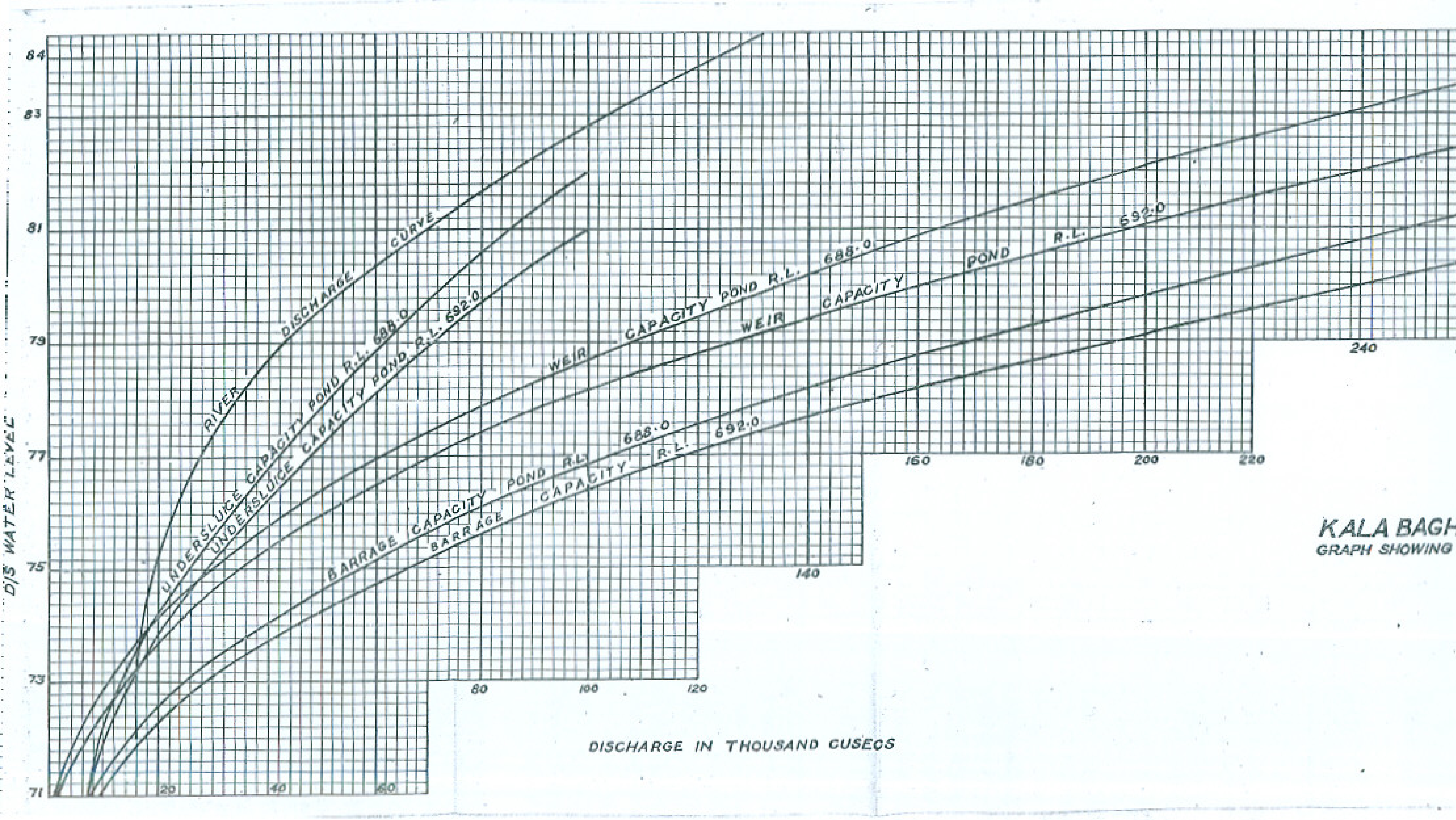
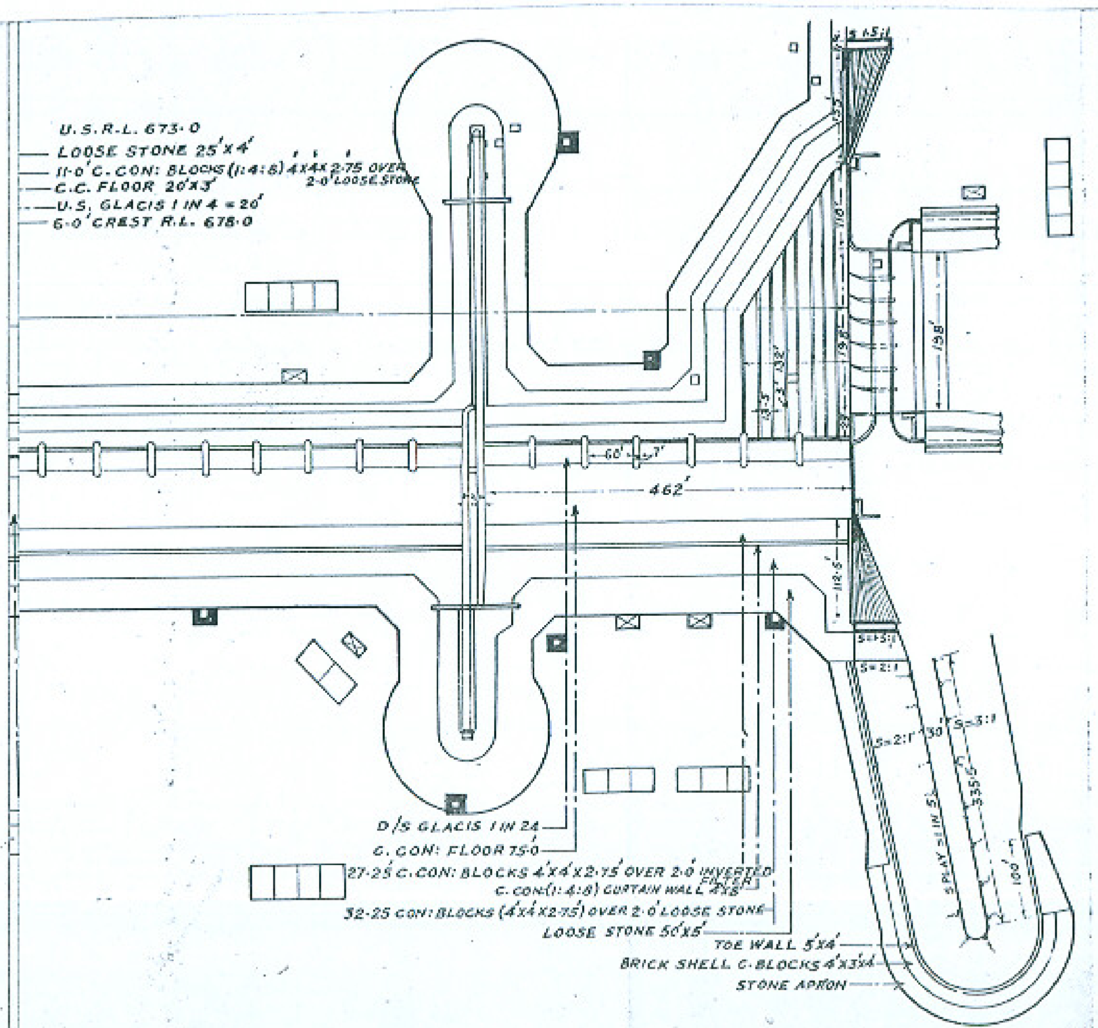


KALA BAGH

GRAPH SHOWING

PLATE II
PAPER NO. 251

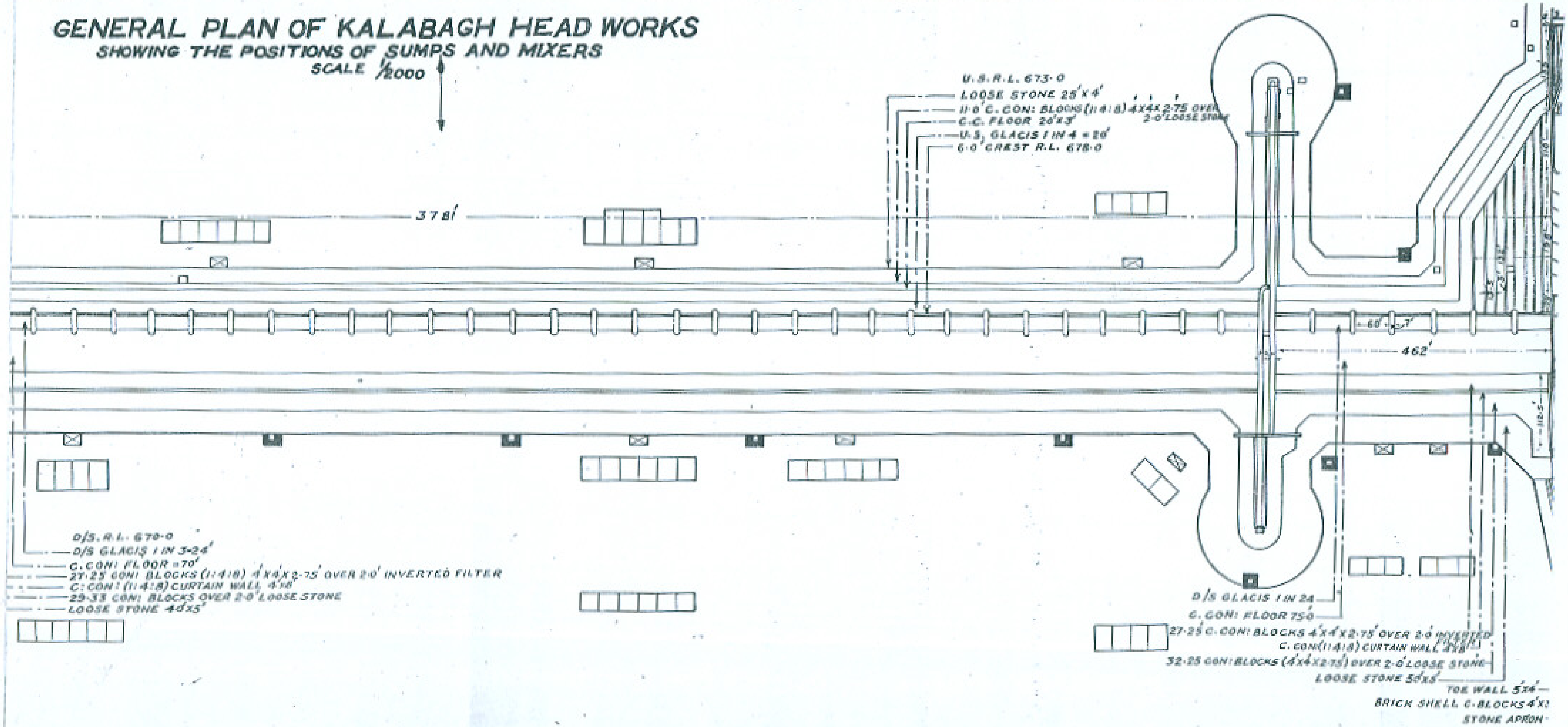


PUNJAB ENGINEERING CONGRESS
1942

GENERAL PLAN OF KALABAGH HEAD WORKS

SHOWING THE POSITIONS OF SUMPS AND MIXERS

SCALE 1/2000



GENERAL PLAN OF KALABAGH HEAD WOR

SHOWING THE POSITIONS OF SUMPS AND MIXERS

SCALE 1/2000

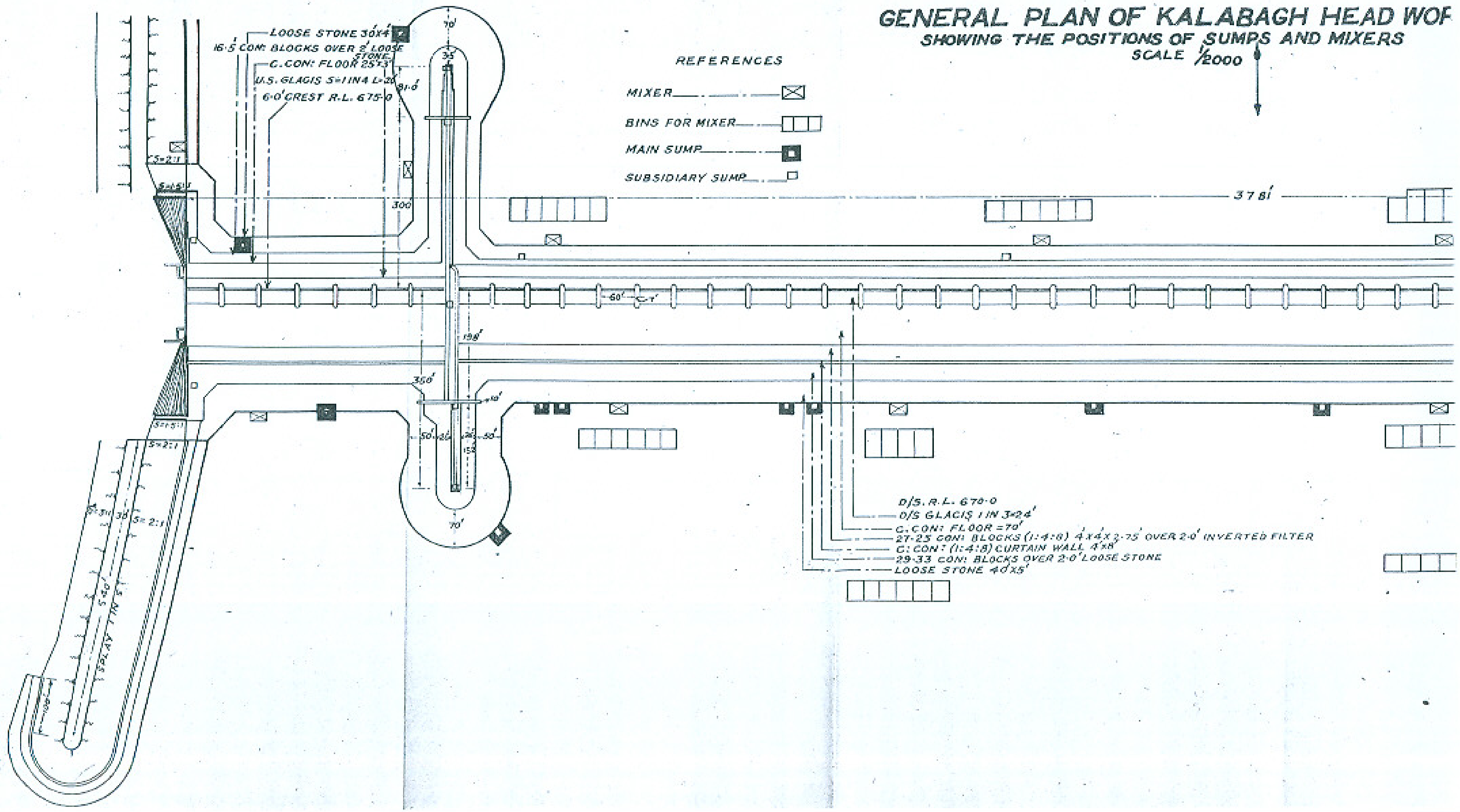


PLATE III
PAPER NO. 251

KALABAGH HEAD WORKS

TYPICAL CROSS SECTIONS OF GUIDE BANKS

SCALE 1/500

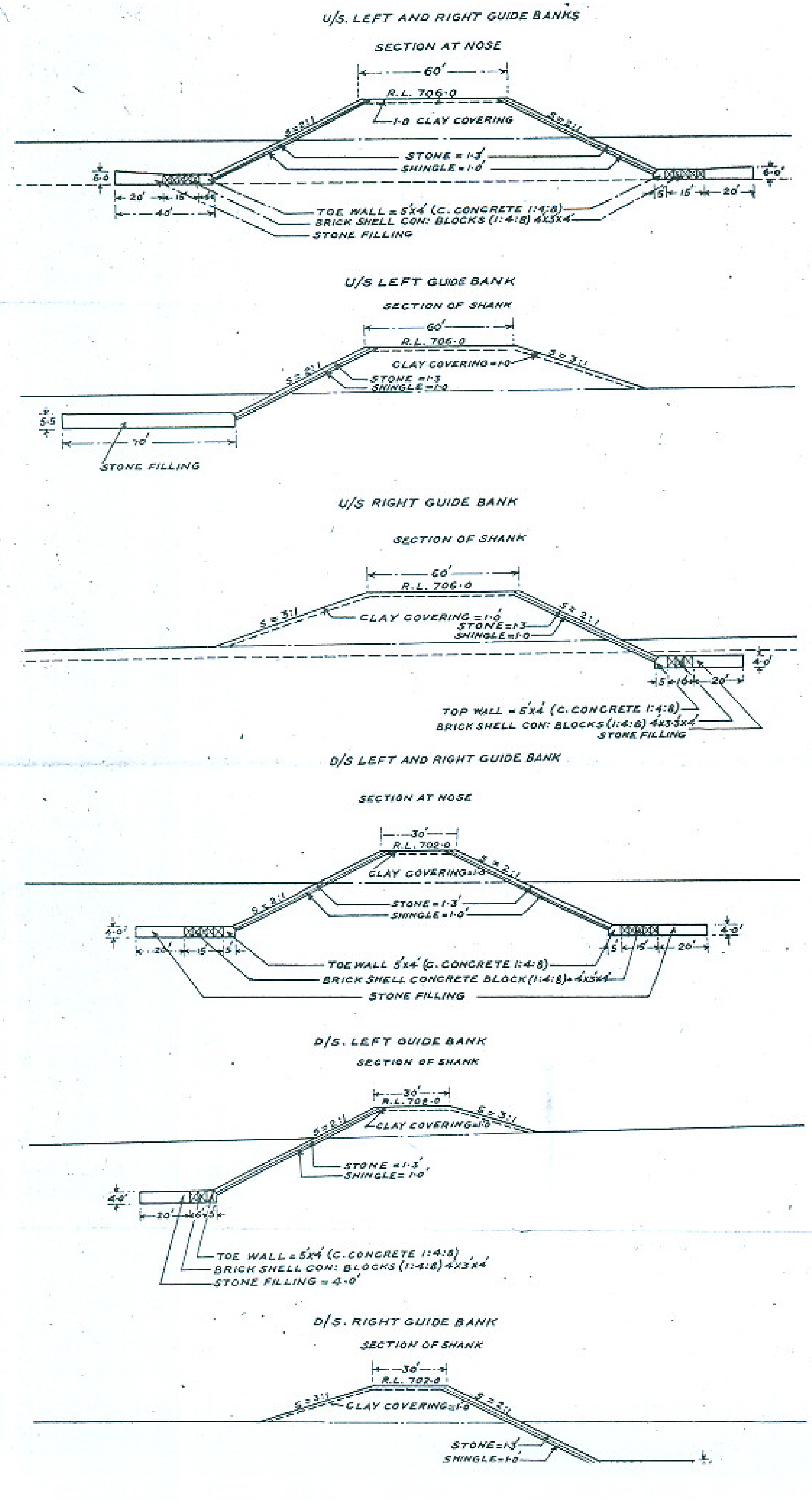
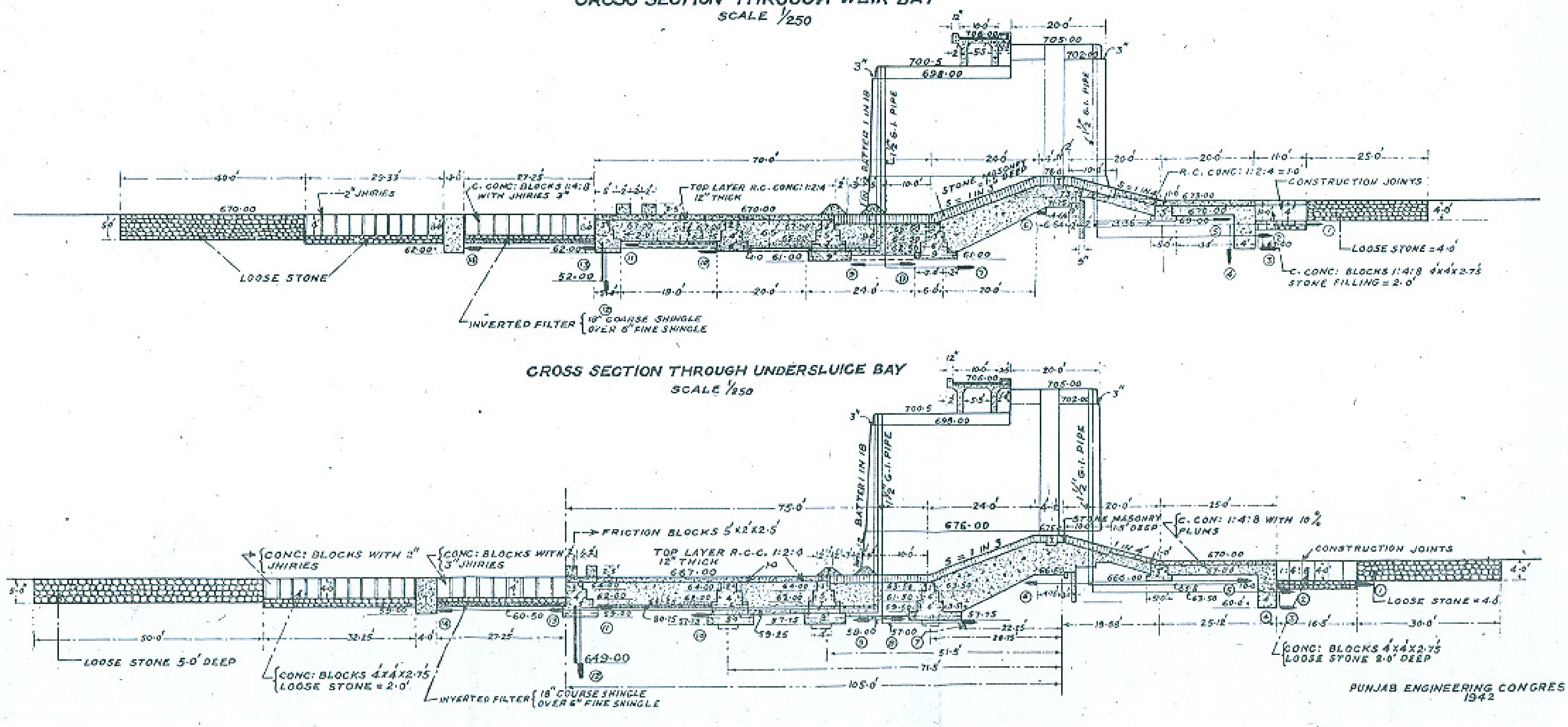


PLATE II
PAPER NO. 2

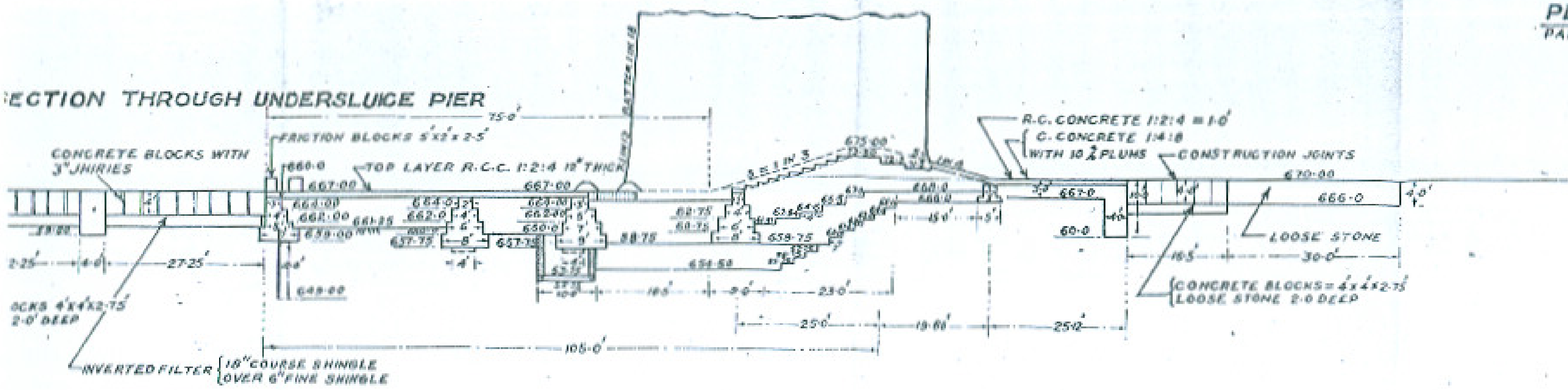
KALABAGH HEAD WORKS



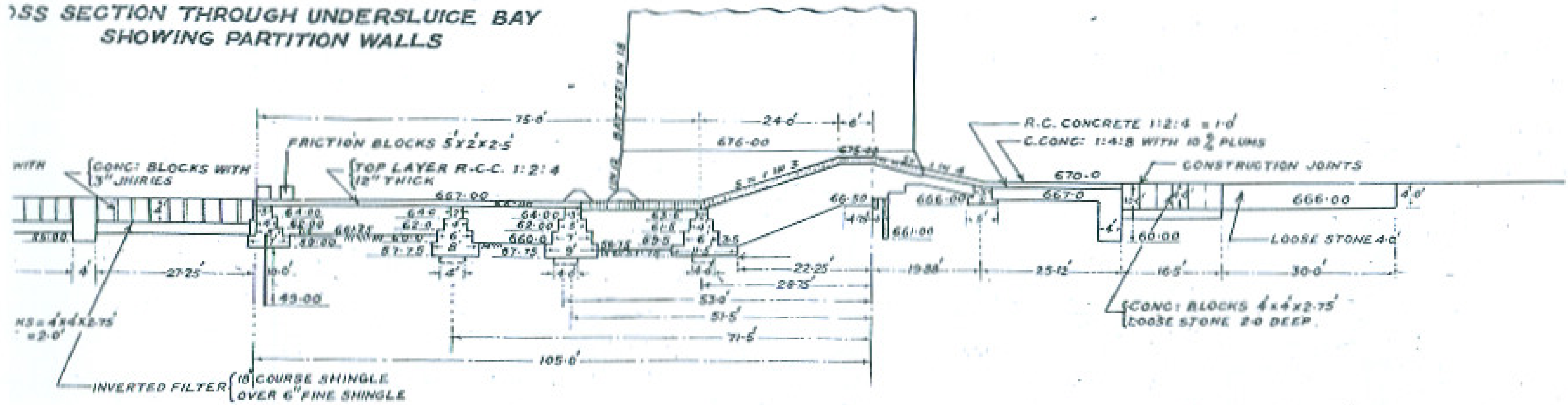
PUNJAB ENGINEERING CONGRES
1942

PLATE V
PAPER NO. 251

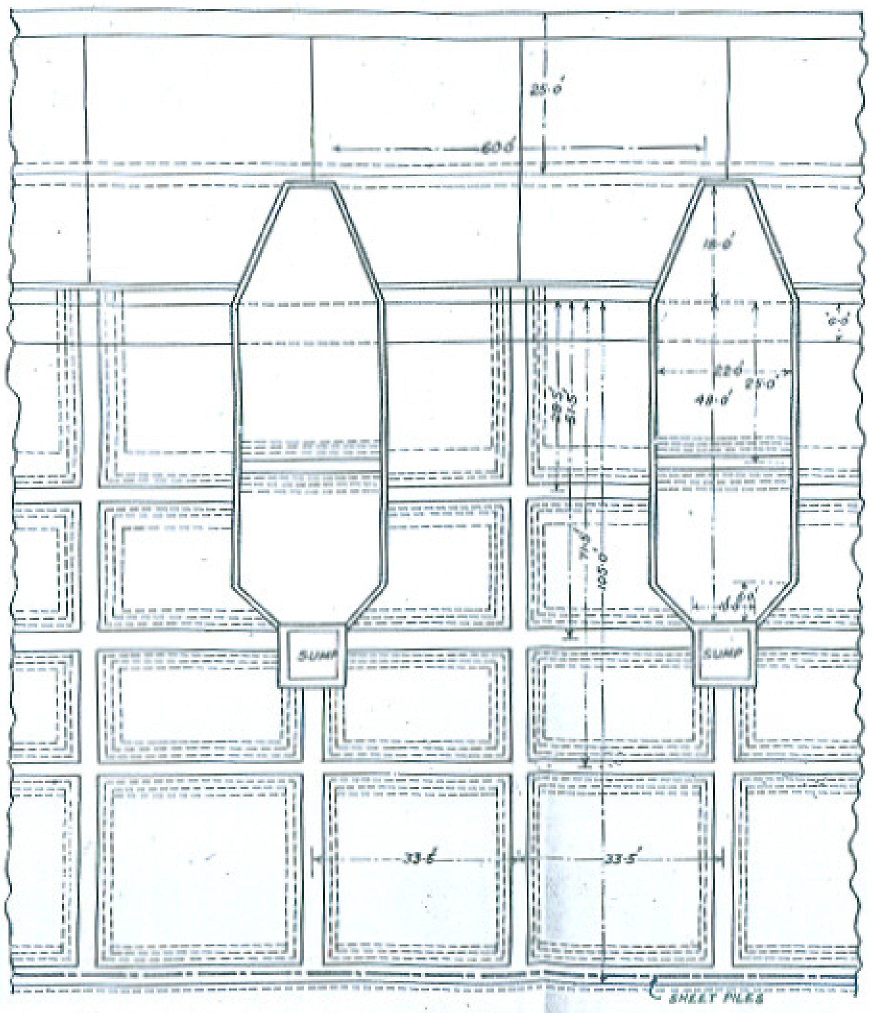
...ECTION THROUGH UNDERSLUICE PIER



...OSS SECTION THROUGH UNDERSLUICE BAY SHOWING PARTITION WALLS

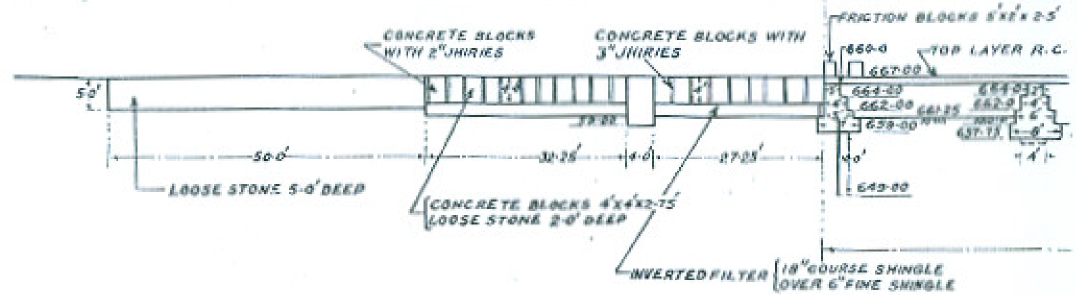


PUNJAB ENGINEERING CONGRESS
1942



KALABAGH HEAD WORKS
CONCRETE POURING PLAN
SCALE 1/250

CROSS SECTION THROUGH UNDERSLUICE PIER



CROSS SECTION THROUGH UNDERSLUICE I SHOWING PARTITION WALLS

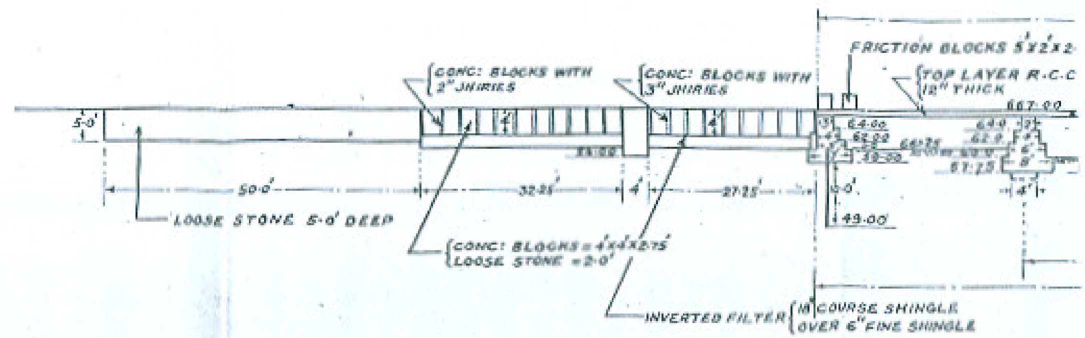
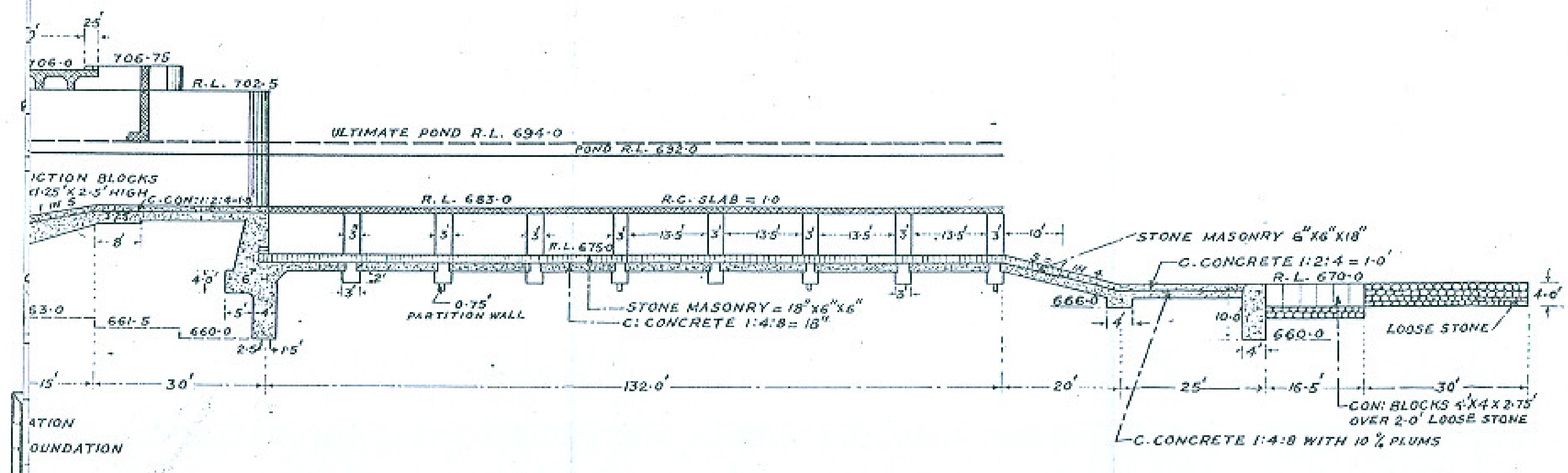


PLATE VI
PAPER NO. 251.

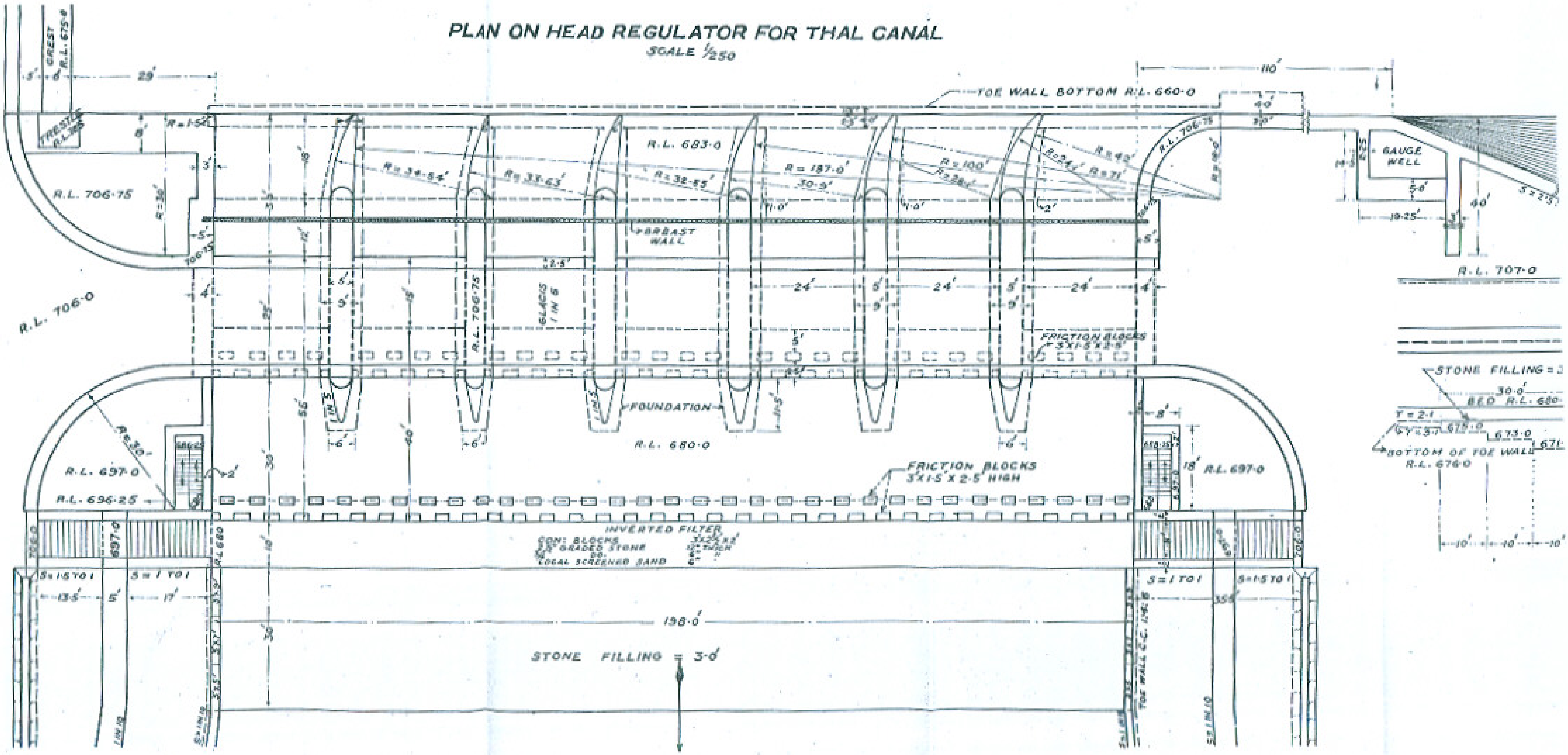
KALABAGH HEAD WORKS
SECTION THROUGH HEAD REGULATOR AND SILT EXCLUDER
SCALE 1/250



PUNJAB ENGINEERING CONGRESS
1942.

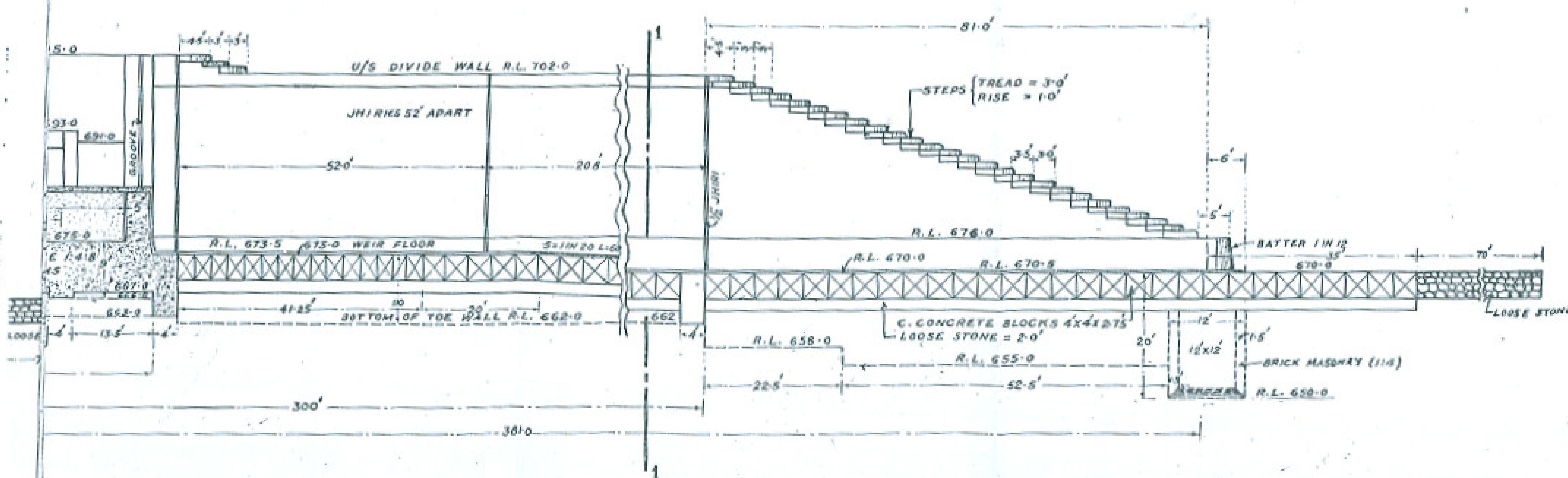
PLAN ON HEAD REGULATOR FOR THAL CANAL

SCALE 1/250

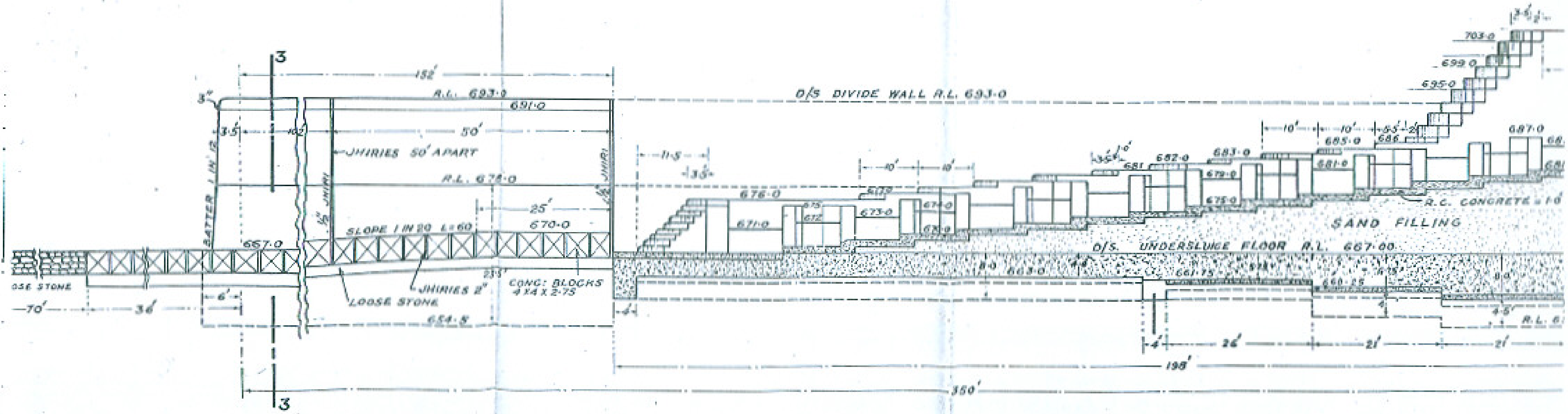


WORKS
IVIDE WALL

PLATE VII
PAPER NO. 251



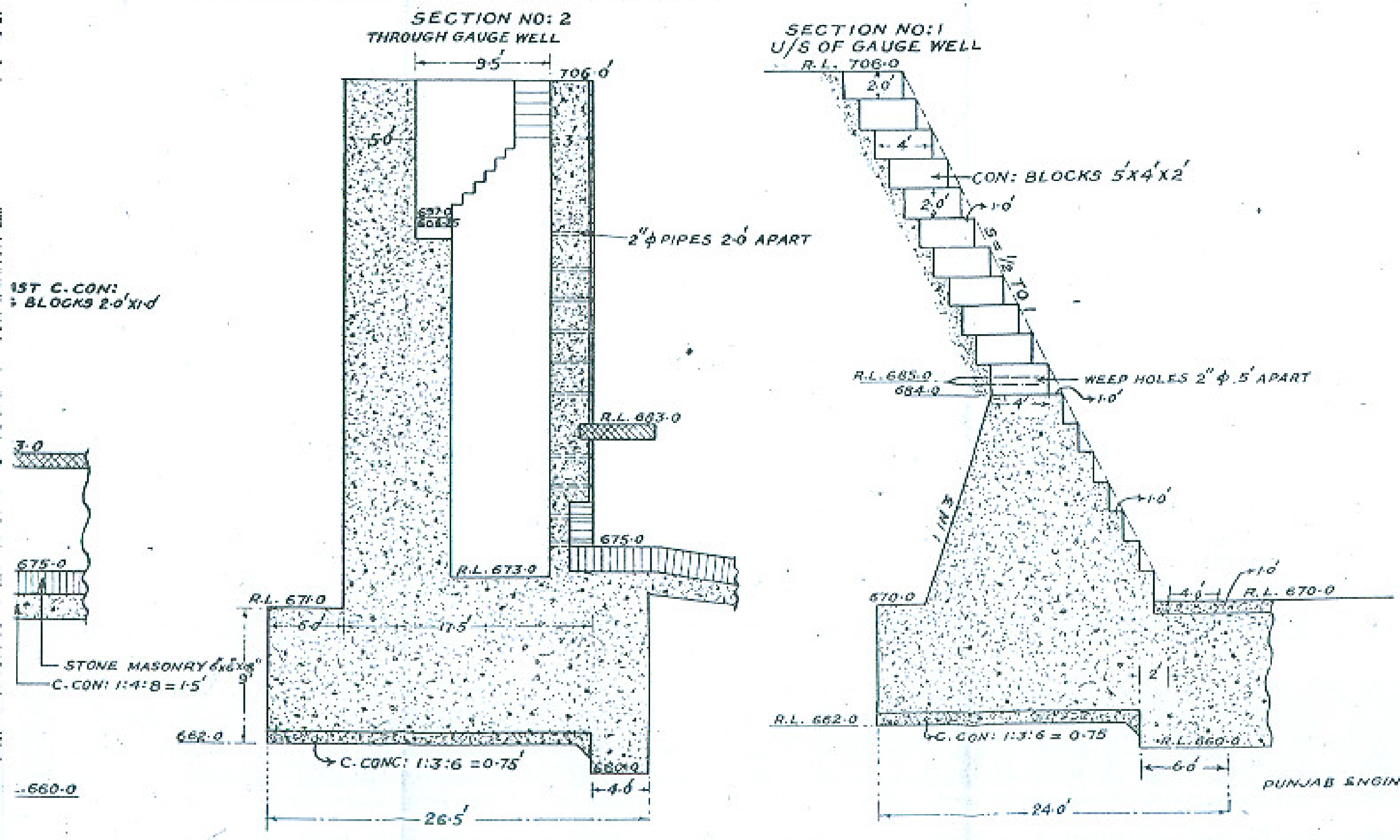
PUNJAB ENGINEERING CONGRESS
1942



OSE STONE
70'
36'
6'
BATTER 1 IN 12
3"
3.5'
667.0
3
152'
R.L. 693.0
691.0
50'
JHIRIES 50' APART
R.L. 678.0
1/2" JHIRI
SLOPE 1 IN 20 L=60
25'
670.0
JHIRIES 2"
LOOSE STONE
CONC: BLOCKS 4 X 4 X 2.75
654.8
4'
D/S DIVIDE WALL R.L. 693.0
11.5
3.5
676.0
671.0
675
672
673.0
10'
674.0
681
682.0
683.0
679.0
675.0
685.0
686
681.0
687.0
695.0
699.0
703.0
R.C. CONCRETE
SAND FILLING
D/S. UNDERSLUICE FLOOR R.L. 667.00
663.0
661.75
660.25
26'
21'
4.5'
198'
350'

PLATE VIII
PAPER NO. 251

CROSS SECTIONS OF FLANK WALL

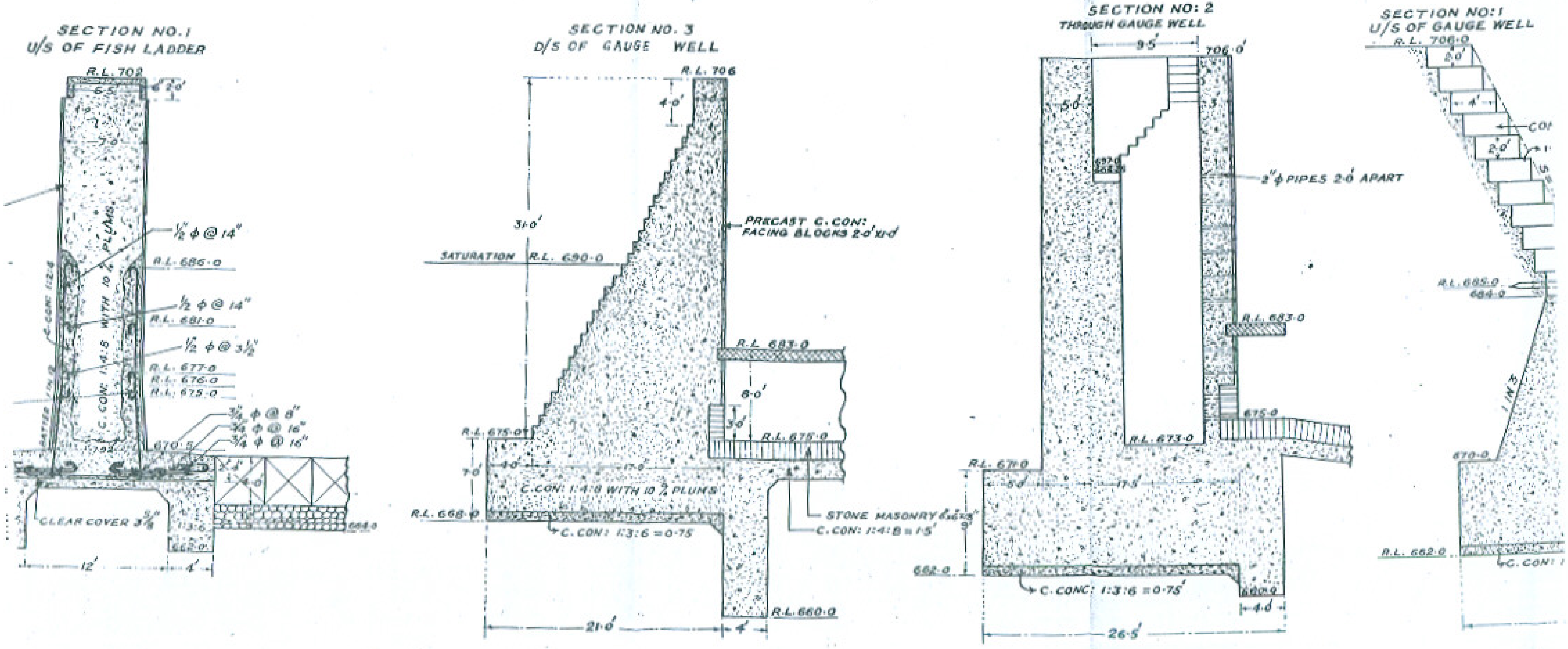


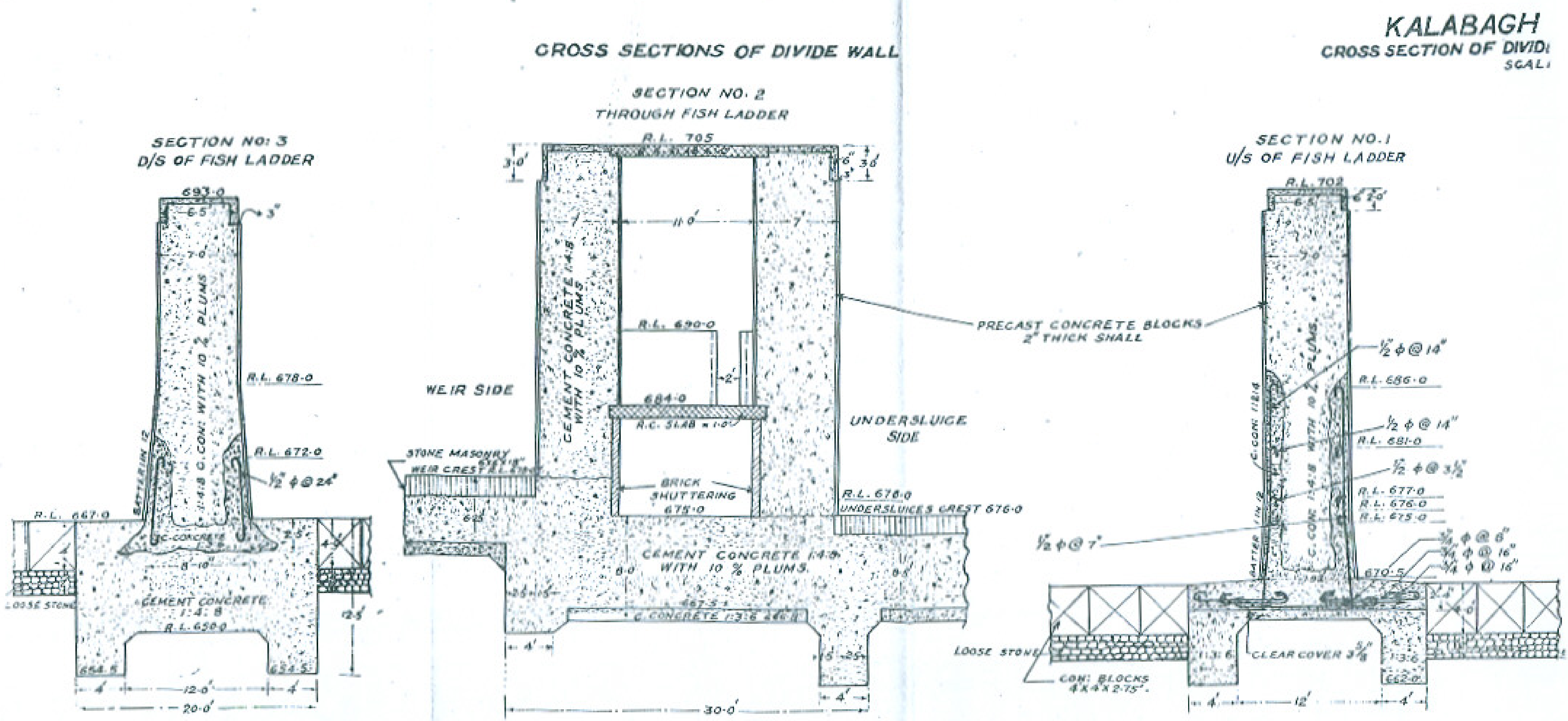
PUNJAB ENGINEERING CONGRESS
1942.

KALABAGH HEAD WORKS

CROSS SECTION OF DIVIDE WALL & FLANK WALL

SCALE 1/100





KALABAGH
CROSS SECTION OF DIVID
SCAL
CROSS SECTIONS OF DIVIDE WALL
SECTION NO: 3
D/S OF FISH LADDER
SECTION NO. 2
THROUGH FISH LADDER
SECTION NO. 1
U/S OF FISH LADDER
R.L. 705
R.L. 702
693.0
R.L. 678.0
R.L. 672.0
R.L. 667.0
R.L. 650.0
1:4:8 C.CON: WITH 10 % PLUMS
CEMENT CONCRETE 1:4:8
CEMENT CONCRETE 1:4:8 WITH 10 % PLUMS
WEIR SIDE
UNDERSLUICE SIDE
STONE MASONRY
R.L. 690.0
684.0
R.C. SLAB
BRICK SHUTTERING
675.0
R.L. 676.0
UNDERSLUICES CREST 676.0
PRECAST CONCRETE BLOCKS 2" THICK SHALL
R.L. 686.0
R.L. 681.0
R.L. 677.0
R.L. 676.0
R.L. 675.0
C. CON: 1:4:8 WITH 10 % PLUMS
C.CON: 1:2:4
LOOSE STONE
CON: BLOCKS 4'X4'X2.75'.
CLEAR COVER 3/8"
20.0'
30.0'
12'

GH HEADWORKS

)AD BRIDGE OVER THE BARRAGE

LES {LONG. SECTION 1/50; CROSS SECTION 1/25}

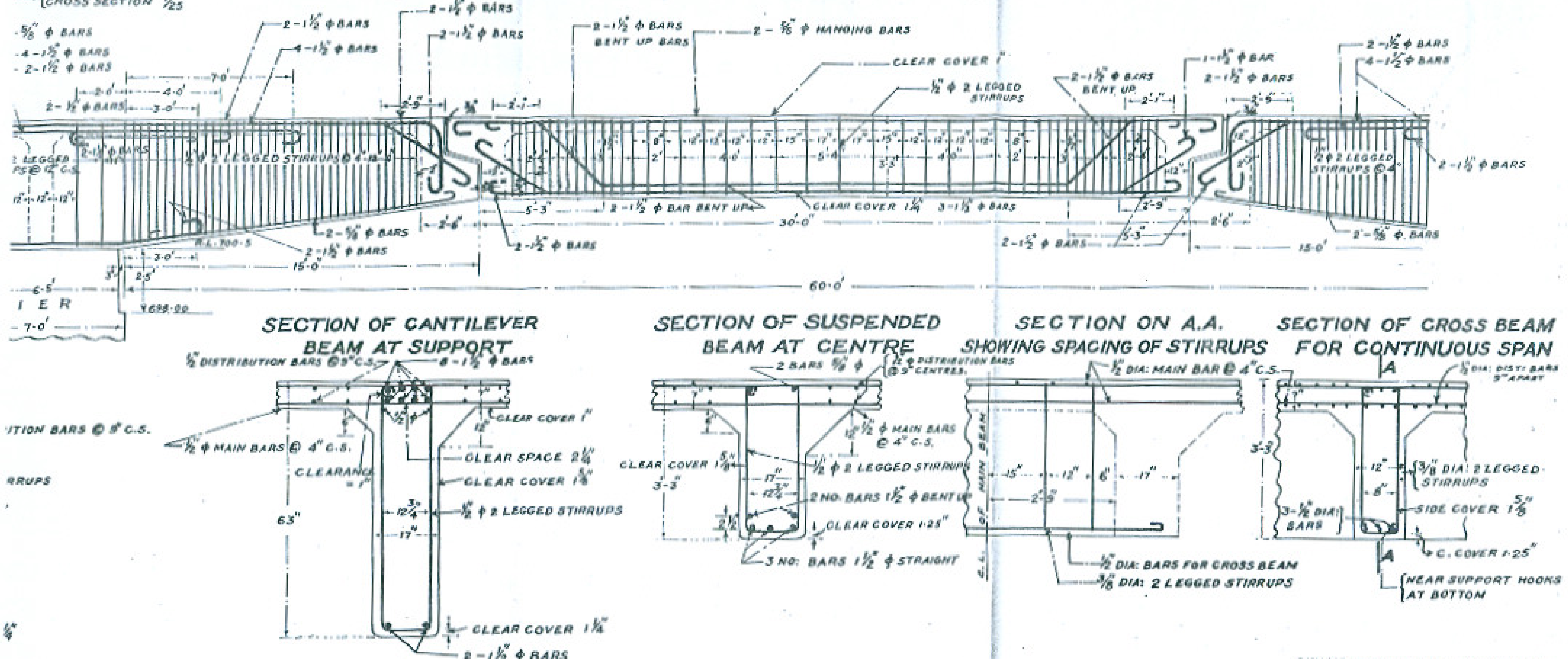


PLATE IX
PAPER NO. 251

PUNJAB ENGINEERING CONGRESS 1942.

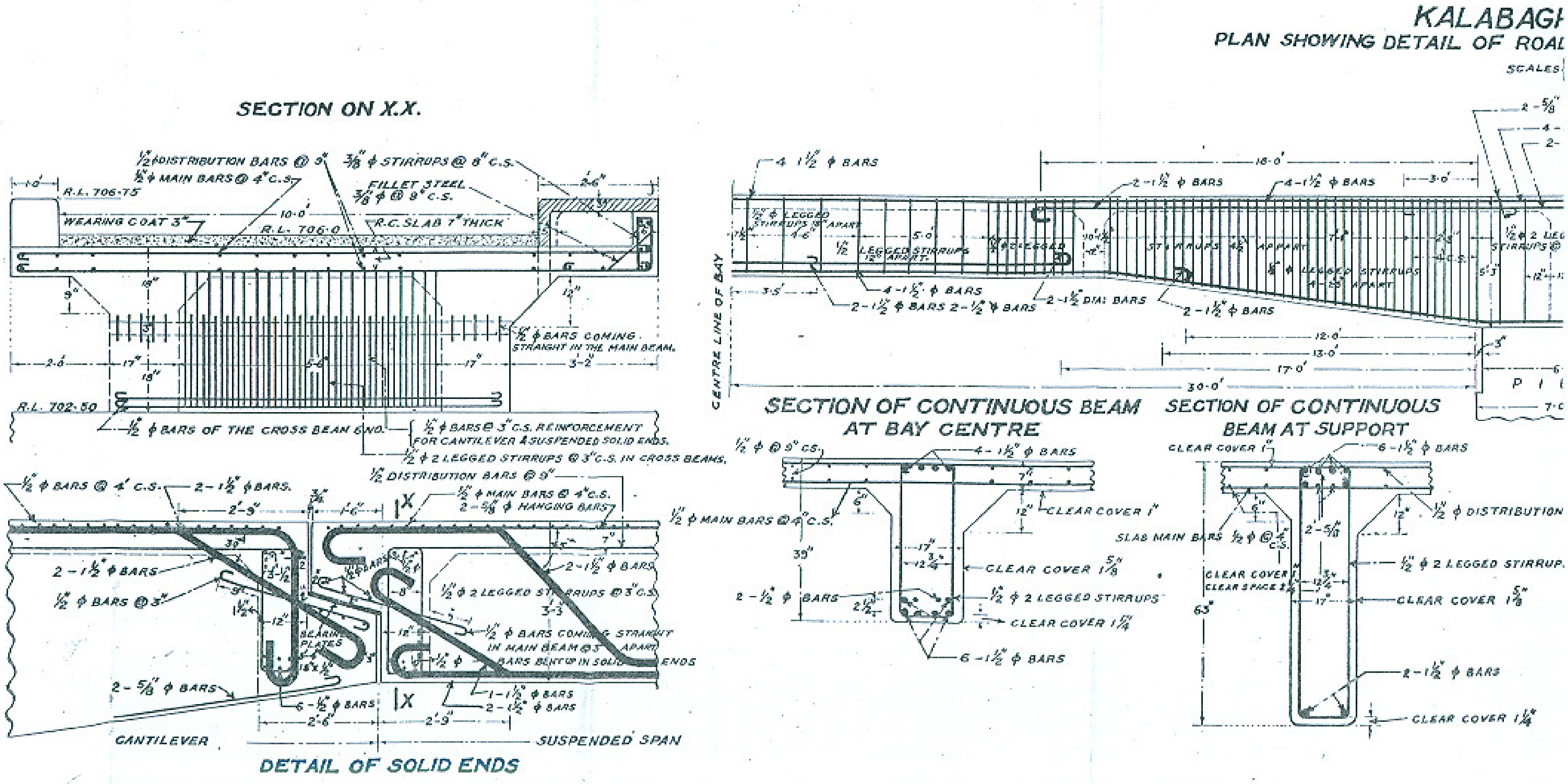

KALABAGH
PLAN SHOWING DETAIL OF ROAD
SCALES
SECTION ON X.X.
½" φ DISTRIBUTION BARS @ 9"
⅜" φ STIRRUPS @ 6" C.S.
½" φ MAIN BARS @ 4" C.S.
FILLET STEEL ⅜" φ @ 9" C.S.
R.L. 706·75
WEARING COAT 3"
R.L. 706·0
R.C. SLAB 7" THICK
½" φ BARS COMING STRAIGHT IN THE MAIN BEAM.
R.L. 702·50
½" φ BARS OF THE CROSS BEAM END.
½" φ BARS @ 3" C.S. REINFORCEMENT FOR CANTILEVER & SUSPENDED SOLID ENDS.
½" φ 2 LEGGED STIRRUPS @ 3" C.S. IN CROSS BEAMS.
½" DISTRIBUTION BARS @ 9"
½" φ BARS @ 4' C.S.
2-1½" φ BARS.
½" φ MAIN BARS @ 4" C.S.
2-⅝" φ HANGING BARS
2-1½" φ BARS
½" φ BARS @ 3"
½" φ 2 LEGGED STIRRUPS @ 3" C.S.
½" φ BARS COMING STRAIGHT IN MAIN BEAM @ 3" APART BARS BENT UP IN SOLID ENDS
BEARING PLATES
2-⅝" φ BARS
6-½" φ BARS
1-1½" φ BARS
2-1½" φ BARS
CANTILEVER
SUSPENDED SPAN
DETAIL OF SOLID ENDS
4 1½" φ BARS
2-1½" φ BARS
4-1½" φ BARS
½" φ LEGGED STIRRUPS 18" APART
½ LEGGED STIRRUPS 12" APART
4-1½" φ BARS
2-1½" φ BARS 2-½" φ BARS
2-1½" DIA. BARS
2-1½" φ BARS
½" φ LEGGED STIRRUPS
½" φ 2 LEGGED STIRRUPS
CENTRE LINE OF BAY
SECTION OF CONTINUOUS BEAM AT BAY CENTRE
½" φ @ 9" C.S.
4-1½" φ BARS
CLEAR COVER 1"
½" φ MAIN BARS @ 4" C.S.
CLEAR COVER 1⅝"
2-½" φ BARS
½" φ 2 LEGGED STIRRUPS
CLEAR COVER 1¼"
6-1½" φ BARS
SECTION OF CONTINUOUS BEAM AT SUPPORT
CLEAR COVER 1"
6-1½" φ BARS
½" φ DISTRIBUTION
SLAB MAIN BARS ½" φ @ 4" C.S.
½" φ 2 LEGGED STIRRUP.
CLEAR COVER 1"
CLEAR SPACE 2¼"
CLEAR COVER 1⅝"
2-1½" φ BARS
CLEAR COVER 1¼"

PLATE X
PAPER NO. 251

KALABAGH HEAD WORKS

SHUTTERING FOR ROAD BRIDGE OVER THE BARRAGE

SCALE 3" = 1 FOOT

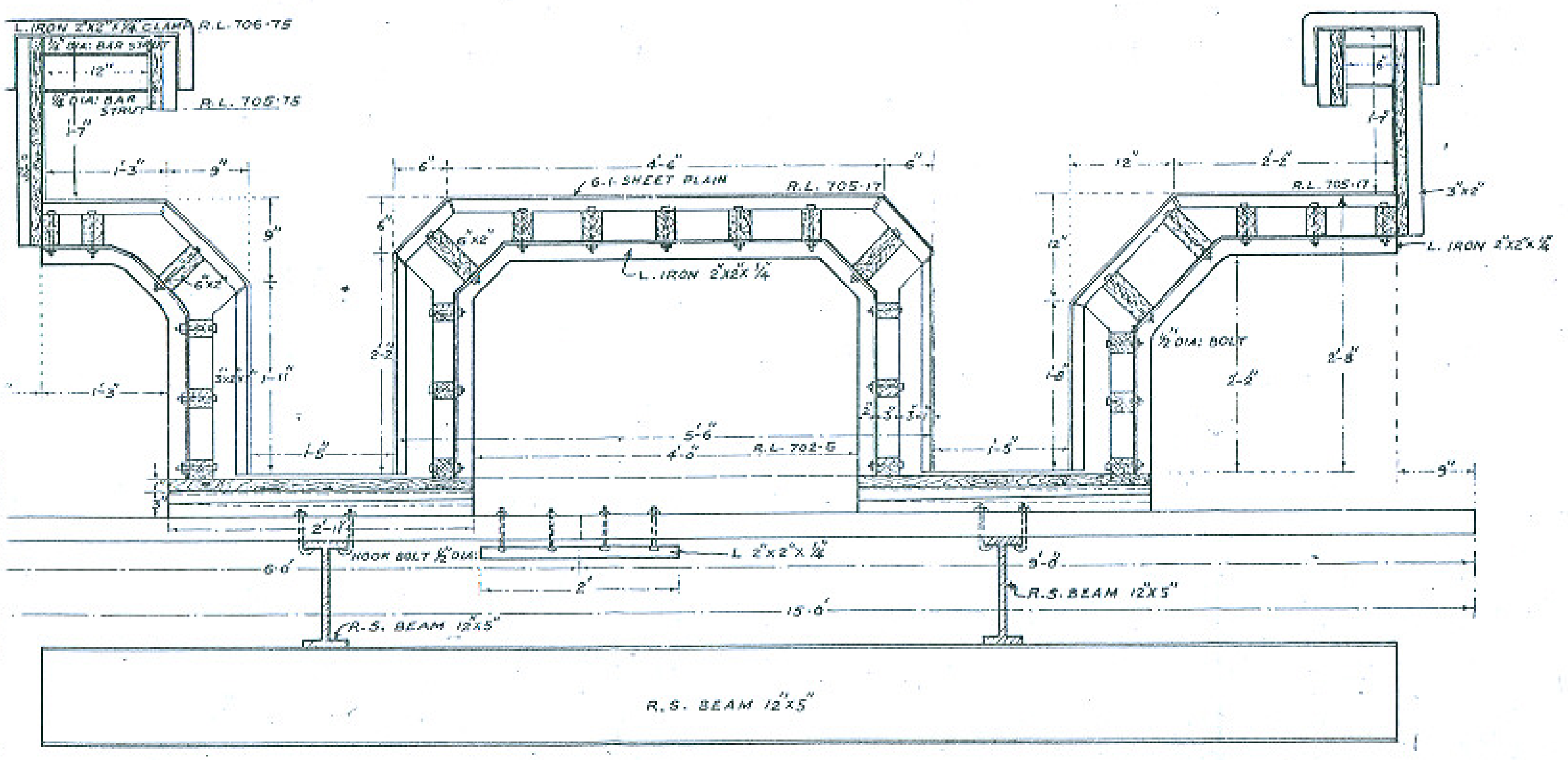


FIG. 1

PUNJAB ENGINEERING CONGRESS
1942.

SUMP PLUGGING ARRANGEMENT

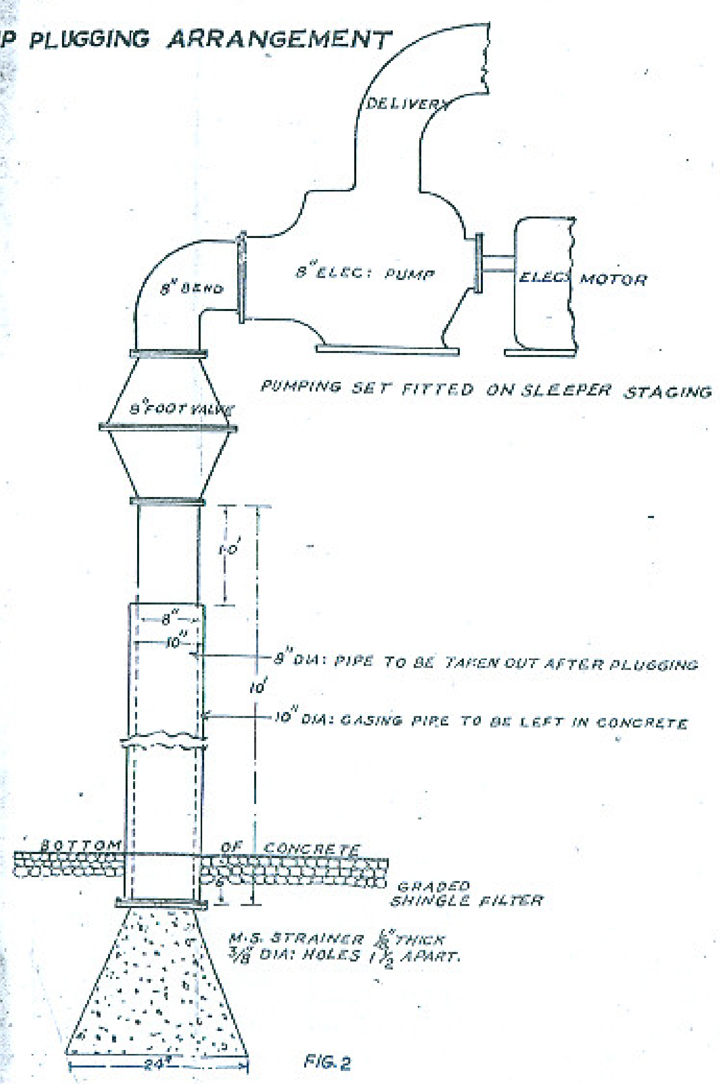


FIG. 2

KALABAGH HEAD WORK:

SHUTTERING FOR ROAD BRIDGE OVER THE

SCALE 3" = 1 FOOT

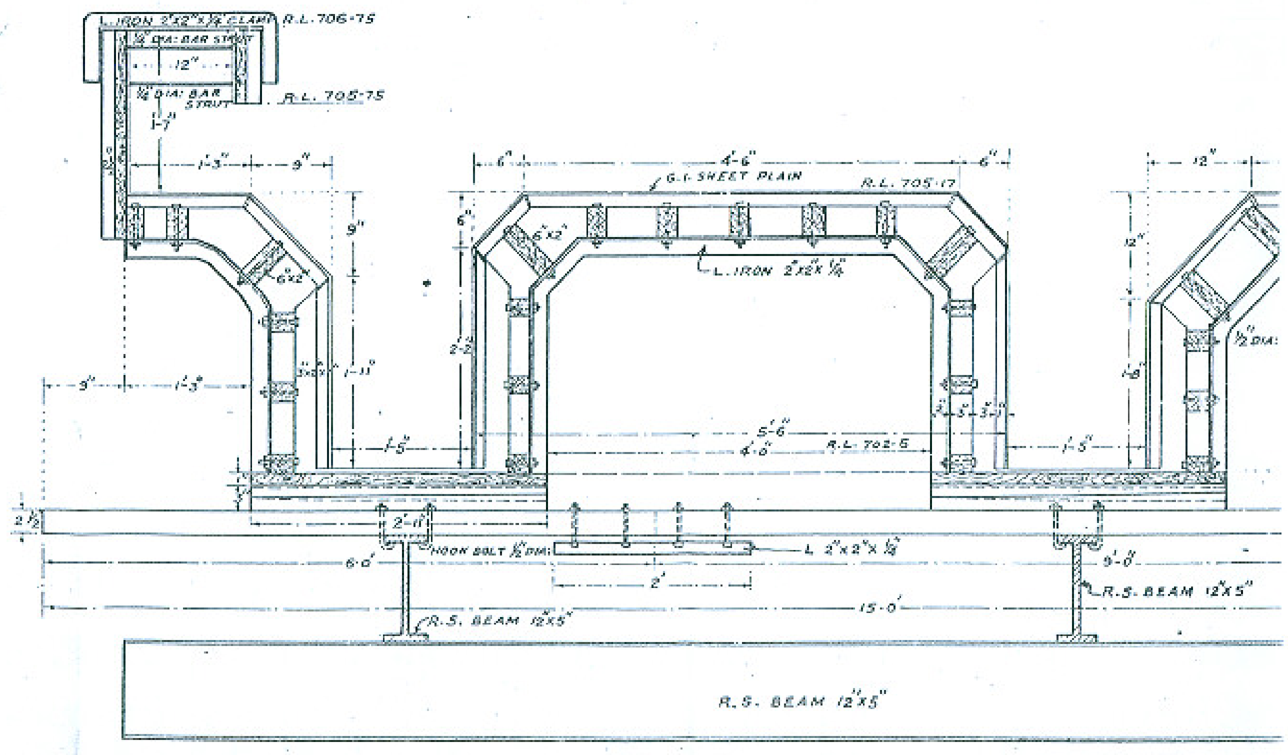


FIG. 1

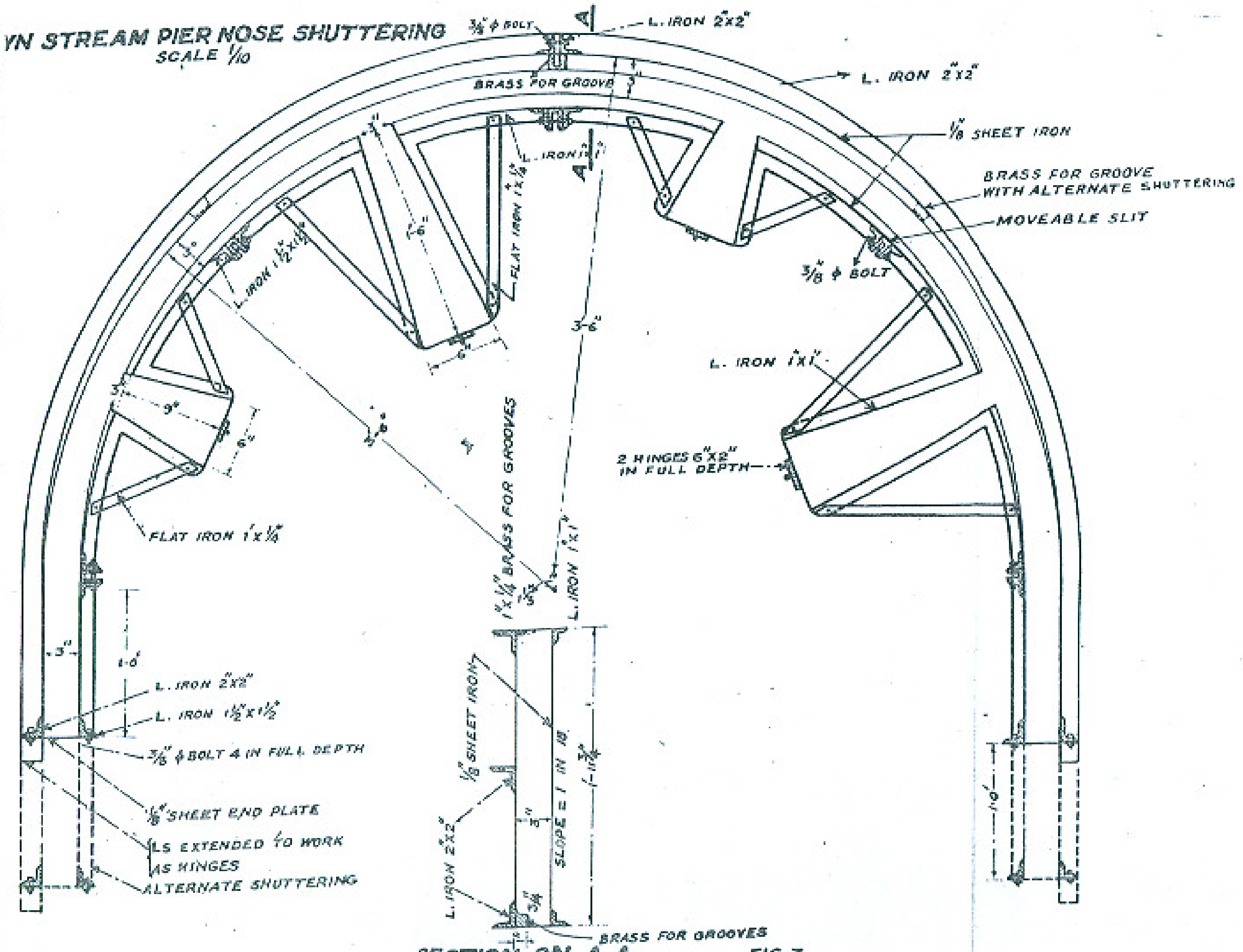

YN STREAM PIER NOSE SHUTTERING
SCALE 1/10
3/4" φ BOLT
L. IRON 2"x2"
BRASS FOR GROOVE
1/8" SHEET IRON
BRASS FOR GROOVE WITH ALTERNATE SHUTTERING
MOVEABLE SLIT
3/8" φ BOLT
L. IRON 1"x1"
2 HINGES 6"x2" IN FULL DEPTH
FLAT IRON 1"x1/4"
L. IRON 1 1/2"x1 1/2"
3'-6"
L. IRON 1 1/2"x1 1/2"
3/8" φ BOLT 4 IN FULL DEPTH
1/8" SHEET END PLATE
LS EXTENDED TO WORK AS HINGES
ALTERNATE SHUTTERING
1"x1/4" BRASS FOR GROOVES
L. IRON 1"x1"
1/8" SHEET IRON
SLOPE = 1 IN 18
L. IRON 2"x2"
BRASS FOR GROOVES
SECTION ON A.A.

FIG.3

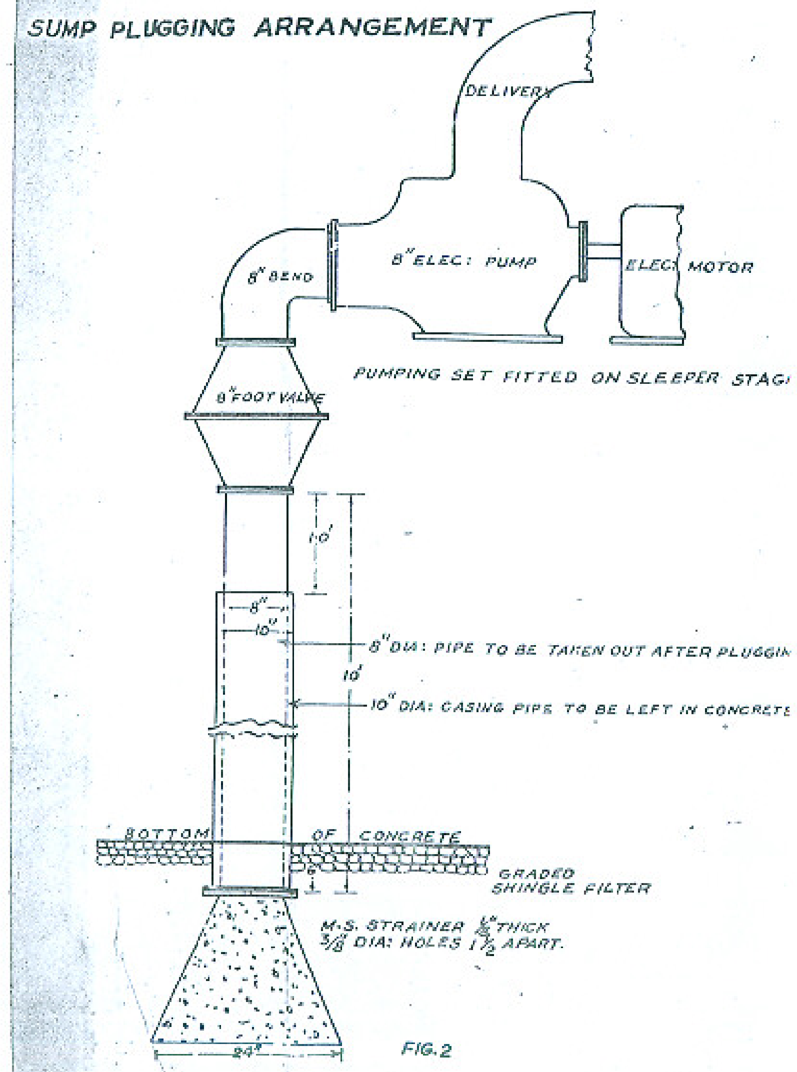

SUMP PLUGGING ARRANGEMENT
DELIVERY
8" ELEC: PUMP
ELEC: MOTOR
8" BEND
PUMPING SET FITTED ON SLEEPER STAG
8" FOOT VALVE
8" DIA: PIPE TO BE TAKEN OUT AFTER PLUGGIN
10" DIA: CASING PIPE TO BE LEFT IN CONCRETE
BOTTOM OF CONCRETE
GRADED SHINGLE FILTER
M.S. STRAINER 1/8" THICK 3/8" DIA: HOLES 1 1/2" APART.
24"

FIG.2

PROPOSED TRESTLE BRIDGE

DOWN STREA

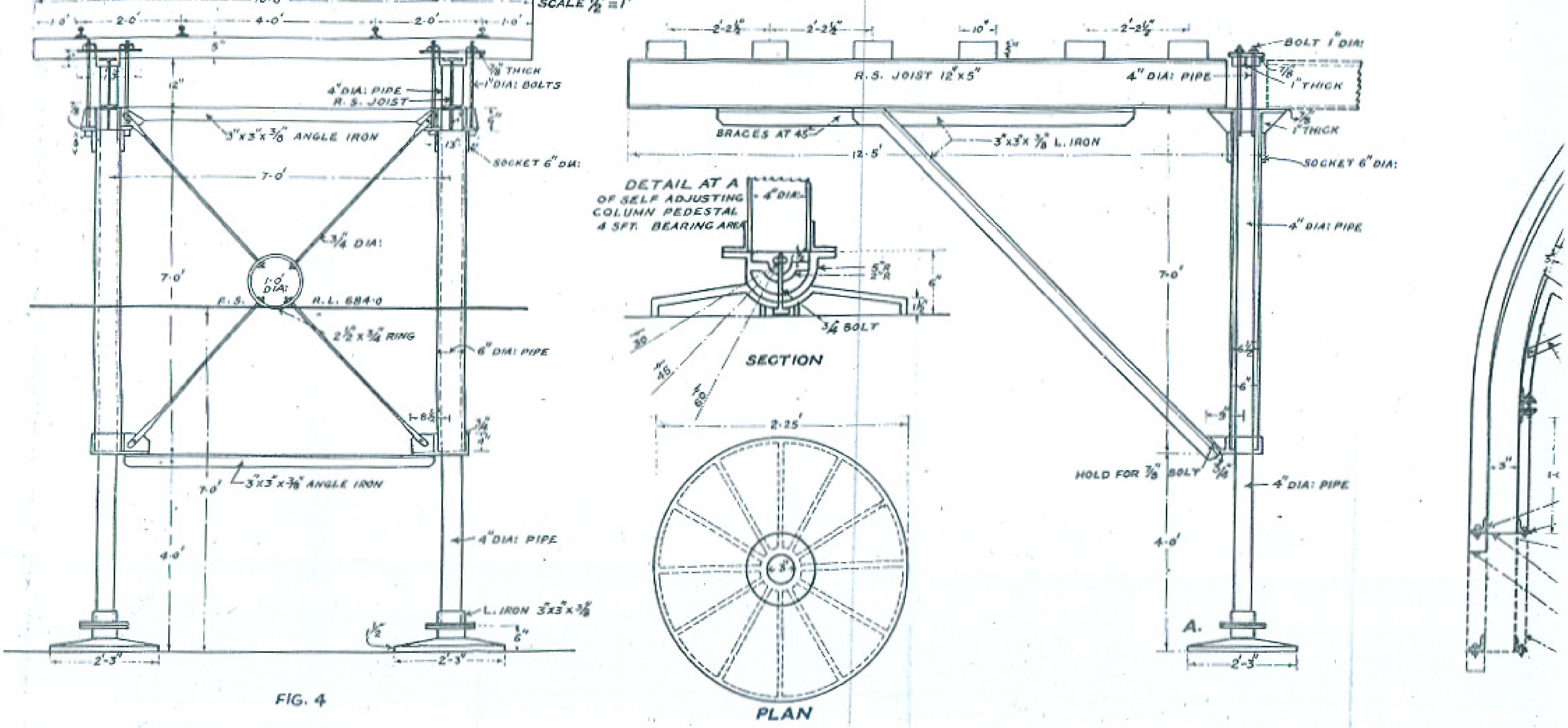


FIG. 4

DISCUSSION

Mr. S. I. Mahbub in introducing his paper said that his paper was written sometimes back and the statements made regarding the supplies available for the Thal were of course subject to the findings of the Indus Commission, the work of which was not yet completed.

The author remarked that the paper was an attempt to present in a connected form the design of a barrage in accordance with the latest principles along with the various details of execution, the difficulties encountered which were inevitable in a work of this magnitude and the measure adopted to overcome them.

Continuing further he remarked that in February last about a hundred members paid a visit to the Kalabagh barrage and the author had the privilege of taking round some of them. They thus had an opportunity of discussing the various problems at site which would enable them to fully appreciate the points dealt with in the paper. The portion relating to construction had a general application and would be of interest even to those in charge of Buildings and Roads and Railways. The speaker said that it was the first barrage in the Province which had to be founded on shingle. One of the earliest problems to be tackled was thus the sinking of wells in shingle, as the normal method of well sinking in sand was not suitable in that case. The method evolved, *viz:* allowing the excavation and sinking to go hand in hand, was both simple and economical.

The author pointed out that the difficulty in obtaining sheet piles and M. S. bars on account of the War, affected the design appreciably and heavy local pumping for putting in the deep pier foundations had to be resorted to. This led to the formation of runnels which if not tackled properly, would have endangered the safety of the work. The measures adopted to tap the runnels and the steps taken to prevent their formation, as far as possible, might be of some interest.

It was the first work of such a magnitude, where practically the whole of the concrete was vibrated mechanically, which helped in reducing the water cement ratio resulting in increased strength and reduced shrinkage. This, however, did not remove the trouble of free water coming to the surface and increasing the water cement ratio of the concrete at a place where it was least desirable. The excess water reduced the strength at the surface, which affected the durability of the structure and would even cause hair cracks, which defect could only be removed by the use of absorptive forms, which were at present being tried on some works in America. These forms removed all surplus water immediately and the surface obtained was better in quality, stronger and more resistant to wear and erosion. The main drawback, however, in this case was that these forms could not be used more than once and had to be removed within 24 hours, to avoid sticking. There was, however, a lot of scope for further investigation in that direction and the use of such forms had great possibilities, which were likely to have an important bearing on improving the quality of concrete.

The author pointed out that a value of fc = 950 was assumed in the design of the bridge. He added that assuming a factor of safety of 3, a crushing strength of 2850 lbs. per square inch was required in the concrete after 28 days. Cubes 6″ in size were taken while concreting was being done and on testing it was found that their strength varied from 2490 lbs to 4075 lbs. As the minimum strength obtained was less than 2850 lbs., the alternatives of improving the grading of sand and increasing the cement content were considered. He remarked that a 10% increase in cement meant an increase in strength of about 15%, with a slump of $1\frac{1}{2}''$, and was found to be cheaper than using coarser sand which could only be imported from Mari Indus and that it was accordingly adopted and a 1·1 : 2 : 4 mix used on the remaining portion of the bridge.

The author remarked that clay grouting, which was initiated by Mr. Haigh was another new thing tried on that barrage and that it was hoped that a more general use thereof would be made in future, in cases where cement grouting was considered to be too expensive.

The author continued that the model experiments conducted by the Research Institute played an important part in the design of divide walls and silt excluder and that the construction of the Khanki type of silt excluder which was found from experiments to be more efficacious than the Trimmu type, saved Government Rs. $3\frac{1}{2}$ lacs. The order of closing the creeks for the River diversion and the quantity of stone required had also been determined beforehand by experiments.

Continuing further the author remarked that it had since been decided to construct a lock channel adjacent to the right abutment to enable the passage of boats which ply between Kalabagh and Sukkur, mainly in connection with the carriage of salt from Kalabagh mines ; that the lock channel is 20′ wide 50′ long and has a minimum depth of 5′ ; the left wall of the lock which would be built on the existing floor would be 7′ thick, in the form of a cantilever retaining wall, with its base countersunk in the floor and that the upper lock gate would be of the lifting type so that the capacity of the lock channel could be used during floods and the lower gate also would be of the same type to avoid providing for the heavy reaction of the conventional lock type in the left wall.

In the end, the author remarked that he would like to take the opportunity of expressing his indebtedness to Mr. Haigh, from whose reports he had freely drawn and for the valuable suggestions made by him during the preparation of the paper.

The author then proceeded to exhibit a film of the Kalabagh barrage showing the various stages of construction and hoped that the members would not be too critical in noting its shortcomings. He stated that the photography was done by an amateur whose time was fully occupied in the actual construction.

MR. F. F. HAIGH remarked that Mr. Mahbub had presented in his paper a very clear and detailed account of the design and construction of the Kalabagh Headworks, on which he was to be congratulated.

He remarked that a year ago they had a similar paper on a similar work, *i.e.* Mr. Kapur's paper on the Emerson Barrage, and that he would like to draw attention to the points of difference between the two works in his remarks.

He said that the main distinction between the two works was, that whereas Trimmu was founded on pure sand, the river at Daud Khel had a shingle bed ; as regards the design, this made surprisingly little difference. He remarked that everybody knew how, up to quite recently, Engineers had the idea that the construction of a headworks on a shingle site was very much easier than on sand ; but the only advantage that the shingle gave, however, was its power of resisting erosion.

He pointed out that the chief points for consideration in the modern design of a weir were :—

(*a*) The pressures produced by subsoil flow under the work.

(*b*) The gradient at exit of the subsoil flow.

(*c*) The level and size of cistern required to take the wave, and

(*d*) The depth of scour likely in the vicinity of the work, for which flexible protection had to be provided.

He added that the only factor which was affected by the presence of sand or shingle was (*d*) which affected the flexible protection only, and consequently the profile of the pakka work should have been much the same at either site. Actually there would have been very little difference between the Trimmu and Kalabagh sections had it not been for the War. It was the difficulty in obtaining steel which made them use a gravity section instead of the Trimmu reft and the profile was actually designed with three lines of piles, as at Trimmu, originally. Two lines of piles were dispensed with when it was found that they could not get delivery of all the piling.

He observed that the only difference in the main section caused by the pressure of the shingle was that it permitted them to use a lower factor of safety on the exit gradient. The justification for that was, however, considered doubtful. Since shingle weighed almost exactly the same as sand in bulk, it would fail under approximately the same exit gradient condition, the only difference being that, with shingle, serious exit gradient conditions were not so liable to be formed by erosion downstream of the work.

The speaker proceeded to say that the effects of the presence of shingle on construction were more marked than on design. There were three points which he would like to mention :—

(1) The first was the driving of piles. They were originally very doubtful whether that would be possible and so had a special experiment made to determine the question. Actually the driving of piles gave no trouble whatever—but their experience was confined to comparatively short piles, not exceeding 14 ft. length and of the robust universal type. Whether longer and lighter piles could be driven was not definitely known, but judging from Kalabagh experience that was most probable.

(2) The second construction point was the sinking of sumps the difficulty in which they did not foresee and which caused them considerable anxiety at one stage of the work. How this was overcome had already been described at length in the paper.

(3) The third and most important point was the disturbance of the sand in the shingle during unwatering. The shingle at Kalabagh was not uniform either in grading or location. Bands of shingle were interspersed with strata of sand. The transmission constant of a sand containing shingle however, was not very different from that of a pure sand, provided the interstices of the shingle were completely full of sand, and variations of pressures from that cause were not serious.

He mentioned that during low level unwatering, despite all normal precautions, it was impossible to prevent some sand being removed from the shingle with the water. That resulted in the formation of runnels, the resistance to subsoil flow of which was negligible. The effect of such runnels on the pressure under the floor was generally liable to be dangerous.

He stated that the measures taken to prevent the formation of runnels and to close those which could not be prevented had been fully described in the paper. It was very doubtful, however, whether any preventive methods were really satisfactory short of the total removal of the shingle down to the lowest level unwatered and its replacement by sand. The seriousness of the runnel formation was not unfortunately realized until a late stage in the construction at Kalabagh, and consequently the replacement of shingle by sand was only given effect to in about 20% of the work. In the remainder they had consequently to undertake a very heavy grouting programme to endeavour to fill any runnel which might have been formed. Whether that was completely successful or not, they would be known only when the barrage was brought into operation and it was then possible to observe the actual pressures occurring under the work.

He indicated that the pressure observations they made under a low head in the right undersluices were higher than design. Mr. Khosla would not accept these observations as reliable, but, personally, he considered that if they were corrected for the variation in distortion, which occurred since the lower water levels were affected more than the upper by the subsoil inflow, they would give fairly accurate representation of the pressure conditions which they would get when the weir was opened. Such observations were made before the final grouting of the right undersluice bays.

In conclusion he said that the Punjab Government was fortunate in getting this great work done so cheaply. A saving of about 16% on an estimate framed by engineers with experience of the Trimmu barrage construction in spite of all the difficulties and disorganisation caused by the war-time conditions was one on which the officers in charge of the construction were heartily to be congratulated for.

R. B. A. N. Khosla remarked that Mr. Mahbub had presented an exceedingly well written and useful paper. The design of the barrage had been based on the principles laid down in Chapters X and XI of the C. B. I. Publication No. 12 entitled "The Design of Weirs on Sand Foundations." The details of design as well as construction were almost identical with those of the Trimmu Barrage constructed between 1937 and 1939, except that the floor at the Kalabagh Barrage had been constructed as a gravity section instead of the Reinforced-Concrete-Raft design adopted at Trimmu. Also the portion of the floor and bottom part of piers which were subject to action by pebbles and shingle passing over the Weir had been given a stone facing instead of concrete. But foundation soil at Kalabagh consisted of layers of sand and stone gravel mixtures in various proportions, whereas that at Trimmu was all pure sand.

Continuing he said that the gravity design of section at Kalabagh was selected on account of economy as ballast was available from the foundation excavation, but later experience had shown that that economy was questionable. The raft design at Trimmu was adopted primarily to minimise the difficulties and dangers inherent in deep and heavy pumping in the foundations. That difficulty had apparently been very acute in the case of Kalabagh Weir and it had been further found that partly as a result of excessive and deep pumping and partly owing to the details of layout of pumping units, very considerable quantities of sand were sucked out with the pumped water. That led to fairly extensive cavities under the floor during construction and before the Weir was opened to the river. Those cavities had subsequently to be filled up by extensive grouting. As stated on page 55 about 19,000 cement bags went in as grout, and one particular pipe in Bay No. 37 took as many as 383 bags. It was hoped that this grout had satisfactorily filled up all the voids and the cavities but it must be kept in mind that the element of uncertainty was still there, although it could not be anything big. The filling of cavities by means of pressure grouting was more or less complete in case of subsoils consisting of pure sand, but it became uncertain where the sub-soil was made up of various mixtures of sand and gravel. In the latter case, sand was sucked out from between the gravel without the soil collapsing or caving in. Thus a series of pipes were formed which, if not grouted, would individually afford free passage of water from the upstream of the Weir to the downstream end, thus endangering the stability of the work. The use of perforated pipes at the bottom of the grout holes and the proper location of grout pipes had, no doubt, helped in overcoming this danger to a large extent but there was yet a possibility that some of these "pipes" formed in the shingle beds as a result of denudation of soil by pumping, might have remained outside the influence of grouting, and, therefore, a potential source of "piping."

The speaker was invited to study and advise on the situation arising out of sand being sucked out from the subsoil due to excessive local pumping. The result of his visit had been partially discussed on pages 52, 53, 54 and 55. The Kalabagh Barrage was visited on the 11th and 12th January, 1941. The Speaker's conclusions were (1) that cavities existed more or less under the entire floor constructed to that date and should be most pronounced in the regions of local pumping and the parts of the crest adjoining: (2) that the method of open pumping employed till then would inevitably lead to the formation of cavities unless it was radically altered, so that only clean water would be pumped and no sand. The speaker made certain recommendations in respect of pumping which were accepted, and as a result of which further denudation of sand from the subsoil was almost wholly stopped. The Speaker made further recommendations to the effect that thorough and extensive grouting was essential for safety. A definite layout of grout-holes was worked out to suit the various zones of cavitation, discussed with Mr. Haigh, the Superintending Engineer, and was finally put into effect after receiving the approval of the Chief Engineer.

Another very important point that came out of this inspection and later investigations was that "the validity of the theory outlined in Chapter X of the C. B. I. Publication No. 12, for the determination of uplift pressures, stands established in case of all foundation soils provided that they are permeable and homogeneous; the word homogeneous comprising all soil mixtures including mixtures of shingle and sand with the provisos (*i*) that the mix is uniform throughout the cross section and (*ii*) that in case of gravel mixtures, the sands completely fill the voids in the gravel.

Tests were carried out on a model of the Kalabagh Weir. The pressures observed on the model with foundation soils consisting of mixtures of sand and gravel (50 : 50% and 33·3 : 66·6%) were almost identical with those obtained from theory irrespective of the proportions of sand and shingle in the mix; provided that (*i*) the mix was more or less uniform throughout the cross sections and (*ii*) the sand was not less in volume than required to fill completely the voids in the shingle.

With a mixture of 25% sand and 75% shingle piping occurred as soon as the head was applied and the pressures under the floor shot up. The sand in that case was insufficient to fill the voids in shingle so that normal escapage flow could not be maintained. The usual theory for determining the uplift pressures would obviously not apply in such a case.

In some experiments, the pressures under a model resting on shingle and sand mixtures were observed to be higher than those under a similar model resting on pure sand. The latter pressures were thus lower than the theoretical ones. This was presumably due to the deposit of a thin film of colloidal matter at the upstream end which would cause a sudden reduction of pressure at that end.

The pressure observations at the Kalabagh Weir, referred to on pages 52 and 53 of the paper, were not taken under normal conditions of flow which latter form the basis of the theory under question. As a result of heavy pumping, the surface water levels both upstream and downstream were lowered to a much greater extent than the general subsoil water level. Consequently the water levels in the pressure pipes in the middle of the weir were higher than that upstream. The seepage flow under the Weir to the downstream end was, therefore, not (except only partially) from the upstream, but from the middle of the floor where the general subsoil water level, as reflected in the pressure observations, was higher than the upstream level. The pressure readings under such conditions could not possibly be comparable with the theoretical ones, as the fundamental basis of the theory of Weir design in determining uplift pressure (that the flow through the subsoil was continuous from the upstream end to the downstream end and that there was a continuous gradient in the direction of flow), did not exist in that case.

Mr. Nand Gopal remarked that the paper was an exhaustive and complete description of Design and Construction of the latest and the last of the Weirs the Punjab Engineers had been called upon to construct. All up-to-date knowledge gained from failures of old Weirs and Experiments made in the Research Institute during recent years had been pressed into service to produce what they hoped to be an impregnable piece of workmanship.

2. The Speaker had to do something with Thal Project of 1918. Speaking from memory the maximum discharge then allowed for design by late Mr. Middleton was 13 lacs cusecs based on a flood of 1901 or thereabout. The present design was stated to be based on the flood of 1929 and assumed an extra maximum flood discharge of 11 lacs cusecs. It might be interesting to know if the calculations of 1918 for the 1901 flood had been found to be wrong or discarded for some other reasons.

3. In describing the construction of the Weir under *Pumping* (page 38) it was stated that 4 main sumps were made on either flank

in the undersluices area and six in the Weir area. On the Plan (Plate No. II) eight were shown in the Weir area, making a total of 16 main sumps. The discharge from each main sump was said to vary from 5 to 8 cusecs. A total maximum of 30 to 50 cusecs was said to have been attained. This indicated that only about 6 main sumps were in operation at one time. Was that so? It would be helpful if the area served by each main sump and its corresponding discharge were given, so that one could design future pumping installations with knowledge.

Dr. J. K. Malhotra remarked that the author had stated at the bottom of page 1 that the Main Line was so designed as to permit its being enlarged to 10,000 cusecs in the event of additional water being required in the *Kharif* and becoming available. He asked about the actual, as distinct from the ultimate, capacity, and suggested that some details, if possible, about the design might be given by the author.

2. On page 3 it was stated that at the site of the headworks it was expected that while the foundation of the work would be on shingle, most of the excavation would be in sand. Were any sections taken at this and other sites in 1936 or since which prove this? If so, details may please be given.

3. On page 4 the bursting of a glacier dam was stated to be a not infrequent phenomenon on the Indus. The speaker asked the author kindly to say how often the glacier dam had burst in the years from 1929 to 1941?

4. On page 5 the retrogression for high flood conditions was taken as 1′. This gave a D/S level of 673·0. Would the author kindly say if there would be, in addition, any scouring D/S of the barrage to the R. L. 670, the level of the shingle bed (page 18) and whether any provision had been made for it? Had it been considered that the overlying sand would scour very easily in high floods?

5. On page 7, the value of f was assumed as 4 for shingle. This gave a mean diameter, from the Lacey relation $d = F^2/64$, of about a quarter of an inch. On page 19 the bed silt of the left pocket was stated to have a mean diameter of about 2″, with an 'f' of 13. The speaker asked the author to kindly explain the reasons for the difference.

The speaker believed that R. B. Khosla had dropped the silt factor from his R—$q\ f$ formula, in light of further observations at Rupar and elsewhere. If R was taken as $\cdot 9q^{2/3}$, this would give a value of 36′ against 22′ taken by the author.

6. On page 10, the author dealt with cut-offs. Before piling was approved for Kalabagh, there was some doubt whether it would be possible to drive the piles through shingle, and Mr. Haigh thought that at the D/S end a sloping toe-wall may be put in as a cut-off. The theoretical solution for uplift pressures and exit gradient for a floor

fitted with a sloping toe-wall were worked out in the Institute for Mr. Haigh, but this form was dropped as it was found that the piling would go through the shingle.

In regard to the cut-off at the toe of the glacis, it was not always of very appreciable value in reducing the pressures under the cistern floor, except in its immediate vicinity. It could be shown that with the depth given at Kalabagh generally it would reduce the pressures by about 2—4% of total head in this region. Its utility as a second line of defence was really its main recommendation.

7. On page 11, the author had taken the pore space in unit volume at the usual value for the Punjab sands, *viz.*, 0·4 He asked the author to kindly state if this value was verified in case of Kalabagh foundation material?

The main consideration in fixing the depth of the D/S cut-off was the probable depth of scour. If this value gave a safety factor less than that given by Khosla for that type of material, then alone was it necessary to increase the depth.

8. On page 12 the author gave the usual formula for exit-gradient. This had been simplified to the following approximate form in the Research Institute. This gave results agreeing to within 1% of the actual provided b was more than 4-5 times d, which would be the case in practice.

$$G = \frac{H}{\sqrt{5d\,(b+d)}}.$$

Taking H=22, b=140, d=8, the approximation gives,

$$G = \frac{22}{\sqrt{40.148}} = \frac{22}{77} = .285,$$

which agreed very closely with the author's .289.

The safety factor could be easily derived by taking

$$S.\ F. = \frac{\sqrt{5d\,(b+d)},}{H}$$

taking the critical gradient as unity.

For the undersluice section where b was 150, the approximation gave G as 22/79·5=·275, the same as the author's value.

At the surface, the approximation would give the value of G as $22/\sqrt{70.154} = .212$ and $22/\sqrt{70.164} = .206$, giving the same safety factors as the author.

The Suleimanke Weir was probably founded on clay. It was still open to question if in such a case the safety factor conveyed the same idea as for weirs founded on coarser material.

10. On page 13 the theoretical pressures were given. These were derived on the usual premises of a homogeneous foundation material of small size. The speaker requested the author to kindly give the details of the model experiments, which were carried out by the Institute with a sand-shingle foundation with particular reference to Kalabagh Barrage. These probably showed higher values of ϕ than the theoretical. The author might kindly say how these compared with the observations mentioned on pages 52-53.

Mr. C. L. Handa congratulated the Author on having produced such an exhaustive Paper on the construction of the Kalabagh Headworks. He thanked the author for having sent him an advance copy of the Paper. In acknowledging this, the speaker had written to Mr. Mahbub that the Paper was so exhaustive that there was very little room to add to it.

In connection with the work at Kalabagh Headworks, the speaker had had the useful opportunity of holding the charge of the Power Division, which charge comprised looking after the pumping, the power-house and the workshop. During this period (September, 1940 to July, 1941), the major part of the Weir and part of the right undersluices and the whole of the left undersluice were constructed, and there are certain important observations to which the speaker would invite the attention of the House.

The foremost of these was regarding the pumping plan. Since 1933, the speaker has had the opportunity of working as Sub-Divisional Officer at five constructions in the Irrigation Branch where large scale pumping was necessary. At all these places, there was nothing to guide the Engineer beforehand, as to how much inflow would have to be faced. Thus the preparation suffered from lack of definite estimation, and the pumping had to be a hand-to-mouth business with always more pumps needed. The speaker then referred to the work done at Marala Headworks Reconstruction in 1936-37, where the inflow was estimated as 1 cusec per acre of area enclosed, the average lift being 12′ to 16′. At Kalabagh Headworks, the speaker had made a similar estimate and it could be stated that the inflow was 1·5 cusecs per acre of area enclosed, the lift involved being 20′ to 25′. As pumping is a vital matter for the success of construction below spring level, the Engineer has everything to gain if he plans his pumping capacity on the basis of known inflow discharge. At Kalabagh Headworks, the discharge pumped out rose to a maximum of 60 cusecs at one stage.

Next to the question of inflow was the capacity of Plant, available to deal with the work. First of all the size of the Power House should have at least a safety factor of at least two. At Kalabagh the average load used to be 500 Killowats and the capacity 900 Killowats and experience showed, that the Power House was undersized. In fact, the Civil Engineer should so restrict the area of his work, that the available power and plant can efficiently serve the operations, otherwise work suffers and mutual recrimination can take place due to the Civil and Mechanical teams both finding themselves unable to cope with the natural forces, and the result would be bad concreting. The speaker next told the House, that the total Pumping capacity installed at the Kalabagh Headworks was 1,600 H. P. of this only 40% was the net effective pumping, 20% was internal or local pumping with 20% Stand-byes and 20% reserved Plant for shut down repairs or servicing. These figures were very enlightening indeed and unless one arranged on this scale, efficient service was not possible.

The speaker then referred to the design of main Sumps. In this connection, his suggestions for having a liberal number of sumps so placed as to be mutually connected were accepted. This enabled the work in the left half of the Barrage to be carried out with much greater facility and speed. It was important to locate the sumps reasonably clear of the flexible aprons and the most important precaution was that the drains leading to the sumps should be continuously excavated by labour working day and night, so that they ran at minimum slopes. This precaution saved the botheration and expense of heavy drudging and interruptions and dislocations were also avoided. The upstream sump in the right undersluice was located too close to the work and there was no proper outfall. The water had to be spread out on the Sand mounds and subsequent infiltration brought it back, thus establishing a vicious circle. In the left undersluice the upstream outfall discharged clear by the bund into the river as was done at Khanki Headworks Reconstruction in 1934. The speaker concluded by inviting the attention of the House to the operation of plugging the internal sumps located within the foundations of the Piers. The method adopted had been explained by the Author in detail, and was the result of a simple device, which the speaker invented for meeting the deadlock. Previously open pumping had been resorted to with a battery of 6 to 8 pumps, of which the Suctions were withdrawn simultaneously with the rise of water level and concreting. Apart from the inconvenience and cost of arranging and running so many small pumps, the process used to fail and the final plug and concrete were rendered less efficient. With the modified "Tube Well Pumping" arrangement devised by the speaker, the difficulty was solved. The idea was new only in so far as its application to the shingle strata was concerned, otherwise the method had been previously used on the Deg Fall and at Marala Headworks. It was the conviction of the speaker, that the better speed with which the work was executed in the Winter of 1940, was largely a result of this improvement.

Mr. Mahbub had produced a very exhaustive Paper embodying all the details of construction of a large project.

R. B. KANWAR SAIN remarked that Mr. Mahbub deserved the thanks of the Punjab Engineering Congress for bringing an exhaustive paper on the Kalabagh Barrage for the general information of the members. The paper was full of interesting information.

The speaker had been connected with the Project at various stages and was mainly responsible for the 1936 Project, which formed the basis of the present work. Mr. Mahbub had done full justice to the various aspects of the problems connected with the work.

He had only to offer his comments on two points :—

(1) In his opinion the site was eminently suited for a raft design even if it had cost slightly more on this account. After however the war was declared not only did the prices of steel go up, but it became exceedingly difficult to obtain steel.

(2) The second point was that of silt excluders. A couple of years ago he had stated on that very platform that model experiments regarding silt problems were not entirely above suspicion. He had then stated that they had full scale models at Trimmu of both the types of silt excluders and that careful observations at this site should bring out the relative worth of the two types. He remarked that he would be interested to know from the author or from the officers incharge of the work if any systematic observation had since been made at Trimmu and if so the conclusions that might have been arrived at.

L. ISHAR DAS remarked that on page 7 the author employed Lacey's formula $R = .9\left(\frac{q^2}{f}\right)^{1/3}$ which was derived from $V = \sqrt{4/_3 \, f R}$ or taking this fundamental scour formula from page 26 of Publication No. 20 of the Central Board of Irrigation or $R = .47 \left(\frac{Q}{f}\right)^{1/3}$.

The speaker's submission was that this formula was wrong fundamentally and was liable to give incorrect results.

For action of scour we all knew that nature of soil did play part but Lacey's formula did not take notice of it. To have the scour formula for finding out scour in gravel as in fine soil looked wrong to the speaker.

The speaker proved his statement by giving another set of fundamental formulæ *viz.*,

$$V = C_1 R^{1/2}$$

$$P = C_2 Q^{1/2}$$

$$R = C_3 Q^{1/3}$$

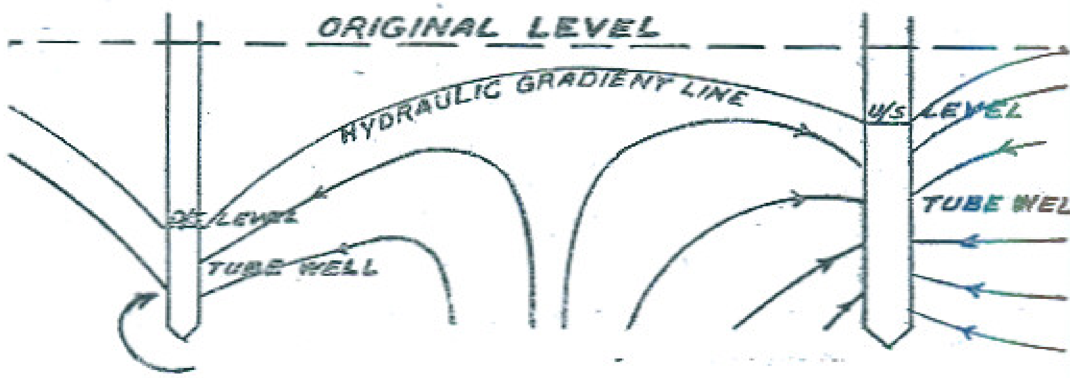
Rewriting $C_1 = \frac{V}{R^{1/2}}$

$$C_2 = \frac{P}{Q^{1/2}}$$

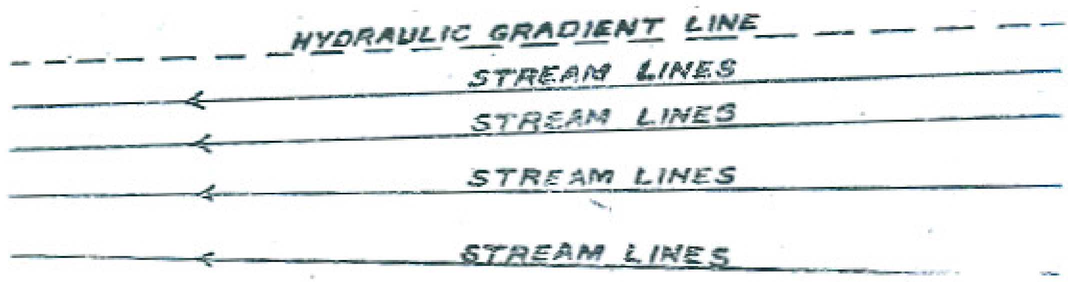
$$C_3 = \frac{R}{Q^{1/3}}$$

From these $C_1 \ C_2 = \frac{Q^{1/2}}{R^{3/2}}$

Dr. N. K. Bose remarked that the only point on which he could speak with some confidence was given on page 52 "Pressure Observations". In this case the author had given the method of finding out the actual hydraulic gradient line when the flow was not the same as in the cases dealt with by the speaker in the Central Board Publication No. 12 "Design of Weirs on sand foundations". In the case under review the two levels upstream and downstream were maintained on certain R. Ls., artificially by putting in a battery of pumps on the upstream and downstream side. In consequence of this, the hydraulic gradient line when there was no weir present would be given by the attached figure.



In the case dealt with in the Central Board Publication No. 12 the streamlines when the weir was not put in were given by the attached figure.



It will be seen how the two cases differ. In one case the streamlines concentrate to the two lines of pumps and in other case they are parallel, flowing from right to left. It was apparent that the effect of putting an obstacle such as a weir structure would be different on these two different configurations of streamlines. It would be possible by assuming that the pressure distribution due to the original field of flow and to the imposed boundary conditions could be added up linearly and the final pressures obtained. How far that would be correct was still to be seen but he could not understand how the Author said on page 53. 1st line that the ratio of (b) minus (a) to (c) minus (a) at any point gave the value of ϕ at that point.

Dr. H. L. Uppal remarked that the model investigations carried out in connection with the Kalabagh Barrage had been mentioned by the author in the paper as well as in the introduction. It had also been stated by Mr. Mahbub that the model experiments effected a saving of three and a half lacs. There was nothing else for him to add to the discussion. However, he wished to reply to the remarks just made by R. B. L. Kanwar Sain regarding the value of the results obtained on the model. Rai Bahadur L. Kanwar Sain had stated that the results from the model experiments for silt investigation should be accepted with caution. Exactly similar remarks were made by him a few years ago on Dr. Bose's experiments which were carried out on a model of Trimmu Headworks. Since the experiments made by Dr. Bose, the technique of experimentation adopted on the river model had been considerably improved and it was now possible to forecast accurately in many cases the river behaviour. The remarks made by L. Kanwar Sain were therefore not justified. Probably he had not been in touch with the model work during the last few years. Some of the improvements introduced were :—

1. The models were made to a very large scale. In some cases the models examined were the largest ever studied in any part of the world.
2. The exaggeration of the vertical scale had been kept low.

3. The approach and exits of models were made very long.
4. In case of river models for silt investigations the addition of silt was done by an automatic arrangement.

By introducing these improvements very reliable results had been obtained. For determining a suitable design of silt excluders for the Kalabagh Barrage two separate tests were made on the modified Khanki type and Trimmu Type silt excluders. In one test the whole of the weir was used and the silt entering the canal with the two types of the excluders was determined using a discharge of about 1,00,000 cusecs. In the second test a part of the weir was used and the tests were carried with a concentrated discharge. The tests were made in the presence of Mr. F.F. Haigh, C.E., Mr. Kapur, Director, Central Designs and Mr. Mahbub, Executive Engineer, Kalabagh. The results obtained on both the cases were :

The modified Khanki type drew 41% of the silt of that which passed into the canal when the Trimmu type was fitted.

Thus it was clear that even for different conditions of flow, the results obtained were similar. This definitely proved the reliability of the model.

Mr. H. C. Kalra remarked that in his paper on Kalabagh Headworks Mr. Mahbub had so thoroughly summarised all details of importance relating to the Barrage that the paper could be considered an Encyclopædia of information. For that the writer deserved to be congratulated.

Having been personally connected as Sub-Divisional Officer in charge of the construction of Right and left undersluices at Kalabagh Headworks, he mentioned for the information of the House, some details regarding the runnels that formed in the shingle strata, while they had to depress the water to levels much below the sub-soil, for the purpose of putting in deep concrete foundations. These runnels were open passages in shingle strata from which sand had been washed out. He attempted to show them with a sketch on board. He demonstrated that these open spaces would be very dangerous if they remained under the finished work as they would set up very high pressures. Hence cement grouting was resorted to on a comprehensive scale and even where the floor had been concreted, holes were bored and grout forced through runnels through perforated pipes. The advantage of using perforated pipes over plain ones was that the grout could be delivered all along the depth so as to chalk up the places where there were cavities. The importance of such work would be realized from the fact that in some pipes as much as over 300 bags or about a wagon load of cement was consumed.

The second point, the speaker wished to mention, was regarding plugging of subsidiary sumps located within the impervious floor. That part of the work was specially important as any flaw in the concrete would have left a weak spot. The usual method of plugging was to resort to open pumping with a number of small pumps and to withdraw the suctions simultaneously with the concreting. In the right undersluices, when they were plugging the last sump, it was found that the inflow was as much as about 6 cusecs and in addition to this, the static water level as registered in some of the pressure pipes was about two feet higher than the floor. The usual method was therefore not applicable here. This would have meant a deadlock in the work and a solution was therefore devised by the then Executive Engineer, Mr. C. L. Handa incharge of Power Division. With that device which had been described in detail by the writer, the difficulty was completely solved and plugging of subsequent sumps was greatly expedited.

Mr. H. L. Sally divided his remark under various subheads.

Lay-out (*Page* 36).

A special feature of the lay-out pillars was that base plates for theodolite—specially cast for this purpose—were embedded at their tops in cement concrete. The same base plate, with a pivot at the centre point, served to hold the sighting plate. Even though the plate was moved by wind or by a coolie, its vertical centre line remained unaffected, as the whole plate would only rotate round the pivot, without throwing out the Central vertical axis. This sort of arrangement gave complete immunity from personal errors that creep in if a theodolite had got to be set up with a plumb bob every time that one wanted to use it. The maximum error ever seen in the crest was $^{1}/_{2}''$ against an error of about a foot on a similar work at Trimmu.

Excavation (*Page* 36).

The author mentioned that actual slopes in sand due to sloughing were 5 to 1, where sloughing actually started, this slope was oftentimes seen by him as 12 to 1. But such places were few. Generally speaking, the side slopes of weir excavation continued to stand at $1\frac{1}{2}$ to 1. As soon as spring levels dropped below shingle levels, all sloughing in the sand above shingle stopped because the sand became quite dry. Below the shingle level the side slopes were hardly 1 to 1.

Pumping (*Page* 38).

Main Sumps for Divide walls were not sumps. They were wells designed to function as well foundations under the U/S and D/S noses of the Divide walls. They were incidentally used as sumps also for a few days only to help in laying the low level concrete. They were soon plugged solid with concrete to form the foundations that they were designed to be.

During the course of discussion, some stress had been laid on the efficiency of pumping during the construction of the left half of the barrage. The facts of the case were that the pumping during the winter was very much easier than in the preceding flood season.

Different conditions under which work was done at different times were briefly stated below :

1. During construction of right half, the river was flowing at R. L. 692 only about 1500 feet away from the right pocket when the left pocket was under construction the winter river was at about R. L. 680 and at a distance of two miles. This was bound to make a vast difference in seepage flow.
2. When the right pocket was concreted, the left half of the weir area was lying unexcavated with a spring level of 684. Lot of water was coming from the weir to the pocket. On the other hand there was absolutely no flow from weir to the left pocket, as the excavation had already been completed in the weir. This made material difference in the discharge to be tackled.

Briefly, the right pocket was worked against a head of 692—659 =33 feet whereas in the left pocket, the seepage head was only 674—659=15 feet. The tremendous difference is obvious and is evidenced by the actual discharges dealt with by pumping as mentioned by the author on page 39.

Concreting. (*Page* 40).

Cubic yard concrete mixers were fitted on concrete and not masonary foundations. Only the retaining walls behind these were made of brick masonry. The foundation block was of 3 feet thick cement concrete.

Plugging of Sump (*Page* 45).

Generally speaking the arrangement worked better than the previous method. But it had its own drawbacks which came to the speaker's notice when he used this arrangement on about 30 sumps. They were :—

1. An 8″ pump fitted on 7′×7′ well, with about 7·5 feet depth of concrete already laid round it, undermined the concrete, inspite of the so called graded filters. These filters only improved conditions and did not stop flow of sand absolutely. Hence the pump should be run for the minimum period, say half-an-hour before plugging was to start.
2. Working under these conditions, the pump had not got a steady discharge. Only a very expert driver could keep the pump working continuously. One minute's failure would fill up the well to a depth of about four feet during concreting and spoil the whole show by washing out cement. This was inevitable in the absence of a stand-by pump.

3. The discharge of the pump had to be adjusted so that it just equalled the seepage water available. If it created a vacuum under the concrete by over-drawing, fluid cement in the body of the fresh concrete, was sucked in the foot valve as the colour of water would immediately show. In some cases, the effect was so great, that the actual subsidence of concrete took place.

When higher officers were present on the weir, the mechanical staff would take extra precautions to ensure smooth working of the pump. This efficiency could not possibly be maintained during routine working from day to day.

Briefly, this arrangement was a very delicate affair and should be used with extreme caution. A little inattention created untold difficulties.

Concreting toe walls (*Page* 45).

The bottom 2 feet of all toe walls was not done by using wooden shutterings. The three toe walls of the weir with a total length of $3 \times 2807 = 8421$ feet—except for a length of 400 feet only—was all laid with 0·8′ thick brick work shuttering for lower 4 feet height. The upper 4 feet were 0·4 feet thick shuttering of brick-work in cement.

Difficulties mentioned in item (*ix*) on page 46 arose only when the side drains mentioned in item (*i*) were not properly attended to. No such difficulty ever arose on the weir. The device was resorted to in the case of left pocket only for want of proper drains.

Erection of Steel Work. (*Page* 51).

Cill girder was proposed to be saved from the action of rolling shingle by fixing stone setts upstream of the girder ¼″ proud of the girder. The speaker was of the opinion that this was not a sufficient precaution. A bull-headed rail fixed just above the Cill girder ½″ proud of it, would have served much better.

A great difficulty was always felt in regulation when rolling shingle got into sluicing pockets and gates did not sit properly on the Cill girder. To safeguard against this, the pier faces, for a height of 2 feet above crest, were splayed towards the centre of the span by 3″ in a length of 4 feet upstream of the Cill girder. This splay would change the direction of rolling shingle and would not let it go into the pockets. The author appeared to have overlooked to have mentioned this point in his paper.

The author had talked about pressure observations on page 52. The paper was not complete without a plan showing the disposition and location of pressure pipes. Their fixing was a delicate affair and some difficulties entailed should have come in.

In the end the speaker said that the paper should have opened with a river survey plan which should have shown the site of the Barrage in relation to the river and the Kalabagh Bridge.

Correspondence

Mr. N. N. Bhandari in correspondence stated that the author should be congratulated for presenting to the congress, such a comprehensive and detailed paper, which was bound to prove an asset to all those engaged on future construction works of the kind dealt with therein. Some of the vital points in the design of Kalabagh Weir, however, needed further elucidation.

1. The first point was about the assumption of the coefficient of discharge for the weir. The assumed value of 3·0 seemed to him to be a bit too low, for a head of about twenty feet. Taking into consideration the upstream and the downstream slopes, the width of the crest and the head, a coefficient of 3·3 (if not 3·5) for the discharge over the weir, would probably have been more appropriate*.

2. The second point was on page 9 of the paper, where it was stated '. . . . that the turbulence subsides in a length equal to five times the height of the waves. . . .' Now, flow in all irrigation channels was always turbulent, with Reynolds Numbers much above 2,000. Such a flow would never be streamline. Therefore, the subsidence of turbulence in a certain length was not clear. Probably the author meant to refer the decay of the turbulent eddies that were seen in the standing wave, but even these eddies continued to exist, much beyond the length equal to five times the height of the standing wave. In fact, that was one of the problems in Hydraulics, which needed extensive scientific investigation, in the light of modern developments in Fluid Mechanics.

The Author in reply to the discussion stated that it was really gratifying to note the interest that had been displayed in his paper by so many speakers participating in the discussion.

The author pointed out that Mr. Haigh had elucidated the points of difference, both in design and construction, between the Kalabagh Headworks and the Emerson Barrage and stressed some of the difficulties encountered during construction. The most serious of these was runnel formation and cement grouting was done at all levels where runnel formation was possible, though how far they had actually succeeded in closing the interstices in the shingle would only be known when pressures under the work were observed, after the barrage had come into action.

Continuing further the author remarked that Mr. Khosla had thrown light on the question of runnel formation and the application of the theory of design of weirs on sand foundations to foundations consisting of a mixture of sand and shingle and pointed out that the question of pressure observations was dealt with fully in his reply to Dr. Bose.

*Proceedings of the second (postponed) meeting of the International Association for Hydraulic Structure Research. Liege, 1939. pp 107-131, 'Weir Coefficients' by N.N. Bhandari.

Replying to Mr. Nand Gopal's query whether Mr. Middleton's calculations for the maximum flood discharge of Indus had been seen by the designers, the author said that all relevant records were naturally consulted in the Central Designs office and Mr. Middleton's calculations were discarded as they were not considered sufficiently accurate.

Regarding the sumps, the author pointed out that some of the sumps shown on the plan were twin-sumps and that the whole of the weir area was not opened up at the same time, as the pumping in the weir was originally restricted to R. D. 1150, as mentioned on p. 39, and they did not generally have more than 8 main sumps working at a time.

The author further pointed out that the figures for inflow had been given by Mr. Handa in his remarks.

In regard to the additional information asked for by Mr. Malhotra, the author said that the present capacity of the canal as clearly stated in the paper was 6000 cusecs. Some probings were made to determine the depth at which shingle existed under the natural soil.

As regards the bursting of glaciers the author observed that each glacier was supposed to have a certain frequency after which it could be expected to burst and that in the case of the Shyok glacier, the period was estimated to be 35 years and therefore it could be expected to burst next in 1964.

The author demonstrated that the scour downstream had been provided for, as the exit gradient had been calculated at the underside of the filter (R. L. 666 in the case of the weir) for safety. The value of 'f' had been taken as 13 for the shingle with a mean diameter of 2″, which might be left after the sand had been washed out while scouring the pocket. The value of $f=4$, corresponding to $d=\frac{1}{4}''$, had, however, been taken as the mean diameter for sand and shingle for calculating the depth of scour.

Regarding the pore space, he said that it was generally assumed as 0·4. Taking the absolute density of soil particles as 2·65, that would correspond to a dry bulk density of 1·59 in the natural soil. The dry bulk density of the soil at Kalabagh was, on an average, 1·45 in the case of pure sand, which corresponded to a pore space of 0·415. That would not, however, make any material difference in view of the factor of safety assumed.

The author admitted that Mr. Malhotra's approximation of the exit gradient formula was quite useful. The model experiments done in the Research Institute with varying proportions of shingle and sand had been dealt with by Mr. Khosla in his remarks. Mr. Handa had given some useful details regarding inflow and the capacity of the pumping plant required.

The author remarked that the method adopted in plugging a sump was no doubt an improvement on the original method as it resulted in a better quality of concrete in the sump area. That, however, in no way affected the speed of the work. The accelerated speed with which the work was executed in the winter of 1940 was mainly dependent on organization, labour arrangements, location of sumps and outfalls and the efficiency of pumping. The first three factors did not come within the scope of the Power Division.

As pointed out by Mr. Kanwar Sain, the author admitted that a raft section would have been preferable for this Barrage, as that would have reduced the pumping and also the formation of runnels. Difficulty in obtaining steel on account of war, was, however, mainly responsible for the adoption of a gravity section. Mr. Kanwar Sain's remarks about model experiments regarding silt excluder had been dealt with at length by Dr. Uppal. As far as the speaker was aware, no systematic observations had been done so far at Trimmu to compare the relative efficiencies of the Trimmu and Khanki type of silt excluders. In the case of Trimmu type, various methods of regulation were being tried to find out which would be the most efficient, so far as silt exclusion was concerned and as regards the Khanki type, the present attempt was to increase the quantity of silt entering the Rangpur Canal.

Regarding Mr. Ishar Dass' remarks, the author stated that before his or any other theory could be accepted, it would have to be proved to the satisfaction of other members of the profession that that was an improvement on Lacey's.

The author remarked that Dr. Bose had failed to understand the method adopted for calculating the fall of pressures under the weir while pumping was in progress. In this case owing to seepage inflow the subsoil water surface in the vicinity of a sump sloped towards the sump. The observations of the water table away from the sump would not give the sump level, but a higher one—the difference representing the seepage flow potential. The problem was to find what the levels would be were there no seepage inflow. In this case were the water levels maintained upstream and downstream at the same level the subsoil level below would be a horizontal plane. If this level was varied they would get a series of horizontal planes representing static pressure contours. And if the water level was maintained at a high level upstream and a low one downstream the subsoil water level would vary in between following some such curves as that shown in diagram I. The difference of level between any two points on the curve represented flow potential due to the difference of level upstream and downstream. With seepage inflow the planes corresponding with equal water levels upstream and downstream were distorted and became surface convex upwards. The static pressure at any point on these curves was that of the free water level and the difference in level represented the flow potential due to the seepage inflow. The actual form of these surfaces could be determined by observation resulting in curves of the form of Fig. II. With a water level upstream higher than downstream the hydraulic gradient could similarly be found by observations on a line which cuts the equal pressure contours at various points. Levels on this line might be resolved into three components :—

(*a*) Static pressure.
(*b*) Seepage flow potential due to seepage inflow.
(*c*) Seepage flow potential due to the difference of level upstream and downstream.

Relative to the contours of Fig. II, they represented (*c*) only, *i.e.* they were identical with the levels of Fig. I relative to the static contours.

The author remarked that actually at Kalabagh only the upper and lower contours were found by observations, intermediate contours being estimated on the assumption that intervals between contours would be proportional to the distortion of the contours at the upper and lower levels and would vary arithmetically in between. Some error might result from this assumption but it was not likely to be great.

FIG I

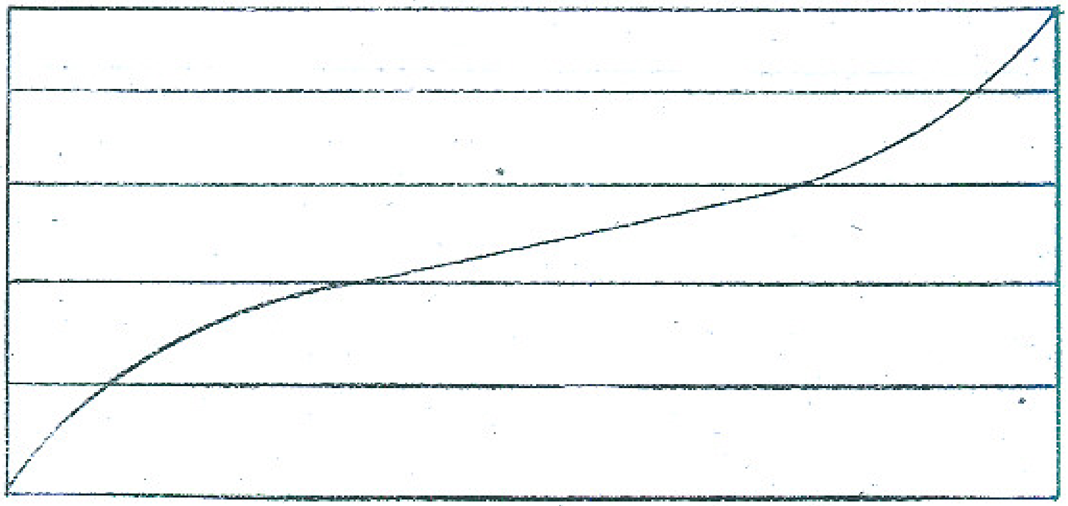
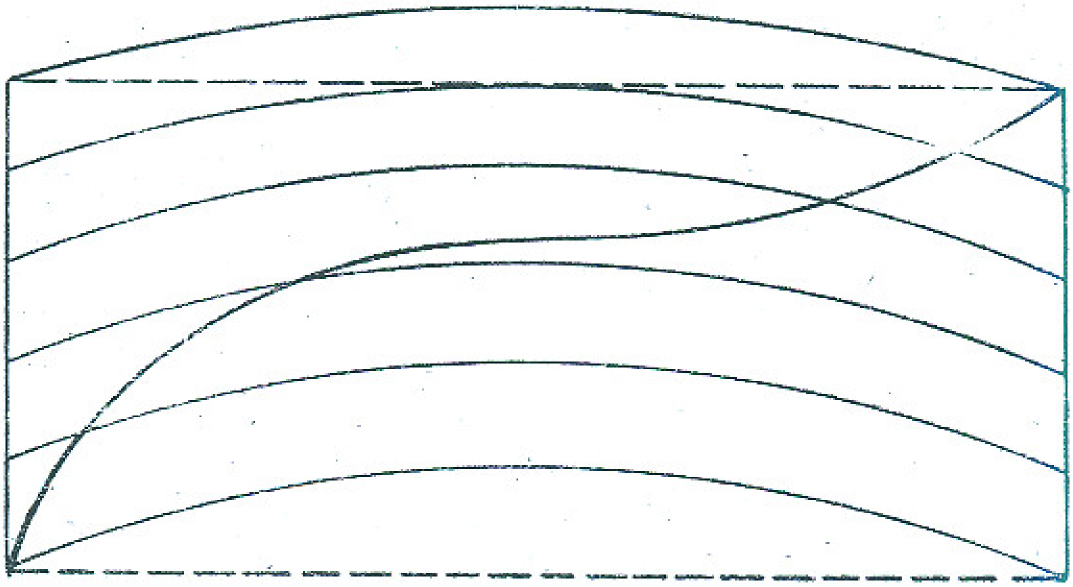


FIG II



The author admitted that Dr. Uppal had thrown some interesting light on the model experiments carried out by him in connection with the design of the Kalabagh barrage and added that Mr. Kalra's remarks did not call for any comments.

As regards Mr. Sally's remarks the author stated that they contained a good bit of misinformed criticism which seemed surprising considering that he himself had been in charge of a portion of the work. He had obviously not taken sufficient pains to go through the paper carefully. The splay in the piers, which Mr. Sally thought had been omitted in the paper was clearly mentioned on page 51. The position of pressure pipes had also been shown in plan No. IV. He might also inform him that the paper did open with a river survey plan showing the position of the Barrage and the Kalabagh Railway bridge but that was omitted by the powers-that-be, in view of the international situation. Some of his remarks were supplementary and did not call for any comments. He would like to inform him, though, that a well used as a sump is also called a sump.

The work in the left pocket was expedited simply to avoid the conditions which prevailed in the right pocket during summer, when the head against which pumping had to be done was necessarily high.

In regard to Mr. Bhandari's point that the co-efficient of 3·0 as adopted in the design was a bit low, he had to say that a low co-efficient was intentionally adopted to be on the safe side. The author stated that the words 'turbulence subsides in a length equal to five times the height of the waves' simply indicated that excessive turbulence subsided in this length for all practical purposes.