, but that the cofferdams will not be closed till 15th October, or later, and that pumping will cease not later than the end of March, in order to allow ample time for removal of cofferdams before the floods come.

During that period the gauge reading on Bukkur will not exceed 7 feet which is equivalent to a water level of R. L. 190 at the barrage.

During the ten years, 1909—1919, the highest average gauge reading during any of these months was 4·3 in November 1914, and only once for a period of ten days in March 1911 did the river exceed 7 feet during those months. It is possible that if such a river level occurred during construction, it would be necessary to stop work for those days and allow the water to rise a few feet in the cofferdam in order to prevent blowing.

Appendix J shows the average and maximum gauge readings for the past ten years and how safe is the assumption of 7 feet during this period. It is proposed therefore to estimate the pumping conditions with water level 190·0 in the river. It is proposed to pump out of the pumping trenches at R. L. 169. Therefore the maximum head is 21 feet. One way of considering this problem is as follows.

351. Mr. Beale states on page 66 of his 1909 report (Volume IV) that the

> "Resistance to flow in sand may be taken as a loss of head of one foot in 10 feet of travel."

Adopting this figure we require a length of creep or travel of $21' \times 10' = 210'$ in order to reduce the pressure to *nil* at point of exit in the pumping trenches.

The bottom of the sheet piling is at R. L. 155 and the natural river bed outside is at 182·0, so that there is 27 feet of travel down the outside of piling, and the loss of head is 2·7 feet. Hence water will not rise at the inside of piling above R. L. 187·3.

352. The direct distance from the cofferdam wall of the pumping trench is 165 feet so the loss of head in this distance is 16·5 feet. Adding to this the 2·7 feet loss in passing under cofferdam piling, gives a total loss of 19·2 feet to this point. Therefore water level on outside of pumping trench will be R. L. (190—19·2)=170·8.

The bottom of the trench piling will be at R. L. 155, and the surface of the sand in the trench at R. L. 168, so that to emerge from the sand the water has to travel a further 16 feet down and up the trench piling, losing a further 1·6 feet of head, so that if water is kept down to R. L. 169 in the trenches practically all head of pressure will be lost by the time the water reaches them.

353 These pumping trenches will completely surround the area of the foundation masonry, so that the greatest head of pressure on the enclosed area is that due to the free surface of water in the pumping trenches, *i.e.*, R. L. 169. The bed level of the upstream apron is at R. L. 172, *i.e.*, above the water level in pumping trenches. The central block of masonry floor is founded at R. L. 165. To reach this, water has to pass down the inside of pumping trench piling = 7 feet and for 35 feet through sand to the upstream edge of the excavation, *i.e.*, the travel is 42 feet and the loss of head 4·2, so that water could flow at R. L. 164·8 only, which is lower than the bottom of the excavation. At a distance of 5 feet beyond this point there is the deep curtain of permanent sheet piling and this will effectually prevent the flow of water to any point beyond it except at a much lower level. It is considered, therefore, that when the central area has once been emptied of water to R. L. 165, the pumping of water to R. L. 169 in the pumping trenches will keep the central area dry. Provision could be made however for small portable electric pumping sets to remove water in the first instance from occasional sumps in the central area. Should it be found, however, that water stands in the central excavation it will only be necessary to make short connecting trenches from this central area to the pumping trenches and to lower the water in these to R. L. 165 by pumping.

354. The calculations for seepage, which follow, are based on another method of considering flow through sand, and on the assumption that water is lowered to R. L. 165, and these represent the worst possible conditions.

355. The heavy main pumping plant will be all located outside the pumping trenches, *i.e.*, clear of the area of masonry and therefore not an obstacle to work.

It is proposed to fix the main pumps, which will be electrically driven, on light wooden or steel pontoons; as many units as considered desirable being fixed on each pontoon. Each pontoon will then be a self-contained pumping plant, requiring only a cable connection to the electric power mains to set it in motion. The weight of an 8" centrifugal pump with motor attached would not be more than about 1½ tons complete so that if 4 of these were fixed on one pontoon the total weight of latter need not exceed about 15 tons. A similar pontoon could support 2 or 3 10" pumps if found more suitable. It is proposed to float these pontoons into the cofferdams and to let them sink with the water as they pump out the enclosure, until finally they will rest on timbers laid on the sand at the positions desired, and outside the pumping trenches. When the masonry has been completed and it is desired to excavate for, and lay the stone pitching underneath the pontoons, the latter can be easily jacked up and rolled along to an adjacent portion already completed, with hardly any interruption to pumping. When the work in cofferdams is completed and pumping stops, the whole plant will float on the rising water and will finally be towed away, ready at once for other work, as soon as the cofferdam is opened.

356. A further great advantage of this arrangement is that all plant can be made ready for work, at the river bank; it can be easily hauled to, and held in, the exact position required, and with one electric connection can be started up at a moment's notice. Moreover, in the event of an accident in the cofferdam, the pumping plant is not disabled by flooding—a very great advantage.

The pumps will discharge into high level open troughs carried on light trestles and draining over the cofferdam wall into the river.

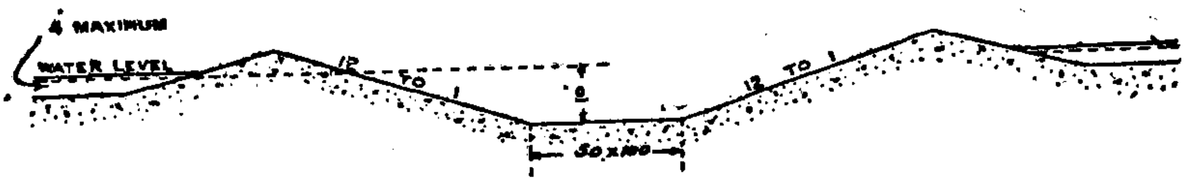
THE QUANTITY OF SEEPAGE WATER FLOWING INTO COFFERDAMS.

357. This is an extremely difficult and uncertain matter to estimate, but it is necessary to make some approximation of the quantity for estimating the pumping capacity to be provided.

THE JAMRAO HEADWORKS.

358. Certain details are available of pumping under somewhat similar conditions during the Jamrao Weir construction, and these will be investigated below.

Here enclosures of cofferdams were formed by the construction of banks of sand round the area to be drained. The sketch below shows a typical cross section of one such enclosure. (Given by Mr. Gebbie.)



It will be seen that the sand took an interior slope of 12 to 1, but this was probably due to water trickling down the face of the sand, there being nothing to prevent water percolating direct to the face of the slope.

359. Mr. Hill states on page 1, Volume IV, 1910 Report on Sukkur Barrage, as follows :—

> "At the Jamrao Weir, a large area of work had to be founded 8 to 10 feet below water in fine sand, much cleaner, and through which water flows more freely than through the silts in the river bed at Sukkur. Depths of 8 to 10 feet below water for areas of 3,000 to 5,000 square feet were easily pumped out, one engine of 12 H. P. being sufficient to keep down the water, but two being necessary to ensure constant running. In this case the bed of the foundation was sand. Work was carried on at three places at once with four engines."

360. Mr. Gebbie states that the pumps were 8" centrifugals with 9" delivery and suction pipes. The discharge of such pumps, *if run at correct speeds* for their lift, should be about 3 cusecs, but a slight variation of speed or head has a very great effect on the discharge, and as it is believed that expert mechanical engineers were not available to ensure correct speeds, the discharge of pumps may easily have been much less than the possible full discharge.

Classification of the Sand.

361. No specimen of the sand at this level is now available with me, but following Mr. Hill's remarks that it is a fine sand, much cleaner than the silts in river bed at Sukkur, I have selected a sample of very clean river sand from Sukkur (there are patches of such on the katchas in river). This is probably the same sand as at the Jamrao, as the latter must have come from the river. This sand although the coarsest at Sukkur, is still extremely fine, and may be classified as of "Effective Size" (see Hazen's rule) of 0·20 millimetres, *i.e.*, 10 per cent. of the sand is finer than 0·20′ millimetres $\left\{\frac{1}{125}\text{th of an inch}\right)$.

362. The weight of this sand when dry is 91·11 lbs. cubic foot and when saturated with water is 125 lbs. cubic foot. Hence the percentage of voids or "porosity" of the sand is 38 per cent.

363. Slichter's Formula (see Buckley's Irrigation Pocket Book, page 324) is—

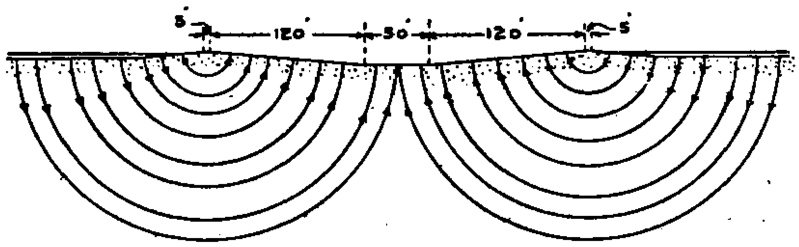
$$V=16272\times d^2\times\frac{1}{k}\times\frac{h}{c}\left\{1+\cdot 0187\ (t-32)\right\}$$

The mean temperature of the water at Sukkur in October is 77° and may be taken the same at the Jamrao.

Hence $1+\cdot 0187\ (t-32)=1+\cdot 0187\times 45=1\cdot 87$.

$d=\cdot 2$ millimetre. $d^2=\cdot 04$.

$\frac{1}{k}$ for 38 per cent. porosity $=\cdot 04154$.



364. Assuming that the water flows in films through the sand on the lines of least resistance, *i.e.*, in concentric semi-circular paths from the river bed outside the cofferdam, as shown above, then these paths will meet at the centre of the cofferdam. The full area through which water can flow is that enclosed by the outermost semicircle whose radius is 150′.

The mean distance of travel for the films is the mean length of the semi-circular paths, *i.e.*, $\frac{o+\pi\times 150}{2}=236'$

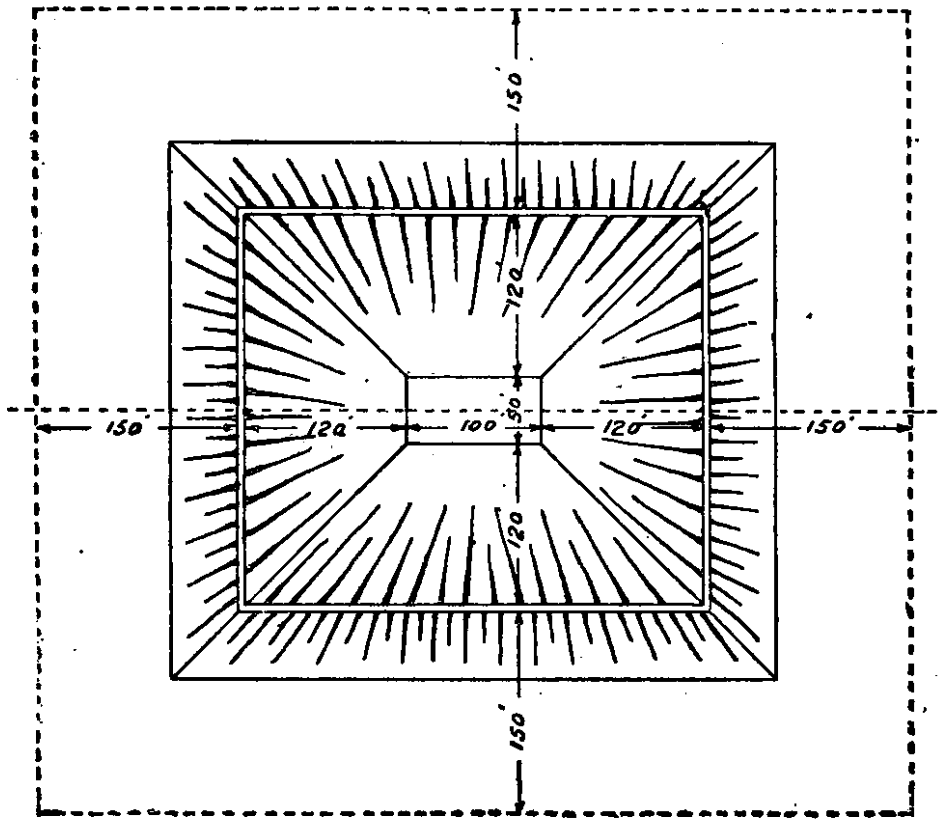
The head is 10′.

$$\therefore\quad \frac{h}{c}=\frac{10}{236}=\cdot 0424$$

$\therefore V=16272\times\cdot 04\times\cdot 04154\times\cdot 0424\times 1\cdot 87$

$=2\cdot 15$ cubic feet per 24 hours.

365. The discharging area will have the full width of 150′ along the whole perimeter of the cofferdam, thus :—



But the discharges from the two directions at ends of cofferdam intercept below the bed, so we need only take the full length of two sides.

This will be $350' \times 2 = 700'$.

Hence the total seepage into cofferdam will be $700' \times 150' \times 2 \cdot 15$ cubic feet per 24 hours.

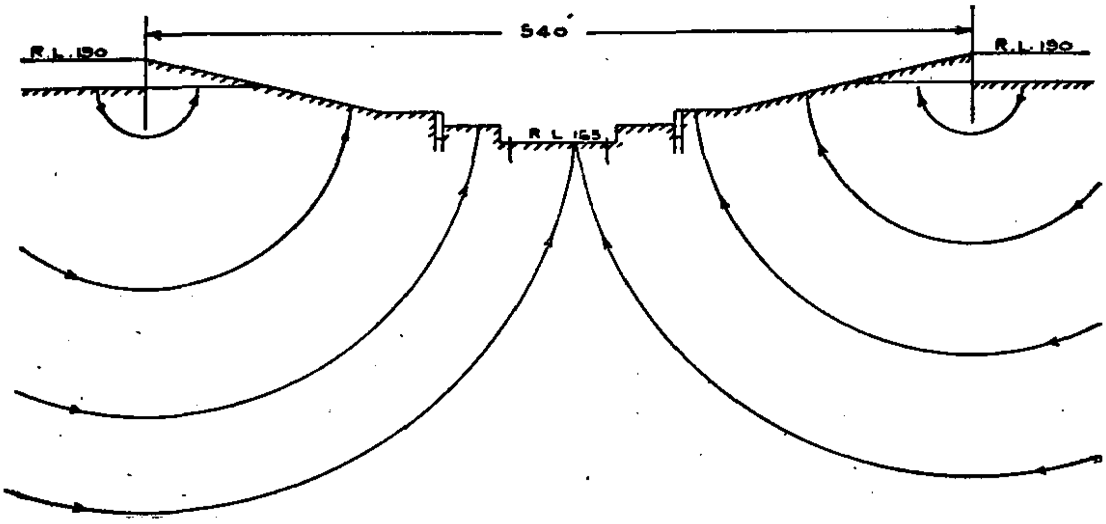
$$= \frac{700 \times 150 \times 2 \cdot 15}{3600 \times 24} \text{ cusecs.}$$

$$= 2 \cdot 61 \text{ cusecs.}$$

As against an actual inflow which could be dealt with by one 8″ pump whose nominal discharge is about 3 cusecs. This method of calculation therefore gives a fairly close approximation to the actual.

The Barrage Cofferdams.

366. Adopting the same method of calculation for these cofferdams, we have the conditions shown below. Here we neglect the beneficial effect of all interior rows of sheet piling, and we assume that all sand is of the same clean and comparatively coarse nature as the sample assumed to represent the Jamrao sand. (Actually most of our sand is much finer, and much less porous than this clean sample, so that we might reasonably assume that the discharge would be less than these calculations will show.)



367. The half-width of the cofferdam is 270′ and the depth of the outer sheet piling is 27′ below the bed level so that the area of percolation is a strip (270 —27′)=243′ deep or wide along the full length of both sides of the cofferdam. (As before, the ends can be neglected as their percolation areas overlap the side percolation areas.) The lowest point of the foundations is at R. L. 165 and the water level outside cofferdam is R. L. 190. Hence head is 25′.

The mean length of percolation line for all films is the mean length of the concentric semi-circular paths, *i.e.* :—

$$\pi \frac{(270+27)}{2} = 466$$

$$\therefore \frac{h}{c} = \frac{25}{466} = \cdot 0537$$

$$\therefore V = 16272 \times \cdot 04 \times \cdot 04154 \times \cdot 0537 \times 1 \cdot 87.$$
$$= 2 \cdot 715 \text{ feet per 24 hours.}$$

Therefore the discharge per 100′ run of the sides of the cofferdam will be 100×243×2·715 cubic feet per 24 hours.

$$= \frac{24300 \times 2 \cdot 715}{3600 \times 24} \text{ cusecs.}$$
$$= \cdot 764 \text{ cusecs}$$

or per foot run ·00764 cusecs.

368. In the 2nd and 3rd year cofferdams (the largest) the total length of two sides will be 2×1,570=3,140 running feet.

∴ Discharge into each cofferdam will be 3,140×·00764 cusecs.
= 24 cusecs.

This neglects all advantage due to the rows of interior piling, and to the fact that the actual sand will be less porous than that assumed.

It also neglects any reduction of head, which will be caused by any sand slope formed on the *outer*, or river side of the cofferdams. As there will be much surplus spoil from the excavation (in addition to the quantity required for the interior slopes) and all this can be deposited outside the cofferdams where it will be further increased by silting, the reduction of head will probably be very considerable.

Pumping in Cofferdams.

369. Length of percolation areas along sides of cofferdams.

1st year's River Cofferdam Right Bank.

			Overlap allowance.	
Upstream end	..	400	—150	= 250′
River side	..	430+600	..	= 1,030′
Upstream projection	..	420	—150	= 270′
Downstream end	..	1,000	..	= 1,000′
			Total	.. 2,550 running ft.

1st year's River Cofferdam Left Bank.

				Overlap allowance.	
Upstream end	..	..	500	—150	= 350′
River side	..	..	210	+600	= 810′
Upstream projection		..	560	—150	= 410′
Downstream end		..	1,200	..	= 1,200′
				Total	.. 2,770 running ft.

2nd year's Regulator Cofferdam Right Bank.

				Overlap allowance.	
Upstream end	..	..	300	—150	= 150′
River side	..	..	750	+380	= 1,130′
Downstream end	..	..	200	—150	= 50′
Earth bank	..	..	240	..	= 240′
				Total	.. 1,570 running ft.

2nd year's River Cofferdam.

Upstream side	..	..	..	..	1,570′
Downstream side	..	..	..	..	1,570′
				Total	.. 3,140 running ft.

2nd year's Regulator Cofferdam Left Bank.

				Overlap allowance.	
Upstream end	..	..	280	—150	= 130′
River side	..	..	1,550	..	= 1,550′
Downstream end	..	..	200	—150	= 50′
Earth bank	..	..	300	..	= 300′
				Total	.. 2,030 running ft.

3rd year's River Cofferdam Left Bank.

Upstream side	.. ..	1,570′
Downstream side	.. ..	1,570′
	Total	.. 3,140 running ft.

4th year's River Cofferdam.

Upstream side	.. ..	1,320′
Downstream side	.. ..	1,320′
	Total	.. 2,640 running ft.

370. The following are the quantities of seepage water calculated to be discharged into each cofferdam as per calculations in paragraphs 366 to 368 *ante*. *The discharge allowed for is double he calculated quantity* and the discharge of an 8″ pump is assumed as 3 cusecs and of a 10″ pump as 5 cusecs :—

Cofferdam.	Effective percolation length of perimeter Runnin feet.	*Calculated* discharge (·764 cusecs per 100 running feet.)	*Allowed* discharge (for pumps).	No. of, 8″pumps required.	*Or* No. of 10″ pumps required.
		Cusecs.	Cusecs.		
1st Year River R. B.	2,550	19·5	39	13	8
1st „ „ L. B.	2,770	21·2	42	14	8
2nd „ „ R. B.	3,140	24	48	16	10
2nd „ Regulator R. B. ..	1,570	12	24	8	5
2nd „ „ L. B. ..	2,030	15·5	31	10	6
3rd „ River L. B.	3,140	24	48	16	10
4th „ „ „	2,640	20·2	40	13	8
			Total ..	90 or	55

371. The maximum pumping requirements will be in the 2nd year, when altogether 103 cusecs discharge is to be provided, or equivalent—

to 34-8″ pumps at average power of 25 B. H. P. per pump=850 B. H. P.

or 21-10″ pumps at average power of 35 B. H. P. per pump=735 B. H. P.

$$or \left\{\begin{array}{c}10\text{—}10''\\ \text{and}\\ 18\text{—}8''\end{array}\right\}\text{Pumps}\begin{array}{l}=350\text{ B. H. P.}\\ \\ =450\end{array}$$

800 B. H. P.

SECTION V.

Laying the Masonry in Cofferdams.

(See Drawings Nos. 42 and 71.)

372. All solid masonry in a width of 190′ in the floor will be laid entirely in the dry, the pumps keeping water below the foundation level.

The first portion to be laid will be the deepest central block founded at R. L. 165. This should be laid as rapidly as possible, as much labour as possible being concentrated on it, since, as soon as this is completed, water can be allowed to rise 5′ to the foundation level of the downstream apron. The reduction of head will very greatly decrease the pumping. As soon as the upstream and downstream masonry aprons are completed in any length, the sand outside them, *i.e.*, in the berms at feet of slopes will be excavated by hand, and on the downstream side the stone pitching below the concrete block apron (but not the blocks) will be laid for 20′ or 30′ width, and on the upstream side the stone pitching apron will be laid for a similar width. The temporary outer row of piling for the pumping trench will then be withdrawn.

373. At the same time the piers will be built up to about R. L. 195 or higher. To complete this work in the large cofferdams proposed, it will require about 1,000 masons working for 100 days, 12 hours per day, or about 750 masons working 16 hours per day, or two shifts of 750 masons each, working 8 hours shifts for 100 days.

374. When this work has been completed in the full length of cofferdam, water will be allowed to rise, the cofferdam will be opened, and the dredger brought in. She will at once commence the removal of the sand slopes and the natural sand below them, to the full width of the upstream pitching, and to its bed level, and on the downstream side for the full width of the downstream apron of concrete blocks, and the stone pitching talus beyond it. The whole width of these aprons lies within the cofferdam. The dredged spoil will be discharged by the dredger from the far end of the cofferdam where it will be carried away by the river current. The stone pitching already laid in the dry in a width of 20′ or 30′ upstream and downstream of the masonry floor will prevent the dredger's suction doing any damage to the masonry. As soon as excavation is finished to required depth in a short length of cofferdam, barges laden with stone will be brought in, and the stone deposited through the water. The heavy concrete blocks will also be brought in on barges, and the floating cranes will lower them to the prepared stone-pitched bed, where they will be set in position by divers.

375. The 6′ thick talus of stone-pitching will be deposited at the same time and this will complete the whole floor of the barrage. As soon as this is done in a given length, the cofferdam piling in that length will be withdrawn. This process will continue until the whole cofferdam has been removed.

376. During the construction of masonry in the dry cofferdam, materials will be brought to site by two methods. As much as possible will be carried by rail from the bank over the completed portion of the permanent barrage road-

bridge (see sectoin II later), but it will not be possible to carry by this route only the enormous quantity of materials needed. The balance will be brought by barge from the shore to the outside of the cofferdams and will be unloaded as far as possible on to mechanical conveyors which will take the materials down the sand slopes to the 50′ berm all round the foundation area. It can be stacked on this berm and distributed to any part of the work by trollies running on a light double track all round the berm. All the stone used will be of man-handled size, so there will be no necessity for cranes, except for lifting on to the piers. For this purpose long-jibbed Scotch Derricks will be set up between two piers, and will be able to lift materials to either pier. Or possibly it may be worth while setting up a temporary cableway running over the centre of the piers for the full length of the cofferdam. This is a detail to be settled later. Mortar can be run down shutes or in conveyors from the barges to the foundations.

SECTION VI.

Arrangements for end of next season's cofferdam on completed floor.

(*See Drawing No.* 71.)

377. Before pumping in the cofferdam ceases, arrangements will be made for the near end of the next season's cofferdam. This will join to the side of the last abutment pier, in the nose of which a special connecting piece for the sheet piling will be built in. In line with the side of the pier, and right across the upstream and downstream masonry pavement, will be laid heavy timber or steel beams as act as a cill, or footstep, to take the thrust of the sheet piling resting against it. These beams will be securely held to the floor by heavy bolts built in to the masonry floor between the two beams, and special arrangements will be made to ensure a water-tight joint round the feet of the piles. Beyond the masonry aprons on the upstream and downstream sides, the ordinary cofferdam piling will be driven to full depth and will be interlocked with, and support, the piling resting on the masonry floor. This will further be strengthened by steel beam walings bolted on both sides near the top and extending from the pier to the extreme end of the piling. When used in the next season's cofferdam it will be of course supported on the inside, against the water pressure, by a bank of sand as usual.

378. This line of piling will be protected at its ends by stone-pitching to prevent scour, and the whole will be left standing in the river, till required for the next season's cofferdam.

379. The end of the barrage floor, where work is broken off, will be supported and protected, by building into it, permanently, the steel piling used for the return end of the pumping trench, while beyond this, stone pitching 6′ thick will be thrown into the river bed for a width of about 100′. This steel piling will connect with the longitudinal rows of permanent piling, and when the next season's cofferdam is made, it will act as the below-foundation curtain of this part of the end of the cofferdam, and will prevent percolation water flowing along under the floor in to the cofferdam.

PART VI.

METHODS OF CONSTRUCTION.

Section B.

The Superstructure.

380. The provision of the heavy abutment piers at intervals of 9 spans enables the arches and superstructure to be built in short lengths as work on the floor progresses.

During the low water season, all labour and plant will be needed for pushing through the work in cofferdams, which includes the raising of all piers to about R. L. 195·0.

But when work in the cofferdams is completed, the completion of the pier up to springing level can at once be taken in hand. For this work labour and material will probably be best conveyed to the piers by water. Plenty of barges and pontoons will be available. As soon as all piers in one bay (*i.e.*, between adjacent abutment piers) are raised to springing level, the steel trusses of the arch centres for the gate-bridge will be fitted up as road-bridge girders, (they are designed for this purpose), with a 12′ roadway, and these will then form complete temporary road bridges of over all length 59′ each. Great quantities of steel beams 15″ × 5″ are available from the piling and a number of these will be bolted down to the tops of the piers and cantilevered out over the sides to form support for the road bridges to rest upon. The cantilevered ends can be further supported, if necessary, by vertical girders and packing resting on the barrage floor. The temporary bridges can then be placed in position on these cantilevered beams, and will form a service roadway across the piers, for carrying the materials required for building the road-bridge arch at the downstream side of the piers.

381. In the meantime the cantilevered beams and longitudinal runners for supporting the arch centres of the road-bridge (see Drawing No. 73) will have been placed in position, and the arch centres, complete, will be floated out and placed in position on their supports. The building of the road bridge arches and spandrils can then be proceeded with, and the permanent bridge be completed up to road level. The parapet walls would not be built at this stage.

382. When the permanent road bridge in this bay has been completed, the temporary bridge on the upstream half of the piers will be removed, the flooring detached from the trusses and the latter then covered with the lagging to convert them to arch centres for the gate bridge.

383. The upstream half of the piers will be raised to springing level of the gate bridge, the cantilever girders and longitudinal runners built into position and the arch centres floated out and placed on their supports. The permanent road bridge will now form a service roadway for supplying materials for the gate bridge, of which the construction can now proceed to completion.

384. Thus during each flood season the superstructure can be completed up to the last abutment pier built during the preceding cold weather, and the completed road bridge will form an invaluable service road for conveying materials and labour to the next year's cofferdam.

It will run right up to, and 25′ inside, the cofferdam, and by placing a temporary girder bridge on to the next pier (built in the previous season) the track can be carried 95′ inside the cofferdam, where cranes or shoots can easily convey materials into the foundation area, where they would be distributed by a light trolley line running right round the 50′ berm outside the pumping trench.

PART VII.

THE CONSTRUCTION PLANT.

INDEX.

PART VII.

CONSTRUCTION PLANT.

SECTION I.

General.

385. A very large quantity of plant has been provided for the execution of this great and difficult work.

Such plant is essential if the work is to be carried out quickly, safely and economically; in fact it may be said that the whole success, or otherwise, of the work will depend primarily on the quantity and suitability of the plant available. The engineers in charge of the work should be in a position to feel that whatever may happen, they have the plant behind them to meet the case, and the Engineer-in-Chief should have complete discretion and full powers to order by cable direct from suppliers or makers, in England, India or elsewhere, any further plant that circumstances lead him to consider necessary.

If he has to refer to Government for sanction in such cases, or is in other ways fettered, any delay or hesitation involved, may lead to stoppages or disasters on the work, which will far more than counterbalance any possible advantage gained by reference to higher authorities not in direct touch with the work, and which may indeed affect the whole success of the work.

386. Successful contractors always realize this, and provide plant for every foreseeable contingency, taking their chance of realizing a fair salvage value for such plant after completion of the work, and if necessary, scrapping the whole of it.

387. This great work at Sukkur will present difficulties and problems, which make it quite impossible to compare it with the *comparatively* small and simple weirs in the Punjab and other parts of India, where usually it has been possible to divert the cold weather channel of the river and construct the works practically in a dry river bed. This will be quite impossible at Sukkur, where at one period of the working season, the river discharge may fall to about 30,000 cusecs and at another period may rise to nearly 350,000 cusecs in normal conditions.

388. Even at the great Sara Bridge Works, the under-water portions of the work were very limited in extent and apart from the pitching of the caissons (a very fine job in itself) presented no difficulty due to the river.

The total cost of this bridge and approaches as per completion report was Rs. 3,51,32,164 in which only Rs. 11,97,000 was charged against Plant, but the actual initial expenditure on Plant exclusive of erection, housing, or repairs was Rs. 88,00,000 or 25 per cent. of the total cost of the work. The small amount charged against Plant in the Completion Report is due to the very high salvage values obtained owing to the war, some items being actually sold for more than their cost price. The whole work was completed with a saving of Rs. 1,25,36,699 on the Project Estimate which amounted to Rs. 4,76,68,863.

389. The following quotations from the Completion Report of the Lower Ganges Bridge (page 3) is of great interest:—

"In explanation of this satisfactory result the remarks by the late Engineer in-Chief, Sir R. R. Gales, Kt., in his letter No. *Nil*, dated 23rd June 1915, may appropriately be quoted.

"(3) This very large saving on bridge proper of over a crore of rupees may be attributed in general terms to the circumstances that no great changes in the course of the river threatened or occurred during the construction of the bridge, and that all arrangements were such that the works were carried through without accident or delay to successful completion a year earlier than anticipated in the estimate."

"(4) A bold expenditure on sinking and other plant, including rolling-stock and permanent-way, for handling the large masses of material required for the training works, the use of electricity for power, the employment of heavy wells for the foundations and of a service girder of large size for girder erection, permitted an accelerating programme to be worked to with comparative ease and certainty. The preparation for several years in advance of careful programmes in which every thing possible was foreseen and provided for, together with a close supervision of expenditure combined to produce the above satisfactory result."

390. In view of these remarks and of the results obtained by a bold expenditure on plant, it is considered that the provisions made for plant in the present estimates for the barrage are fully justified, and will result in true economy.

391. The plant has been selected, as far as possible, to consist of units of a size and nature to be suitable for ordinary engineering work, so that they will find a ready market when they come to be disposed of. Even the large floating cranes will be suitable for Harbour Commissioners, while the steamers will be suitable for ordinary service on the Indus, or any river in India, and the dredgers are specially arranged to be suitable for maintaining canals such as the Eastern Nara or for clearing channels from the river at the heads of the large inundation canals, or for almost any sort of general dredging service in sand, clay or silt.

392. The pile drivers and pumps are all standard machines which will be suitable for any ordinary work. The electric generating plant will be specially designed to be suitable for service in any very hot or damp climate and will be in units of efficient sizes easily disposed of. It is possible that the plants on either bank could be disposed of *in situ* and in working order, to the Municipalities of Sukkur and Rohri respectively for lighting the towns; or to the North-Western Railway for running their shops on either bank.

393. The cost of plant, and of working same, has been extracted from various sources such as maker's catalogues, market quotations, reports of works carried out in India, information obtained privately from engineers of experience and from my own experience. I am particularly indebted to Mr. Pierce, Executive Engineer, North-Western Railway, for much valuable information regarding the Sara Bridge plant, and to the very full and detailed Completion Report of this work, which was very kindly supplied to me through the courtesy of Sir Robert Gales, Chief Engineer, North-Western Railway and the Secretary, Railway Board, Simla. This Completion Report gives the fullest details of cost of plant and of working same on that great work.

394. As all their plant was purchased at pre-war rates I have added to these rates on the average about 40 per cent. to allow for the rise of prices. I am also unable to give credit for such high salvage values as were actually obtained for the Sara Bridge plant, since the latter was sold during the war, and prices obtained were quite abnormal.

395. I have allowed salvage values which my experience leads me to believe likely to be obtainable. This is of course an indeterminate matter, depending on personal judgment and others may differ from my estimates. I have endeavoured to err on the safe side after assuming businesslike arrangements for the advertisement and sale of the plant.

396. Many details of methods of using plant have been thought out, but are not included in this report, as they are not necessary for the general consideration of the project.

SECTION II.

Railways.

397. A broad-gauge (5′-6″) railway system (see plans Nos. 69 and 70) will be required to connect with the North-Western Railway and to convey stone, sand, cement, iron and steel work, and plant, etc., to the works.

ON THE RIGHT BANK.

(See Plan No. 69.)

398. There will be a double line track running from the North-Western Railway (near mile 5 from Rohri to Ruk), parallel to the canals, to the river bank near the barrage. There will be six through sidings each about 6,000′ long to serve the various work yards lying to the west of the canals. All these will connect to the service line along the river bank. There will also be a single line track running right along the river edge, from the downstream end of the Bunder wall, to below the end of the downstream guide-bank, with sidings to serve the Power House, the wharf and the downstream guide-bank.

The total length of track on this bank will be about 14 miles.

ON THE LEFT BANK.

(See Plans Nos. 70 *and* 69.)

399. There will be a double line track from the quarries to river bank at upstream end of regulators. This line will run from the quarries as shown, issuing into the Aror valley, where it will cross over the alignment of the new head of the Eastern Nara to its northern bank. It will run parallel to the new head, along the north and eastern side, right round to the river. There will be two branch terminal sidings to serve the quarries, and two sidings to collect sand from the sand hills to the north of The Aror Valley.

The whole of this system, to the river, will be double track, as there will be heavy traffic of stone and sand continually passing. It will connect to the North-Western Railway from Pad-Idan to Rohri near mile 3 from Rohri.

400. At the river there will be a single line track running upstream along the guide bank for a distance of about 11,000′, *i.e.*, to the limit of the stone-pitched guide bank. From this line will be sidings to serve the power house and the river-wharf.

There will also be a double track line running downstream across the canal heads to connect with the sidings serving the works yards.

A single track shunt runs along the river bank to below the downstream guide bank with a siding to serve the latter.

There are 6 terminal sidings each about 5,000′ long to serve the works yards to the west of the canals.

The total length of the track on this bank of the river will be about 26 miles.

401. Total broad-gauge track on both banks
=14+26=40 miles.

402. The cost of earthwork, laying, and carriage to site, signals and temporary quarters for signalmen, may be taken as approximately Rs. 6,500 per mile (see Part IV, page 73 of Sara Bridge Completion Report).

∴ cost of 40 miles=Rs. 2,60,000.

403. The following will be required on each bank of river :—

	(One on each bank). Rs.
Engine sheds, 100′×30′	5,000
Ashpit, 60′ long	400
Loco. Well, 8′-0″ diameter	1,800
Lighting arrangements	300
	7,500×2=Rs. 15,000.

NARROW-GAUGE RAILWAYS, 2′-0″ GAUGE.

404. This will be required for general light service in the works yards and in the construction of cofferdams.

There will be a double track right round the foundation areas in cofferdams. This will require about 4 miles of track in the 2nd year's work.

About 2 miles of track may be allowed for in the works yards on each bank and in the quarries. Total length of track, say 10 miles.

405. The approximate cost of earth work, carriage to site, laying, moving, relaying, signals and crossings, etc., may be taken as 2,000 per mile. Total cost of 10 miles, Rs. 20,000.

406. The following will be required on each bank :—
One engine shed complete with ash-pit, Loco. well, etc., at Rs. 4,000=Rs. 8,000.

ROLLING STOCK.

407. It has been assumed that second-hand engines will be obtainable in India from the main railways, and if these can be got at reasonable prices, they will serve our purpose. If not, it is possible that fewer new engines could take their place, but the first cost would probably be higher, though greater economy of working, less repairs, and more regular service, make this an alternative well worth consideration. For ordinary low-sided trucks all new plant has been provided, as the work will last sufficiently long to make this worth while. If old trucks were obtained they would probably not last out the duration of the work. Also by purchasing new trucks they can be specially designed to suit the work.

408. *5′-6″ Gauge.*—

			Rs.
6	Nos.	Second-hand four-wheeled tank locos. for shunting and shifting trains and rakes of trucks in yards, quarries, etc., at Rs. 22,000	1,32,000
6	,,	Second-hand engines and tenders for running trains on both banks at Rs. 30,000	1,80,000
2	,,	Officers' saloons at Rs. 15,000	30,000
400	,,	New low-sided trucks at Rs. 4,000	16,00,000
10	,,	Second-hand covered wagons at Rs. 3,000 ..	30,000
50	,,	Second-hand rail carriers at Rs. 2,000	1,00,000
24	,,	Brake vans at Rs. 7,000	1,68,000
2	,,	Hand accident cranes, 10 tons, at Rs. 10,000 ..	20,000
2	,,	Steam loco. accident cranes to lift 15 tons at 15′ radius, at Rs. 50,000	1,00,000
6	,,	Motor Inspection Trolleys at Rs. 3,000	18,000
			23,78,000

409. *2′-0″ Gauge.*—

			Rs.
10	Nos.	Second-hand 4 coupled tank locomotives at Rs. 8,000	80,000
400	,,	Low-sided trucks at Rs. 500	2,00,000
10	,,	Brake vans at Rs. 800	8,000
1	No.	Hand accident crane at Rs. 5,000	5,000
			2,93,000

410. *Permanent-way.*—

Here again second-hand material has been assumed, in all items where it is at all likely to be available and suitable for the work.

411. *Broad-gauge 5′-6″ track.*—

	Rs.
40 miles of 64 lb. second-hand track at Rs. 2-8-0 per foot ..	5,28,000
D. & O. plate sleepers complete 90,000 Nos. at Rs. 9 ..	8,10,000
Crossings, 80 sets, at Rs. 160	12,800
Switches, 80 sets, at Rs. 250	20,000
	13,70,800

412. *Narrow-gauge 2′-0″ track.*

	Rs.
10 miles of second-hand track at Rs. ·75 per foot	39,600
24,000 C. I. sleepers at Re. 1 each	24,000
Crossings and switches, 150 sets, at Rs. 120	18,000
	81,600

413. *Total outlay on railways—*

			Rs.
Rolling-stock,	5′-6″	gauge	23,78,000
„ „	2′-0″	„	2,93,000
Permanent-way	5′-6″	„	13,70,800
„ „	2′-0″	„	81,600
Earthwork, laying, etc.,	5′-6″	gauge	2,60,000
„ „ „	2′-0″	„	20,000
Engine sheds, etc.,	5′-6″	„	15,000
„ „ „	2′-0″	„	8,000
		Rs.	44,26,400

SECTION III.

Fleet.

414. Provision is made for two dredgers required for work in the cofferdams, and for a fleet of steamers and barges capable of handling all plant and necessary materials.

Towing steamers for a river of this class are best fitted with paddles in preference to screw propellers. The paddles should be independent to ensure great manœuvring power in a strong current and when hampered with tows alongside. The hulls should be spoon-bowed, and the draft fully loaded must not exceed the figures specified. Such vessels will be able to handle their tows under all conditions of the river, and in the event of running on sand banks (as they frequently will) their independent paddles and spoon bows will enable them to wriggle off with the least possible difficulty. All vessels should be oil-fired, as oil-fuel should be cheaper and more easily obtained (from Persia) than coal, and is more easily handled, stored and stocked, and is more economical as fuel.

The motor launches will be needed for shifting labour, staff, light materials, etc., and for standing by and assisting in manœuvring barges and pontoons into position.

For rough specification and description of dredgers, see Appendix **K**.

RIVER FLEET.

	Rs.
415. 2 paddle steamers with independent paddles, length 130′, beam 25′, draft 3′ loaded, 1′-6″ light, width over paddles 40′. Power about 350 I. H. P. Complete with water tube boilers fitted for oil fuel, with search-lights and all fittings complete. Speed about 15 miles per hour at Rs. 1,80,000	3,60,000
Would handle the largest pontoons and floating cranes.	
2 steam tugs with independent paddles, 80′ long, 20′ between paddles, 32′ overall, about 200 I. H. P. Draft about 2′-6″ loaded and 1′-3″ light. Boilers fitted for oil fuel. To handle 2—50 ton barges or 1—100 ton barge at Rs. 90,000.	1,80,000

	Rs.
1 steam launch, twin screw, length 70′, beam 13′, draft 2′-6″ loaded ; complete with cabins and all fittings and fitted with oil fired boilers. For general service, inspection, survey, etc , at Rs. 40,000	40,000
4 motor launches, length 35′, beam 6′-9″, draft 1′-4″, fitted with 36 B. H. P. engines for petrol or kerosine at Rs. 12,500.	50,000
2 motor life boats with single cylinder petrol engine at Rs. 3,000.	6,000
2 dredgers (suction), length about 220′, beam say 40′, draught loaded not to exceed 3′ when carrying overside discharge pipe full of clay and balance tanks full (see separate specification of various parts) complete with all pipes, tenders and launches at £40,000 each.	12,00,000
5 steel pontoons, 80′×20′×6′, capacity each 100 tons, fully decked, with inside boards, anchors, chains, etc., suitable for carrying arch centres at Rs. 18,800	94,000
4 steel pontoons, 80′×66′×6′, carrying capacity 300 tons, suitable for carrying electrically driven Scotch Derrick Crane of 10 tons capacity at 60′ radius with 70′ jib at Rs. 55,000..	2,20,000
15 steel barges with wooden decks, approximate capacity 16 tons, size about 40′×9′×3′ for pumps at Rs. 1,200	18,000
30 steel barges with wooden deck about 80′×16′×4′-6″, approximate capacity 80 tons for stone carrying at Rs. 5,000 ..	1,50,000
30 steel pontoons with wooden decks, size about 60′×20′×3′, approximate capacity about 50 tons suitable for carrying pile drivers at Rs. 4,500	1,35,000
1 heave-up boat, length 49′, beam 14′, moulded depth 4′-3″, Calcutta Port Commissioners' type, fitted with double-geared windlass and 5-ton capstan at Rs. 20,000	20,000
3 life boats of sizes at Rs. 1,000	3,000
10 jolly boats of sizes at Rs. 700	7,000
Total Cost of fleet .. Rs.	24,83,000

SECTION IV.

Cranes.

416. All these will be operated electrically or by hand.

Provision is made for 2 Goliath Cranes, one for the block moulding yards on each bank of the river. These will span the moulding ground and the stacking yard, and will have a cantilevered arm on one side for loading blocks on to the broad-gauge railway track running along one side of the ground.

The four large 10-ton Scotch Derrick Cranes will be mounted on pontoons and will be used for setting the concrete block apron, and for pulling piles and general service.

The two 25-ton cranes will be fixed in the steel-work erection yards and will be able to lift a complete gate, or arch centre on to the railway trucks, as well as performing any similar heavy work. Assembly of heavy items would be done within their lifting radii. The four 10-ton hand cranes would be for similar but lighter work in the yards.

The 20 hand-operated Scotch Derricks of $1\frac{1}{2}$ tons capacity would be used for erection of piers in cofferdams and for general service in yards, etc.

The four 5-ton and two 12-ton loco. cranes would be used for lifting and shifting materials in the erection yards. These will be broad gauge and will be most useful for all kinds of work.

Cranes.

	Rs.
417. 4 electrically operated three motor Scotch Derrick Cranes of 10 tons lifting capacity at 60′ radius, length of jib 70′, hoisting speed 40 feet/min. for block setting, etc., at Rs. 30,000	1,20,000
2 electrically operated three motor Scotch Derrick Cranes of 25 tons capacity at 50′ radius, jib 80′ long for lifting centres, gates, etc., at Rs. 60,000	1,20,000
4 hand operated Scotch Derrick Cranes to lift 10 tons at 40′ radius, length of jib 55′ for steel erection yards, etc., centre pins to be drilled for taking hoisting rope to electric hoist, if desired, at Rs. 7,500	30,000
20 hand operated Scotch Derrick Cranes to lift $1\frac{1}{2}$ tons at 35′ radius, 45′ jib, centre pins to be drilled for taking hoisting rope to electric hoist, if desired, at Rs. 1,200	24,000
4 electric or steam loco. cranes to lift 5 tons at 16′ radius at Rs. 10,000	40,000
2 electric or steam loco. cranes to lift 12 tons at 16′ radius at Rs. 20,000	40,000
2 electrically operated Goliath Cranes about 53′ span with 15′ cantilever at one end or both ends to lift 10 tons, height to hook (maximum) 20′, travelling speed 200′ per minute, for block moulding yards at Rs. 45,000	90,000
Total cost of cranes	4,64,000

Section V.

Pumping Plant for Cofferdams.

418. Full details of the method of calculating the plant required are given in Part VI, Section IV *ante*, which shows the maximum requirements to be 34 sets of 8 inches pumps and motors. To allow for breakdowns and odd work 40 sets may be provided.

The cost per set, including 8 inches pump, electric motor, auto-starter and suction and delivery pipes may be taken as Rs. 4,500 each.

The total cost of pumping plant will therefore be 40×4,500=Rs. 1,80,000. This is exclusive of the cost of pontoons for mounting the pumps, which will be about Rs. 18,000 and is provided under "Fleet".

It is also exclusive of the cost of power generators, which is provided under the heading "Power Houses" and will be approximately Rs. 3,00,000, provision being made for working 34 pumps at one time, requiring about 850 B.H.P.

Section VI.

Pile Drivers.

419. In estimating the cost of labour for working pile drivers it is assumed that each machine will drive one pile and locking piece to a depth of 46 feet per hour, *i.e.*, will drive 61 square feet of piling per hour, see paras. 480 to 486. This is a reasonable rate of progress for work in fine sand, but to be on the safe side in providing plant it will be assumed that each machine will drive only 45 square feet per hour. This allows for breakdowns and other delays.

The pile drivers will work with 2 shifts of 8 hours each per day, and may be taken to work 26 days per month.

Therefore each machine would drive—

26×16×45 square feet per month,
= 18,720 square feet per month.

It is desired to complete all pile driving in each cofferdam in about one month so the quantity per pile driver may be taken as 20,000 square feet.

The total quantity of pile driving required in the year of greatest work is as follows :—

Second year's work—

Temporary piles	..	..	312,000 square feet.
Permanent ,,	..	..	228,000 ,, ,,
	Total	..	540,000 ,, ,,

Therefore 27 pile drivers would be needed. Allow for 3 spare machines, or say 30 machines.

Withdrawing Piles.

420. All pile drivers will be fitted with special arrangements for pulling piles. Where conditions are easy this may be possible with a steady pull from the winch through a system of 2 or 3 sheave pulleys, and in difficult work it will be done by a special appliance for giving upward blows to an attachment on the top of the pile, or by special hydraulic jacks. The floating cranes will also be able to assist with this work, and there should be no difficulty in removing all cofferdam piles, and pumping trench piles in one month, as pile drivers are provided for driving far more piling (all the permanent piling also) than will have to be withdrawn.

It is probable that a few downward blows would be given to shift the pile to break the sand accumulated between pile and locking piece, before pulling was started.

421. The cost of each machine may be taken as under :—

Pile drivers complete with steel frames for driving 40 foot piles and with telescopic leaders, fitted with double barrelled electric winch, and with electro-magnetic pile driving hammer of 40 cwt. Price complete say each	Rs. 13,500
Therefore cost of floating pile drivers will be 30×13,500	„ 4,05,000

422. *Note.*—Some of the above 30 machines might be steam driven and with 40 cwt. B.S.P. double acting steam pile-driving hammers in case pile driving is required before electric power is ready. The cost of the steam plant would not be more than the electric, so it is not necessary to differentiate in this estimate. In addition to these floating sets, a few extra sets of pile drivers will be provided for work on land. Say 4 complete plants at Rs. 13,500=Rs.54,000

Total cost of all pile drivers	Rs. 4,59,000
Add—Cost of 30 sets of pile drawing appliances at Rs. 1,500 =	„ 45,000
	Rs. 5,04,000

423. This is exclusive of the cost of pontoons on which the pile drivers will be mounted. This item is included in the estimate for " Fleet " and amounts to Rs. 1,35,000. This is also exclusive of the cost of power generators, which is included in the estimate for "Power Houses". Allowing 15 B.H.P. per pile driver and for working 30 sets at one time ; provision is made for 450 B.H.P. costing about Rs. 1,60,000.

SECTION VII.

Stone Crushers and Concrete Mixers.

424. Provision has been made for sufficient plant to break all stone and mix all concrete for the whole quantity of concrete blocks in about three years, this work to be in progress all the year round.

The small mixers will be used for making the smaller blocks for regulators, etc., and for stand-bye. They will also be useful for increasing output temporarily at any time of excessive demand, and for sundry concrete work not foreseen.

425. The following plant is required :—

	Rs.
6 Baxter's compound toggle stone breakers, 20″×9″, complete with screens and elevators, at Rs. 7,000 ..	42,000
2 portable engines, 12 N.H.P., for ditto for temporary use till electric power is ready, at Rs. 6,000	12,000
6 25 B.H.P. motors, complete with pulleys and slide rails, for ditto, at Rs. 2,300	13,800

	Rs.
6 oil immersed auto-starters, for ditto, at Rs. 200 ..	1,200
2 No. 2 size, 20 cubic feet, Ransome's concrete mixers, complete with elevating hopper, steel frame, water tank and electric motor and oil immersed auto-starter, at Rs. 10,000	20,000
1 ditto but, with engine and boiler instead of electric motor, at Rs. 10,000	10,000
2 No. 0 size, 5 cubic feet ditto with belt drive complete, at Rs. 2,200	4,400
6 sets Ransome's standard hopper gates complete, at Rs. 75	450
Total .. Rs.	1,03,850

Section VIII.

Moulds for Blockyard.

426. Steel forms would be used throughout for all standard blocks, as they will be cheaper in the long run, and much quicker and easier to handle, requiring less room and less repairs than wooden forms.

Provision is made for moulds sufficient for ten days output in each yard. This allows for the moulds standing for eight days on the (lime) concrete blocks, and two days for removing and resetting for fresh work.

The approximate cost of each mould will be about Rs. 400 and 400 of these will be needed.

Total cost of moulds, Rs. 1,60,000.

Section IX.

Air Compressors and Pneumatic Tools.

427. Provision is made for pneumatic drills and pneumatic hammers, for drilling and rivetting in the steel erection yards and for drilling piles and walings in position. For the latter purpose one or more air compressors would be mounted on a pontoon, so as to avoid long leads for the air mains.

428. The following plant is required:—

	Rs.
12 pneumatic drills, to drill holes up to $2\frac{1}{2}''$ diameter, at Rs. 450	5,400
2 pneumatic drills, fig. 1, size 1, to drill holes upto 2″ diameter, at Rs. 500	1,000
20 Nos. pneumatic hammers, size No. 80, for closing rivets upto $1\frac{1}{8}''$ diameter, at Rs. 300	6,000
5 Nos. pneumatic hammers, size No. 1, for heavy clipping and caulking, at Rs. 300	1,500

3 air compressors, direct coupled to electric motors, each capable of delivering 300 cubic feet of free air per minute at pressure of 180 lbs. per square inch, motors of 70 B.H.P., at Rs. 12,000	Rs. 36,000
3 air receivers, 3′-6″×8′-0″, complete with safety valves, at Rs. 900	2,700
100 lengths ¾″ hose with connections at Rs. 50	5,000
Total .. Rs.	57,600

SECTION X.

Diving Gear and Apparatus.

429. This will be required for divers setting concrete blocks in position. There are four floating cranes for this work, and provision is made for two divers at each crane requiring eight sets of gear. Two further sets are provided for sundry work or stand-bye, and four sets of spare parts. Necessary submarine lamps are also provided.

430. The following is required:—

	Rs.
10 diving gear complete sets, at Rs. 4,500	45,000
Each consisting of—	
Air pumps.	
Diving helmets.	
Signal lines and telephone lines.	
Telephone apparatus.	
Chest for above.	
Air pipe, 200 feet.	
Diving dress.	
Lead weights.	
Boots.	
Signal line.	
Knife, stockings, guernseys.	
Cap, neckerchief, etc.	
Chest for above.	
4 sets of spares for above, at Rs. 2,100	8,400
Each comprising—	
Spare two cylinder, double acting air pump.	
Spare two cylinder air pump.	
Spare diver's helmet.	
Spare diver's boots lead soles.	
4 self-contained electric hand lamps for submarine work, at Rs. 115	460
16 submarine electric lamps for 110 volts, 350 candle power, capable of withstanding a pressure of 80 lbs./square inch, each complete with 250 feet of insulated cable, at Rs. 175	2,800
Total .. Rs.	56,660

SECTION XI.

Workshops.

431. The main workshops will be located on the Sukkur side of the river as more land, and cheaper, is available at this site, and it will be more convenient for main line railway connections and for inspection by officers, etc.

Auxiliary shops of about one-third the capacity will be provided on the Rohri side, and small shops at the quarries for local repairs.

432. A lump sum provision has been made for machinery for these shops but this has been arrived at from an approximate detailed estimate of the plant required. It is not an excessive estimate, as complete shops are essential for expeditiously carrying out repairs and making appliances for use on the work. The plant for metal working shops includes the following :—

Equipment for Smithies complete—

Lathes, drilling, planing, milling, shaping, slotting and screwing machines and pulleys, shafting, etc., for engineer's shops.

The equipment for wood-working shops includes following :—

Circular saw bench, vertical log saw frame, pendulum cross cut saw, wood-boring machine and saw sharpening machine, etc., with pulleys, shafting, belts, etc.

433. *Sukkur side*—

		Rs.
Machinery for metal working shops		60,000
Machinery for wood working shops		12,500
	Rs.	72,500
Foundation for machines		1,800
Erection of machinery and shafting		9,000
Marking out floor 90′×30′		900
Gantry		500
Fencing and erection		4,000
Lighting arrangements		2,000
	Rs.	18,200
Total for Sukkur side excluding buildings	Rs.	90,700

434. *Rohri side and the quarries*—

		Rs.
Machinery for metal shops		10,000
Machinery for wood shops		5,000
		15,000
Foundations, erection, lighting, etc.		4,000
Total for Rohri side excluding buildings	Rs.	19,000
Total for workshops equipment excluding buildings.	Rs.	1,09,700

Section XII.

Water Supply Plant.

435. Provision is made for a complete water supply system to provide water under pressure for the whole works.

Separate installations will be used for drinking water and boiler supply and for water required for concrete mixing and other works as the former will require some settlement and possibly purification treatment.

436. The potable water supply will probably give some trouble on the Sukkur side, as the site of bungalows and camp is below, and not far distant from, the (Sukkur) town sewage outfall. It may be necessary to divert this outfall to a point below the barrage, a distance of about 1½ miles. Provision has not been made for this, as without considerable investigation it cannot be definitely decided. In any case the cost could come out of the contingencies.

437. On the Rohri side the camp is 2½ miles below the lowest point of the town and it is assumed that river water would be safe at this distance, and safe also from contamination from the Sukkur side, which is separated from the intake by a mile of river water.

438. The lump sum estimate for water supply at the quarries will include about half the pumping plant, tanks, etc., at Rohri and Sukkur sides, but either wells, or a longer lead for mains to bring water from the Eastern Nara, as the quarry site is high and dry.

Water Supply.

439. *Sukkur side.*—

	Rs.
2 30,000-gallon C. I. tanks on steel staging 30′ high including erection at Rs. 6,500	13,000
Pipes, bends, tees, etc., including laying say at Rs. 25,000	25,000
Fire protection arrangements, hoses, nozzles and fire extinguishers	4,000
Well, 20′×60′, at Rs. 10,000..	10,000
2 horizontal direct coupled electrically driven centrifugal pumps to deliver 200 gallons—min. against total head of 70′ complete with motors and starters at Rs. 4,000	8,000
1 10 B. H. P. oil engine and pulleys, etc., for driving one of above before electric installation is ready at Rs. 2,000	2,000
Erection of plant	1,000
Total ..	63,000

440. *Rohri Side.*—

	Rs.
As above	63,000

441. *Quarries.*—

Say	44,000
Total cost of water supply ..	1,70,000

SECTION XIII.

Mortar Mills.

442. These will be fixed in sets of five 9′ diameter mills, driven by a 40 B. H. P. electric motor.

The outturn of a 9′ diameter pan is about 12 cubic feet per batch and a complete operation, including filling, grinding and emptying pan, takes about 20 minutes, so that each pan produces 36 cubic feet of mortar per hour.

443. The maximum quantity of masonry to be laid is in the second year, when there will be about 2,100,000 cubic feet of masonry in the barrage requiring 700,000 cubic feet of mortar. In the regulators and connecting walls the quantity will be about 2,500,000 cubic feet of masonry requiring 800,000 cubic feet of mortar. Therefore maximum quantity of mortar required is 1,500,000 cubic feet in the second season. This will be spread over 120 days work, and the mills can be run for 16 hours per day (two shifts) like the masonry. This gives required output of mills $\frac{1,500,000}{120 \times 16}$ =782 cubic feet per hour. The output of one pan being 36 cubic feet per hour we need $\frac{782}{36} = 22$ pans. To this we may add about 30 per cent. to allow for rush periods and for breakdowns, etc., say 8 pans extra, making total of 30 pans, or 6 sets of 5 pans each requiring $6 \times 40 = 240$ B. H. P. to drive them. The price of each pan of the under-driven type may be put at Rs. 2,300 and a set of shafting, bearings, pulleys and belts at Rs. 1,500 per set of 5 pans, while a 40 B. H. P. electric motor and auto-starter may be put at Rs. 3,500.

		Rs.
Therefore total cost per set of 5 pans	=	16,500
Cost of 6 sets	=	99,000
Erection	=	1,000
	Rs.	1,00,000

SECTION XIV.

Disintegrators for Grinding Surkhi, etc.

444. An Edgar Allen Disintegrator, size N, type F, requires about 40 B.H.P. to drive it and turns out 200 cubic feet of surkhi per hour, ground from $1\frac{1}{2}''$ broken brick.

Assuming that surkhi is required in the mortar (this is not certain but may give better results) and that proportions of mortar are—

1	lime.
$1\frac{1}{2}$	sand.
$\frac{1}{2}$	surkhi.
3	cubic feet, making $\frac{3}{4} \times 3 = 2\frac{1}{4}$ cubic feet

of mortar. Then for every $2\frac{1}{4}$ cubic feet of mortar we require $\frac{1}{2}$ cubic foot of surkhi, so that for 1,500,000 cubic feet of mortar we need—

$$\frac{1,500,000}{2\cdot25} \times \tfrac{1}{2} \text{ cubic feet} = 334,000 \text{ cubic feet.}$$

of surkhi in 120 days of 16 hours each—

$$= \frac{334,000}{120 \times 16} \text{ cubic feet per hour.}$$

$$= 174 \text{ cubic feet per hour.}$$

So that one disintegrator as above would be sufficient.

Say one extra machine for stand-bye against breakdown.

	Rs.
Total cost 2 disintegrators at Rs. 3,000	6,000
2 Electric motors 40 B. H. P. with auto-starters at Rs. 3 500	7,000
Total ..	13,000

Section XV.

Electric Power Plant.

445. The total power required for each of the foregoing items of plant estimated in detail is shown below in column 1. These figures however represent the maximum power required for each item of plant, fully engaged. Under actual working conditions each item would seldom be working at full load, and all items would never be fully working together at the same time. In the second column is shown the approximate loads for each item of plant, which may be assumed as the maximum requirements for the combined load with all plants working together.

—	B. H. P.	
	Maximum for full load.	Demand on power station.
Pumps	850	425
Pile drivers	450	225
Cranes	600	300
Stone crushers and mixtures	220	220
Air compressors	210	210
Workshops	200	200
Water supply	100	100
Mortar Mills	240	240
Disintegrators	80	80
Fans and lighting for bungalows and offices	100	100
	3,050	2,100

446. Thus 2,100 B. H. P. may be taken as full load demand from the power stations. Adding 20 per cent. for losses in transmission, etc., we get—

Demands	2,100
Losses 20 per cent.	420
Total ..	2,520 B. H. P.

447. A further 100 B. H. P. will be allowed for sundry plant not estimated in detail. This is divided up between two power houses—a larger one on the Sukkur side and a smaller plant on the Rohri side. (Possibly one of the small generating units will be fixed at the quarries instead of on the Rohri side of river.)

448. The cost of the plant, transmission lines, etc., is based on cost of similar plant at the Sara Bridge Works, an allowance of about 40 per cent. being made for increased prices. The power units are so sub-divided, that it is unnecessary to provide stand-byes. The cost of housing the plant is included under "Temporary Buildings."

449. The plant will consist of triple expansion or compound condensing engines, or steam turbines, supplied with steam from water tube boilers, oil or coal fired, and driving three phase revolving field generators, with excitors direct coupled. These will generate current of 440 volts 50 periods which will be transformed up to 3,300 volts for transmission and again transformed down to 440 volts at sub-stations on the works for use in the motors.

The following plant is provided :—

450. *On Sukkur Side—*

3 units of 500 B. H. P. each	1,500 B. H. P.
2 units of 185 B. H. P. „	370
	1,870 B. H. P.

	Rs.
Cost of plant complete, with boilers, engines, generators, switches, transformers, etc., will be approximately ..	4,00,000
Foundations for plant	15,000
Erection of plant	30,000
Total Sukkur Side ..	4,45,000

451. *On Rohri Side—*

1 unit of	500 B. H. P.
1 unit of	185 „
1 unit of	75 „
Total ..	760 B. H. P.

	Rs.
Cost of plant complete will be approximately	2,00,000
Foundations for plant	7,000
Erection for plant	15,000
	2,22,000

Transmission lines and erection.

	Rs.
On Sukkur Side..	1,10,000
On Rohri Side	60,000
	1,70,000

452. Total cost of Electric Power Supply Plant—

—	Sukkur side.	Rohri side.	Total.
	Rs.	Rs.	Rs.
Plant and erection	4,45,000	2,22,000	6,67,000
Transmission lines and erection	1,10,000	60,000	1,70,000
			8,37,000

SECTION XVI.

Steel Sheet Piling (for temporary construction works).

453. Under this heading is provided all steel piling except that embodied in the permanent structures.

As explained in paragraphs 323 to 325, Part VI, Section A, sufficient piling is provided to meet the requirements of the heaviest season's work in cofferdams, after taking into temporary use for this purpose, such quantities of the permanent piling as will serve the purpose. Provision has also been made for piling with which to form wharves on either bank of the river.

454. The total quantities required are as follows :—

	Rs.
For the barrage and regulator cofferdams.	
366,000 square feet of 15″ × 5″ Universal Sheet Piling, at Rs. 4 per square foot	14,66,400*
272 tons rolled steel beams for walings, at Rs. 160 per ton	43,520
Rs.	15,09,920
For two wharves as under—	
60,400 square feet of steel Sheet Piling, at Rs. 4 per square foot	2,41,600
53 tons rolled steel beams for walings	8,480
	2,50,080
Add—for second wharf	2,50,080
Total outlay for piling ..	20,10,080

* This should read 14,64,000.

Section XVII.

Arch Centres and Supports.

Drawing No. 73.

455. All arch centres will be formed entirely of steel, both as regards the trusses, the lagging and the supports. There are many reasons in favour of steel, as against wood, for this purpose. In the first place on a span of 60 feet for heavy arches, wooden trusses would require to be very heavy, and after much use, and exposure to the sun and water they would warp and their joints loosen, with the result that they would sag considerably. Moreover wooden lagging would get badly damaged by repeated use with heavy stone blocks being dropped on it, and even if not broken it would require considerable repairs after each operation and would have no salvage value on completion of the work. Well made steel trusses on the other hand will not be very heavy and will be as good when done with as when taken into the works. The lagging will need no repairs and will have a fair salvage value on completion of the work. It is proposed to use each road-bridge centre 8 separate times, and each gate-bridge centre 16 separate times, 9 complete sets of centres being provided to complete 9 spans of both the Barrage bridges. The barrage comprises 66 spans, divided into 6 bays of 9 spans each, one bay of 7 spans, and one bay of 5 spans, *i.e.*, 8 bays altogether.

456. The trusses are specially designed to be convertible into girders for carrying a road-bridge flooring, suspended from the bottom chord of the truss.

All that will be necessary is to remove the lagging from the complete arch centres, when done with as such, and to rivet on to the bottom chord the angles and plate for carrying the trough flooring of road-bridge.

It is proposed, therefore, to use all these trusses, after completion of the barrage, to form road-bridge spans for the bridges across the canals. Each bridge will have a clear span of 55 feet, so that obstruction by piers in the canals will be much reduced, while full value will be obtained from the trusses.

457. The trough flooring and necessary angles and plates for converting some of the trusses to road-bridges will be purchased at the time of starting arch construction, and with these some trusses of the gate-bridge will be converted and used as a temporary road-bridge, for a service road to supply materials for the construction of the road-bridge arches of the barrage, *vide* paragraphs 380 to 382, Part VI, Section B *ante*. The maximum possible use will thus be made of all plant.

458. The salvage value, of the trusses only, is therefore put at 75 per cent. of cost price, and this amount will be debited to the canals, the remaining 25 per cent. being charged to the arch masonry. For the steel lagging a salvage value of Rs. 150 per ton or about 30 per cent. of cost is allowed, as these will be large plates which will be useful for tank making, etc., and will command a good price.

459. In the designs submitted (see plan No. 73) the trusses are designed of ample strength to carry all loads coming on them when used as arch centres, and alternatively, to carry from the bottom chord, the loads due to a flooring and roadway with live load of 75 lbs. square foot for a clear width of 12 feet roadway.

The design is not intended to be a final working drawing, but it provides ample strength for the above purposes. The final design would be made in consultation with the structural engineers building the trusses, and it is probable that their experience would enable them to design a more economical girder for the purpose.

460. Two designs are submitted for methods of supporting the arch centres (see plan No. 73).

One design uses a system of removable cantilever girders and longitudinal beams (which will be available each year from the sheet piling girders). This is the system adopted in the estimates.

The other design, which was the first worked out, is for cast-iron bracket supports. This is not recommended, but is shown for comparison. It would be much more expensive and more troublesome.

461. Provision is made for 9 complete sets of centres for the 25 feet wide road-bridge arches, and for 9 complete sets of centres for the 8 feet wide rib of the gate-bridge arches. After the completion of the 8 feet wide rib, these centres will be slid along the runners to the position of the 5 feet wide rib and the latter can then be built on the same centres, which again effects a large economy in centering.

462. For the supports of centres, 8 complete sets to suit the 10 feet piers are provided and 2 complete sets to suit the 25 feet abutment piers. This provides all the supports necessary for the 9 sets of centres.

In addition to this, 2 complete extra sets of supports, to suit 10 feet piers are provided, so that these may be set in position ready to receive the centres from the first two completed spans, as soon as they can be shifted. The method of operation, and cost of moving the centres and supports has been very fully and carefully worked out, and liberal rates allowed for all items.

463. Liberal provision is also made for timber staging on pontoons for carrying centres and supports to position, and a large provision is made for special tackle, jacks, winches, rollers, etc., for placing the centres on the pontoons. The whole cost of all the plant enumerated above, after deducting very reasonable salvage values, together with cost of placing and removing, etc., has been debited entirely to the centering, and thence to the cost of the arch masonry. The cost of arch-centering, thereby arrived at, works out to Rs. 44·5 per 100 cubic feet of arch masonry.

464. The initial outlay for plant required will be as follows:—

	Rs.
9 spans of centering for road-bridge arches complete .. } 9 spans of centering for one rib of gate-bridge complete .. }	3,09,600
10 sets of bolts, plates, etc., for supports in 10 feet piers ..	3,880
2 sets of bolts, plates, etc., for 25 feet piers ..	1,140
Timber stagings on 2 pontoons for centres and supports ..	20,000
1 special-tackle, jacks, winches, etc.	30,000
Total .. Rs.	3,64,620

SECTION XVIII.

Scientific Instruments, etc.

465. It will be necessary to have the very finest theodolites for giving and checking the main alignment of the barrage and the regulators. Masonry towers are provided on either bank for theodolite stations for this purpose, and the instruments for these will be kept on them permanently till completion of the work.

The following instruments will be required :—

	Rs.
2 12″ micrometer theodolites for barrage alignment reading to single seconds at £200	6,000
2 8″ micrometer theodolites for regulator alignment reading to 2 seconds at £120	3,600
4 6″ micrometer theodolites for general service reading to 5 seconds at £75	4,500
4 5″ micrometer theodolites for general service reading to 10 seconds at £67-10-0	4,050
30 14″ Dumpy levels at Rs. 250	7,500
2 16″ Dumpy levels at Rs. 300	600
Staves, cross staves, flags, steel tapes, chains, measuring standards, umbrellas, prismatic compasses, binoculars, etc., say	6,250
Drawing instruments, boards, etc.	5,000
Paper and materials	5,000
Total ..	42,500

SECTION XIX.

Miscellaneous General Plant and Tools.

466. Under this heading is included all general plant appliances and tools not estimated in detail in the following sections, such as—

Lifting tackle, ropes, chains, jacks, winches, engines, hand pumps, sundry pumps, bollards, buoys, moorings, drills, taps, stocks and dies, orges, furnaces, girders, grindstones, weighing machines, tanks, tents, trollies, vices, etc., and all hand tools, etc. .. .. .. Lump sum say Rs.	10,00,000

SECTION XX.

467. *Office Furniture required at all sites*—

		Rs.
General Staff (Direction)	Offices	2,500
General Works	,, ...	15,000
Power Supply	,, ...	6,000
Stores	,, ...	4,000
Audit and Accounts	,, ...	4,000
Medical and Sanitary	,, ...	8,000
Police	,, ...	200
Posts and Telegraphs	,, ...	300
		40 000
Maintenance and repairs at 5 per cent. per annum for 5 years.		10,000
	Total ..	50,000

SECTION XXI.

468.—Estimate of Plant.

—	Estimated initial cost.	Anticipated salvage value.	Included in rates or charged in Service Works.	Net debit to "Plant."
II.—Railway.	Rs.	Rs.	Rs.	Rs.
Permanent-way—				
5'-6" gauge	13,70,800	6,85,000	6,85,800	*Nil.*
2'-0" ,, ...	81,600	35,000	46,600	*Nil.*
Rolling stock—				
5'-6" Gauge	20,66,000	10,00,000	*Nil.*	10,66,000
Heavy repairs at Rs. 6 per month per vehicle, for 5 years on 496 cars ..	1,78,500	....	*Nil.*	1,78,500
2'-0" gauge	2,93,000	1,00,000	*Nil.*	1,93,000
Heavy repairs at Rs. 3 per vehicle per month for 5 years on 411 vehicles ..	74,000	*Nil.*	*Nil.*	74,000
Locomotives—				
5'-6" gauge	3,12,000	40,000	*Nil.*	2,72,000
Heavy repairs on above at Rs. 70 per month per engine for 5 years on 12 engines ..	50,400	*Nil.*	*Nil.*	50,400
2'-0" gauge	80,000	10,000	*Nil.*	70,000
Heavy repairs at Rs. 30 per month per engine for 6 years on 10 engines ..	21,600	*Nil.*	*Nil.*	21,600
	45,27,900	18,70,000	7,32,400	19,25,500
III.—Fleet.				
2 dredgers	12,00,000	9,00,000	3,00,000	*Nil.*
2 paddle steamers	3,60,000	2,40,000	*Nil.*	1,20,000
2 steam tugs	1,80,000	1,35,000	*Nil.*	45,000
1 steam launch	40,000	20,000	*Nil.*	20,000
4 motor launches	50,000	20,000	*Nil.*	30,000
2 motor lifeboats	6,000	3,000	*Nil.*	3,000
Heavy repairs and annual overhaul on above at 5 per cent. per annum of original cost for 5 years, *i.e.*, on Rs. 18,36,000	4,59,000	*Nil.*	*Nil.*	4,59,000
Pontoons and barges	6,47,000	3,00,000	*Nil.*	3,47,000
Heavy repairs and annual overhaul at 3 per cent. per annum for 5 years	97,000	*Nil.*	*Nil.*	97,000
	30,39,000	16,18,000	3,00,000	11,21,000
IV.—Cranes.				
6 electric derrick cranes	2,40,000	1,80,000	..	60,000
24 hand cranes	54,000	27,000	..	27,000
4 electric loco. cranes	40,000	20,000	..	20,000
2 do.	40,000	20,000	..	20,000
Repairs to above at 5 per cent. per annum for 5 years	93,500	..	..	93,500
2 electric Goliath cranes	90,000	45,000	..	45,000
Repairs at 5 per cent. per annum for 5 years .	22,500	*Nil.*	..	22,500
	5,80,000	2,92,000	..	2,88,000
V.—Pumping Plant for Cofferdams.				
40 sets 8" pumps, motors, etc.	1,80,000	1,35,000	45,000	*Nil.*
Repairs at 1 per cent. per annum for 5 years.	9,000	*Nil.*	9,000	*Nil.*
	1,89,000	1,35,000	54,000	*Nil.*

—	Estimated initial cost.	Anticipated salvage value.	Included in rates or charged in Service Works.	Net debit to "Plant."
	Rs.	Rs.	Rs.	Rs.
VI.—Pile Drivers.				
34 sets of machines	5,04,000	2,52,000	2,52,000	*Nil.*
Repairs at 2 per cent. per annum for 5 years.	50,400	*Nil.*	50,400	*Nil.*
	5,54,400	2,52,000	3,02,400	*Nil.*
VII.—Stone Crushers and Concrete Mixers.				
Complete Plant	1,03,850	20,000	83,850	*Nil.*
Repairs at 5 per cent. per annum for 5 years.	25,960	*Nil.*	25,960	*Nil.*
	1,29,810	20,000	1,09,810	*Nil.*
VIII.—Moulds for Blocks.				
Cost of moulds	1,60,000	10,000	1,50,000	*Nil.*
Repairs at 3 per cent. per annum for 5 years.	24,000	*Nil.*	24,000	*Nil.*
	1,84,000	10,000	1,74,000	*Nil.*
IX.—Air Compressors and Pneumatic Tools.				
Outlay	57,600	18,000	*Nil.*	39,600
Repairs at 5 per cent. per annum for 5 years.	14,400	..	..	14,400
	72,000	18,000	..	54,000
X.—Diving Gear and Apparatus				
Outlay	56,660	15,000	41,660	*Nil.*
Repairs at 5 per cent. per annum for 5 years.	14,160	..	14,160	*Nil.*
	70,820	15,000	55,820	*Nil.*
XI.—Workshops.				
Plant and erection	1,09,700	70,000	*Nil.*	39,700
Repairs at 4 per cent. per annum for 5 years on Rs. 87,000	17,600	*Nil.*	*Nil.*	17,600
	1,27,300	70,000	*Nil.*	57,300
XII.—Water Supply Plant.				
Plant and erection	1,70,000	50,000	..	1,20,000
Repairs at 4 per cent. per annum for 5 years on Rs. 1,00,000	20,000	*Nil.*	..	20,000
	1,90,000	50,000	..	1,40,000
XIII.—Mortar Mills.				
Plant and erection	1,00,000	60,000	40,000	*Nil.*
Repairs at 6 per cent. per annum for 5 years.	30,000	*Nil.*	30,000	..
	1,30,000	60,000	70,000	*Nil.*
XIV.—Disintegrators				
Plant	13,000	3,000	10,000	..
Repairs	5,000	*Nil.*	5,000	*Nil.*
	18,000	3,000	15,000	..

—	Estimated initial cost.	Anticipated salvage value.	Included in rates or charged in Service Works.	Net debit to "Plant".
	Rs.	Rs.	Rs.	Rs.
XV.—Electric Power Plant.				
Plant and erection	6,67,000	4,50,000	2,17,000	*Nil.*
Repairs at 2 per cent. per annum for 5 years .	66,700	*Nil.*	66,700	..
Transmission lines	1,70,000	34,000	1,36,000	..
	9,03,700	4,84,000	4,19,700	*Nil.*
XVI.—Steel Sheet Piling.				
Piling	19,49,600	9,74,800	*Nil.*	9,74,800
Walings	60,480	40,480	*Nil.*	20,000
	20,10,080	10,15,280	..	9,94,800
XVII.—Arch Centres and Supports.				
Trusses	1,72,800	1,29,600	43,200	*Nil.*
Lagging	1,08,000	28,350	79,650	..
Bolts, plates, etc.	5,020	2,510	2,510	..
Timber staging on pontoons	20,000	7,000	13,000	..
Special tackle	30,000	10,000	20,000	..
Cylinders	28,800	4,050	24,750	..
	3,64,620	1,81,510	1,83,110	*Nil.*
XVIII.—Scientific Instruments.				
8 Theodolites	14,100	13,000	..	1,100
4 do.	4,050	3,000	..	1,050
32 Levels	8,100	4,000	..	4,100
Staves, Cross staves, tapes, etc.	6,250	1,250	..	5,000
Drawing instruments, boards, etc.	5,000	2,500	..	2,500
Paper and materials	5,000	..	..	5,000
	42,500	23,750	..	18,750
XIX.—Miscellaneous Plant and Tools ..	10,00,000	4,00,000	*Nil.*	6,00,000
XX.—Office Furniture	40,000	10,000	..	30,000
Repairs to same at 5 per cent. per annum for 5 years	10,000	..	..	10,000
	50,000	10,000	..	40,000
Total ..	1,41,83,130	65,27,540	24,16,240	52,39,350
Add.—Contingencies at 5 per cent.	7,09,156	3,50,000	..	3,59,156
Grand Total ..	1,48,92,286	68,77,540	24,16,240	55,98,506

469. For comparison the corresponding figures for the Sukkur Barrage and the Sara Bridge (Completion Report figures) are given below, in both cases excluding the cost of repairs and contingencies :—

—	Estimated initial cost.	Anticipated salvage value.	Included in rates or charged in Service Works.	Net debit to "Plant."
Barrage Project	1,28,99,410	65,27,540	21,91,020	41,80,850
Sara Bridge Project	88,00,828	60,75,228	15,28,216	11,97,384

Thus it will be seen that the gross outlay on plant proposed for the Sukkur Project is about 40 per cent. in excess of that at Sara Bridge, and as prices have been increased about 40 per cent. over pre-war prices this means that the total amount of plant is about the same for each work.

PART VIII.

SERVICE WORKS.

470. *Summary and Index*—

SECTION I.

Service railway on both banks (permanent-way and maintenance).

471. 40 *miles of track*, 5′-6″ *gauge*—

	Rs.
Earthwork, laying, carriage to site may be taken at Rs. 5,000 per mile	2,00,000
Depreciation on permanent-way	6,85,800
Maintenance for 5 years at Rs. 1,250 per year per mile	2,50,000
Signallers' quarters, signals, stations, buffers, etc., at Rs. 1,000 per mile	40,000
	11,75,800

472. 10 *miles of track*, 2′-0″ *gauge*—

	Rs.
Earthwork, laying, carriage to site, removing and relaying may be taken at Rs. 2,000 per mile	20,000
Depreciation on permanent-way	46,600
Maintenance for 5 years at Rs. 600 per mile per year	30,000
Quarters, signals, etc., at Rs. 500 per mile	5,000
	1,01,600

473. *Engine sheds, etc., 5′-6″ gauge on each bank of river—*

	Rs.
1 engine shed, 100′×30′, at Rs. 5,000	10,000
1 ashpit, 60′ long, at Rs. 400	800
1 loco. well, 8′ diameter, at Rs. 1,800	3,600
1 lighting arrangement at Rs. 300	600
	15,000

474. *Engine sheds, etc., for 2′-0″ gauge on each bank—*

1 engine shed, complete with ashpit, loco. well and lighting at Rs. 4,000	8,000
Total ..	13,00,400

SECTION II.

475. *Service roads and bunds—*

		Rs.
A lump sum provision of Rs. 20,000 is made for roads *plus* Rs. 5,000 for maintenance during 5 years		25,000
The temporary bunds required will cost.. ..	*25,242	
Add—Maintenance for 5 years	2,758	
		28,000
Total ..		53,000

476. **Details of cost of temporary bunds—*

(*a*) New bunds .. .. Top R.L. 202·0.
Average ground 197·0 area=44×5=220 square feet.

(*b*) Widening old bunds .. Top R. L. 202·0.
Average ground 197·0 area=26×5=130 square feet.

Righ' Bank—

New bunds—

Length.	Area.	C. ft.
500 ×	220=	110,000
1,700 ×	220=	374,000
Widening old bunds—		
1,200 ×	130=	156,000
1,500 ×	130=	195,000
		835,000

Left Bank—

New bunds—		Rs.	Rs.
400 ×	220=	88,000	
600 ×	220=	132,000	
3,400 ×	220=	748,000	
			968,000
		Total ..	18,03,000 cubic feet.

Cost of 18,03,000 cubic feet at Rs. 14 per 1,000 cubic feet=Rs. 25,242

SECTION III.

477. *Water Supply—*

	Rs.
Treating water	3,000
Electric power for pumps	70,000
Pump drivers and attendants	9,000
Oil and waste, etc.	1,000
Temporary watering arrangements, plant, material, erection and working for 12 months	25,000
Settling tanks and maintenance	6,000
Maintenance tanks and stagings	4,000
Fire Protection Chowkidars	4,000
Maintenance of pipe lines, hydrants, etc.	2,000
	1,24,000

SECTION IV.

478. *Cost of Electric Power.*—The average cost of producing electric power at the Sara Bridge Works (Calcutta side power house) was about 2·67 annas per unit. This cost included depreciation charges on plant, put down as Rs. 23,736 on plant costing Rs. 2,01,005. Had this plant been sold under normal conditions it would not have realized more than 50 per cent. of cost price, and depreciation charges would have been increased by about Rs. 76,000 and the unit rate would rise to about 3·4 annas per unit.

Allowing for the general rise of prices we may assume that it will cost not less than 4 annas per unit to produce power at Sukkur. The cost of power supplied for working cranes, mortar mills and other plant whose working charges are not charged separately, is included in the rates for setting concrete blocks laying masonry, etc., and hence no separate estimate is required of total cost of producing electric power.

SECTION V.

479. *Alignment Towers—*

On right bank—

	Rs.
Two towers for gate bridge alignment, 50′ high, at Rs. 5,000.	10,000
One „ „ road bridge „ 30′ „ at Rs. 3,000.	3,000
Two „ „ regulator „ 30′ „ at Rs. 3,000.	6,000
Line of sight towers	1,000
Total .. Rs.	20,000

	Rs.
Left bank—	
As above	20,000
Total .. Rs.	40,000

SECTION VI.

Cost of Pile Driving.

480. On the North Platte Irrigation Project (see Engineering Record, 27th June 1908) the cost of driving piles was as follows :—

	Per foot depth of pile.
Depreciation of plant	\$ 0·016=0·8 annas.
Labour	\$ 0·067=3·35
Coal and oil (coal 5·5 per ton)	\$ 0·012=0·6
Total annas	..4·75

481. *For Sukkur Barrage—*

Per foot depth of pile.

Take depreciation and repairs $\dfrac{\text{Rs. } 3{,}02{,}400}{25{,}00{,}000 \times \cdot 75}$ = Rs. ·165=2·6 annas.

Coal and oil or electric power .. Double .. 1·2

For Labour—

Pile driver would require following crew for each shift :—

	On Rs.
1 Mistri	150
1 Driver	75
1 Stoker	40
2 Coolies for fuel	50
7 „ for handling ..	210
Rs.	525 per month per shift 8 hours or Rs. 1,050 for 2 shifts.

482. *On Platte River one pile driver drove—*

25 piles 22′ in 12 hours=one pile 46 feet deep per hour (60 square feet).

At Sukkur 2 shifts of crew would work 16 hours a day for 26 days per month=say 400 hours per month.

∴ Cost of labour=1,050=2·625 Rs. per hour.

∴ Cost of labour for driving per foot depth of pile= $\dfrac{2\cdot625 \times 16 \text{ annas.}}{46}$

=·915 annas per foot of pile.

=Say 1 anna.

483. *Cost of moving piles from rail to pile driver—*

This may be taken at 12 annas per ton as sections are easily handled Weight of pile and clutch=55 lb. per foot depth (43 lb./square foot).

∴ Cost per foot depth for moving= $\dfrac{55 \times 12}{2240}$ = ·3 annas.

484. Hence total cost of *driving* piles—

	Per foot of pile.
Depreciation	2·6 annas.
Coal and oil	1·2 „
Labour	1·0 „
Moving to site	·3 „
	5·1 annas per foot depth.

But every 3 piles with 3 clutches makes 4′ width.

Hence 3 feet depth of one pile (and clutch) makes 4 square feet.

∴ Cost of driving per square foot $= \frac{3}{4} \times 5\cdot1$ annas.

$= 3\cdot82$ annas per square foot.

Say 4 annas per square foot.

485. For withdrawing and removing pile to yard, take same rate as above, 4 annas.

486. Total cost of driving, withdrawing and moving per square foot of piling=8 annas.

Pile Driving and withdrawing.

For all temporary piling in cofferdams and wharves.

487. *Driving piles* at 4 annas per square foot—

			Rs.
1st year's work in cofferdams,	221,185	square foot ..	55,296
„ „ „ wharves,	90,600	„ ..	22,650
2nd „ „ „ cofferdams,	311,565	„ ..	77,891
3rd „ „ „ „	172,740	„ ..	43,185
4th „ „ „ „	159,240	„ ..	39,810
		Total for driving ..	2,38,832

488. *Withdrawing piles* at 4 annas per square foot—

	Sq. ft.	
1st year's work in cofferdams	221,185	
2nd „ „ „ „	311,565	
3rd „ „ „ „	172,740	
4th „ „ „ „	159,240	
„ „ „ „ wharves	90,600	
Total for withdrawing	955,330	2,38,832

489. Total for driving and withdrawing 4,77,664

Section VII.

Wharves.

Abstract.

490. *Wharves for loading and unloading—*	Rs.	Rs.
120,800 square feet steel sheet piling at Rs. 4 per square foot	4,83,200	
106 tons walings at Rs. 160 per ton	16,960	
90,600 square feet driving and withdrawing piles at 0-8-0 per square foot	45,300	
1,288,000 cubic feet earth filling inside at Rs. 12 per 1,000 cubic feet	15,456	
41,800 cubic feet metal on top at Rs. 8 per 100 cubic feet	3,344	
270,000 cubic feet loose stone pitching	21,600	
Total cost ..	5,85,860	
		5,85,860

491. *Deduct—*

(*i*) Provision made under *Plant*, Section XVI,		—	
Piling, 120,800 square feet ..	4,83,200		
Walings, 106 tons	16,960		
		5,00,160	
(*ii*) Under *Service Works*, Section VI,	—		
	Rs.		
Driving piles, 90,600 square feet ..	22,650		
Withdrawing piles, 90,600 square feet	22,650		
		45,300	
Deduct—Total ..		5,45,460	5,45,460

492. Net amount charged in this section		40,400

Measurement.

493. 1. *Universal steel sheet piling required—*

	Sq. ft.	Sq. ft.
1 front row A, 350×40	14,000	
8 cross rows B, 100×40	32,000	
2 ends C, 50×40	4,000	
2 ends D, 30×40	2,400	
4 cross Piles E, 50×40	8,000	
	60,400	
For another wharf on the other bank ..	60,400	
		1,20,800

494. 2. *Driving and drawing piles—*

Say ¾th of the above	90,600

495. 3. *Walings.*

15″×5″	R. S.	beams.		Running feet.
4	front	350	.. ..	1,400
8	sides	50	.. ..	400
8		50	.. ..	400
8		20	.. ..	160
8		30	.. ..	240
8		50	.. ..	400
				3,000
For another wharf on the other bank			..	3,000
				6,000 running feet at 39·5 lb. per foot run=106 tons.

Section VIII.

Cofferdams.

Abstract.

496. *Piles provided for cofferdams.*

	Rs.
366,600 square feet Universal steel sheet piles at Rs. 4 per square foot	14,66,400
272 tons Walings, 15″×5″ beams at Rs. 160 per square foot	43,520
Provided for under *Plant,* Section XVI, Total ..	15,09,920

497. *Driving and withdrawinig piles—*

				Rs.
221,185 square feet	1st year	at As. 8	per square foot	1,10,592
311,565	2nd „	at As. 8	„ „	1,55,782
172,740	3rd „	at As. 8	„ „	86,370
159,240	4th „	at As. 8	„ „	79,620
Provided for under *Service works,* Section VI.			Total ..	4,32,364

498. *Loose stone pitching—*

				Rs.
320,000 cubic feet	1st year	at Rs. 8	per 100	25,600
140,000	2nd „	at Rs. 8	„ 100	11,200
140,000	3rd „	at Rs. 8	„ 100	11,200
				48,000

499. Net total charged to cofferdams in this section 48,000

Temporary Steel Sheet Piling.

Measurement.

(See Drawing No. 71.)

500. *First year's cofferdams.*

Note 1.—Outer row of piles will have top at R. L. 195 and will be driven from R. L. 182 to R. L. 155. Their lengths will be 40 feet and they will be driven 27 feet.

Note 2.—Pumping trench piles will have top at R. L. 176 and bottom at R. L. 156. Their lengths will be 20 feet and they will be driven 20 feet.

501. *Right Bank—Temporary steel sheet piling—*

Top at R. L. 195. Bottom R. L. 155. Length 40 feet. To be driven 182—155=27 feet.

Outer piling	400 running feet.		
	440		
	415		
	610		
	1,080		
	2,945×40′=117,800 square feet.		

Pumping trench—Top R. L. 176. Bottom R. L. 156. Length 20′. To be driven 20′.

	450 running feet.		
	400		
	500		
	1,350×20=27,000 square feet.		Sq. ft.
Right Bank. Total		1,44,800	1 44,800

502. *Left Bank—*

	515 running feet.		
	205		
	560		
	610		
	1,320		
	3,210×40=128,400 square feet.		
Pumping trench	600 running feet.		
	530		
	270		
	1,400×20 =28,000 square feet.		
Left Bank. Total		156,400	156,400
	Total piling in 1st season ..		301,200

503. *Driving and pulling out piles*—

			Sq. ft.
Right Bank—Outer row	.. 2,945×27	.. .. ..	79,515
Pumping Trench.	1,350×20	.. .. ..	27,000
Left Bank—Outer row	.. 3,210×27	.. .. ..	86,670
Pumping Trench.	1,400×20	.. .. ..	28,000
		Total ..	221,185

504. *Second Year's Cofferdams*—

Barrage—

Outer row .. .. 1,570 running feet.
540
1,570
540

4,220×40= Sq. ft. 168,800

Pumping trench .. .. 1,290 running feet.
180
180
1,290

2,940×20= 58,800

505. *Regulators Right Bank*—

Outer row .. .. 300 running feet.
380
760
200

1,640×40= 65,600

Pumping trench .. .. 50 running feet.
180
690

920×20= 18,400

311,600

506. *Left Bank Regulators.*

Outer row .. .. 270 running feet.
415
1,150

1,835×40= 73,400

Pumping trench .. .. 50 running feet.
180
1,100

1,330×20= 26,600

1,00,000

Total piles 2nd season square feet 4,11,600

507. *Driving and pulling out piles.*

Right Bank, Barrage—

Outer row, 4,220×27=	113,940 square feet.	
Pumping Trench, 2,940×20=	58,800	
Regulator—		
Outer row, 1,640×27=	44,280	
Pumping Trench, 920×20=	18,400	
Left Bank. Regulators—		
Outer row, 1,835×27=	49,545	
Pumping Trench, 1,330×20=	26,600	
Total 2nd season pile driving		3,11,565 sq. ft.

Third Year's Cofferdams.

508. *Barrage—*

Outer row	1,570 running feet.		
	540		
	1,570		
	540		
	4,220×40=	168,800	
Pumping trench	1,290		
	180		
	180		
	1,290		
	2,940×20=	58,800	
Total piling, 3rd season's work			2,27,000 sq. ft.

509. *Driving and drawing out piles—*

	Sq. ft.	
Outer row, 4,220×27=	113,940	
Pumping trench, 2,940×20=	58,800	
Total pile driving, 3rd season work		1,72,740 sq. ft.

Fourth Year's Cofferdam.

510. *Barrage—*

Outer row	1,320 running feet.		
	540		
	1,320		
	540		
	3,720×40=	148,800 square feet.	
Pumping trench	1,110 running feet.		
	360		
	1,110		
	360		
	2,940×20=	58,800	
Total piles, 4th season			2,07,600 sq. ft.

511. *Driving and Pulling out Piles.*—

		sq. ft.	sq. ft.
Outer row,	3,720×27 ..	100,440	
Pumping trench,	2,940×20 ..	58,800	
Total pile driving, 4th season, square feet			159,240

512. *Note.*—It is only necessary to provide sufficient piling for cofferdams to make the walls of the 2nd season's cofferdams, *plus* the quantity necessary to make the pumping trench in the 4th season's cofferdam. (See paragraphs 323 to 325.

i.e., 2nd season's	40′	piling	307,800	square	feet
4th ,,	20′	,, ...	58,800	,,	,,
		Total provided ..	366,600	,,	,,

513. *Walings required*—

	First Year.				
Right Bank	2	2,945′	long	5,890′	
Left Bank	2	3,210′	,,	6,420′	
					12,310′
	Second Year.				
Right Bank—					
Barrage	2	4,220′	long	8,440′	
Regulator	2	1,640′	,,	3,280′	
Left Bank	2	1,835′	,,	3,670′	
					15,390, Maximum required.
	Third Year.				
Barrage	2	4,220′	long	8,440′	8,440′
	Fourth Year.				
Barrage	2	3,720′	,,	7,440′	7,440′

514. *Walings provided for*—

15″×5″ joists

(required for *Second Year*)

15,390 feet at 39·5 lbs. per ft. 272 tons — 272 tons.

515. *Loose Stone Pitching.*

			C. ft.
Round 1st Year's Cofferdam		2×800′×50′×4′	= 32,000
2nd ,,	,,	1×700′×50′×4′	= 14,000
3rd ,,	,,	1×700′×50′×4′	= 14,000
			60,000 cubic feet.

Section IX.

Cost of Pumping in Cofferdams.

516. This item being a very large and uncertain one, cannot be included in the rates for masonry, excavation, etc., and hence is estimated separately here.

Assuming that all pumping units are 8″ pumps (less efficient than 10″ pumps), the total number of pumps working during whole period of construction will be 90-8″ pumps (see paragraph 370, Section IV, Part VI) Assuming they all work for the full pumping season of 150 days, there will be—

$$90 \times 150 \times 24 \text{ pumping hours}$$
$$=324{,}000 \text{ pumping hours.}$$

517. Assuming all pumps work under the full head (35′ including friction allowances) and that at this lift an 8″ pump requires 25 B.H.P., the cost per month (30 days) for one pump may be taken as—

	Rs.
Electric units, $25 \times \cdot746 \times 30 \times 24 = 13{,}420$ at 4 annas	3,355
Oil waste, etc.	30
Attendance	50
Depreciation on pump and motor 4 years, 5 months per year $\frac{40 \text{ per cent. on } 4{,}500}{5 \times 4} = \frac{1{,}800}{20} =$	90
Repairs	20
Fitting up pontoons and moving	155
Per month total .. Rs.	3,700

or cost per hour per pump

$$= \frac{3{,}700}{30 \times 24} = \text{Rs. } 5\cdot14$$

518. The total pumping hours are estimated at 324,000 hours.

Therefore total cost of pumping $= 324{,}000 \times 5\cdot14$
$= \text{Rs. } 16{,}65{,}000$
say Rs. 17,00,000.

Section X.

519. *Service Stores Depôt.*

	Rs.
Maintenance of sheds, etc.	5,000
Lighting arrangements	2,000
Sorting and stacking plant and stores	50,000
Rs. ..	57,000

Section XI.

520. *Local Carriage of Stores*—

	Rs.
Labour in depots, 60 months, at Rs. 1,700 per month ..	1,02,000
Cost of maintaining 20 trucks for 60 months, at Rs. 20 per month	24,000
Working and maintenance of locomotives	60,000
Handling stores	40,000
Demurrage charges	30,000
Working launches	8,000
„ steamers	13,000
„ cranes (electric power, etc.)	9,000
Drivers and cleaners, etc.	2,000
Out-Agency staff at Sukkur and Rohri stations	5,000
Rs. ..	2,93,000

SECTION XII.

521. *Lighting and Fans—Bungalows and Offices.*—

	Rs.
Wiring, etc., for bungalows and offices	5,000
Plugs, switches, etc.	3,000
Shades, pendants, wall brackets, etc.	3,000
House lamps	2,000
Ceiling fans	10,000
Desk fans	5,000
Erection and wiring	7,000
Repairs and maintenance for 4 years	4,000
Consumption of current including arc lamps on works and roofs, 400,000 units, at 4 annas per unit	1,00,000
Rs. ..	1,39,000

SECTION XIII.

522. *Telegraphs and Telephones—Both Banks and Quarries*—

	Rs.
Hire of telephone instruments Nos. 20 at Rs. 4-8-0 per month per instrument for 5 years	5,400
Hire of telegraph instruments Nos. 6 at Rs. 4-8-0 each per month for 5 years	1,620
Special exchange wiring	4,000
Hire of telegraph wire, 40 miles at Rs. 2 per mile per month for 5 years	4,800
Hire of telephone wire, 50 miles, at Rs. 2 per mile per month for 5 years	6,000
Cost of cable under river including repairs and renewals	12,000
	33,820

SECTION XIV.

Cost of Dredging.

523. For details of dredgers, see Appendix K.

I estimate the annual working expenses of each dredger, approximately, as follows :—

	Per annum. Rs.
Dredge Master at Rs. 600 per month	7,200
1st Engineer „ „ 500 „ „	6,000
2nd „ „ „ 350 „ „	4,200
3rd „ „ „ 200 „ „	2,400
4th „ „ „ 150 „ „	1,800
	21,600

	Rs.
Crew of 40 men at average of Rs. 40 per month	19,200
Coal 5 tons per day of 12 hours at Rs. 15 per ton (or equivalent in oil fuel) 260 days per annum	19,500
Oil, waste, etc., at Rs. 400 per month	4,800
Annual overhaul, painting, etc.	25,000
Interest at 6 per cent. and depreciation at 5 per cent. on £40,000= Rs. 600,000	66,000
Total per annum ..	1,56,100

or per working day, 260 days per annum $=\frac{156{,}100}{260}=$ Rs. 600 per day of 12 hours.

As they are to dredge 7,000 cubic feet per hour or $12 \times 7{,}000 = 84{,}000$ cubic feet per day of 12 hours.

The cost of dredging per 1,000 cubic feet will be Rs. $\frac{600}{84}=$ Rs. 7-15.

say Rs. 8 per 1,000 cubic feet (see note below).

This is for any lead up to 1,000′ and any lift upto 30′ + 25′=55′.

524. If the excavation in cofferdams could be done by hand, the average lead would be about 200′ and the average lift about 15′. This is equivalent to lead only of $200+15 \times 12=380'$. The rate for dry excavation with this lead, by hand work, would be not less than Rs. 9-5-0 per 1,000 cubic feet (see page 47 of Rohri Canal Project 1909, Volume 6) to which Dr. Summers added Rs. 3 for wet excavation. Hence the rate would have been not less than Rs. 12-5-0 in 1909. At present rates of labour it would probably be not less than Rs. 15 per 1,000 cubic feet. In addition to this would be the very heavy charge for pumping during the whole time excavation was in progress. The cost of pumping would come to about Rs. 7 per 1,000 cubic feet (if every man possible were crowded into cofferdam, and work continued day and night), so that the total cost of hand excavation would be about Rs. 22 per 1,000 cubic feet, as against Rs. 8 per 1,000 cubic feet estimated as the cost of dredging, or a saving of Rs. 14 per 1,000 cubic feet by dredging. The total quantity of dredging to be done in all cofferdams and for the divide walls, etc., is estimated at about 52,000,000 cubic feet, so that the saving by substituting dredging for hand labour comes to $52{,}000 \times 14=$ Rs. 7,28,000 on this item alone, or more than the estimated cost of one dredger.

525. Besides this work the dredgers will probably be of great use in excavating the toe of river banks for the guide bank slopes and for laying the protective apron.

There is also an enormous quantity of excavation to be done in widening and deepening the existing head of the Eastern Nara Supply Channel, all which can be done by the dredgers under-cutting the banks and dredging from the bed. To do this by hand would necessitate closing the supply channel throughout one cold weather, and thereby stopping all rabi cultivation on the Jamrao Canal.

This item alone would pay for the cost of the dredgers, apart from the fact that one dredger will be useful for permanent maintenance of the Eastern Nara, and the other for sundry work on the river in clearing the heads of inundation canals.

526. The actual estimated cost of dredging is included in the estimates under "Excavation".

Note on Rate taken for excavation by dredgers.

527. *If dredgers are used only for the barrage* } at 7,000 cubic feet per hour,
Total work in each year— } at 84,000 ,, ,, day.

1st year	.. .. 16,404,893 c. ft.	196 days' work.
2nd ,,	.. .. 14,398,776 ,,	171 ,,
3rd ,,	.. .. 11,374,800 ,,	136 ,,
4th ,,	.. .. 10,448,700 ,,	125 ,,
	52,627,169 ,,	628 days' work in 4 years.

It is presumed that the dredger will work 260 days per year, *i.e.*, 22 days each month and so 628 days actual work will mean $\frac{628}{22}$ $=28\frac{1}{2}$ months, say 29 months, or $14\frac{1}{2}$ months for each dredger.

If no other work is found for the dredgers the cost for four years will be—

For two dredgers.

	Rs.
(1) Dredge Master and Engineers' two dredgers, for four years at Rs. 21,600	1,72,800
(2) Dredge Crew of 40 men, four years, at Rs. 19,200	1,53,600
(3) Coal, 5 tons per day of 12 hours for each dredger, for 628 days in all at Rs. 15 per ton	47,100
(4) Oil waste in 29 months at Rs. 400 per mensem	11,600
(5) Annual overhaul, $\frac{29}{48}\times 100{,}000$	60,000
(6) Interest at 6 per cent. on Rs. 12,00,000, cost of two dredgers ..	2,88,000
(7) Depreciation at 5 per cent. on Rs. 12,00,000 for four years	2,40,000
Total Rs. ..	9,73,100

which is the actual cost of 52,627,169 cubic feet of excavation. Hence the rate would be, if dredgers do *only* Barrage work, Rs. 18-7-0 per 1,000 cubic feet.

528. But if full work is found for the dredgers, cost will be—

2 dredgers for 4 years at Rs. 1,56,100 per year=Rs. 12,48,800.

Total work done will be—

$2\times4\times260\times84{,}000$ cubic feet .. =174,720,000 cubic feet out of which 52,627,169 cubic feet is provided for the Barrage.

Leaving 122,092,831 cubic feet

of work which will have to be found for these dredgers to reduce rate from Rs. 18-7-0 to Rs. 7-3-0.

529. *Note.*—The approximate quantity of earthwork in widening the Eastern Nara Channel from mile 4 to 12—

$210 \times 16 \times 40{,}000 = 134{,}400{,}000$, cubic feet and this will provide enough work for the dredgers, during the period they are not required at the Barrage.

The dredgers can pass in and out of the Eastern Nara Channel each year through a cut by the side of the new head regulator, which cut can be closed, by a row of sheet piling or earthen bund if necessary. The rate for barrage excavation is therefore taken as Rs. 7-3-0, say Rs. 8 per 1,000 cubic feet.

Service Works.

Section XV.

530. *Moulds and Core boxes for Blockyard—*

On Sukkur Side—

	Rs.
Core boxes	20,000
Moulds, depreciation and repairs..	87,000
	1,07,000
Same on Rohri Side	1,07,000
Total Rs. ..	2,14,000

PART IX.

ESTABLISHMENT.

INDEX.

PART IX.

Establishment.

SECTION I.

The Staff and Divisions required for Barrage Construction.

I Division. Direction.

1 Superintending Engineer (Engineer-in-Chief).
1 Executive Engineer as Personal Assistant.
1 Assistant Engineer as Personal Assistant.
1 Assistant Traffic Superintendent as Personal Assistant, Rs. 500.

II Division. River Works (Barrage Proper).

1 Executive Engineer.
2 Assistant Engineers.

III Division. Right Bank Works.—Regulators and Guide Banks.

1 Executive Engineer.
1 Assistant Engineer. Regulators.
1 Assistant Engineer. Guide Banks and Permanent way.
1 Assistant Engineer. Blockyard and Materials.

IV Division. Left Bank Works.

1 Executive Engineer } As on Right Bank.
3 Assistant Engineers }

V Division. Quarries and Stone Supply.

1 Executive Engineer.
2 Assistant Engineers (one at each quarry).

VI Division. Power Supply, Workshops, Fleet and Loco. and Carriage.

1 Executive Engineer.
2 Assistant Engineers. (Electrical).
1 Assistant Engineer. (Workshops, Loco. and Carriage and Water Supply).
1 Assistant Engineer. (Fleet).

VII Division. Stores.

1 Chief Storekeeper. (Executive Engineer).
1 Assistant Storekeeper.

VIII Division. Accounts.

1 Examiner. (Executive Engineer).

IX Division. Medical and Sanitary.

1 Chief Medical Officer (Captain, I.M.S.).
1 Assistant Surgeon.

SECTION II.

Technical Establishment.

I Division. Direction.

	Rs.
1 Superintending Engineer	2,500
1 Executive Engineer	1,250
1 Assistant Engineer	800
1 Assistant Traffic Superintendent	600
1 Upper Subordinate	200
1 Lower Subordinate	60
2 Menials at Rs. 15	30

Traffic Sub-Division.

	Rs.
2 Subordinates at Rs. 200	400
4 Menials at Rs. 15	60
Total for Division	5,900

II Division. River Works (Barrage Proper).

1 Executive Engineer	1,250

Sub-Division. Lime Supply.

	Rs.
1 Assistant Engineer	800

SECTION.

	Rs.
Supply, 1 Upper Subordinate	200
Kiln, 1 "	200
Grinding 1 "	200
Testing 1 "	200
Menials 4	60
Total for Sub-Division	1,660

Sub-Division. River Works.

	Rs.
1 Assistant Engineer	800

SECTION.

			Rs.
Pile driving, pumping, arch centres, cranes	2 Mechanical Foremen ..	..	600
Dredging and hand excavation.	1 Upper Subordinate	..	200
Pile driving and pumping ..	1 Lower ,, ..	..	60
Masonry	2 Upper ,, ..	..	400
	2 Lower ,, ..	..	120
Centering and block laying ..	1 Upper ,, ..	..	200
	2 Lower ,, ..	..	120
Divers	16 at Rs. 150 ..	..	2,400
Menials	29 at Rs. 15 ..	..	435
	Total for Sub-Division	..	5,335
	Total for Division	..	8,245

III *Division. Right Bank Works.*

1 Executive Engineer 1,250

Sub-Division. Blockyard and Material Supply—

1 Assistant Engineer 800

SECTION.

Crusher and Sand and Surkhi Supplier	1 Upper Subordinate	..	200
Moulding	1 Upper ,,	..	200
	1 Lower ,,	..	60
Stone Supply and dressing ..	1 Upper ,,	..	200
	1 Lower ,,	..	60
Transport and stacking and marking	1 Lower ,,	..	60
Menials at Rs. 15	6	..	90
	Total for Sub-division	..	1,670

Sub-Division. Regulator Works.

1 Assistant Engineer 800

SECTION.

Pile and pumping	2 Mechanical Engineers	..	600
Dredging and excavation, and pumping	1 Upper Subordinate	..	200
	1 Lower ,,	..	60
Masonry	2 Upper ,,	..	400
	2 Lower ,,	..	120
Menials at Rs. 15	10	..	150
	Total for Sub-Division	..	2,330

Sub-Division. Guide Banks and Permanent Way.—

1 Assistant Engineer 800

SECTION.		Rs.
Earthwork	1 Upper Subordinate ..	200
	2 Lower „ ..	120
Stone pitching, laying and transport	1 Upper „ ..	200
	1 Lower „ ..	60
Stone Apron	1 Upper „ ..	200
	1 Lower „ ..	60
Bunder Wall	1 Upper „ ..	200
	1 Lower „ ..	60
Maintenance of buildings ..	1 Upper „ ..	200
	1 Lower „ ..	60
Permanent way	1 P. W. I. ..	200
	2 Lower Subordinates ..	120
Menials at Rs. 15	14 ..	210
	Total for Sub-Division ..	2,690
	Total for Division ..	7,940

IV *Division. Left Bank Works.*

Same as Right Bank Works Division	7,940

V *Division. Quarries and Stone Supply.*

1 Executive Engineer	1,250

Sub-Division. Aror Quarry.

1 Assistant Engineer	800

SECTION.		
Stone quarrying and measurements	1 Upper Subordinate ..	200
Collection and despatch	1 Lower „ ..	60
Dressing	1 Upper „ ..	200
	1 Lower „ ..	60
Plant	1 Mechanical Foreman ..	200
Menials at Rs. 15	5 ..	75
	Total for Sub-Division ..	1,595

Sub-Division. Kalka Quarry.

1 Assistant Engineer .. .. SECTION. Same as above	Total for Sub-Division ..	1,595

Sub-Division. Permanent Way and Transport.

1 P. W. I.	.. ..		200
2 Menials	.. ..		30
2 Sections each	2 Lower Subordinates ..	120	
	2 Menials	30	
		150×2	300
	Total for Sub-Division ..		530
	Total for Division		4,970

VI Division. Power Supply. Workshops. Fleet. Loco. and Carriage. Rs.

1 Executive Engineer		1,250

Sub-Division. Power Supply and Distribution Left Bank.

	Rs.	
1 Assistant Engineer (Electrical)	800	
2 Electrical Engineers in Power House	400	
1 Upper Subordinate transmission	200	
3 Lower „ „	180	
6 Menials at Rs. 15	90	
Total for Sub-Division	1,670	
		1,670

Sub-Division. Power Supply and Distribution Right Bank.

	Rs.	
1 Assistant Engineer (Electrical)	800	
As above	870	
Total for Sub-Division	1,670	
		1,670

Sub-Division. Workshops, Loco., Carriage and Water Supply.

1 Assistant Engineer	800	
1 Works Manager	400	
1 „	200	
1 Loco. Foreman	300	
1 „	200	
1 Carriage and Wagon	300	
1 „	200	
1 Mechanical Engineer for water mains	100	
10 Menials at Rs. 15	150	
Total for Sub-Division ..	2,650	
		2,650

Sub-Division. Fleet.

1 Assistant Engineer (Marine Superintendent) 800

SECTION.

Fuel Supply	1 Upper Subordinate ..	200		
Repairs	1 Mechanic	200		
Ship Stores	1 Subordinate	200		
Menials	3	45		
	Total	645		
			645	
	Total for Sub-Division ..		1,445	
				1,445
	Total for Division ..			8,685

VII Division. Stores. Right Bank.

1 Chief Storekeeper 1,250

Sub-Division.

		Rs.	Rs.
Purchases	1 Assistant Storekeeper	200	
Stock	1 Storekeeper	80	
Issues	1 Storekeeper	180	
.	2 Storekeepers ..	100	
Audit	1 Stock Accounts Clerk	150	
Menials	6	90	
	Tota for Sub-Division ..	700*	
			700

Sub-Division Left Bank Section.

1 Storekeeper		800	
Stock	1 Assistant Storekeeper	100	
Issue	,, ..	80	
	2 Menials	30	
Quarries Section.			
Stocks and Issue	1 Assistant Storekeeper.	80	
	1 Menial ..	15	
	Total for Sub-Division ..	1,105	
			1,105
	Total for Division		3,055

VIII Division. Audit and Accounts.

1 Examiner	1,250

IX Division. Medical and Sanitary.

1 Chief Medical Officer	1,250

Right Bank. Medical.

	Rs.	
1 Assistant Surgeon	250	
1 Sub-Assistant Surgeon	75	
3 Compounders	120	
3 Dressers	90	
1 Laboratory Assistant	60	
1 Hospital Cook	25	
2 Hospital Orderlies, 1 Waterman, 1 Peon, 2 Khalasis	96	
6 Ward Coolies at Rs. 16	96	
6 Sweepers at Rs. 15	90	
Total Medical	902	
		902

* This should read 800.

Sanitary and Water Supply. Station and Cooly Lines.

	Rs.	Rs.	Rs.
1 Sub-Assistant Surgeon	75		
2 Overseers	150		
3 Havildars at Rs. 25	75		
40 Sweepers at Rs. 15	600		
3 Khalasis at Rs. 15	45		
Total Sanitary ..	945		
		945	
Total Right Bank ..		1,847	
			1,847

Left Bank. Medical.

	Rs.	Rs.	Rs.
1 Assistant Surgeon	250		
1 Sub-Assistant Surgeon	75		
2 Compounders	80		
2 Dressers	60		
1 Cook	25		
2 Orderlies, 1 Waterman, 1 Peon, 2 Khalasis } 6 at 16	96		
3 Ward Orderlies at Rs. 16	48		
3 Sweepers at Rs. 15	45		
2 Medicine carriers at Rs. 15	30		
Total Medical ..	709		
		709	

Sanitary and Water Supply.

	Rs.	Rs.	Rs.
2 Overseers	150		
2 Havildars	50		
25 Sweepers at Rs. 15	375		
2 Khalasis at Rs. 15	30		
Total Sanitary ..	605		
		605	
Total for Left Bank ..		1,314	1,314

Medical and Sanitary at Aror Quarries. Medical.

	Rs.	Rs.	Rs.
1 Sub-Assistant Surgeon	75		
1 Compounder	40		
1 Dresser	30		
1 Orderly at Rs. 16	16		
1 Waterman at Rs. 15	15		
1 Peon at Rs. 16	16		
1 Khalasi at Rs. 15	15		
1 Ward Cooly at Rs. 15	15		
1 Sweeper at Rs. 15	15		
Total Medical ..	237		
		237	

Sanitary and Water Supply.	Rs.	Rs.	Rs.
1 Overseer	75		
1 Havildar	25		
10 Sweepers	150		
1 Khalasi	15		
Total Sanitary ..	265		
		265	
Total at Aror ..		502	
			502
Total for Division (Medical and Sanitary) ..			4,913

SECTION III.

534. *Clerical and Drawing Office Establishment.*

I Division. Direction.

	Rs.
1 Office Superintendent to Chief Engineer	300
2 Office Superintendents to Executive „	150*
1 Head Clerk to Executive Engineer	150
3 Clerks to „ „	180
1 Head Clerk to Assistant Engineer	80
2 Clerks to „ „	100
4 Draftsmen at Rs. 80	320
5 Tracers at Rs. 50	250
20 Menials at Rs. 15	300
Total for Division ..	1,830

II Division. River Works.

Executive Engineer's Office—

1 Head Clerk	150
3 Clerks at Rs. 60	180
1 Draftsman at Rs. 100	100
2 Tracers at Rs. 50	100
8 Menials at Rs. 15	120
	650
1 Accountant	120
6 Clerks, Accounts, at Rs. 75	450
	570
	1,220

2 *Sub-Divisional Officers each office.*

1 Head Clerk at Rs. 80	80
2 Clerks at Rs. 50	100
6 Menials at Rs. 15	90
	270
Rs. 270 per sub-division or for 2 sub-divisions ..	540
Total for Division ..	1,760

* This should read 300.

	Rs.
III. Division. Right Bank Works.	
Executive Engineer's Office as for River Works	1,220
3 Sub-Divisions at Rs. 270	810
Total for Division	2,030
IV. Division. Left Bank Works.	
Executive Engineer's Office	1,220
3 Sub-Divisions at Rs. 270	810
Total for Division	2,030
V. Division. Quarries and Stone Supply.	
Executive Engineer's Office	1,220
3 Sub-Divisions at Rs. 270	810
Total for Division	2,030
VI. Division. Power Supply.	
Executive Engineer's Office—	
1 Head Clerk	150
6 Clerks at Rs. 60	360
1 Draftsman	100
2 Assistant Draftsmen	150
6 Tracers	300
15 Menials at Rs. 15	225
1 Accountant	150
8 Accounts Clerks at Rs. 75	600
	2,035
4 Sub-Divisions at Rs. 270	1,080
Total for Division	3,115
VII. Division Stores.	
Executive Engineer's Office—	
1 Head Clerk	150
8 Clerks at Rs. 60	480
1 Draftsman at Rs. 100	100
2 Tracers at Rs. 50	100
1 Accountant	150
8 Accounts Clerks at Rs. 75	600
20 Menials	300
16 Store Khalasis at Rs. 15	240
	2,120
1 *Sub-Division : Left Bank.*	
1 Sub-Divisional Clerk	100
4 Clerks	240
5 Menials	75
12 Store Khalasis	180
Total for Sub-Division	595

At Quarries. Rs.

1 Clerk	60
2 Clerks	100
3 Menials	45
5 Store Khalasis	75
Total for Sub-Division Rs.	280
Total for Division Rs..	2,995

VIII. Division : Medical and Sanitary.

1 Head Clerk	120
5 Clerks at Rs. 60	300
6 Menials at Rs. 15	90
Total for Division ..	510

IX. Division : Audit and Accounts.

Examiner's Office and branch office on Left Bank—

1 Accountant, 2nd grade	300
2 Accountants, 3rd „ at Rs. 200	400
2 „ 4th „ „ 100	200
20 Clerks at Rs. 60	1,200
12 Menials at Rs. 15	180
Total for Division ..	2,280

SECTION IV.

535. *Abstract showing total cost of Technical and Clerical Staff.*

Division.	Technical.			Clerical.			Total.
	Months.	Per month	Total.	Months.	Per month	Total.	
		Rs.	Rs.		Rs.	Rs.	Rs.
I. Direction	80	5,900	4,72,000	80	*1,830	*1,46,400	*6,18,400
II. River Works	60	8,245	4,94,700	60	1,760	1,05,600	6,00,300
III. Right Bank Works ..	46	7,940	3,65,240	46	2,030	93,380	4,58,620
IV. Left Bank Works ..	46	7,940	3,65,240	46	2,030	93,380	4,58,620
V. Quarries and Stone ..	60	4,970	2,98,200	60	2,030	1,21,800	4,20,000
VI. Power Supply, etc. ..	65	8,685	5,64,525	65	3,115	2,02,475	7,67,000
VII. Stores	60	*3,055	*1,83,300	60	2,995	1,79,700	*3,63,000
VIII. Medical and Sanitary	62	4,913	3,04,606	62	510	31,620	3,36,226
IX. Audit and Accounts ..	77	1,250	96,250	77	2,280	1,75,560	2,71,810
			*31,44,061			*11,49,915	*42,93,976

* These figures will be slightly modified according to footnotes on pages 162 and 164 ante.

Add Secretariat Charges—

1/5th salary of Chief Engineer for Irrigation.	Rs. 600
1 Supervisor	„ 250
2 Clerks at Rs. 100	„ 200
	Rs. 1,050 per month.
	„ 12,600 per year.

For 7 years at Rs. 12,600 per annum Rs. 88,200

Grand Total, Establishment Rs. 43,82,176*

SECTION V.

536. *Summary of Technical and Clerical Establishment graded for housing accommodation.*

Division.	Sukkur.	Rohri.	Aror.
I. Direction.			
Subordinates on salaries over Rs. 200	1	..	..
„ „ „ between „ 100 and 200..	3	1	..
„ „ „ „ „ 60 „ 100..	11	..	..
„ „ „ „ „ 25 „ 60..	7	..	..
„ „ „ below „ 25	24	2	..
II. River Works.			
Subordinates on salaries over Rs. 200	2	..	..
„ „ „ between „ 100 and 200..	23	4	..
„ „ „ „ „ 60 „ 100..	15	1	..
„ „ „ „ „ 25 „ 60..	4	2	..
„ „ „ below „ 25	43	10	..
III. Right Bank Works.			
Subordinates on salaries over Rs. 200	2	..	..
„ „ „ between „ 100 and 200	15	..	..
„ „ „ „ „ 60 100	26	..	..
„ „ „ „ „ 25 „ 60	8	..	..
„ „ „ below „ 25	56	..	..
IV. Left Bank Works.			
Subordinates on salaries over Rs. 200	..	2	..
„ „ „ between „ 100 and 200	3	12	..
„ „ „ „ „ 60 „ 100	9	17	..
„ „ „ „ „ 25 „ 60	2	6	..
„ „ „ „ „ 25	8	48	..
V. Quarries and Stone Supply.			
Subordinates on salaries over Rs. 200	..	..	..
„ „ „ between „ 100 and 200	..	1	9
„ „ „ „ „ 60 „ 100	..	2	18
„ „ „ „ „ 25 „ 60	..	..	8
„ „ „ below „ 25	..	4	36
VI. Power Supply.			
Subordinates on salaries over Rs. 200	7	..	..
„ „ „ between „ 100 and 200	6	6	..
„ „ „ „ „ 60 „ 100	19	7	
„ „ „ „ „ 25 „ 60	14	..	..
„ „ „ below „ 25	49	15	..

* See footnote on page 166 ante.

SECTION V—*contd.*

Summary of Technical and Clerical Establishment graded for housing accommodation.

Division.	Sukkur.	Rohri.	Aror.
VII. Stores.			
Subordinates on salaries over Rs. 200	..	..	..
" " " between " 100 and 200	6	1	..
" " " " " 60 " 100	23	..	2
" " " " " 25 " 60	2	2	2
" " " below " 25	53	8	9
VIII. Medical and Sanitary.			
Subordinates on salaries over Rs.200	1	1	..
" " " between " 100 and 200	1	..	..
" " " " " 60 " 100	10	3	2
" " " " " 25 " 60	6	4	2
" " " below " 25	69	45	18
IX. Audit and Accounts.			
Subordinates on salaries over Rs. 200	1	..	..
" " " between " 100 and 200	4	..	..
" " " " " 60 " 100	20	..	..
" " " " " 25 " 60	..	..	..
" " " below " 25	12	..	..
Totals—			
Subordinates on salaries over Rs. 200	14	3	..
" " " between " 100 and 200	61	25	9
" " " " " 60 " 100	133	30	22
" " " " " 25 " 60	43	14	12
" " " below " 25	314	132	63

PART X.

BUILDINGS.

INDEX.

PART X.

BUILDINGS.

SECTION I.

Bungalow Accommodation.

General.

537. The importance to the health, efficiency and contentment of the staff, of providing good bungalows and accommodation, for officers, subordinates and men cannot be over-estimated. The great Panama Canal Project defeated its early engineers, not by engineering difficulties, but by climatic severity, and the isolation, and lack of amenities, for the people engaged on its construction. As soon as the Government of the United States of America realised this, and provided healthy, convenient bungalows, and all the amenities possible in such a situation, the works progressed without any other troubles than those involved in engineering problems, and these have all been successfully overcome. Similarly on the great Sara Bridge works, comfortable and healthy accommodation was provided for all staff, with the result that work made most satisfactory progress. At the Rotherhithe Tunnel works in the heart of London, surrounded by shops and eating houses in every direction, and with public baths near by, arrangements were made, *on the works*, for all men to have hot baths, their clothes to be cleaned and dried and for hot food and drink to be supplied to them. The result was one of the most successful and speedy engineering contracts on record.

538. The climate of Sukkur is trying in the extreme. In the hot weather the temperature is very high indeed—up to 125° in the shade, and in the cold weather the nights can be bitterly raw and cold. It is essential therefore to provide good accommodation.

For the officers it is proposed to build good pakka bungalows provided with electric light and fans, and for the subordinate staff a scale of accommodation suitable to their circumstances.

The officers' bungalows will be permanently required at Sukkur for the future canal staff (and the district officers). Hence pakka construction for these is fully justified.

SECTION II.

Site for Bungalows for Staff and Subordinates Quarters.

539. It is proposed to keep nearly all these on the Sukkur side for the following reasons :—

(*a*) A good cheap site is available in a convenient place for access to the town of Sukkur and to the works. This site lies between the river and Adamshah in one direction, and between the Railway workshop road (from river to Adamshah) and the new Right Bank Canals in other direction. Most of the land is kalarish, is the property of Government and is at present unoccupied. For officers whose works are on the left bank, communication during construction can always be had by motor launch, etc. After completion of works the bungalows will be occupied by the Executive Engineer and Assistant Engineer in charge of the barrage, the Left Bank Canals and the Right Bank-canals and possibly by Sukkur District officers. For the Barrage and Right Bank Canals officers the site could not be more convenient. For the Left Bank Canals officers communication will be only 1½ miles *via* the barrage bridge to their canals.

(*b*) This site has a river frontage and gets the full benefit of the hot weather winds which blow from the south-east and cross the one mile width of river on their way to the site, thus being cooled down. The same breeze on the Rohri side is very much hotter.

It will be necessary to remove the Hindu burning ground to a new site below the barrage. This would be necessary in a few years, in any case, as the town extends. The new site will be only about 1 mile below the present site, or about 2 miles from the centre of the town. There is a direct main road leading to it from the town and there will be a second direct line of access along the river front and over the regulator bridges. The new site would be enclosed and protected by bunds, like the existing ground. The distance from the town is a reasonable one. At Satara the only burning ghat is 3 miles from the nearest point of the town, or 4 miles from the farthest point. If the local Hindu community of Sukkur eventually build a modern sanitary crematorium, it is possible that this could be nearer to the town, without being a nuisance, but the proposed new site for the open burning is sufficiently convenient for present arrangements, and is none too far to avoid being a nuisance. The present site is sometimes most objectionable to the Adamshah colony behind it as it lies to windward of same.

(c) On the Rohri side of river, all the river-side land above the barrage consists of very valuable fruit gardens, for a depth of 1 to 2 miles inland.

To acquire these for building sites would be very expensive, and it is undesirable to destroy these good gardens.

Moreover if a strip of land were taken up along the river edge it would be completely screened from the wind in the hot weather by the gardens inland, and would be unbearably hot and unhealthy. The only site at reasonable cost and of moderately healthy conditions would be right inland of the gardens and this would be no nearer to the works than the Sukkur site, while it would be far hotter, less healthy, and cut off from easy communication with the civil station of Sukkur and from the bazars. Rohri is also distant and is a dirty town with no amenities for officials.

(d) The main workshops, power houses and stores will be on the Right Bank and only such quarters will be erected on the Rohri side as are necessary for the officers and subordinates who must remain there on the spot, such as the quarries staff, the sub-medical staff, auxiliary power house and workshop staff, and blockyard staff.

SECTION III.

Quarters.

Excluding Officers' bungalows for Technical and Clerical Establishment.

540. It is assumed that all labour paid by Government, or work charged, must be housed.

This will include all upper and lower subordinates, clerks, inspectors, foremen, maistries, mechanics, police, telegraphists, etc., and all menials employed by Government such as peons, sweepers, regular coolies employed in workshops, and on works, etc.

541. It is assumed that labour paid by contractors will be housed by them or that they will make their own arrangements, except as regards water supply, sanitation and bazar, etc.

A large market will be maintained on the Sukkur side, with a Market Superintendent and Chowkidars, who will perform the double duties of Bazar Police and Fire Brigade. A small market will be opened on the Rohri side and another at the quarries. All markets will be under control of the Market Superintendent and all stall holders will be licensed by the Superintending Engineer.

The Market Superintendent will issue a list of prices every week, and any stall holder selling at higher rates will be liable to loss of his license and dismissal from the market.

542. It is assumed that the maximum number of people employed on the barrage works will be 25,000. On the Sara Bridge Works they were never able to exceed this number, although they employed recruiting parties for two or three years. In order to complete their earthworks in time they had to employ Lubecker excavators to assist the manual labour. (They also proved considerably cheaper than the latter.) Slightly less accommodation is provided than was actually

built at Sara, though the cost per unit is greater owing to rise of prices which has been allowed for.

543. *Quarters for Subordinates, Clerks and Menials.*

These quarters are of 5 main types and have been roughly designed and estimated as below :—

A-I. Type Quarters for temporary engineers and highly paid subordinates over Rs. 200 per month. These consist of a compound 100′×50′ with house giving following accommodation :—

One living room	12′×14′
Two bed rooms	12′×14′
Verandah	6′ in front.
„	5′ at back.
Kitchen	12′×10′
Bathroom	10′×10′
Store shed	10′×10′

All floors of 3″ concrete over brick and teak doors and windows. Estimated cost of each Rs. 6,000.

A Type Quarters for Family Quarters.

These consist of a low walled compound 40′×40′ with house giving following accommodation :—

One living room	12 ×12′
„ bed „	12′×12′
Verandah	4′ wide
One cook „	12′× 8′
„ bath „	6′× 8′
„ shed store room	12′× 8′ Estimated cost per each Rs. 950.

B Type Quarters for Family Quarters.

These consist of a low walled compound 40′×20′ with house giving following accommodation :—

One room	16′×12′
Verandah	4′ wide
Cook room	10′× 8′
Bath „	6′× 8′ Estimated cost per each Rs. 650.

C Type Quarters. Barrack Type in lines for single men.

These give the following accommodation :—

One room	12′×10′
Verandah	5′ wide
Cook room	12′× 8′ Estimated cost per each Rs. 400.

D Type Quarters. Barrack Type in lines for single men. (Menials).

These give following accommodation :—

One room	12′× 8′
Verandah	4′ wide. Estimated cost per unit Rs. 250.

544. All quarters are built of walls of unburnt brick laid in mud and mud plastered with plinth of burnt brick in lime 1 foot high, 1′-6″ wide and concrete footing 2′-0″ × 6″. Doors and windows of Deodar.

Doors 6′×3′. Windows $3\frac{1}{2}' \times 2\frac{1}{2}'$.

Roof consists of a lower covering of galvanized corrugated iron sheets laid on wooden rafters. Above this will be a 6″ air space, with an outer roof—covering of thatch covered with $\frac{1}{4}$ inch of mud plaster and supported on bamboo rafters built into end walls and with hoop iron ties and distance pieces at 3′ intervals attached to the corrugated sheeting or main rafters. The thatch covering and air space will give a cool roof, the mud plaster will give protection from fire due to sparks from engines, etc., and the galvanized iron roof gives permanent protection from rain.

545. It is assumed that all quarters on the Sukkur side can be disposed of, *in situ*, after the work is completed, at half their original cost (excluding cost of land, if any, as the site is on the outskirts of the town of Sukkur and the houses will be useful for merchants, tradespeople, etc., and their establishments, as the town must extend in this direction. They will be complete with a water supply system which could, if desired, be handed over in working order to the Municipality for serving the area.

546. As the land itself, on which the quarters will stand, will then be valuable, it is considered that this is a very reasonable, if not a low, salvage value to take.

547. On the Rohri side there is no demand for houses except for canal subordinates and barrage staff, and it is unlikely that they will have much, if any, salvage value. This is another reason in favour of concentrating as much staff accommodation as possible on the Sukkur Side. Fifty per cent. salvage value is allowed for such buildings as would be useful for the barrage maintenance staff and the canals staff, etc.

548. A cheaper type of quarter could be built with bamboo rafters and thatch for walls and roof, but the maintenance charges of such quarters is at least 5 per cent. per annum, and they would not be very satisfactory, while the risk of fire is very great. They would have practically no salvage value, as it may be assumed that they would be almost beyond repair at the end of 5 years, and in any case it would not pay Government or private persons to maintain them.

549. Allowing salvage value, as shown, for the better class of accommodation provided, the net capital cost to the work would be only Rs. 33,450 more than for the inferior quarters after taking into account the difference in cost of maintenance for 5 years. The extra cost may be considered as a fire insurance premium.

550. The following method has been adopted for arriving at the accommodation required for the staff shown in the preceding summary, Part IX, *ante* :—

A1 type of quarters will be provided for all men drawing higher salaries than Rs. 200 per month.

A type quarters are for men, with families, drawing salaries between Rs. 100 and 200 per month.

B type quarters are for single men drawing salaries between Rs. 100 and Rs. 200 or for men with families drawing between Rs. 60 and Rs. 100 per month.

C type quarters are for single men drawing salaries between Rs. 25 and Rs. 100 per month, or for men with families drawing between Rs. 25 and Rs. 60 per month.

D type quarters are for all men (menials) with or without families, drawing less than Rs. 25 per month.

551. For the establishment on the Sukkur side of the river it is assumed that 25 per cent. of each grade will have their families with them and the remaining 75 per cent. be living alone. From enquiries made it is believed that this will represent actual conditions, as most of the men will prefer to leave their families in Sukkur or at their native places

552. For the establishment on the Rohri side and at Aror it is assumed that 50 per cent. of each grade will be given family accommodation. As this side will be more isolated, it is possible that more men will bring their families for company, and the allowance also provides for some of the higher paid single men of each grade being given the better family accommodation, in compensation for the fewer amenities of the site.

553. The following statement shows the accommodation provided for technical and clerical establishment as per Part IX, *ante* :—

——	Sukkur.		Rohri.		Aror.		
Men on salaries over Rs. 200	14		3		....		
Quarters type A1	14		3		....		
,, ,, .. between Rs. 100 and Rs. 200 ..	61		25		9		
Quarters type A	15	25%	12	50%	4	50%	
,, ,, B	46	75%	13	50%	5	50%	
,, ,, ,, between 60 and 100	133		30		22		
Quarters type B	33	25%	15	50%	11	50%	
,, ,, C	100	75%	15	50%	11	50%	
,, ,, ,, between Rs. 25 and Rs. 60 ..	43		14		12		
Quarters type C	43		14		12		
,, .. below Rs. 25	314		132		63		
							Total.
Total A1 type	14		3		..		17
A	15		12		4		31
B	79		28		16		123
C	143		29		23		195
D	314		132		63		509

SECTION IV.

554. Approximate estimate of Quarters required for work-charged monthly establishment engaged for various works.

Type of Quarters.	Sukkur.					Rohri.					Aror.				
	A1	A	B	C	D	A1	A	B	C	D	A1	A	B	C	D
Power Houses	..	1	1	4	20	..	1	1	2	8	..	..	1	1	2
Workshops	..	..	2	6	70	..	..	1	2	25	..	1	..	..	5
Permanent	..	1	..	3	30	..	..	..	2	10	..	..	..	..	10
Fleet	..	1	1	4	40	..	..	..	1	10	..	..	..	..	..
Cranes	..	..	..	1	30	..	..	..	1	15	..	..	..	..	5
Pumps	..	..	..	4	40	..	..	..	..	10	..	..	..	..	..
Pile Drivers	..	..	..	4	40	..	..	..	..	10	..	..	..	..	..
Masonry	..	..	..	2	35	..	..	..	..	15	..	..	..	..	..
Mortar Mills	..	..	..	..	..	..	..	..	1	6	..	..	..	..	..
Blockyards	..	..	..	2	22	..	..	..	1	22	..	..	..	..	..
Total ..	..	3	4	30	327	..	1	2	10	131	..	1	1	1	22
Add—Quarters as estimated above ..	14	15	79	143	314	3	12	28	29	132	..	4	16	10	63
Grand total of Quarters at each site ..	14	18	83	173	641	3	13	30	39	263	..	5	17	17	85

Total of each class at all sites :—

Type	A1 Quarters	17	Units.
	A ,,	36	,,
	B ,,	130	,,
	C ,,	238	,,
	D ,,	989	,,

SECTION V.

Total cost of all quarters.

(a) For Katcha Brick Wall construction.

——	Sukkur.		Rohri.		Aror.		Total.
	Units.	Rs.	Units.	Rs.	Units.	Rs.	Rs.
Type A1 at Rs. 6,000 per unit	18	84,000	3	18,000	..	..	1,02,000
,, A ,, ,, 950 ,, ...	18	17,100	13	12,350	5	4,750	34,200
,, B ,, ,, 650 ,, ...	83	53,950	30	19,500	17	11,050	84,500
,, C ,, ,, 400 ,, ...	173	69,200	39	15,600	26	10,400	95,200
,, D ,, ,, 250 ,, ...	641	1,60,250	263	65,750	85	21,250	2,47,250
	..	3,84,500	..	1,31,200	..	47,450	5,63,150
Salvage value at 50 per cent. on all *on Sukkur Side* ..	..	1,92,250	..	..	..	..	
On Rohri Side to be retained for permanent staff on canals and barrage at 50 per cent. { 3 at Rs. 6,000; 10 ,, ,, 950; 15 ,, ,, 650; 15 ,, ,, 650; 20 ,, ,, 400; 60 ,, ,, 250 } Rs. 60,250	..	..	..	30,125	..	..	
At Aror to be retained for permanent use for quarries and sub-divisional quarters at 50 per cent. { 4 at ,, 950; 2 ,, ,, 650; 3 ,, ,, 400; 15 ,, ,, 250 } 10,050	..	..	..	..	..	5,025	
	..	..	..	..	..	..	
Net cost to Project	..	1,92,250	..	1,01,075	..	42,425	3,35,750
Add—Maintenance for 5 years at 2 per cent. per annum.	..	19,250	..	10,107	..	4,242	33,599
	..	2,11,500	..	1,11,182	..	46,667	3,69,349
Total net cost of quarters and maintenance ..	Rs. 3,69,349						

Total cost of all quarters.

555. (*b*) For Bamboo and Thatch construction.

—	Sukkur.		Rohri.		Aror.		Total.
	Units.	Rs.	Units.	Rs.	Units.	Rs.	Rs.
Type A1 Quarters at Rs. 5,000	14	70,000	3	15,000	..	..	85,000
A „ „ „ 500	18	9,000	13	6,500	5	2,500	18,000
B „ „ „ 300	83	24,900	30	9,000	17	5,100	39,000
C „ „ „ 200	173	34,600	39	7,800	26	5,200	47,600
D „ „ „ 80	641	51,280	263	21,040	85	6,800	79,120
	..	1,89,780	..	59,340	..	19,600	2,68,720
Deduct—Salvage value	..	..	..	..	..	..	..
Net cost to project	..	1,89,780	..	59,340	..	19,600	2,68,720
Add—For maintenance for 5 years at 5 per cent. per annum	..	47,445	..	14,835	..	4,900	67,180
	..	2,37,225	..	74,175	..	24,500	3,35,900

Total net cost to project including maintenance ..	Rs. 3,35,900
Total net cost of better type of quarters as above.	„ 3,69,350 (*Vide* Page 175)
Excess for better accommodation	„ 33,450

SECTION VI.

Officers' Bungalows.

556. *On Sukkur Side.*

		Rs.
1	Bungalow for Superintending Engineer	35,000
1	„ „ 2 Personal Assistants	25,000
1	„ „ Executive Engineer, Right Bank .. .. „ „ River Works	25,000
1	„ „ 2 Assistant Engineers, River Works	15,000
1	„ „ 1 „ „ R. B. Regulators .. 1 „ „ Guide Banks	15,000
1	„ „ 1 „ „ Blockyard .. .. 1 „ „ Electrical	15,000
1	„ „ 1 Executive Engineer, Left Bank Works .. 1 Assistant „ „ „ Blockyard ..	25,000
1	„ „ 1 „ „ „ Regulators .. 1 „ „ „ Guide Banks ..	15,000
1	„ „ 1 „ „ Workshops .. .. 1 „ „ Electrical	15,000
1	„ „ 1 „ „ Fleet .. .. 1 Executive „ Power Supply	25,000
1	„ „ 1 Examiner of Accounts .. .. .. 1 Chief Storekeeper	25,000
1	„ „ 1 Assistant Traffic Superintendent .. .. 1 Works Manager for Workshops	15,000
1	„ „ Chief Medical Officer	20,000
13		2,70,000

557. *On Rohri side at River.*

1	Bungalow for {Assistant Surgeon / Assistant Storekeeper}	15,000

558. *At Quarries.*

1	Bungalow for Executive Engineer	15,000
1	,, 2 Assistant Engineers	15,000
2		30,000
	Total 16 bungalows — Total cost	3,15,000
	Add—Maintenance at 2 per cent. per annum for 5 years	31,500
	Salvage value at 70 per cent.	2,36,250

SECTION VII.

Office Buildings, etc.

559. *Rohri Side at River Works.*

		Rs.
General Works—	Offices	12,000
Power Supply—	,,	4,500
Stores—	,,	1,000
Audit and Accounts—Office		500
Medical and Sanitary—Hospital Dispensary and Office		7,000
Police—Office		100
	Total	25,100

560. *Rohri Side at Aror Quarries.*

		Rs.
(*b*) *General Works*—	Offices	10,000
(*c*) *Power Supply*—	,,	1,500
(*d*) *Stores*—	,,	1,000
(*e*) *Audit and Accounts*—Office		500
(*f*) *Medical and Sanitary*—Hospital, Dispensary and Office		5,000
(*g*) *Police*—Office		600
	Total	18,600
	Total Rohri and Aror	43,700
	Salvage value at 10 per cent.	4,370

561. *Sukkur Side.*

		Rs.
General Staff (Direction)—Offices		12,500
General Works—	,,	16,000
Power Supply—	,,	7,000
Stores—	,,	4.000
Audit and Accounts	,,	9,000
Medical and Sanitary—Hospital, Dispensary and Office		29,000
Police—Office		600
	Total Sukkur Bank ..Rs.	78,100

	Rs.
Salvage value at 20 per cent.=15,620—	
Add—Rohri and Aror	43,700
Total Offices, etc.	1,21,800
Add—For maintenance for 5 years at 3 per cent. per annum	18,270
	1,40,070
Deduct—salvage Rs. 15,620 *plus* 4,370 ..	19,990
Net cost to works for Offices, etc. ..	1,20,080

SECTION VIII.

Temporary Sheds for Service Works.

562. *Sukkur Side.*

Division : Direction.

Markets—

	Rs.
Bungalow for Market Superintendent	7,000
Market sheds, 20,000 square feet	15,000
Erection and earthwork	8,000
Office	600
Bakery	500
Slaughter-house	400
Dhobikhana	250
Railway Out-Agency sheds 50×20..	1,500
Firewood shed	600
Rs.	33,850

Institutes—

For Europeans	1,500
,, Indians	1,500
Tennis Courts for Europeans	600
,, ,, ,, Indians	600
Pavilion	900
Fencing	500
Rs.	5,600

Water Supply—

Building for housing plant	4,000
Total Sukkur Side .. .. Rs.	43,450

Division : General Works.

Workshops : Sukkur Side—

	Rs.
Saw mill shed, 60×30 / Carpenters shop, 60×30	3,500
Erection	2,000
Smiths shop, 170×30	8,500
Erection	4,000
Store room shed, 100×30	3,000
Erection	700
Office shed, 30×30	800
Erection and masonry	4,000
Turning and fitting shops, 120×40	9,500
Erection	2,500
Masonry	500
	39,000

Blockyards : Sukkur Side—

Mixer tower	1,000
Sand bins	8,000
Runway for Goliath cranes	7,000
Moulding floor complete	40,000
Cement shed and erection, 100′×30′	7,000
Lime shed, 200′×30′	14 000
Goliath crane erection	3,000
Tramways	6,000
Rs.	86,000

Coolie Lines—

16 sheds, 100′×16′ / 44 sheds, 45′×16′	30,000
Erection	10,000
Rs.	40,000

Mortar Mills and Disintegrator—

3 sheds, 100′×25′ roofs only erected on frames	5,000
1 shed for disintegrator 40′×20′	500
Rs.	5,500
Total	1,70,500

Division: Power Supply.

Power Stores Shed: Sukkur Side—

1 shed, 100′×30′	6,000
Erection	1,500
	7,500
1 Power House ; complete buildings erected	45,000
Total	52,500

Division: Stores.

Store Depôt: Sukkur Side—

	Rs.
2 store sheds, 200′×30′ at Rs. 9,500	19,000
Erection	5,000
1 oil shed, 40′×20′	2,000
Erection	900
Coal bins for 200 tons (or oil tanks)	2,000
Fencing	3,800
Erection	600
Platform with ramps	1,000
Lighting arrangements	700
Total ..	35,000

Division. Sanitary and Medical.

Latrines—

140 seats, Rs. 40	5,600
Store shed, lock-up and buffalo stables	2,500
Total .. Rs.	8,100

563. *Rohri Side.*

Division: Direction.

Markets—

Sheds, etc., 5,000 square feet	3,500
Erection and earthwork	1,000
Slaughter-house	400
Dhobikhanas	200
Rs.	5,100

Institutes—

Reading room for Indians	600
Tennis court for Indians	600
Tennis court for Europeans	1,200
Fencing round football ground	500
	Rs. 2,900

Water Supply—

Housing plant complete	4,000
Total ..	Rs. 12,000

Division: General Works.

Workshops: Rohri Side—

Iron workshops shed, 100′×30′	7,000
Erection and masonry	3,500
Office shed, 40′×30′	3,500
Erection and masonry	2,500
Wood working shops, 60′×30′	2,500
Erection	1,500
	Rs. 20,500

	Rs.
Blockyard—	
As on Sukkur Side	86,000
Coolie Lines—	
8 sheds, 100′×16′ / 22 sheds, 45′×16′ }	15,000
Erection	5,000
	Rs. 20,000
Mortar Mills and Disintegrators—	
3 sheds, 100′×25′ roofs only erected on frames ..	5,000
1 shed for disintegrators, 40′×20′	500
	5,500
Total ..Rs.	1,32,000

Division: Power Supply. Rohri Side—

Power house complete erected	35,000
Power stores shed, 40′×30′	3,000
Total ..	38,000

Division: Stores.

Store Depôt: Rohri Side—

1 store shed, 200′×30′	9,500
Erection	2,500
1 store shed, 40′×20′	1,800
Erection	700
1 oil shed, 40′×20′	2,000
Erection	900
Fencing	1,800
Erection	300
Platform and ramps	500
Lighting arrangements	700
Total ..	Rs. 20,700

Division: Medical and Sanitary.

	Rs.
Store shed	300
Latrines, 60 seats, at Rs. 40	2,400
Total ..	Rs. 2,700

564. *Aror Quarries.*

Division: Direction.

	Rs.
Market buildings	2,000

Division: Stores.

Store Depôt: Sukkur Side—

	Rs.
2 store sheds, 200′×30′ at Rs. 9,500	19,000
Erection	5,000
1 oil shed, 40′×20′	2,000
Erection	900
Coal bins for 200 tons (or oil tanks)	2,000
Fencing	3,800
Erection	600
Platform with ramps	1,000
Lighting arrangements	700
Total ..	35,000

Division. Sanitary and Medical.

Latrines—

140 seats, Rs. 40	5,600
Store shed, lock-up and buffalo stables	2,500
Total .. Rs.	8,100

563. *Rohri Side.*

Division: Direction.

Markets—

Sheds, etc., 5,000 square feet	3,500
Erection and earthwork	1,000
Slaughter-house	400
Dhobikhanas	200
Rs.	5,100

Institutes—

Reading room for Indians	600
Tennis court for Indians	600
Tennis court for Europeans	1,200
Fencing round football ground	500
	Rs. 2,900

Water Supply—

Housing plant complete	4,000
Total ..	Rs. 12,000

Division: General Works.

Workshops: Rohri Side—

Iron workshops shed, 100′×30′	7,000
Erection and masonry	3,500
Office shed, 40′×30′	3,500
Erection and masonry	2,500
Wood working shops, 60′×30′	2,500
Erection	1,500
	Rs. 20,500

	Rs.
Blockyard—	
As on Sukkur Side	86,000
Coolie Lines—	
8 sheds, 100′×16′ / 22 sheds, 45′×16′ }	15,000
Erection	5,000
	Rs. 20,000
Mortar Mills and Disintegrators—	
3 sheds, 100′×25′ roofs only erected on frames ..	5,000
1 shed for disintegrators, 40′×20′	500
	5,500
Total ..Rs.	1,32,000

Division: Power Supply. Rohri Side—

Power house complete erected	35,000
Power stores shed, 40′×30′	3,000
Total ..	38,000

Division: Stores.

Store Depôt: Rohri Side—

1 store shed, 200′×30′	9,500
Erection	2,500
1 store shed, 40′×20′	1,800
Erection	700
1 oil shed, 40′×20′	2,000
Erection	900
Fencing	1,800
Erection	300
Platform and ramps	500
Lighting arrangements	700
Total ..	Rs. 20,700

Division: Medical and Sanitary.

	Rs.
Store shed	300
Latrines, 60 seats, at Rs. 40	2,400
Total ..	Rs. 2,700

564. *Aror Quarries.*

Division: Direction.

	Rs.
Market buildings	2,000

Institutes, etc.—

	Rs.
Tennis court	600
Reading room	600
	Rs. 1,200

Water supply—

Housing plant	2,000
Total ..	Rs. 5.200

Division: *General Works.*

Workshop, 60′×30′	2,500
Office, 40′×30′	3.500
Erection	3,000
	Rs. 9,000

Coolie Lines—

3 sheds, 100′×16′ / 7 sheds, 45′×16′	5,000
Erection	1,500
	Rs. 6,500
Total ..	Rs. 15 500

Division: *Power Supply.*

Stores shed .. .. .. Total .. Rs. 1,000

Division: *Stores.*

Store Depôt at Aror—

2 store sheds, 40′×20′	3,600
Erection	1,400
1 oil shed, 40′×20′	2,000
Erection	900
Fencing	1,500
Platform and ramps	500
Lighting	700
Total ..	Rs. 10,600

Division: *Medical and Sanitary.*

Store shed	300
Latrines, 25 seats, at Rs. 40..	1,000
Total ..	Rs. 1,300

565. *Abstract of Sheds, etc.*

—	Division.				
	Direction.	General Works.	Power Supply.	Stores.	Medical and Sanitary.
	Rs.	Rs.	Rs.	Rs.	Rs.
Sukkur Side	43,450	1,70,500	52,500	35,000	8,100
Rohri Side	12,000	1,32,000	38,000	20,700	2,700
Aror Quarries	5,200	15,500	1,000	10,600	1,300
Total ..	60,650	3,18,000	91,500	66,300	12,100
Grand Total ..			5,48,550		
Deduct Salvage value—					
Sukkur Side	8,650	29,350	26,250	4,000	..
Rohri Side	2,500	8,350	15,000	2,000	..
Aror Quarries	1,000	4,500	100	1,800	..
Total	12,150	42,200	41,350	7,800	..
Net cost to project	48,500	2,75,800	50,150	58,500	12,100

Grand Total net cost .. .. Rs. 4,45,050

Maintenance at 2 per cent. per annum for 5 years .. .. Rs. 54,855

SECTION IX.

566. *Abstract of total cost of all buildings.*

—	Initial cost.	Salvage value.	Net cost to Barrage.
	Rs.	Rs.	Rs.
Officers' bungalows	3,15,000	2,36,250	78,750
Office buildings	1,21,800	19,990	1,01,810
Sheds, etc.	5,48,550	1,03,500	4,45,050
Quarters for subordinates, clerks, menials, etc.	5,63,150	2,27,400	3,35,750
	15,48,500	5,87,140	9,61,360

Note.—It is assumed that the actual amount these buildings will fetch will cover the expenditure that may have to be incurred for demolishing any buildings in addition to the salvage reckoned here.

SECTION X.

567. *Abstract of cost of maintenance of all Buildings.*

	Rs.
Officers' bungalows, 2 per cent.	31,500
Office buildings, 3 per cent.	18,270
Sheds, etc., 2 per cent.	54,855
Quarters, 2 per cent.	33,599
Total maintenance of buildings ..	Rs. 1,38,224

PART XI.

LAND.

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PART XI.

LAND.

SECTION I.

568. The land proposed to be acquired in connection with the Barrage Construction is shown on Plan No. 69.

A considerable portion of this land is needed for the canals construction and such portion is not debited to the barrage, as it will eventually be occupied by the canals and their banks, etc.

(a) *On the Left Bank.*

569. All land bounded by the river edge on the north, the Khairpur State boundary on the west and south, and the Khairpur Feeder West on the east will be acquired for sites for works yard, quarters and coolie lines as shown.

570. A strip of land will be acquired all along the river edge from the barrage up to Satyan jo Astan. This is required for the Guide Bank construction The river bank in this length has accreted or silted up for a considerable width in the last 50 years or so, and the land thus gained from the river is Government property and is leased on short terms to zamindars. The whole of this land will be required. It varies in width from about 300 feet at the eastern extremity of the Shahi Bund to very little at Satyan jo Astan. It is represented in fact by all existing land lying to the riverside of the boundaries of the survey numbers printed in black on the old deh maps. Where the width of this accreted land is insufficient, a portion of the original survey numbers will be required to an average distance of about 150 feet from the edge of the bank of the river.

571. All land covered by the proposed canals as far south as the Kangan-Rohri Road will be taken up and used for the barrage and canal construction as shown on the plan. The average width and length of the land acquired to the west of the eastern boundary of the Eastern Nara New Head, *i.e.*, up to the Khairpur Boundary will be about 3,000 feet and its depth about 4,500 feet

572. To the east of this a short strip of land along the river side in a length of about 1,400 feet and depth 400 feet will be needed for power house, etc., and wharf bunder.

573. The quarry railway will run inside the boundaries of the Eastern Nara New Head, so no special land is required for the rai way except for the branch to the North-Western Railway and for the branches into the quarry valleys at Aror and Kalka. Most of the land in the quarry valleys is Government property, and only a few small survey numbers of occupied land will be required where these valleys debouch into the main Aror valley. The bungalows for officers, the quarters for subordinates and the works offices and sheds, etc., will all be built on suitable sites on plateaus or in valleys in the hills. All such land is Government property.

(*b*) *On the Right Bank.*

574. Starting from the western end of the present Sukkur Bunder wall and going downstream the land between the river edge and the existing municipal bund is required right down to the barrage. This is needed for the guide-banks.

575 Inland of the municipal bund there is a piece of land marked A on Plan No. 69 surrounded by roads ; on the west by the road leading from river to North-Western Railway Workshop. This plot contains an Ice Factory, a temple and a few houses. All land in this plot not at present covered with buildings will be required and also the houses in the centre of plot at river side, as the power house will be built here, this being a convenient site in case the power house is subsequently taken over by the municipality for lighting the town.

(If this is not likely and if the North-Western Railway is likely to take it over for running their workshop, an alternative site is shown near the latter. At this site the service line to power house would have to be taken off as a Branch of the North-Western Railway Workshops Railway)

576. To the west of the Railway Workshop—River Road, all land and buildings between the municipal bund and the main Sukkur-Larkana Road (passing the North-Western Railway Workshops) except the existing North-Western Railway bungalows and compounds will be required, in fact starting from the river to Workshop Road all land between the Sukkur Larkana-Road and the river for a distance of 5,600′ westward will be acquired.

577. This land includes the Hindu burning ghat which must be closed and another ground given in its place, a disused Mahomedan burying ground (without tombs) and a Hindu children cemetery which is believed to be also disused. It is not proposed to build on either of these burying grounds, but it will be desirable to acquire them and prevent further burials, and roadways may be necessary across them. It is believed there will be no local objection to this. The Hindu burning ghat is not sacred ground in itself, and when it ceases to be used as a burning ghat there will be no religious objections to demolishing the walls and few sheds at the site, and, if necessary, building on the land.

578. To the north of the Sukkur-Larkana Road a strip of land 3,300′ wide which includes all land required for proposed canals in this portion) and extending northward for about 3,800′ will be needed. North of this, as far as the North-Western Railway, the width required will be about 1,700′ while the eastern boun-

dary line of this strip will be continued north to meet the Sukkur Canal, and all land to the west of this between the Sukkur Canal and the North-Western Railway will be required for canal construction. It is shown on the plan as land to be acquired, though it is not needed for the barrage works, but will be needed for the canals.

SECTION II.

579. Statement showing area to be acquired on each bank of river.

—	Area in acres.	Rate per acre.	Amount	Charged to barrage.	Charged to Canals.
On Sukkur Side.		Rs.	Rs.	Rs.	Rs.
For Power House	35.6	1,000	35,600	35,600	..
For Bungalows for officers	75.8	500	37,900	37,900	..
For Subordinates' quarters	104.0	50	5,200	5,200	..
For Burning Ghat	9.5	200	1,900	1,900	..
For works yards up to Larkana Road	73.4	200	14,680	14,680	..
Do. north of Larkana Road ..	104.9	200	20,980	20,980	..
Do. between Larkana Road and Railway	28.6	200	5,720	5,720	..
For Canals up to Larkana Road	92.0	200	18,400	..	18,400
Do. north of Larkana Road ..	119.0	200	23,800	..	23,800
Do. between Larkana Road and Railway	140.0	200	28,000	..	28,000
Do. between Sukkur Canal and Railway	188.0	200	37,600	..	37,600
Total on Sukkur Side	..	..	2,29,780	1,21,980	1,07,800
On Rohri Side.					
For Guide Banks, 11,500′ × 150′	33.6	10	336	336	..
For Power House	11.4	1,000	11,400	11,400	..
For Workshed lines	129	1,000	1,29,000	1,29,000	..
Junction with N. W. Ry.	9.5	200	19,000	19,000	..
For Quarry Sidings—					
Stone { 8,000 × 100, 3,000 × 100, 4,000 × 100 }	34.4	30	1,032	1,032	..
Sand { 5,000 × 100, 3,500 × 100 }	19.3		free.		
For Canal Head North of Khairpur Road ..	82.0	1,000	82,000	..	82,000
Do. between Kangan and Khairpur Roads	112.5	1,000	1,12,500	..	1,12,500
Total on Rohri Side ..	..	..	3,55,268	1,60,768	1,94,500
Grand Total ..	..	..	5,85,048	2,82,748	3,02,300
Add—Contingencies 5 per cent.	..	..	..	14,137	..

SECTION III.

Abatement of land revenue.

580. All land valued at Rs. 500 and upwards per acre is assumed to bring in a total assessment of Rs. 5 per acre, and all land valued at less than Rs. 200 per acre, a total assessment of Rs. 3-8-0 per acre

The total loss of revenue will be as follows :–

Sukkur Side—

35·6 acres at Rs. 1,000 per acre
75·8 acres at Rs. 500 per acre

Rohri Side—

11·4 acres at Rs. 1,000 per acre
129·0 acres at Rs. 1,000 per acre.

251·8 acres of land valued at Rs. 500 per acre and upwards.

	Rs.
Loss of revenue at Rs. 5 per acre	1,259

Sukkur Side—

104·0 acres at Rs. 50 per acre.
216·4 acres at Rs. 200 per acre.

Rohri Side—

33·6 acres at Rs. 10 per acre
9·5 acres at Rs. 200 per acre.
34·4 acres at Rs 30 per acre.

397·9 acres of land valued at Rs. 200 and less.

	Rs.
Loss of Revenue at Rs. 3-8-0 per acre	1,392·6
Total loss of Land Revenue	2,651·6
Capitalization of same at 25 years' purchase	66,290

PART XII.

TIME REQUIRED FOR CONSTRUCTION.

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PART XII.

TIME REQUIRED FOR CONSTRUCTION.

SECTION I.

Introduction.

581. The total time assumed from the opening of the Barrage Circle to its final c'osure is 7 years. It is also assumed that sufficient labour can be found, at all periods, for the work in hand, up to a maximum of 20,000 men.

The time is divided up as follows.

SECTION II.

First 2 months—April to June.

582. General Direction Division making arrangements, for work to start on quarters, letting contracts, arranging for labour and materials, etc. Two-thirds of establishment engaged.

SECTION III.

Next 10 months—June to March—Construction of Buildings.

583. Whole of Right Bank Works and Left Bank Works Divisions to be opened, half the establishment of Power Supply Division, one-fourth the establishment of Medical and Sanitary Division and half the Audit and Accounts Division to be opened.

584. The Right and Left Works Divisions will at once commence survey and laying out of site for quarters and works and making arrangements for starting construction in August, of one-half the officers' bungalows, and one-fifth of the subordinate quarters, on either bank, and at quarries. These subordinate quarters should be complete by about the end of September and can then be

occupied by officers and subordinates until the bungalows are ready for former. All staff in the meantime has been living in tents or temporary huts. As soon as these are completed the remainder of the quarters will be taken in hand, and construction of earthwork for railways, bunds, roads, etc., started. In October laying of permanent-way, and pile driving for the wharves will commence. In November work can be started on the blockyards—laying floors, goliath runaways, sheds, etc.

585. By the end of December the wharves will be completed.

In February the buildings for power houses, workshops and store sheds will be commenced.

By end of March all Railways, two small generating units of power house and blockyards to be working and store sheds to be ready.

SECTION IV.

Next 6 months—April to September.

586. In April all remaining divisions will be opened and those already open brought up to full strength.

The Power Division will take up the erection of all the main power plant, workshops, machinery, etc., and this must be in working order by August. The Stores Division will be arranging and stocking its depôts.

The River Works Division will be working out all details for starting work and collecting, arranging and testing plant.

The Right and Left Bank Works Divisions will be doing the same.

The Quarries Division will be supplying stone to blockyards, and accumulating a reserve at the quarries and at both river banks.

SECTION V.

Next 12 months—September to September.

587. This will be the "First Season's Work" on the barrage structure. The River Works Division will co-operate with the Right and Left Bank Works Divisions in superintending 1st Season's cofferdams on either bank, the Right and Left Bank Works Divisions looking after the regulator portions (see Plan No. 71). Similarly all divisions will co-operate on the regulators and barrage floor construction. The River Works Division will also be responsible for all mortar supplies.

All the other divisions will have their full normal work. After completion of this season's part of floors, and underwater portions of barrage and regulators the superstructure of these portions will be taken in hand and full preparations made for next season's cofferdams, etc. In the meantime work has been proceeding on guide banks and most of the earthwork should be completed by September, as well as stone pitching on the slopes.

SECTION VI.

Next 12 months—Second Season's Work.

588. During these 12 months all regulators will be completed except as regards gates and machinery. The guide banks and their aprons and the raising of bunder wall will be nearly completed.

In the river a further 1,200′ of barrage will be completed and the erection of gates, counterweights and machinery in the first season's portion will be commenced.

SECTION VII.

Next 12 months—Third Season's Work—September to September.

589. During the first 6 months of this season all regulators and guide banks will be completed, and the Right Bank and Left Bank Works Divisions will be closed down at the end of March, after being in operation for 46 months The River Works and all other Divisions will continue at full strength, doing similar work to the previous season.

SECTION VIII.

Next 12 months—Fourth Season's Work.

590. During this season the final length of floor and superstructure of the barrage will be completed to the same extent as the remainder.

SECTION IX.

Next 6 months—September to March—Final Season's Work.

591. During this period placing of all gates and counterweights and the erection of lifting machinery will be completed, parapets will be built, roadway and footpaths completed over all bridges, and general finishing off done :—

(1) At the end of March the Power Division will be closed down, after being in operation for 10 months at half strength and for 60 months at full strength.

(2) The Stores Division will also be closed in March the last six months having been spent in disposal of surplus plant, etc. This division will have been in operation for 60 months.

(3) The Medical and Sanitary Division will also be closed in March, after being in operation at ½ strength for 10 months and at full strength for 60 months.

(4) The River Works Division will be closed in March after being in operation for 60 months at full strength.

(5) The Quarries Division will also be closed in March after being in operation for 60 months at full strength

SECTION X.

Last 12 months—April to March—Closing down Season.

592. During this period the only outdoor work will be the demolition of temporary buildings, railways, etc., and the final collection and disposal of surplus plant and stores.

In the office the accounts have to be finally adjusted and closed, and the completion report and plans to be prepared.

It is assumed that the Personal Assistants of the Engineer-in-Chief—one Executive Engineer and one Assistant Engineer will be able to look after all outdoor work, in addition to assisting in the preparation of the completion report. The Audit and Accounts Division will also be in full strength throughout the year. Both divisions will be closed by the end of March after completing the whole project.

593. The General Direction Division will have been in operation for 12 months at two-thirds strength and for 72 months at full strength.

The Audit and Accounts Division will have been in operation for 10 months at half strength and for 72 months at full strength.

SECTION XI.

Summary.

594. Thus from first opening, to final closing, of the work, will be 7 years of which only 5 years will be spent on the construction of the permanent works.

PART XIII.

ANNUAL EXPENDITURE.

INDEX.

PART XIII.

ANNUAL EXPENDITURE.

SECTION I.

General.

595. These estimates of annual expenditure are based on the programme of work explained in Part XII *ante*. Plant is purchased, as needed, with the progress of the work.

To the cost of this is added the cost of the establishment employed each year, the cost of temporary and permanent works completed during that year, and the cost of Service Works in operation.

SECTION II.

Method of Allocating Expenditure.

596. In this part of report each complete year is from April to March.

Out of the seven years that the work will be in progress the first is called the preliminary year. The next year, in September of which actual work on the barrage will be started is called the first year and so on, the last year being called the closing year.

In the case of plant, the date by which the plant is required in India, is noted against each item in the details and the expenditure is included in the financial year in which this date falls.

597. In the case of permanent works, the actual working season will be from September to September. The details show the full value of each season's work taken from September to September. But before work can be begun in September, a large portion of the money will have to be spent in collection of materials and stock, dressing, etc., so it is assumed for purposes of annual expenditure that the whole amount is spent before the end of the financial year. The value of work to be finished in a season ending September thus comes in the financial year ending

March 31st of that year. The whole of the expenditure on permanent works is thus divided over four years, corresponding to four seasons work on the barrage, the fifth year being devoted to finishing off.

598. During the last year (closing year) the only outdoor work to be done will be demolishing of buildings and sheds, and it is assumed that the probable realizations from the buildings will cover the cost of this demolishing in addition to the salvage value reckoned on, and so in this year only the establishment is provided.

599. The contingencies are not spread out over each year, as they may not be needed, but are shown as lump sums at the end of the programme of expenditure. The abstract thus gives the expected annual outlay, and total outlay including contingencies. The anticipated salvage on plant and buildings is then deducted, giving the net outlay on each head. Adjustments on account of depreciation, etc., first charged to one head and ultimately transferred to another are then indicated. We thus get the final expected outlay on each head of direct charges.

Details of each year's expenditure are given :—

SECTION III.

Abstract showing expenditure in each year on all heads.

——	A	B	C Works.		K				
	Preliminary expenses.	Land.	Permanent Works.	Service Works.	Buildings.*	Tools and Plant.	Establishment.	Total.	
	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	
Preliminary year	1,95,550	2,82,748	60,000	5,75,600	15,48,500	47,76,560	3,61,336	78,00,294	
First "	....	....	31,82,997	8,19,106	27,645	77,74,474	8,70,336	1,26,74,558	
Second "	....	....	60,14,383	9,81,896	27,645	6,61,864	8,70,336	85,56,124	
Third "	....	....	28,79,941	5,72,484	27,645	3,56,744	8,70,336	47,07,150	
Fourth "	....	....	27,30,251	4,98,534	27,645	3,56,744	6,31,056	42,44,230	
Fifth "	....	....	....	1,66,264	27,644	2,56,744	6,31,056	10,81,708	
Closing "	....	....	....	....	....	....	1,47,720	1,47,720	
Total ..	1,95,550	2,82,748	1,48,67,572	36,13,884	16,86,724	1,41,83,130	43,82,176*	3,92,11,784	
Add—Contingencies	....	14,137	8,18,871	2,26,014	....	7,09,156	....	17,68,178	
Total outlay ..	1,95,550	2,96,885	1,56,86,443	38,39,898	16,86,724	1,48,92,286	43,82,176	4,09,79,962	
Deduct—Anticipated salvage including contingencies.	....	....	....	....	—5,87,140	—68,77,540	....	—74,64,680	
Net cost to Works	1,95,550	2,96,885	1,56,86,443	38,39,898	10,99,584	80,14,746	43,82,176	3,35,15,282	
Adjustment between heads	....	....	15,09,840	9,06,400	....	—24,16,240	....	....	
Final debit to each head	1,95,550	2,96,885	1,71,96,283	47,46,298	10,99,584	55,98,506	43,82,176	3,35,15,282	
						Grand Total	..	3,35,15,282	Direct charges.

* See footnote on page 166 *ante*.

Section IV.

Abstract of Annual Expenditure on Permanent Works.

—	Barrage.	Details on page.	Left Bank Regulator.	Details on page.	Right Bank Regulator.	Details on page.	Left Guide Bank.	Details on page.	Right Guide Bank.	Details on page.	Total.	*Deduct*— Cost of Plant charged to Works.	Net Total.
	Rs.		Rs.		Rs.		Rs.		Rs.		Rs.	For details see below. Rs.	Rs.
Preliminary year ..	60,000	197	....	..	....	..	..	..	....	..	60,000	....	60,000
First " ..	25,15,032	197	3,16,730	197	5,11,927	197	99,826	197	71,164	197	35,14,679	3,31,682	31,82,997
Second " ..	31,62,391	199	18,41,179	200	11,71,506	200	99,826	200	71,164	200	63,46,066	3,31,683	60,14,383
Third " ..	27,81,631	201	....	..	2,59,001	..	99,826	201	71,165	201	32,11,623	3,31,682	28,79,941
Fourth " ..	27,10,108	201	3,51,826	201	....	..	..	..	....	..	30,61,934	3,31,683	27,30,251
Total ..	1,12,29,162	..	25,09,735	..	19,42,434	..	2,99,478	..	2,13,493	..	1,61,94,302	13,26,730	1,48,67,572

Details of Adjustments.

Debit :—Permanent Works—

	Rs.
(1) Cost of Centres	1,83,110
(2) Expenditure on other items as per details in estimate for plant with the exception of railways, moulds and centering divided equally over 4 years	13,26,730
Total ..	15,09,840

Credit :—Plant—

	Rs.
Same amount, *i.e.*	15,09,840
Total ..	15,09,840

Permanent Works.

Expenditure in preliminary year.

600. Purchase 300 tons of steel sheet piling for use in scaffolding, etc., out of stock required for 3rd year.

300 tons or 15,000 square feet.	at Rs. 200 per ton or at Rs. 4 per square foot.	.. .. .. Rs. 60,000

Permanent Works.

601. *Expenditure in First Year.*

		Rs.	Rs.
	Barrage—		
(A)	Right Bank	7,06,039	
(B)	Left „	8,95,869	
(C)	Centrès and shifting	20,827	
(D)	Driving piles	23,353	
(E)	Cross piles at end of season's work	63,360	
(F)	Excavation	1,09,164	
	Barrage gates—12 at Rs. 58,035 each	6,96,420	
			25,15,032
	Regulators—Left Bank—		
(G)	Khairpur West Regulator	1,66,814	
(H)	Connecting wall—152½ feet	63,234	
(I)	End abutment of Rohri Canal Regulator ..	52,039	
(J)	Centering—Half number	6,772	
(K)	Driving piles	4,558	
(L)	Cross piling at end of season's work	5,060	
(M)	Excavation	18,253	
			3,16,730
(N)	Left Guide Bank, one-third	99,826	99,826
	Regulators—Right Bank—		
(O)	South-Eastern Canal Regulator	2,90,986	
(P)	Connecting wall	1,30,614	
(Q)	End abutment of Central Canal Regulator ..	52,039	
(R)	Centering—Half number	4,946	
(S)	Driving piles	7,252	
(T)	Cross piles at end of season's work	5,060	
(U)	Excavation	21,030	
			5,11,927
(V)	Right Guide Bank one-third	71,164	71,164

602. *Details for First Season's Works—*

(A) Barrage—Right Bank—

	Rs.	
1 land abutment	53,346 per one	53,346
1 end „ —Floor	56,136 „ „	56,136
1 „ „ —Superstructure	39,542 „ „	39,542

	Rs.	Rs.
5 pier spans (scouring sluice)—Floor	66,229 per one	3,31,145
4 " " " " —Superstructure .	28,686 " "	1,14,744
1 abutment pier (scouring sluice)—Floor ..	81,093 " "	81,093
" " " " " —Superstructure	60,066 " "	30,033
	Total ..	7,06,039

(B) Barrage—Left Bank—

1 land abutment	53,346 per one	53,346
1 end " —Floor	56,136 " "	56,136
1 " " —Superstructure	39,542 " "	39,542
7 scouring sluice pier span—Floor	66,229 " "	4,63,603
6 " " " " —Superstructure ..	28,686 " "	1,72,116
1 " " abutment pier—Span Floor ..	81,093 " "	81,093
½ " " —Superstructure	60,066 " "	30,033
	Total ..	8,95,869
(C) Centres—Total cost Rs. 83,309, say one-fourth in 1st year	20,827	20,827

(D) Driving Piles—Barrage—

2 End abutments	1,616½ per each	3,233
2 Abutment Piers	1,360 " "	2,720
12 Ordinary "	1,120 " "	13,440
4 Rows Cross Piles	990 " "	3,960
	Total ..	23,353
(E) Cross Piles, 15,840 square feet	4 per square foot.	63,360
(F) Excavation—By dredger	95,196	
" hand	13,968	
	1,09,164 Total..	1,09,164

Regulator—Left Bank—

(G) Khairpur West Regulator		1,66,814
(H) Connecting wall, 152½ feet		63,234
(I) End abutment of Rohri Canal Regulator—		
Floor	24,467	
Superstructure	27,572	
		52,039
(J) Centering—Total provision Rs. 13,543 say ½ in first year.		6,772
(K) Driving Piles—3 End abutments at Rs. 734..	2,202	
1 Pier at Rs. 555	555	
152½ feet connecting wall at Rs. 975 per 100′	1,487	
Cross piles row	314	
		4,558
(L) Cross Piles		5,060
(M) Excavation—By dredger	16,633	
By hand	1,620	
		18,253

		Rs.	Rs.
Regulator—Right Bank—			
(O) South-Eastern Canal	.. ..		2,90,896
(P) Connecting wall, 315′	.. ..		1,30,614
(Q) End abutment of Central Canal Regulator—			
Floor	.. ..	24,467	
Superstructure	.. ..	27,572	
			52,039
(R) Centering—Total provision Rs. 9,892 say half in first year	.. ..		4,949
(S) Driving Piles—3 End abutments at Rs. 734 each		2,202	
3 Piers at Rs. 555 each	.... ..	1,665	
Connecting wall, 315′ at Rs. 975-100	.... ..	3,071	
Cross Piles	.. ..	314	
			7,252
(T) Cross Piles	.. ..		5,060
(U) Excavation—By dredger	.. .. ..	19,410	
„ —By hand	.. ..	1,620	
			21,030

603. *Expenditure in 2nd year.*—

Barrage—

		Rs.	Rs.
2 abutment piers—Floor	.. ..	77,992 per each	1,55,984
2 „ „ —Superstructure	..	60,066 „ „	1,20,132
16 pier spans—Floor	.. .. ..	63,676 „ „	10,18,816
16 „ „ —Superstructure	..	28,686 „ „	4,58,976
Centres—Shifting	.. .. ..		20,828
(A) Driving piles	.. .. ..		22,620
(B) Cross piles	.. .. ..		31,680
(C) Excavation	.. .. ..		81,485
			19,10,521
18 barrage gates	.. ..	58,035 „ „	10,44,630
Purchase 1,290 r. ft. of 22′ piling, *i.e.*, 28,380 square feet out of third year's requirement at Rs. 4 each square foot	.	1,13,520	
And 1,065 r. ft. of 22′ piling, *i.e.*, 23,430 square feet out of 4th year's requirement for temporary use for pumping trenches	.. ..	93,720	
			2,07,240
		Total ..	31,62,391

Left Bank Regulator—		
(D) Rohri Canal Regulator	.. .. ..	6,19,394
Connecting wall	.. .. ..	63,234
Khairpur East Canal Regulator	..	1,66,814
Connecting wall	.. .. ..	63,234

			Rs.	Rs.
	Eastern Nara Regulator	.. .. ..		7,95,605
	End sloping wall	.. .. ..		68,347
	Centering	.. .. ..		6,771
(E)	Driving piles	.. .. ..		20,693
(F)	Excavation	.. .. ..		37,087
				18,41,179
	Left Guide Bank, one-third	.. ..		99,826
	Right Bank Regulators—			
(G)	Central canal	.. .. ..		6,19,394
	Connecting wall, 208′	.. .. ..		86,247
	Northern canal	.. .. ..		3,53,722
	End sloping wall	.. .. ..		68,347
	Centering	.. .. ..		4,946
(H)	Driving piles	.. .. ..		13,766
(I)	Excavation	.. .. ..		25,084
				11,71,506
	Right Guide Bank	.. .. ..		71,164

604. *Details of Second Season's Work—*

(A)	Barrage—			
	Driving piles—			
	2 abutment piers at Rs. 1,360 each	.. ..	2,720	
	16 piers at Rs. 1,120 each	.. ..	17,920	
	Cross piles, 2 rows, at Rs. 990 each	.. ..	1,980	
				22,620
(B)	Cross piling—7,920 square feet at Rs. 4 each			31,680
(C)	Excavation—By dredger	.. .. ..	66,486	
	„ —By hand	.. .. ..	14,999	
				81,485
	Regulators—Left Bank—			
	Rohri Canal Regulator	.. .. ..	6,71,433	
(D)	Deduct work done last year	.. .. ..	52,039	
				6,19,394
	Driving piles—Total	.. .. ..	25,251	
(E)	Done last year	.. .. ..	4,558	
				20,693
	Excavation—By dredger	.. .. ..	29,011	
(F)	„ —By hand	.. .. ..	8,076	
				37,087
	Regulators—Right Bank—			
	Central Canal	.. .. ..	6,71,433	
(G)	Deduct end abutment done 1st year	..	52,039	
				6,19,394
	Driving Piles—Total	.. .. ..	21,018	
(H)	Done 1st year	.. .. ..	7,252	
				13,766
	Excavation—By dredger	.. .. ..	19,693	
(I)	„ —By hand	.. .. ..	5,391	
				25,084

605. *Expenditure in 3rd year—*

	Rs.	Rs.
Barrage—same as 2nd year	19,10,521	
18 gates at Rs. 58,035 each	10,44,630	
	29,55,151	
Deduct—		
28,380 square feet of piling purchased in 2nd year	1,13,520	
15,000 square feet purchased in preliminary year	60,000	
	1,73,520	27,81,631
Right divide wall	2,34,489	
Excavation	24,512	
		2,59,001
Left Guide Bank, one-third ..		99,826
Right Guide Bank, one-third ..		71,165
Total expenditure in 3rd year.. ..		32,11,623

606. *Expenditure in 4th year—*

Barrage—		
14 pier spans—Floor	63,676 per each.	8,91,464
16 „ „ —Superstructure	28,686 „ „	4,58,976
1 abutment pier spans—Floor	77,992 „ „	77,992
2 „ „ —Superstructure	60,066 „ „	1,20,132
18 barrage gates	58,035 „ „	10,44,630
Crane track		22,540
Cranes		24,000
Motor trollies		25,000
Lights		40,000
Driving piles [For details see below (A)] ..		17,040
Centering		20,826
Excavation		61,228
		28,03,828
Deduct—		
23,430 square feet of piling purchased in 2nd year at Rs. 4 per square foot		93,720
		27,10,108
Left divide wall		3,16,228
Excavation		35,598
		3,51,826
Total Expenditure in 4th year ..		30,61,934

607. *Details of 4th year's work—*

(A) Driving Piles—

		Rs.
14 spans at Rs. 1,120 each	.. .. ..	15,680
1 abutment at Rs. 1,360	.. .. ..	1,360
	Total ..	17,040

SECTION V.

Annual Expenditure on Plant.

608. *Abstract of Annual Expenditure on Plant—*

		Rs
Preliminary year	.. ..	47,76,560
First „	.. ..	77,74,474
Second „	.. ..	6,61,864
Third „	.. ..	3,56,744
Fourth „	.. ..	3,56,744
Fifth „	.. ..	2,56,744
	Total outlay on Plant	1,41,83,130

Plant.

609. *Expenditu e in Preliminary year—*

		Rs.		Required in India by
(1) Railways				
Permanent way, 2′ 0″	.. .. ..	81,600		August
Rolling stock, 2′ 0″	.. .. ..	2,93,000		August
Locomotives, 2′ 0″	.. .. ..	80,000		August
Permanent way, 5′ 6″	.. .. ..	13,70,800		September
Rolling stock, 5′ 6″	.. .. ..	5,96,000		September
Locomotives—3 tank engines	.. ..	66,000		September
	Total		24,87,400	
(2) Fleet—				
4 pontoons for pile driving	.. .. ..	18,000		September
2 motor boats	.. .. ..	25,000		September
1 steam tug	.. .. ..	90,000		September
	Total ..	——	1,33,000	
(3) Cranes—				
2 Ten-ton hand derricks	.. .. ..	15.000		September
4 one and a half ton derricks	.. ..	4,800		September
1 five-ton steam loco.	.. .. ..	10,000		September
2 goliaths	.. .. ..	90,000		February
	Total ..	——	1,19,800	
(4) Pile drivers—				
4 sets—Steam	.. .. ..	54,000		September
	Total ..	——	54,000	

(5) Crushers—

	Rs.	Rs.	
2 stone breakers	14,000		August
1 portable engine, 12 N. H. P.	6,000		August
Total ..		20,000	

		Rs.	
(6)	Moulds	1,60,000	February
(7)	Workshop—Whole	1,09,700	February
(8)	Water-supply—Whole except electric Pumps ..	1,46,000	August
(9)	Mortar mills—One set	17,000	August
(10)	Electric power plant—Whole	6,67,000	February
(11)	Piling—For wharves	5,00,160	September
(12)	Surveying instruments—Theodolites, levels, etc.	42,500	August
(13)	Miscellaneous Tools	3,00,000	August
(14)	Furniture	20,000	August
	Total for Preliminary year	47,76,560	

610. *Expenditure in 1st year*—

(1) Railways—

Rolling stock, 5′ 6″—

	Rs.		
300 trucks	12,00,000		April
Saloons	30,000		April
20 brakes	1,40,000		April
Loco. crane	1,00,000		April
Locomotives 5′ 6″	2,46,000		
Deducting last year's purchase ..			
Total ..	....	17,16,000	

(2) Fleet—

Boats	17,21,000		
Pontoons and barges	6,29,000		
Total ..	....	23,50,000	June.

(3) Cranes—

Lot—deducting last year's purchase ..		3,44,200		
Total ..		....	3,44,200	June.
(4) Pumps—Plant	1,80,000	,,	1,80,000	June.
(5) Pile drivers— Lot—deducting last year's purchase	4,50,000	,,	4,50,000	June.
(6) Crushers and mixers	83,850	,,	83,850	April.
(7) Air compressors—Lot	57,600	,,	57,600	June
(8) Diving gear	56,660	,,	56,660	June
(9) Water supply—Electric pumps	24,000	,,	24,000	April.
(10) Mortar mills—Balance	83,000	,,	83,000	April.
(11) Disintegrators—Lot ..	13,000	,,	13,000	April.
(12) Electric plant transmission lines	1,70,000	,,	1,70,000	April.
(13) Piling for 1st year's work 301,200 square feet	12,04,800	,,	12,04,800	July.
(14) Arch centres—whole	3,64,620	,,	3,64,620	January.

		Rs.		Rs.	
(15) Miscellaneous tools	.. ..	4,00,000	..	4,00,000	June.
(16) Furniture ..	.. ..	20,000	..	20,000	April.
(17) Annual repairs	.. ..	2,56,744	..	2,56,744	
Grand Total for 1st year	.. .. ..		..	77,74,474	

611. *Expenditure in Second year—*

				Rs.
1. Annual repairs		2,56,744	.. ..	2,56,744
2. Piling balance	15,09,920			
	12,04,800			
	3,05,120		.. .. ..	3,05,120
(Required in India by July.)				
3. Miscellaneous tools		1,00,000	.. ..	1,00,000
Total for second year		.. ..	.. ..	6,61,864

612. *Expenditure in Third year—*

1. Annual repairs	2,56,744
2. Miscellaneous tools	1,00,000
Total for third year	3,56,744

613. *Expenditure in Fourth year—*

1. Annual repairs	2,56,744
2. Miscellaneous tools	1,00,000
Total for fourth year	3,56,744

614. *Expenditure in Fifth year—*

1. Annual repairs	2,56,744
Total for fifth year	2,56,744

615. *Details of Annual Repairs to Plant—*

Railways—

Repairs to 5′-6″ rolling stock	.. ..	35,700		
" to 2′ " "	.. ..	14,800		
" to 5′-6″ locomotives	.. ..	10,080		
" to 2′ "	.. ..	4,320		
		—	Total	64,900

Fleet—

Repairs to boats	.. ..	91,800		
" " pontoons	.. ..	19,400		
		—	Total ..	1 11,200

Cranes—

Repairs to cranes	.. ..	18,700		
" " goliaths	.. ..	4,500		
			Total ..	23,200

		Rs.
Pumping Plant—	Repairs for same	1,800
Pile drivers—	,, ,, ,, ...	10,080
Crushers and mixers—	,, ,, ,, ...	5,192
Moulds—	,, ,, ,, ...	4,800
Air compressors—	,, ,, ,, ...	2,880
Diving gear—	,, ,, ,, ...	2,832
Workshop—	,, ,, ,, ...	3,520
Water supply—	,, ,, ,, ...	4,000
Mortar mills—	,, ,, ,, ...	6,000
Disintegrators—	,, ,, ,, ...	1,000
Electric power—	,, ,, ,, ...	13,340
Office furniture—	,, ,, ,, ...	2,000
	Annual Total for Repairs	2,56,744

SECTION VI.

Annual Expenditure on Service Works.

616. *Abstract of Annual Expenditure on Service Works—*

	Rs.
Preliminary year	5,75,600
First ,, ...	8,19,106
Second ,, ...	9,81,896
Third ,, ...	5,72,484
Fourth ,, ...	4,98,534
Fifth ,, ...	1,66,264
Total outlay on Service Works ..	36,13,884

617. *Details of adjustments—*

Debit to Service Works—

Vol. I of Report.	Railway Permanent Works—Depreciation	7,32,400
	Moulds—Depreciation and Repairs	1,74,000
	Total ..	9,06,400

Credit to plant the same amount, *i.e.*, Rs. 9,06,400.

Service Works.

618. *Expenditure in Preliminary year—*

(1) Railways—

		Rs.	
Earthwork and laying signals	.. .. ..	2,00,000	
Stations, etc., 5′-6″	.. .. ..	40,000	
2′-0″ Signals, etc.	.. .. ..	5,000	
2′-0″ 4-mile track in yards laying	.. ..	8,000	
5′-6″ engine sheds	.. .. ..	15,000	
2′-0″ engine sheds	.. .. ..	8,000	
		Total ..	2,76 000

(2) Roads and bunds—	Rs.	
Bunds	25,250	
Roads	20,000	Rs.
	Total	45,250
(3) Temporary water arrangements		25.000
(5) Alignment towers		40,000
(6 Pile driving—Wharves		22,650
(7) Wharves		40,400
(10) Store: —Depot lighting arrangements		2,000
(11) Stores—Carriage of Stores, one-tenth		29,300
(12) Lights and fans		39,000
(13) Telegraph		16,000
(15) Core boxes		40,000
Total in Preliminary year		5,75,600

619. *Expenditure in First year—*

(1) Railways—	Rs.	
5′-6″ line, M. and R.	50,000	
2′-0″ relaying	8,400	
	Total	58.400
(2) Roads—		
Roads, M. and R.	1,000	
Bunds	550	
	Total	1,550
(3) Water supply		19,800
(9) Piling—Pile driving and withdrawing		1,10,592
(8) Cofferdams		25,600
(9) Pumps—27 pumps—5 months		5,10,000
(10) Stores—Stores Depot—M. and R shifting		11,000
(11) Stores— Carriage		58.600
(12) Lighting		20,000
(13) Telegraphs and phones—Hire		3,564
Total Expenditure in First year		8,19,106

620. *Expenditure in Second year—*

(1) Railways—M. and R.	58,400
(2) Roads and bunds—M. and R.	1,550
(3) Water supply	19,800
(6) Piling	1,55,782
(8) Cofferdams	11,200
(9) Pumping—34 pumps—5 months	6,42,000
(10) Stores—M. and R.	11,000
(11) Stores—Carriage one-fifth	58,600
(12) Lights	20,000
(13) Telegraphs—M. and R.	3,564
Total Expenditure in Second year	9,81 896

621. *Expenditure in Third year—*

	Rs.
(1) Railways—M. and R. ..	58,400
(2) Roads and Bunds—M. and R.	1,550
(3) Water supply ..	19,800
(6) Piling ..	86,370
(8) Cofferdams	11,200
(9) Pumping—16 pumps—5 months	3,02,000
(10) Stores—Shifting	11,000
(11) Stores—Carriage one-fifth	58,600
(12) Lights	20,000
(13) Telegraphs	3,564
Total Expenditure in Third year	5,72,484

622. *Expenditure in Fourth year—*

(1) Railways	58,400
(2) Roads and bunds	1,550
(3) Water supply	19,800
6 Piling	79,620
9 Pumping—13 pumps—5 months	2,46,000
(10) Stores—Shifting	11,000
(11) Stores—Carriage one-fifth	58,600
(12) Lights	20.000
(13 Telegraphs	3,564
Total Expenditure in Fourth year	4,98,534

623. *Expenditure in Fifth year—*

(1) Railways	58,400
(2) Roads and bunds	1,550
(3) Water supply	19,800
(6) Pile withdrawing—Wharves	22,650
(10) Stores—Shifting	11,000
(11) Stores—Carriage one-tenth	29,300
(12) Lights	20,000
(13) Telegraphs and telephones	3,564
Total Expenditure in Fifth year	1,66,264

SECTION VII.

Establishment.

ANNUAL EXPENDITURE.

624. *Preliminary year—*

Direction,	Rs. 7,730	per month	$\times 12 \times \frac{2}{3}$	=		Rs. 61,840
Right Bank,	„ 9,970	„	×10	=		„ 99 700
Left Bank,	„ 9,970	„	×10	=		„ 99,700
Power Supply,	„ 11,800	„	×10/2	=		„ 59,000
Medical,	„ 5,423	„	×12/6	=		„ 10,846
Audit,	„ 3,530	„	×10/2	=		„ 17,650
						3,48,736
		Add—Secretariat				12,600
Total Establishment for Preliminary year						Rs. 3,61,336

625. *First year*—

	Rs.
Direction	7,730
River Works	10,005
Right Bank	9,970
Left Bank	9,970
Quarries	7,000
Power Supply	11,800
Stores	6,050
Medical	5,423
Audit	3,530
Total per month	71,478

71,478×12 = ..	8,57,736	
Add—Secretariat	12,600	
Total Establishment for First year ..		8,70,336

626. *Second year*—

Same as first year.	8,57,736	
Add—Secretariat	12,600	
Total Establishment for Second year ..		8 70,336

627. *Third year*—

Same as last year.	8,57,736	
Add—Secretariat	12,600	
Total Establishment for Third year		8,70,336

628. *Fourth year*—

All except two divisions Right and Left Bank 71,478 per month, —19,940 (Rs.)

51,538×12 = ..	6,18,456
Add—Secretariat	12,600
Total Establishment for Fourth year	6,31 056

629. *Fifth year*—

	6,18,456
Add—Secretariat	12,600
Total Establishment for Fifth year	6 31 056

630. *Closing year*—

	Rs.	
Direction	7,730	
Audit	3,530	
Total per month ..	11,260×12	= 1,35,120
Add—Secretariat		12,600
Total Establishment for closing year		1,47,720
Grand Total for Establishment		43,82,176

631. *Secretariat Establishment to be charged to Barrage—*

		Rs.	
One-fifth of the Chief Engineer's salary	..	600	
One Supervisor	.. .. ..	250	
2 Clerks on Rs. 100 each	.. .. ..	200	
		1,050	per month.
		12,600	per year.

PART XIV.

RATES FOR WORKS AND MATERIAL.

INDEX.

PART XIV.

THE RATES ADOPTED IN THE ESTIMATE.

SECTION I.

The Effect of the War and the general method of estimating rates.

632. Had the war not occurred it is contended that there still would have been a general tendency for rates to increase, owing to the general upward tendency of wages, and the improved condition of labour. Such increase would however be comparatively small and gradual. It is considered that a rise of 15 per cent. in 10 years might occur from these causes.

633. Schedules of rates from all the Sind Districts were called for in 1916 showing current rates (*i.e.*, during the war) as compared with rates 10 years previous. In many cases rates for 10 years previous could not be given, owing to district schedules having been then very incomplete. In some cases the earlier rates were shown, having been taken as items from contractor's bills, but it is contended that such rates are entirely misleading since they may or may not give even an approximate indication of the true cost of such items at that time. It is generally known and admitted that contractors "rig" their tenders by putting high rates for some items, and low rates for others, so that such rates may not represent the true value of any item.

634. Unfortunately very little departmental work has been done in Sind and for the barrage, departmental work appears to be indicated. Even if work is let on contract, the quantities will be so great, and competition so keen, that the work will be done at *bona fide* (real) rates.

635. The incidence of the war, and the great temporary enhancement of wages of all classes will no doubt leave some permanent increase after the war, though it is very difficult to forecast what this will amount to.

636. It seems probable that rates for labour will remain permanently about 30 per cent. above the rates ruling immediately prior to the war. It has to be remembered that there is a great influx of returning labour corps, and great numbers of casual skilled and unskilled labour recently employed abroad. Also the prices of foodstuffs should fall again almost to pre-war level, while the great development of industries in India and of its natural products, during the war, will give far cheaper indigenous substitutes for many of the articles hitherto imported from Europe. All this will tend to reduce the cost of works in India. For instance, India 5 years hence ought to be self-supplying as regards iron and steel, cement and many chemicals. It is true these industries will absorb labour, but they will also create new classes of skilled labour hitherto unobtainable, besides presumably reducing the cost of these commodities.

637. Now for the barrage construction, very large quantities of *Material* will be used, principally stone and lime, which is found locally and is already the property of Government. There will therefore be no increase in the cost of the natural product, the only increase being due to the labour and plant used in obtaining and adapting it for use in works.

638. I have already assumed that the cost of labour will be increased by 30 per cent. over pre-war rates, but for work at the barrage conditions will be very special. The work will be very large, the site is healthy and convenient for labour, it is in a good labour centre, and will be well advertised. Arrangements for housing the labour and for all their supplies will of course be made and there ought to be no difficulty in attracting all the labour required at not more than local rates.

639. But in addition to this, the work will be so large that the most up-to-date and efficient methods of work and of plant will be used, so that at similar rates for labour it ought to be possible to attain considerably lower rates for works, than would be possible for small local works. I consider that such reduction of cost ought to amount to at least 10 per cent. of the pre-war rates for small local works, so that allowing for a rise of 30 per cent. in cost of labour and a reduction of 10 per cent. due to greater efficiency, the net increase in cost should not be more than 20 per cent. above pre-war local rates.

640. The North-Western Railway has carried out far more works in the Sukkur and Rohri neighbourhoods than the Public Works Department especially masonry and earthworks and some river works. They also have a very full and detailed schedule of rates for such works (pre-war rates) and the Executive Engineer, Sukkur, informs me that he found it necessary in May 1918 to increase certain rates in this schedule for masonry and allied works, but such increases amount to only about 20 per cent. over the pre-war rates. It appears therefore that this schedule may be taken to give liberal *pre-war* rates and that it may form a useful basis for estimating post-war rates.

641. I propose therefore to add 20 per cent. to the rates in the North-Western Railway schedule to give reasonable rates for masonry and such items for the barrage.

642. In his 1910 estimates, Mr. Beale advised very high rates for the various sorts of masonry, but he appears to have been guided in this, principally by his

very wide experience of the cost of masonry in the Deccan. The conditions are so entirely different in the Deccan, that this would seem to be misleading as a guide to Sind rates. The Deccan stone is a very hard trap which is difficult to quarry, comes out in rough blocks needing a good deal of dressing, and is extremely difficult to cut, trim, or dress on the works. The Aror stone on the other hand although very strong, is easy to quarry, can be wedged out in blocks of any size and almost to shape, and is very easily worked.

643. Mr. Beale also collected a list of actual rates paid for various classes of masonry on works in Sind, but as already explained, these are very little guidance, as they are "rigged" contractors rates for one item. taken out of tenders for comparatively small works. The Public Works Department has not carried out any really large stone masonry work near Sukkur or Rohri, on which it would have been really worth while for contractors to compete at low prices. The reconstruction of the Eastern Nara Head Regulator is the biggest work of the kind, and this was comparatively small, and a very troublesome work, with many petty items to be included under main heads, so that it does not form a reliable guide.

644. The Jamrao Headworks form a far better indication of rates, though this site is 130 miles from the Aror quarries from which it obtained its stone supplies. The rates now adopted for the barrage estimates will be found to be very considerably higher than those at the Jamrao.

Section II.

Iron and Steel Work.

645. It is a more difficult matter to form any idea of rates for iron work, plant, etc., and experience is no guide here. Some engineers' suppliers whom I have consulted say that rates for the next two or three years may be 100 per cent. to 125 per cent. above pre-war rates. Others tell me that 50 per cent. is a reasonable and likely figure to take, but there can be no approach to certainty about these items until tenders are invited, when the goods are to be actually purchased.

646. For estimating purposes I have added 50 per cent. to pre-war rates for this class of work.

647. In the case of the gates and machinery I have taken Mr. Ashford's estimate of pre-war cost and added 50 per cent. to it.

648. For arch centres, etc., I have added 50 per cent. to quotations for lattice girder work at pre-war prices by Messrs. Richardson and Cruddas. Bombay.

649. For "Universal" Steel Sheet Piling I have estimated as follows:

The cost of rolling the sections is no more than the cost of rolling ordinary I beams, channels, etc. The pre-war price for the piling was, however, higher than that of ordinary beams, the difference being due presumably to patent royalties.

The pre-war prices were roughly as follows :—

	Per ton. Rs.
"Universal" steel piling, 15″×5″, delivered Karachi ..	145
Ordinary beams, 15″×5″	110
Royalty—Difference ..	35

The royalty is assumed to remain unchanged while 50 per cent. is added to the cost of ordinary beams=110 *plus* 55=Rs. 165. Adding royalty at 35 we have Rs. 200 per ton delivered Karachi. To this must be added freight from Karachi to Sukkur, say Rs. 8 per ton. Total cost =Rs. 208 per ton at Sukkur. The weight of the piling interlocked, being 43 lb. per square foot, there are 52 square feet to the ton. Hence the cost is Rs. 4 per square foot.

Cost of Iron Work.

650. Details of rates taken for various items of iron work are given in the preceding pages. A margin of about 50 per cent. has been allowed over the pre-war rates. But it is possible that rates may not come down to this level by the time the works are started. It is not possible to estimate this.

651. A list of the principal items of iron work, required for permanent works, is therefore given. The total value of iron work will be about 75 lakhs at the estimated rates. The net increase in cost, if iron work in each item costs Rs. 10 more per ton than the estimated rate, is also given in the statement, so that the effect of any increase in the rate for each item can be readily seen.

652. In addition to the iron work required for permanent works, the initial outlay on plant will be about 130 lakhs. If the plant cannot be purchased at the rates provided, the provision must be increased.

SECTION III.

Principal items of Iron Work required for Barrage and Regulators, Permanent Works.

Item.	Weight Tons.	Rate per ton.	Amount.	Additional cost for each rise of Rs. 10 per ton.
		Rs.	Rs.	Rs.
(1) Steel Sheet Piling—				
Permanent 5,27,607 square feet	10,552	....	21,10,428	1,05,521
(2) Barrage Gates and Counterweights—				
66 gates at 46 tons each, 3,036 tons				
66 counterbalance casings at 25 tons each, 1,650 tons	4,686	555	26,00,730	46,860
66 grooves at 14 tons each, 924 tons	924	420	3,88,080	9,240
66 sets of free rollers	No. 66	3,000 each	1,98,000	....
66 sets of mechanism for lifting gates, ropes, etc.	No. 66	9,750 each	6,43,500	....
(3) Regulator Gates and Counterweights—				
45 gates (sets) at 17·4 tons each, 783 tons				
45 counterbalance casings at 6 tons each, 270 tons	1,053	555	5,84,415	10,530
45 grooves at 7·9 tons	355½	420	1,49,310	3,555
45 sets of rollers at Rs. 52½ per roller	No. 45	1,365 each	61,425	....
45 sets of mechanism for two gates	No. 45	4,000 each	1,80,000	....
45 sets of mechanism for cill	No. 45	1,500 each	67,500	....
(4) Rolled steel Built Sections—				
66 × 4 compound beams for supporting barrage gates at 1·35 tons each	356·4	250	89,100	3,564
(5) Crane track for barrage	161	140	22,540	1,610
(6) Centerings for barrage—				
9 sets trusses, lagging, etc., at 49 tons each, 441 tons				
9 sets trusses for gate bridge at 16 tons each, 144 tons	585	370	2,16,450	5,850
144 cylinders at Rs. 200 each	No. 144	200	28,800	....
Tie bolts and holding down bolts	52	180	9,360	520
Cast iron plates	133	150	19,950	1,330
(7) Cranes—				
2-3-ton steam cranes	No. 2	12,000 each	24,000	....
6 motor trolleys	No. 6	4,166 each	25,000	....
(8) Lamps	No. 130	300	39,000	....
Electric motors for regulators	No. 23	1,300	29,900	....
Total	....	....	74,87,488	....

SUKKUR BARRAGE PROJECT, 1919.

SECTION IV.

Schedule of Rates.

		Rs. a. p.	C. ft.
1.	Loose stone pitching and chips	8 0 0	100
2.	Lime concrete	17 8 0	100
3.	Cement concrete	45 0 0	100
4.	Concrete blocks (composite), large size	30 0 0	100
	" " (") small size	25 0 0	100
5.	Random rubble masonry in floors	27 0 0	100
6.	Masonry, cement pointed 3" deep	32 0 0	100
7.	Coursed rubble in piers and abutments	40 0 0	100
8.	Extra rate for dressing curved stones for cut and ease waters	20 0 0	100
9.	Masonry in pilasters, string-courses, parapets, caps, etc., coursed rubble in lime with chisel hand-dressing in large blocks	90 0 0	100
10.	Pavement	70 0 0	100
11.	Arching—(Centering extra)	100 0 0	100
12.	Special hardstone masonry	80 0 0	100
13.	Road metal	4 0 0	100
14.	Reinforced concrete slabs	120 0 0	100
15.	Reinforced concrete beams	150 0 0	100
16.	Rolled steel beams	160 0 0	Ton
17.	Cast iron	150 0 0	Ton
18.	Bolts, etc.	180 0 0	Ton
19.	Iron work in gates	555 0 0	Ton
20.	Iron work in girders and trusses	480 0 0	Ton
			C. ft.
21.	Excavation with dredger	8 0 0	1,000
22.	Excavation with hand in foundation	15 0 0	1,000
23.	Embankment in guide banks down-stream side, mean lead 350' and lift 12'..	14 0 0	1,000
24.	Embankment in guide banks up-stream side, mean lead 110' and lift 20'	11 0 0	1,000
25.	Excavation not used in bank, lead 100'	6 0 0	1,000
26.	Steel sheet piling	4 0 0	One sq. ft.

SECTION V.

Details of Rates.

(1) *Loose Stone Pitching*—

	N. W. R. pre-war rates. Rs.	a.	p.
(*a*) Stones not less than 10 seers in weight, good hard stone, at quarry ready for loading per 1,000 cubic feet	16	0	0
(*b*) Carriage of stone to barrage assume lead 5 miles— Assuming 25 cubic feet per ton at 2·4 pies per ton per mile— =12 pies per 5 miles/ton. =40×12 pies per 1,000 cubic feet/5 miles. ∴ Rs. 2-8-0 per 1,000 cubic feet	2	8	0
(*c*) Unloading from trucks including shifting and stacking per 1,000 cubic feet	10	0	0
(*d*) Hand packing in floor including lead of 100 feet labour only	40	0	0
	68	8	0
Add—20 per cent. for post-war rates	13	8	0
	82	0	0

Say Rs. 80 per 1,000 cubic feet.
Rate: Rs. 8 per 100 c. ft.

(2) *Lime Concrete* 1 : 2 : 4—
Per 100 cubic feet.

	Rs.	a.	p.
(*a*) Lime, cubic feet 25 at Rs. 35 per 100 cubic feet	8	12	0
(*b*) Sand, cubic feet 50 at Rs. 5 per 1,000 cubic feet	0	4	0
(*c*) Stone metal, cubic feet 100 at Rs. 3 per 100 cubic feet ..	3	0	0
(*d*) Mixing and laying	2	4	0
	14	4	0
Add—20 per cent. post-war rates, say	3	4	0
∴ Rate is Rs.17-8 per 100 C. ft.	17	8	0

(3) *Cement Concrete* 1 ; 3 : 6 *of* $1\frac{1}{2}''$ broken stone—
Per 100 cubic feet.

	Rs.	a.	p.
(*a*) Cement, 16 cubic feet at Rs. 2 per cubic foot..	32	0	0
(*b*) Sand, 50 cubic feet at Rs. 5 per 1,000 cubic feet	0	4	0
(*c*) Metal (stone), 100 cubic feet at Rs. 3 per 100 cubic feet ..	3	0	0
(*d*) Mixing and laying	2	4	0
	37	8	0
Add—20 per cent. for post-war rates	7	8	0
	45	0	0

∴ *Rate is Rs.* 45 per 100 cubic feet.

(4) *Composite blocks of* {80 per cent. lime concrete— 20 per cent. cement concrete)—

Per 100 *cubic feet.*	Rs.	a.	p.
80 cubic feet of lime concrete at Rs. 17-8-0	14	0	0
20 cubic feet of cement concrete at Rs. 45	9	0	0
	23	0	0

(*a*) *Large sized blocks*—

Add—For handling on to barges and laying in position by floating crane and divers	7	0	0
∴ *Rate for large sized blocks is Rs.* 30 per 100 cubic feet.	30	0	0
(*b*) *Small sized blocks*	23	0	0
Add—For handling on to barges, etc...	2	0	0
∴ *Rate for small sized blocks is Rs.* 25 *per* 100 *cubic feet.*	25	0	0

(5) *Random Rubble Masonry*—

N. W. R. pre-war rate Rs. 22 per 100 cubic feet.

Add—20 per cent. for post-war rate Rs. 5 (say).

∴ *Rate for* 100 *cubic feet* = Rs. 27.

(6) *Masonry in lime mortar, cement pointed* 3″ *deep*—

$$3\times 6''=18$$
$$3\times 6''=18$$
$$2\times 36''=72$$

$110''\times 3''\times 1''$ =330 cubic inches per 3 square feet.
=100 cubic inches per 1 square foot.
=10,000 cubic inches per 100 square feet.
=6 cubic feet per 100 square feet.

Cement mortar 1 : 1—	Rs.	a.	p.
100 cubic feet sand at Rs. 5 per 1,000 cubic feet	0	8	0
100 cubic feet cement at Rs. 2 per cubic foot	200	0	0
Mixing and laying	4	8	0
∴ 160 cubic feet of mortar cost	205	0	0
100 cubic feet of mortar cost	130	0	0
We have 150 cubic feet of masonry at Rs. 27	40	0	0
100 square feet of pointing = 6 cubic feet of mortar at Rs. 130 for 100 cubic feet	8	0	0
	48	0	0
	for 150 cubic feet.		

∴ *Rate is Rs.* 32 *for* 100 *cubic feet.*

(7) *Coursed rubble in piers and abutments*—	Rs.	a.	p.
N. W. Ry. pre-war rate per 100 cubic feet	34	0	0
Add—20 per cent. for post-war rates say—	6	0	0
∴ *Rate per* 100 *cubic feet* Rs. 40.	40	0	0

(8) *Extra rate for dressing curved stones* for cut and ease waters :—

Rate Rs. 20 *per* 100 *cubic feet.*

(9) *Masonry in pilasters, etc.*—

	Rs.	a.	p.
Per 100 cubic feet, N. W. Ry. pre-war rate	50	0	0
Add—20 per cent. for post-war rates	10	0	0
Add—50 per cent. for dressing of more than one face	30	0	0
∴ *Rate per* 100 *cubic feet*	90	0	0

(10) *Pavement*—

Rate for coursed rubble masonry per 100 cubic feet	40	0	0
Add—75 per cent. for dressing, etc., per 100 cubic feet ..	30	0	0
Rate—Rs. 70 *per* 100 *cubic feet.*	70	0	0

(11) *Arching* (*Centering extra*)—

Based on current rates at Karachi and Sukkur.

Rate—Rs. 100 *per* 100 *cubic feet.*

(12) *Special hardstone masonry for paving floor of barrage.*

1″ joints.

Cement mortar required $=13'' \times 1'' \times 15''$

$=195$ c. in.

plus Bed $=7'' \times 7'' \times 1''$

$=49$ c. in.

$=244$ c. in.

∴ Cement mortar required for masonry $7'' \times 7'' \times 15'' = 735$ cubic inch is 244 cubic inch.

∴ Cement mortar required per 1 cubic foot of masonry $=\frac{244}{735}$ cubic feet.

∴ " " " per 100 cubic feet $=\frac{24{,}400}{735}$ cubic feet.

$=33 \cdot 2$ cubic feet.

	Rs.	a.	p.
Cost of cement mortar 1 : 1—			
100 cubic feet of sand at Rs. 5 per 1,000 cubic feet	0	8	0
100 cubic feet of cement at Rs. 2 per cubic foot	200	0	0
Mixing and laying	4	8	0
∴ For 160 cubic feet of cement mortar=	205	0	0
∴ For 100 cubic feet of cement mortar=	130	0	0
∴ Cost of 100 cubic feet of hardstone masonry—			
33·2 cubic feet of cement mortar will cost	43	0	0
Stone at Re. 0-4-0 per cubic foot	25	0	0
Laying at Re. 0-2-0 per cubic foot	12	0	0
	80	0	0

∴ *Rate is Rs.* 80 *per* 100 *cubic feet.*

(13) *Road Metal—*

	Rs.	a.	p.
N. W. Ry. pre-war rate for 100 cubic feet..	2	8	0
Add— 20 per cent. for post-war rate	0	8	0
Carriage	1	0	0
	4	0	0

∴ *Rate for* 100 *cubic feet=Rs.* 4.

(14) *Reinforced concrete slabs,* $2'\text{-}7\frac{1}{2}'' \times 5'\text{-}3'' \times 3\frac{1}{2}''$.

Contents of slab=4 cubic feet at 45 per 100 c. ft.	2	0	0
Steel, 12 lb. (6 rods $\frac{3}{8}'' \times 5'\text{-}3''$ long)=$\frac{1}{9}$ cwt. at Rs. 13-8-0 per cwt.	1	8	0
Labour for laying and mixing and forms	1	0	0
∴ Cost per 4 cubic feet	4	8	0
∴ Cost per 100 cubic feet	112	8	0

Say Rs. 120.

∴ *Rate per* 100 *cubic feet=Rs.* 120.

(15) *Reinforced concrete beams—*

Rate per 100 cubic feet of reinforced concrete slabs	120	0	0
Add—25 per cent. more for extra reinforcement which will be required in the beams	30	0	0
	150	0	0

∴ *Rate for reinforced concrete beams=Rs.* 150 *per* 100 *cubic feet.*

(16) *Rolled steel Beams—*

	Rs.	a.	p.	
Pre-war rate	5	4	0	per cwt.
Add—50 per cent. for post-war rate.	2	10	0	„ „
	7	14	0	

Say Rs. 8 per cwt.

∴ *Rate per ton—Rs.* 160.

(17) *Cast iron—*

	Rs.	a.	p.
Pre-war rate per cwt.	5	0	0
Add—50 per cent. for post-war rate	2	8	0
∴ Cost per cwt.	7	8	0

∴ *Rate per ton, Rs.* 150

(18) *Bolts, etc.—*

Rate, Rs. 180 *per ton.*

(19) *Ironwork in gates—*

	Rs.	a.	p.	
Ashford's pre-war estimate	370	0	0	per ton.
Add—50 per cent. for post-war rate	185	0	0	„ „
	555	0	0	„ „

∴ *Rate per ton—Rs.* 555.

(20) *Ironwork in girders and trusses*—

	Rs.	a.	p.
Pre-war rates—Ironwork, per ton	230	0	0
Carriage ,, ,, ...	20	0	0
Handling ,, ,, ...	10	0	0
Erection	60	0	0
	320	0	0
Add—50 per cent. for post-war rates	160	0	0
∴ *Rate per ton, Rs.* 480.	480	0	0

(21) *Excavation with dredger*—

Rs. 8 *per* 1,000 *cubic feet.*

Details in Report, paragraphs 523—529.

(22) *Excavation with hand in foundation*—

Wet excavation Rs. 15 *per* 1,000 *cubic feet.*

(23) *Embankment in guide banks, downstream side, etc.*—

Mean lead 350′, lift 12′—

Dr. Summer's rate per 1,000 cubic feet	11	8	0
Add—20 per cent. for post-war rates	2	8	0
∴ *Rate per* 1,000 *cubic feet is Rs.* 14.	14	0	0

(24) *Embankment in guide banks upstream side*—

Mean lead 100′, lift 20′—

Dr. Summer's rate per 1,000 cubic feet	8	14	0
Add—20 per cent. for post-war rates, say	2	2	0
∴ *Rate per* 1,000 *cubic feet, Rs.* 11.	11	0	0

(25) *Excavation not used in bank*—

Mean lead 100′—

Dr. Summer's rate per 1,000 cubic feet	4	14	0
Add—20 per cent. for post war rates, say..	1	2	0
∴ *Rate per* 1,000 *cubic feet Rs.* 6.	6	0	0

(26) *Steel Sheet Piling*—

Universal steel sheet piling as per details in para. 649.

Rate per square foot Rs. 4.

PART XV.

LIST OF ESTIMATES.

SECTION I.

Abstracts.

Abstract of total cost of Barrage ..
,, of Preliminary expenditure ..
Estimate of land to be acquired ..
Summary of estimates of Main Heads of Permanent Works of Barrage ..
,, ,, of all items of Service Works ..
Estimate of cost of all Buildings ..
Summary of estimate of all items of Plant ..
Estimate of cost of Establishment ..
General Abstract of Main Heads of Barrage ..
,, ,, of Main Heads of Regulators on Left Bank ..
,, ,, ,, ,, on Right Bank ..

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SECTION II.

Detailed Estimates.

List of complete detailed estimates ..

BARRAGE:

Floor—centre to centre of arch and one ordinary pier—ordinary sluices ..
,, ,, ,, ,, abutment pier—ordinary sluices ..
,, ,, ,, ,, ordinary pier scouring sluice portion ..
,, ,, ,, ,, abutment pier scouring sluice portion
,, end abutment and junction with road bridge (centre to centre of gate bridge arches and road abutment) ..
Superstructure—centre to centre of arch and one ordinary pier ..
,, ,, ,, and one abutment pier ..
,, road bridge end abutment with ½ span of arch ..
,, gate ,, ,, ..
Abstract of cost of centres for Barrage Arches ..
Cost of one set of centres including trusses and lagging ..
Weight of one truss for centering of Barrage Arches, 60′ span ..
,, set of centres for Road Bridge Arch ..
,, ,, Gate for Bridge Arch ..
Details of removable portions of support for centres—ordinary piers ..
,, ,, —abutment piers ..
,, built in portions of support for centres—ordinary piers ..
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Cost of placing and removing centres ..
One set of gates complete ..
Cost of Crane Track, crane, motor trolleys and lights for Gate Bridge ..
Total cost of Driving Piles (for Barrage, Left and Right Bank Regulators) ..
Total cross Piling at end of season's work (for Barrage, Left and Right Bank Regulators) ..
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See Index to Vol. III.

PART XVI.

Some principal items of Interest in the Barrage Work.

Item.			
(1)	Loose Stone Pitching	15,540,000	c. ft.
(2)	Ordinary masonry	13,000,000	„
(3)	Cut Stone masonry	1,000,000	„
(4)	Excavation by dredger	52,600,000	„
(5)	Wet excavation by hand in foundation	5,000,000	„
(6)	Earth work in Guide Banks	10,400,000	„
(7)	Concrete Blocks	2,350,000	„
(8)	Steel Sheet Piling—		
	Permanent 527,000 square feet or	10,500	Tons.
	Temporary 500,000 square feet or	10,000	„
(9)	Iron Works in Barrage Gates	5,600	„
(10)	Iron Work in Regulator Gates	1,400	„
(11)	Lifting Machinery and rollers for Barrage Gates	Rs. 8,50,000	
(12)	Lifting Machinery and rollers for Regulator Gates	„ 3,10,000	
(13)	Rolled Steel Sections, plain, and worked into trusses, etc.	1,300	Tons.
(14)	Electric Power required	2,600	H. P.
(15)	Railways, Broad-gauge	40	miles.
	2′ Gauge	10	„
(16)	Fleet—		
	Dredgers 2		
	Steamers 5		
	Motor Boats 6		
	Barges and Pontoons .. 85		
(17)	Cranes	38	
(18)	Pumps with Electric Motors, 8″	40	
(19)	Pile Drivers	34	
(20)	Initial outlay on Plant	Rs. .. 1,39,00,000	

PART XVII.

Frontispiece Perspective View.

Vol. IV.

General Plans.

Sections of River Banks.

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Sections of River Banks.

River Sections.

* These plans have not been reproduced.

Vol IV. Plan No.

River Sections.

Esna, Barrage Egypt.

Details of Barrage.

Alternative Designs.

Barrage Stability Diagrams.

Details of Gates.

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Details of Gates.

Alternative Design—Steel Superstructure.

Regulators.

Stability Diagrams.

Alternative Type Design for Regulators.

Working Plans.

* These plans have not been reproduced.

PART XVIII.

List of Appendices (Volume II).

Appendix A. Brief History of Sukkur Barrage and Sind Triple Canals Projects 1904 to 1919.

" B. Report of Secretary of State's Committee, appointed to investigate the scheme for the Sukkur Barrage and Rohri Canal.

" C. Correspondence of the Government of Bombay in their letter No. W.I. 10515, Public Works Department, dated Bombay, 23rd September 1915.

" D. A note on the Proposed Barrage and Canals System by the Honourable Mr. H. S. Lawrence, C.S.I., I.C.S., Commissioner in Sind.

" E. A note on Surface and Bed Levels of the River Indus at Sukkur during great floods and the estimated Afflux due to Barrage by Mr. A. A. Musto, Executive Engineer, Sukkur Barrage Project District.

" F. Tables of Heights of the River Indus on the Bukkur Gauge from 1848.

" G. A note by Mr. A. A. Musto, Executive Engineer, on the design of floors of weirs and undersluices.

" H. Report on Quarries by Captain Townshend, R.E., Executive Engineer attached Sukkur Barrage Project District.

" I. Tests of Compressive strength of Kalka and Aror Limestone.

" J. Statement showing average monthly and maximum gauge readings of Indus at Sukkur during period 25th September to 15th April in years 1909-19.

" K. A note on Suction Dredgers by Mr. A. A. Musto, Executive Engineer, Sukkur Barrage Project District.

" L. Stability Calculations for Barrage and Regulators.

" M. Statements showing River and Canal Discharges.

" N. Comparative estimates for Barrage with masonry superstructure and Barrage with steel superstructure.

" O. Saving due to making counterweights for Barrage Gates of Reinforced Concrete.

" P. Cost of Road Bridge debitable to Provincial Funds.

The Times Press Bombay.—411 20·