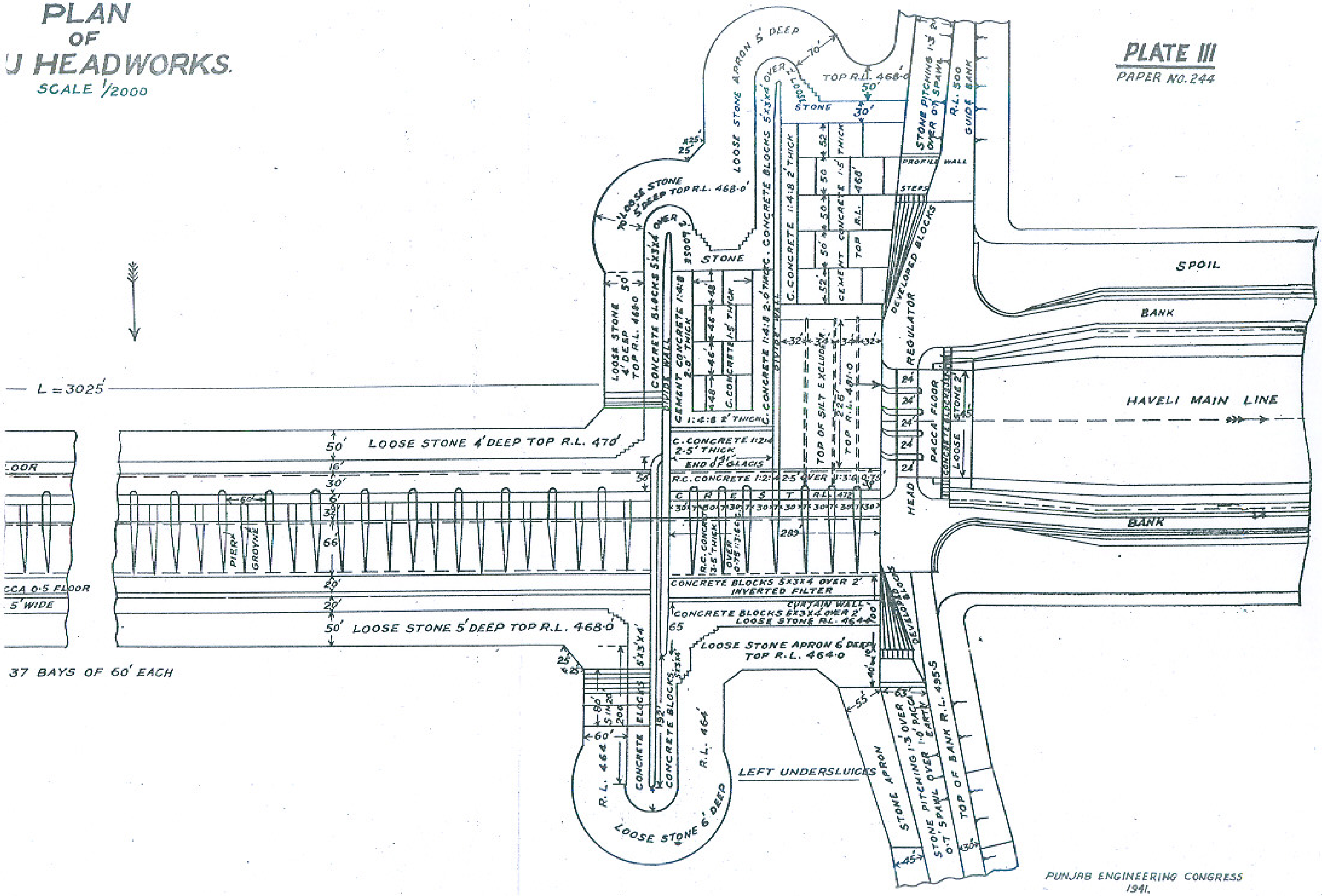
PLAN OF J HEADWORKS.

SCALE 1/2000

PLATE III

PAPER NO. 244



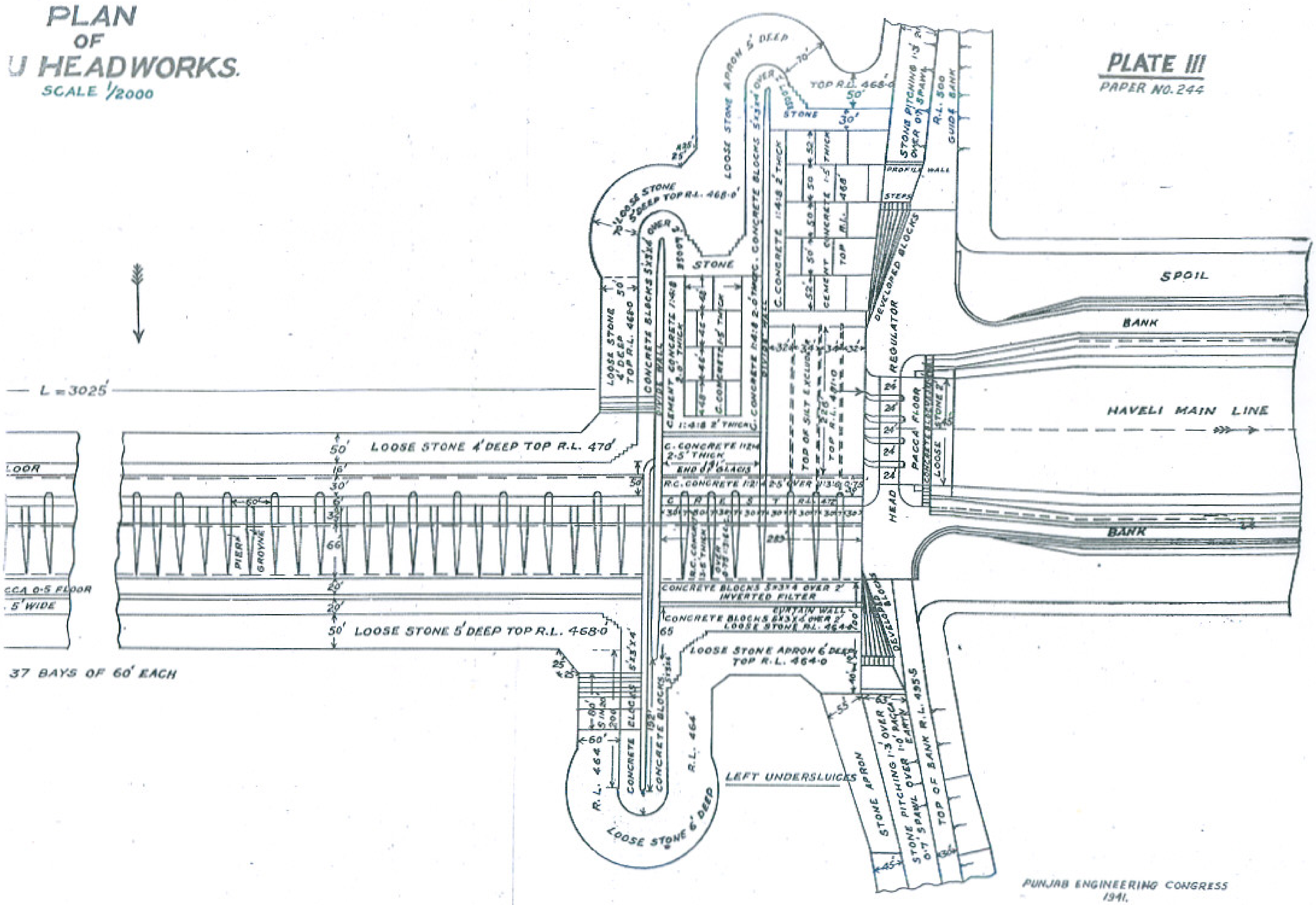
PUNJAB ENGINEERING CONGRESS
1941.

PLATE III

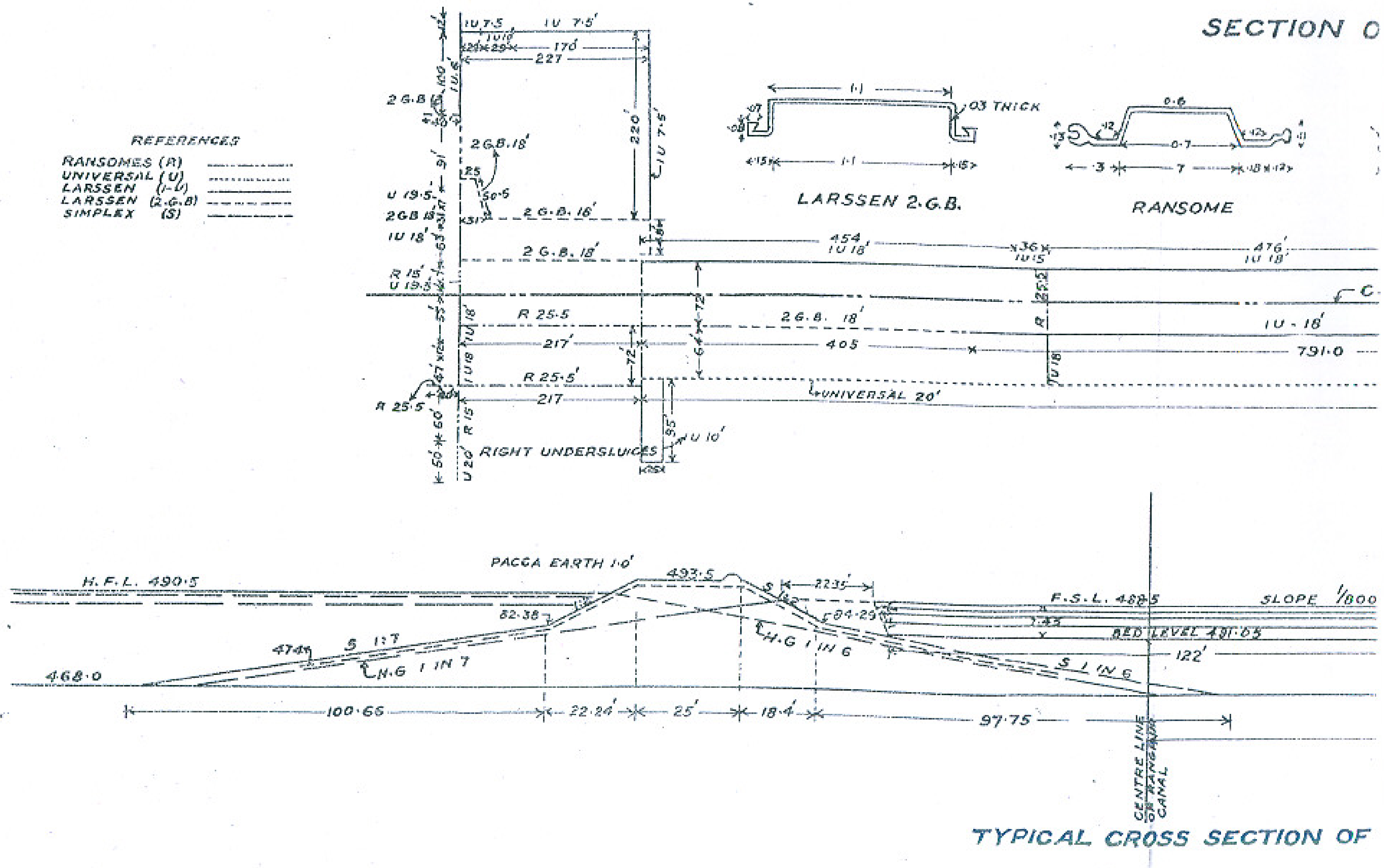
PAPER NO. 244

PLAN OF U HEADWORKS.

SCALE 1/2000



PUNJAB ENGINEERING CONGRESS 1941.



TYPICAL CROSS SECTION OF

SECTION OF SHEET PILES

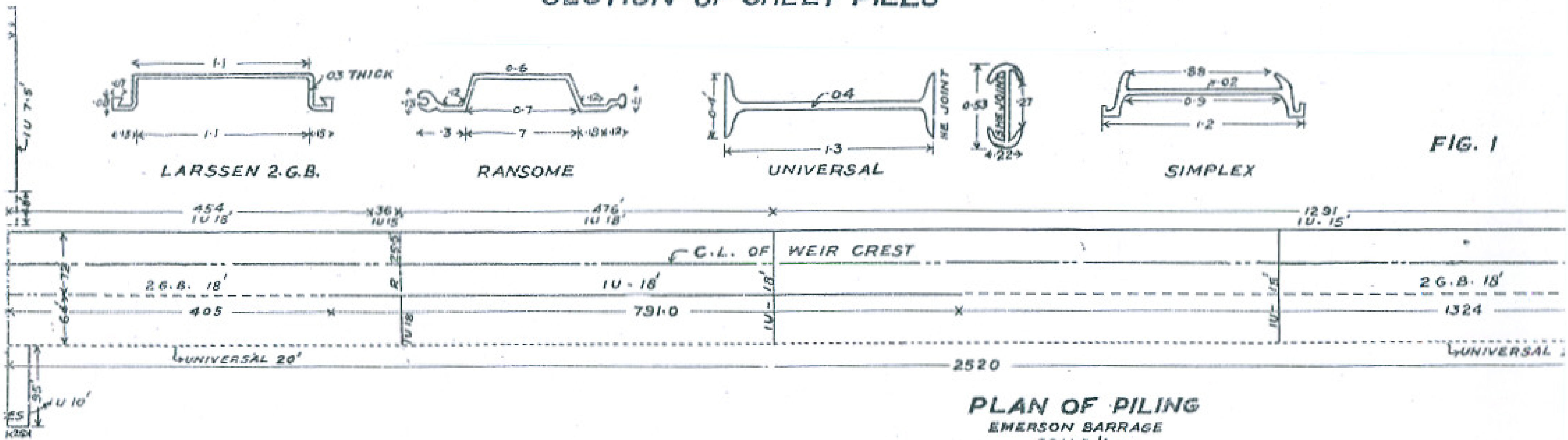


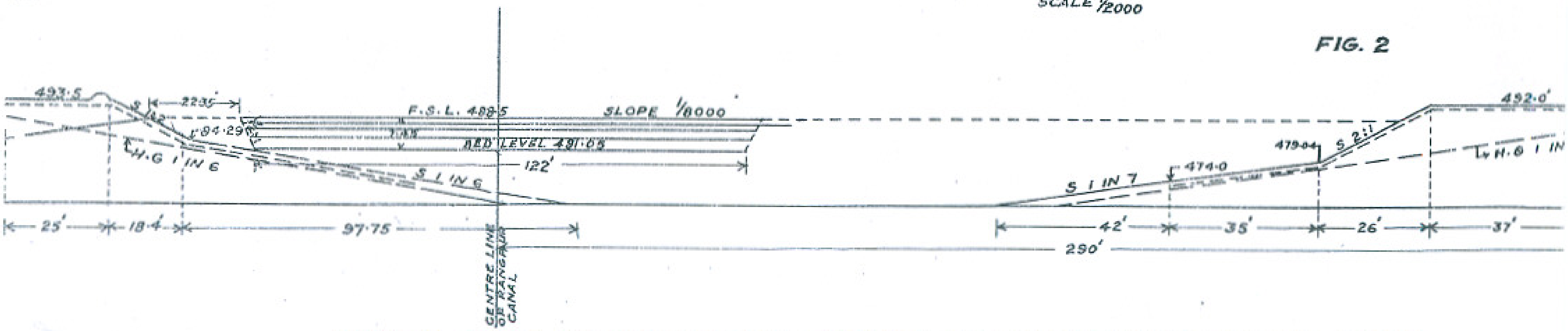
FIG. 1

PLAN OF PILING

EMERSON BARRAGE

SCALE 1/2000

FIG. 2

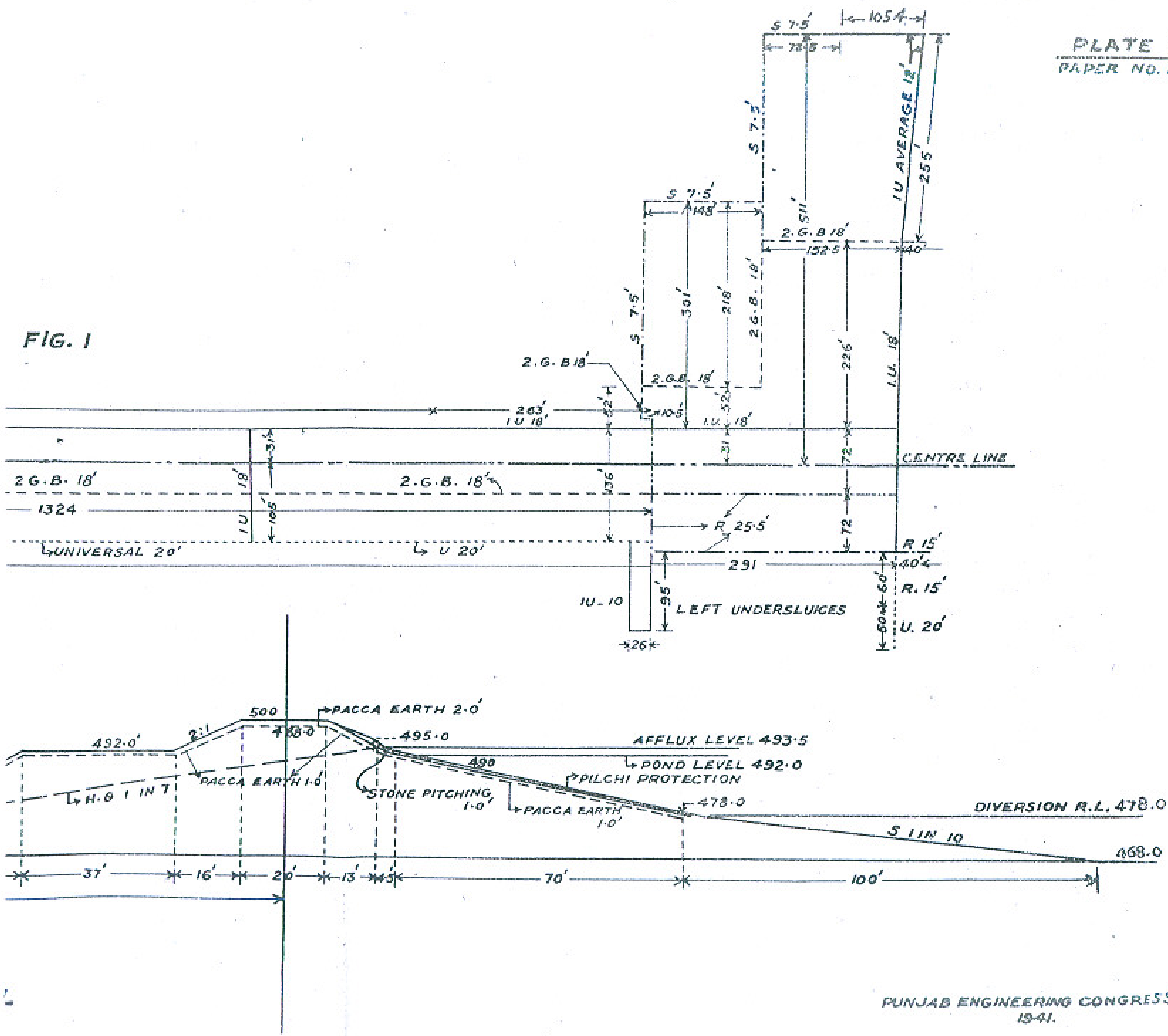


TYPICAL CROSS SECTION OF RIGHT RETIRED EMBANKMENT AND RANGPUR CANAL

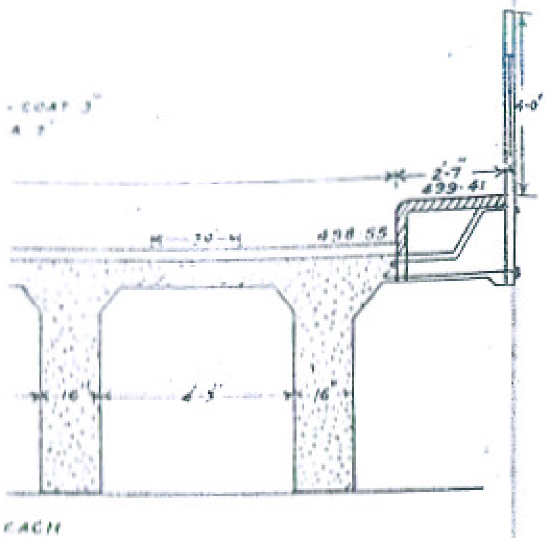
SCALE 1/400

PLATE VI
PAPER NO. 244

FIG. I

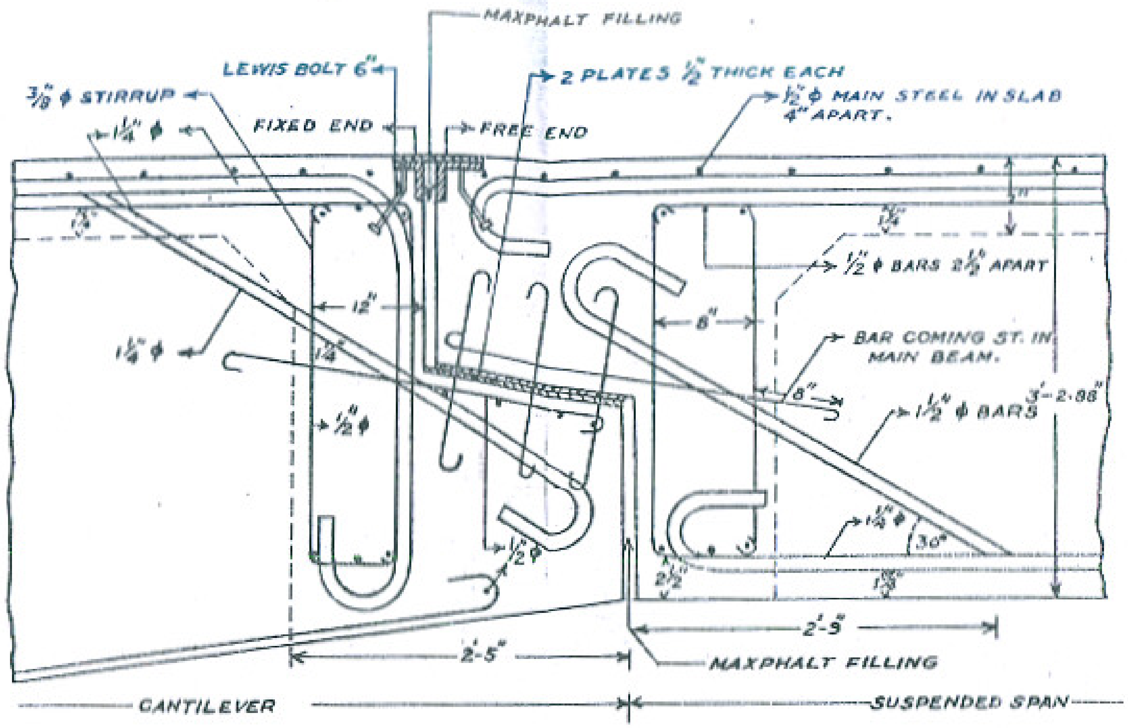


THE BRIDGE AT TRIMMU

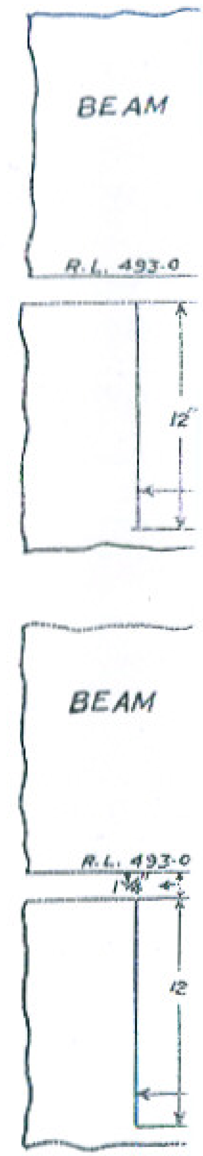


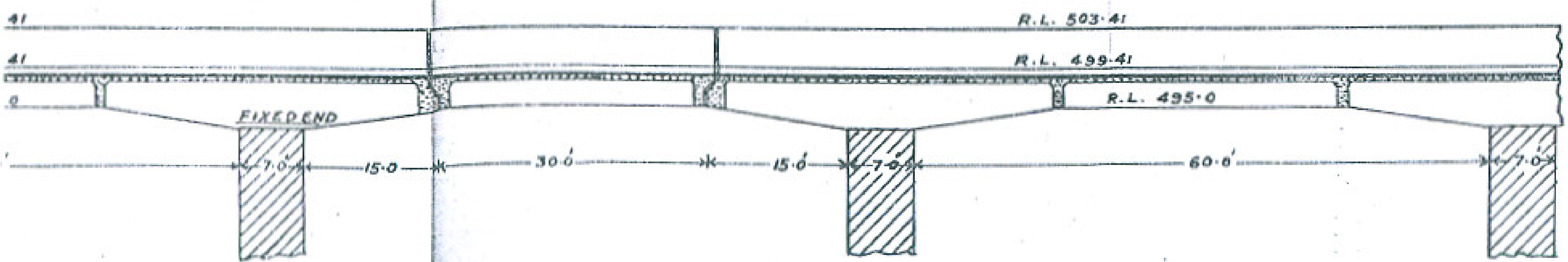
ON OF BRIDGE
SCALE 1/50

41
℄ 499·41
·67
3"



DETAIL OF REINFORCEMENT IN SOLID END
SCALE 3/50

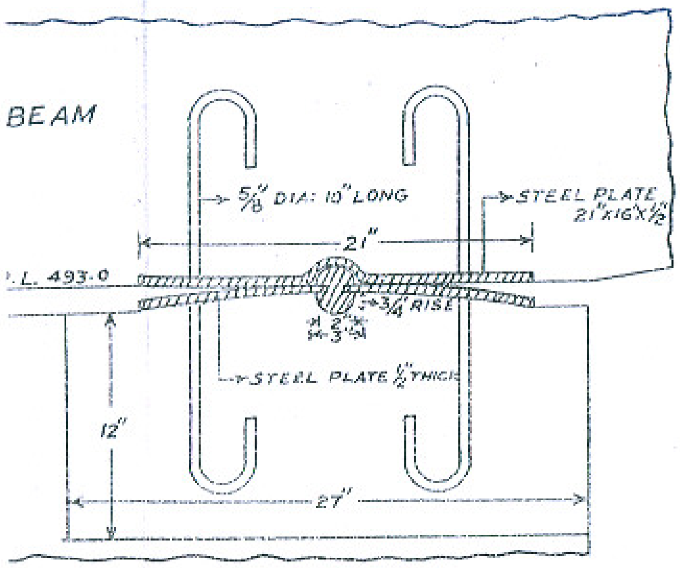




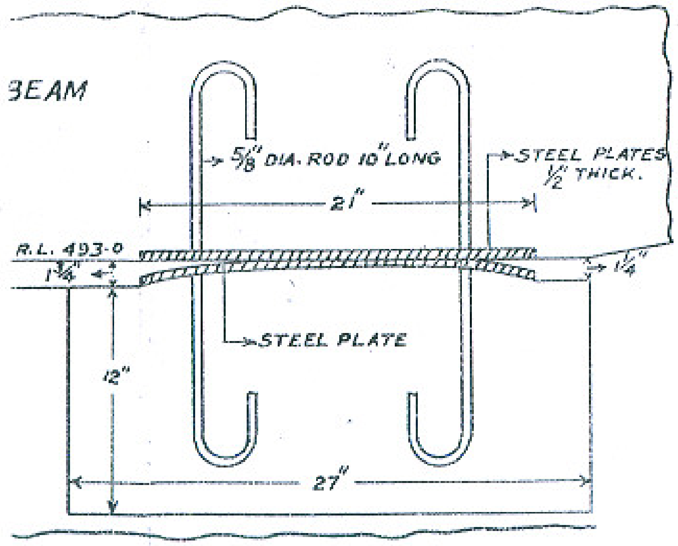
LONG: SECTION OF BRIDGE
SCALE 1/200

PLATE VII
PAPER No. 244

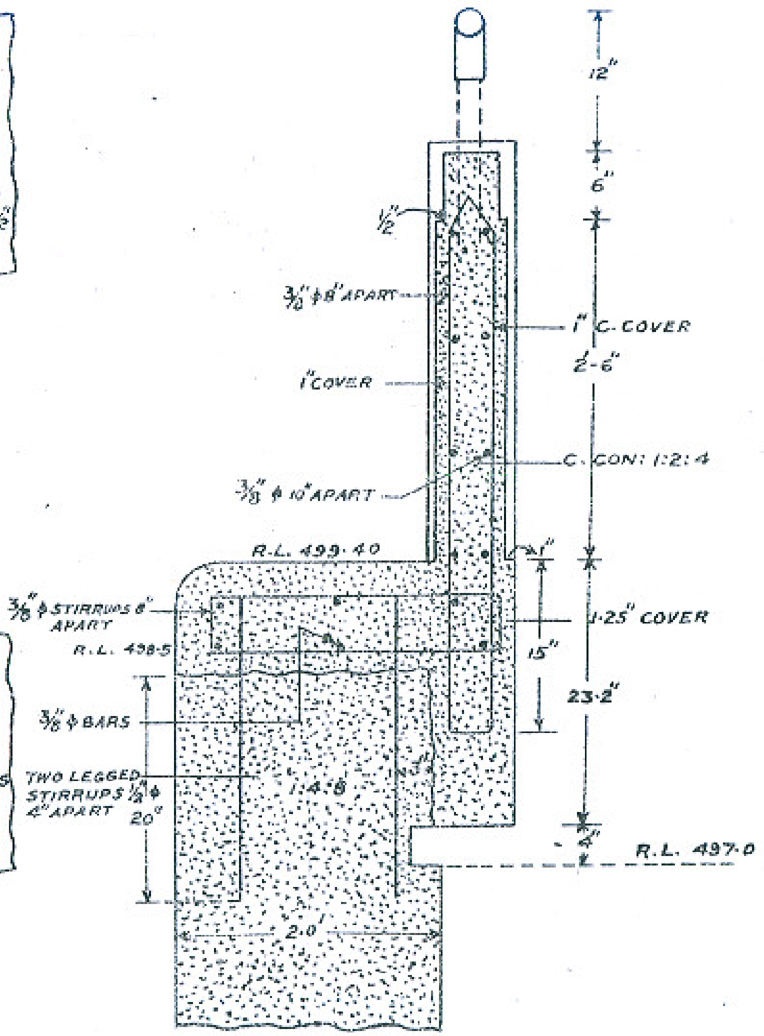
DETAILS
SCALE 1/10



AT FIXED END



AT FREE END

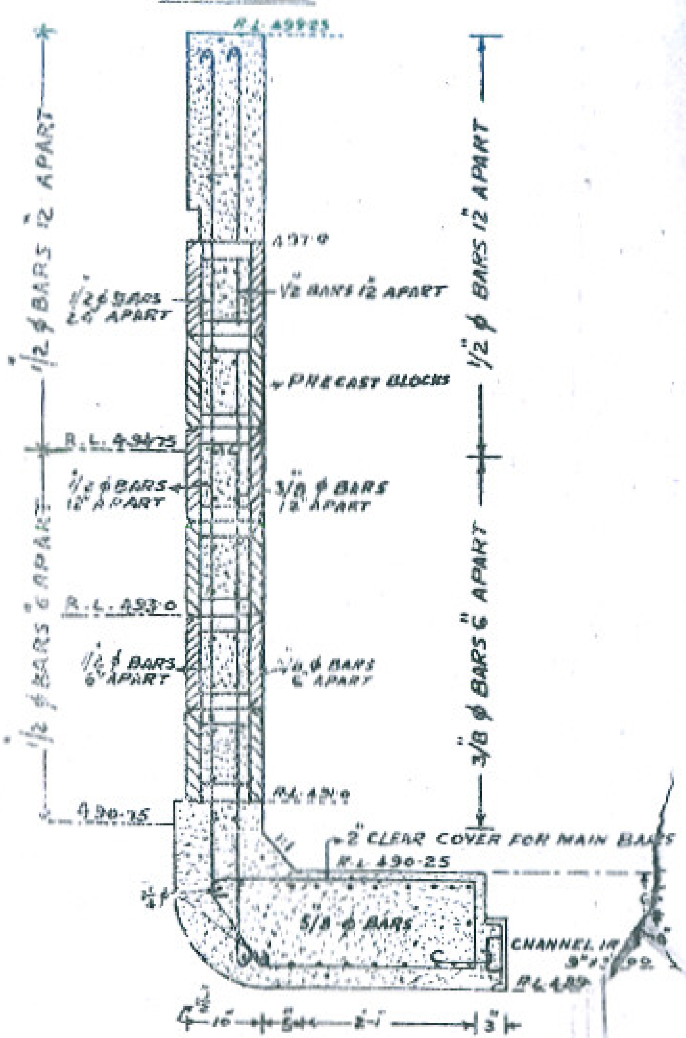


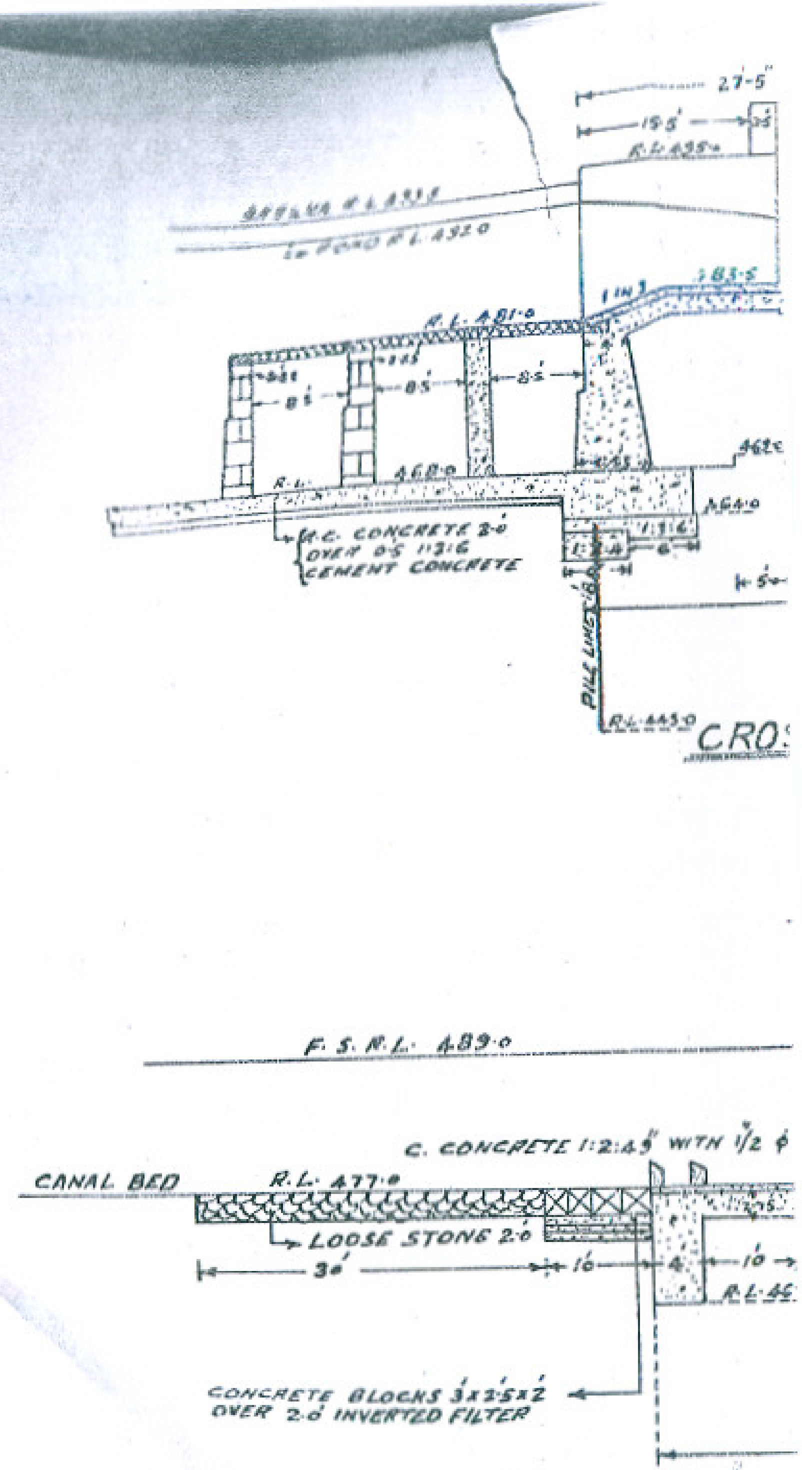
DETAIL OF PARAPET OVER REGULATORS & FLANKS
SCALE 3/50

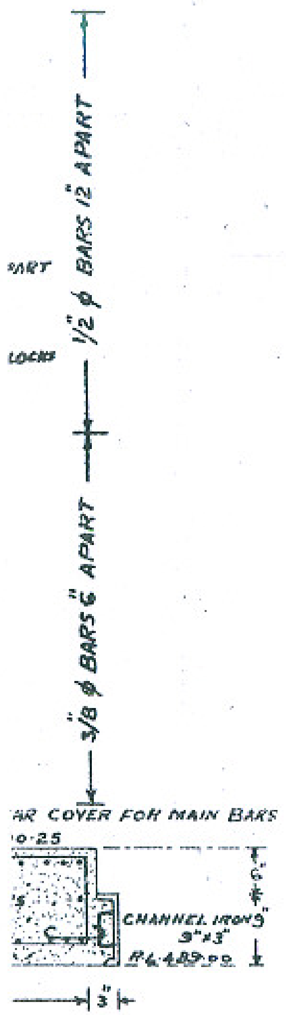
PUNJAB ENGINEERING CONGRESS
1941.

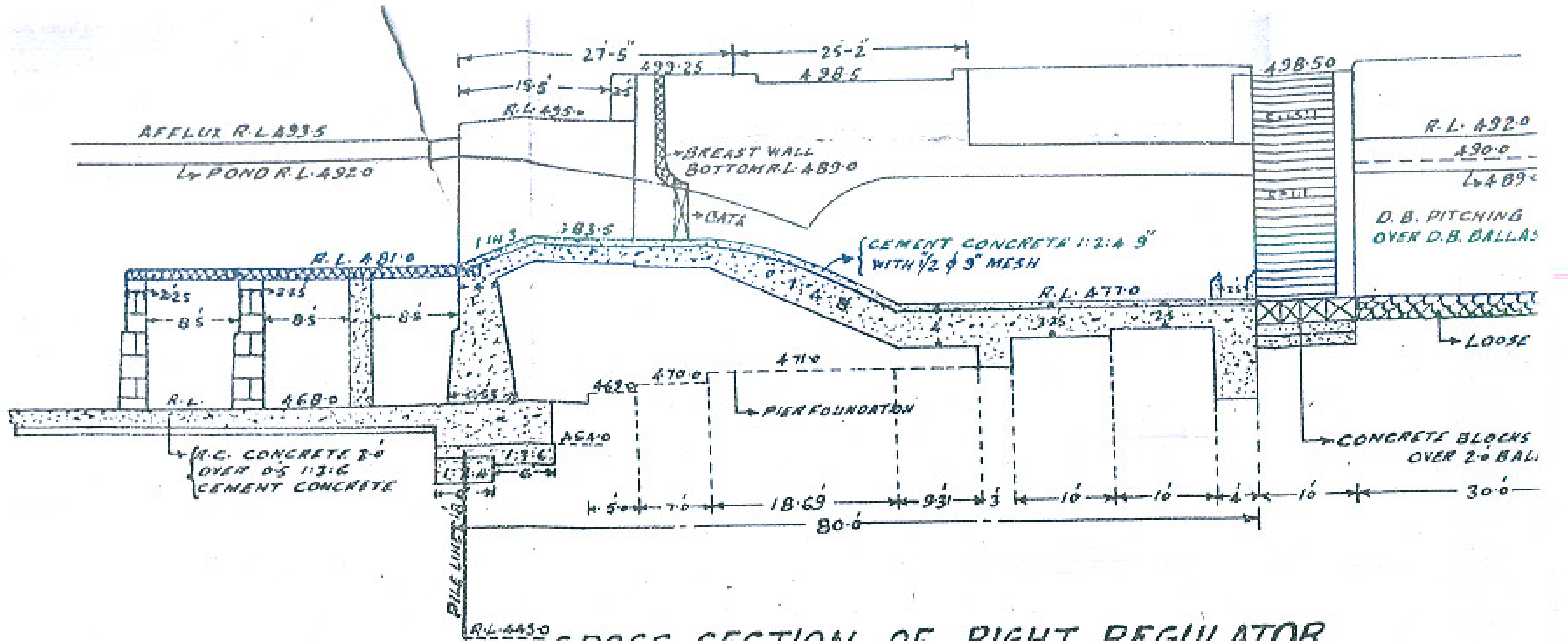
SECTION OF BREAST WALL

SCALE 1/25



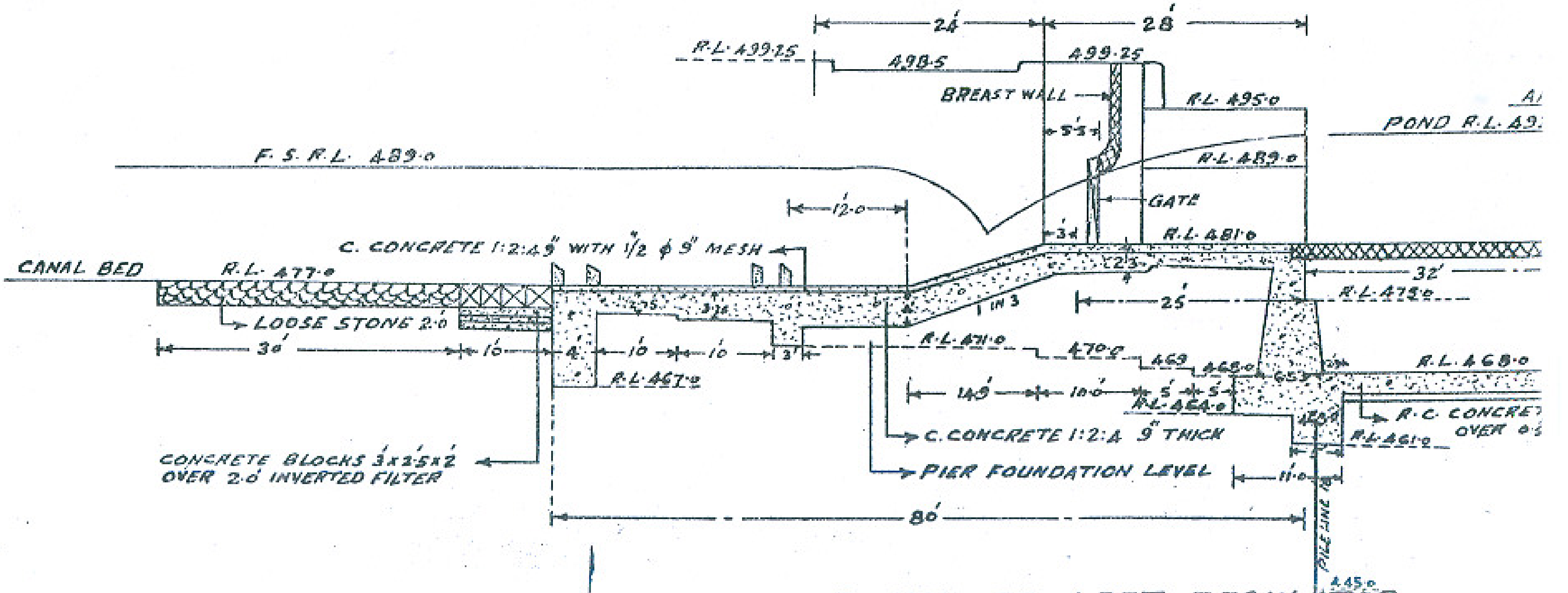




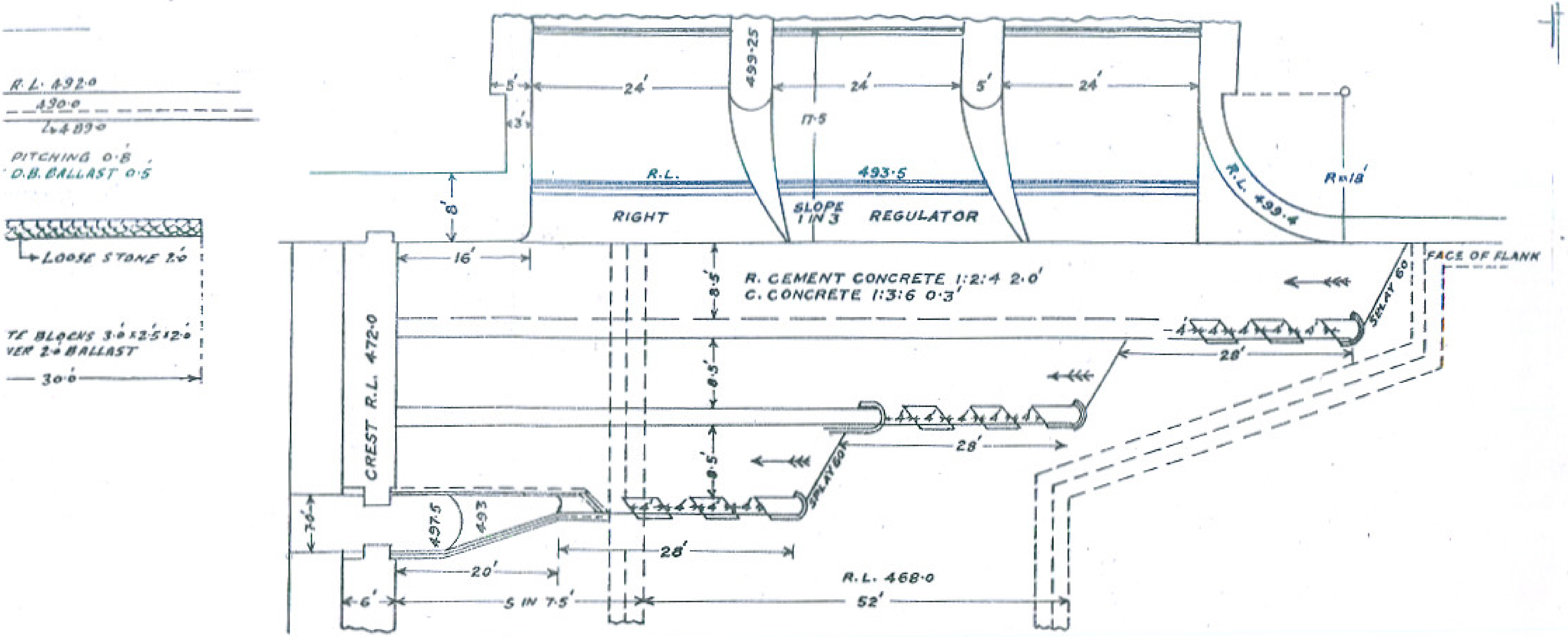


CROSS SECTION OF RIGHT REGULATOR

SCALE=1/200

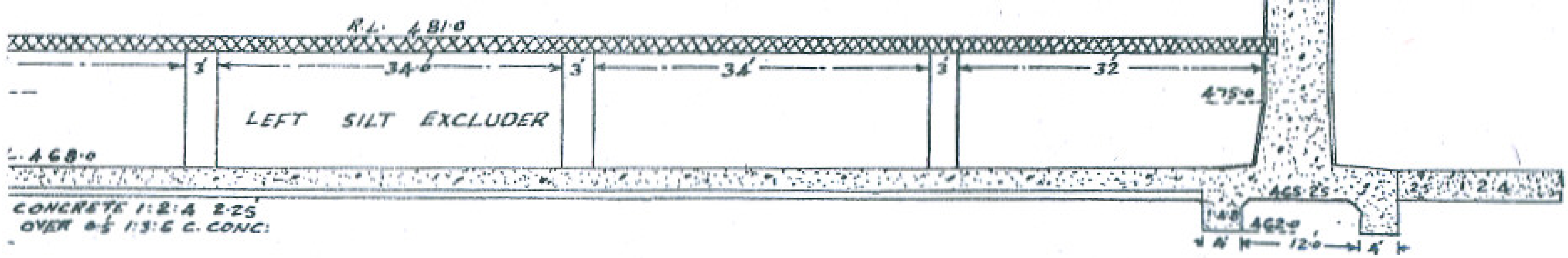


CROSS SECTION OF LEFT REGULATOR



PLAN OF SILT EXCLUDER IN RIGHT POCKET

SCALE=1/200



REGULATORS AND SILT EXCLUSION

DISCUSSION

In introducing the paper the AUTHOR said that his object in writing this paper was to present to the Congress a brief description of the design, planning, organization and construction of the Trimmu Barrage, with a view to put on record, for the benefit of the profession, the special features involved and the difficulties encountered and overcome during the course of construction.

The organization for construction was as conceived and planned by Mr. Khosla and the design-work was done by Mr. Kanwar Sain in conjunction with Messrs. Haigh and Khosla.

On page 77 it had been assumed that the minimum river-bed level prior to construction was 469·0. In the design, allowance was made for retrogression of levels to 464·0, but no retrogression took place till 1940; in fact there was a rise of minimum water level by 2·2 feet. This was due to the fact that the outfall had not been completely scoured out and that bars had formed some 3 to 4 miles downstream. The works had, therefore, not been subjected, so far, to the maximum head assumed for design. The maximum head would, however, obtain in the near future.

Referring to the design of flanks on page 95 the author stated that saturation levels had been assumed as per diagram 1. Those were lower than N. S. levels. Subsequent behaviour showed that it would have been better if the saturation levels behind the flanks had been assumed the same as N. S. levels. On the upstream side the subsoil water level would go on rising as a result of high pond level till water appeared above N. S. On the downstream side the rise of subsoil water level would be controlled by surface drainage, and although with the drop of water level in river downstream, the subsoil water level behind the flank wall would drop but as the outlet for this subsoil water was situated at a distance from the flank wall, the drop in subsoil water level might not be as quick as the drop in the water level in the river. Thus the saturation level behind the flank might be higher than the level assumed in the design. Though the subsoil water reservoir in the proximity of the flanks would be fed at full supply levels of canals, it would be safe enough to assume saturation levels at N. S. On the upstream side the seepage had no out-flow and was fed by even higher level, *i.e.* pond, but as this saturation reservoir was connected with the downstream saturation reservoir, it would be safe to assume the upstream saturation level at N. S.

During the weir closure of 1939 the upstream pond was released on 20th December. On 21st, the pitching of the upstream Left Guide Bank, adjacent to the developed blocks, collapsed in a length of 110 ft. and a crack appeared in the upstream-developed blocks.

Examination showed that the water level behind the flanks was high and was not getting proper relief, and as such pushed the pitching clean out. Similarly the downstream left guide bank adjacent to the steps had been showing considerable settlement of pitching as a result of excessive seepage and removal of the sand fill, and this also pointed to the existence of high pressure behind the flanks and the necessity of the more efficient means of release of pressure or, in the alternative, stronger sections both in the guide banks adjacent to pacca work and the flanks.

For pressure relief during construction, weep holes filled with Bajri were provided in the developed blocks. After the first summer, the Bajri was found to have settled away from the blocks and the weep holes, blowing sand. A crack had appeared in the blocks. To avoid further cavities at the back of the developed blocks it was proposed to insert metal filters, but as a measure of economy these weep holes were ordered to be filled with Bajri and covered on the face by ordinary wire gauze. In September, 1940, after a heavy rainfall the downstream-developed blocks showed settlement and the crack widened by $\frac{1}{2}$ inch. These blocks were overhanging and resting on fill and as such the settlement and the development in the crack indicated cavities which were either freshly created or were existing previously but had increased. A few days later, water level further dropped and examination of the weep holes showed that the wire-gauze covers had been completely choked with rust. These were removed. Examination of Bajri showed choking with clay, with the result that the weep holes could not function. It appeared that sand and clay passed through these till the covers got rusted and Bajri got choked with clay. Filters were then inserted in the weep holes. It may, therefore, be emphasized that the fill behind the flanks must be clean sand without any trace of clay and the pressure relief through developed blocks should be efficient.

As the designed slope of the guide bank stone-pitching was $1\frac{1}{2}:1$ adjacent to pacca work flaring to 2 to 1 upstream, and as saturated sand fill would not stand at this slope, the pitchings had been settling. It was, therefore, desirable that guide bank slopes should be flatter and the steeper slopes in the transitional seetions should be pacca and provided with means of pressure relief.

As to the subsoil water pressures below the floor, the pressure pipe observations generally showed lesser value of ϕ than designed. The observations had however been plotted and pressures contoured as per diagram 2 to show the general configuration of subsoil pressure diffusion which presented a very interesting study. It would be noticed that pressures in the undersluices were much higher than in weir—left undersluices showed very high values. Immediately the divide wall or a second pile line from the flank side was crossed, pressures dropped. The subsoil levels in the undersluices were subjected to pressure from two directions, *viz.* from the upstream and from behind the flanks. Left side showed high values because of the canal off-taking on the left side being perennial, causing higher subsoil pressures behind left flank.

These contours were plotted every 10 days and the configuration did not change. Extra pressure pipes were put in behind the flank and they proved the correctness of observations. The author, therefore, opined that it seemed desirable for future to design the downstream undersluice floor from consideration of pressure transmission from behind the flank as well and to either strengthen the floor near the flanks or introduce another cross pile line either at the back by extending the footing or in the front of the flank wall. Further, the question of diffusion of subsoil pressure beyond the downstream pacca floor should be given careful consideration and deep toe-walls and floor or blocks provided for a distance nearly 12 to 15 times the head across the flank.

As regards the size of undersluices and shape of regulator for streamlining, mentioned on page 78 and 104, respectively, the author said that his feeling was that they were still groping in dark and a few observations made by him on Sidhnai Headworks might be of interest and provide a subject for further investigations.

The configuration of Left Pocket at Sidhnai was shown as per diagram 3. Its width at its upstream tight section was 112 feet, depth 12 feet and the total discharge which it was required to pass was 4,100 cusecs.

The author said that the aim was to permit such velocities in pockets which would cause dropping of heavy silt in suspension and avoid its being taken into the canal. In the most favourable conditions the full, pocket width would be active to pass the requisite discharge.

The author suggested to divide up the filaments as they travelled and to draw imaginary partition walls in continuation of regular approaches as per diagram. The tight section could also be divided up in bits so as to correspond to each bay. If the discharge passing through each bay was the same, the discharge through these bits would also be equal. The discharge entering the pocket being equal to the discharge passed in the canal regulator, the time taken for each filament to travel to regulator face must be the same and as such the velocities in each compartment would be in ratio of the distance travelling. Consequently $V = Kl$; $q = bdlk$, d being the same, c being the same, bl is constant. The exact partition could be done by trial and error, but it would appear that extreme velocity would not be very different from twice the mean velocity. This highest velocity should not be more than 2 ft. / sec. ; as such, average velocity should be 1 ft./ sec. which should give the width of pocket. On page 78 it was stated that present practice was to keep pocket-width $1\frac{1}{2}$ times the regulator face-width, but as this might result in general tendency to increase discharge per ft. run of off-taking regulators and reduce the width of undersluices for economy, this point had to be specially stressed. These imaginary partition lines indicated the shape of regulator approaches which would cause minimum interference, but as these would vary with variation in discharge, it would seem desirable to keep this part of construction flexible and adjustable so as to suit each supply condition because if they were to be rigid and designed only for full supply conditions, they might be causing unnecessary obstruction at lower supplies.

The theoretical partitioning was worked out by the author in case of Sidhnai and tested in actual working by floats tracing the actual partition line. Extreme velocity as checked by current meter was found to correspond with calculated values. The partitioning was not, however, accurate though approximate and the probable causes were that he had ignored the existence of a Silt Excluder which changed the depth and as such the shape, and the small discharge that escaped through the excluder.

With the tight section of the pocket as above, still pond regulation, he said, was a misnomer, because the velocities obtained caused churning and pushed more silt into the canal and as such this was a subject which deserved serious study.

The author then referred to the last point, namely pumping, and said that it would be appreciated that as the soundness of structures was entirely dependent on the subsoil remaining intact without any cavitation, it was of the utmost importance that pumping was discreet and did not damage the work. There was a general tendency to overdo pumping to get good working conditions. Again pumping at the right place might be beneficial but extremely harmful to the structure if done at the wrong place.

In a normal gravity section, as shown in diagram 4, the deepest founds were at the downstream end of glacis. Open pumping or sump pumping in this region would cause concentration of flow, heavy suction and cavitation in its proximity. Tube-well pumping, unless extensvie, would not drop the water-table sufficiently. Main pumping must therefore be well outside the pacca work and the deepest floor must be laid with the help of outside pumping. The deepest work must be completed before taking up the shallower work otherwise the latter work would suffer from cavitation. After the deep foundations were laid, the pumping level could be gradually raised, and even if there had been any cavitation there would be a tendency to fill it up. It was for this reason that the 9 inches layer of concrete was laid as quickly as possible as stated on page 89. If any pumping were to be done in the pacca floor area it must be through a series of tube-wells extending over a large area so that there would be no suction of sand and heavy cavitation.

The general tendency, however, might be to lay easier and shallower work first and get on to the deepest work last of all, by which time the area would get outside the effective zone of the main outside pumps. Then local pumping would be resorted to and it would be considered that laying work in the dry was good working condition. This pumping would be damaging because it would cause concentrated subsoil movements under existing work and as such cavitation.

The general notion of working in the dry was unsound. There must be one or two inches of standing water. It was well known that sand when moist expanded and shrunk when saturated. Consequently, if sand-founds were fully saturated there would be no subsequent shrinkage, and whatever inequalities existed under adjacent work those would be filled up with laitance of mortar from the new adjoining work.

On page 89 it had been stated that boxing by piles increased subsoil pressure in the box and cut it from the effective zone of the main pumps. To avoid this he suggested that opposite each main sump, a few piles should be left undriven or extracted after driving and driven after the deepest work was completed. Judicious pumping in each case was to be devised in view of local conditions but the main principle should be, deeper foundations first with the help of main sumps, and shallower afterwards, and no pumping in the pacca floor portion ; but where pumping in the floor area was absolutely essential, tube-well pumping should be permitted, and in such cases cross-piles should be introduced so as to localise possibility of cavitation.

The component parts of the barrage on a complete model on a scale of 1/300 were then shown and explained.

The entire layout during the construction period, which had been painted on a big board was then explained briefly describing the protective works and the scheme of the river diversion.

Rai Bahadur A. N. Khosla said that Mr. Kapur had presented a most valuable paper on the construction of the Emerson Barrage at Trimmu and deserved to be congratulated on its excellence. It was exhaustive in the treatment of almost every major detail and should prove of great value to engineers engaged in a study of existing or projected works of a similar nature. His discussion, he said, would be restricted to a review of the salient points in the organization, design and execution of this work.

Organisation.—From the experience gained by the speaker during the reconstruction of the Khanki Headworks in 1934-35, he became convinced that the work on the construction of a new barrage could be very greatly speeded up as compared with past constructions, resulting in large economies in establishment charges, and in the advancement of the date of opening of the Canal system and of the consequent revenue returns. As early as March, 1937—a month before the opening of the Trimmu Division—it was proposed and agreed to, that the entire construction of the Trimmu Barrage could be and should be completed in two years. The organization of establishment, supply of tools and plant and other materials, and the programme of works was arranged accordingly.

The work was divided into six sub-divisions, namely Executive, which in addition to buildings, precast concrete work, sanitation, welfare work and general discipline, dealt with indent of Stores and matters of general policy; Headworks Left, Weir and Headworks Right, which dealt with river works; Power, which dealt with everything electrical and mechanical and had complete charge of pumping; and Materials, which controlled the railway line and the receipt and distribution of all classes of materials. The unusual team spirit and devotion to duty which characterised the officers in charge of these six sub-divisions made it possible to have a high degree of co-ordination of effort. These officers were Messrs. Handa, Khanna, Chopra, Kapur, Sakhuja and Saeed, to each one of whom he owed the deepest debt of gratitude for their loyal co-operation, untiring zeal and exceedingly hard work.

The speed-up was further assisted by the formation of a Central Designs Office with Mr. Kanwar Sain as Director working directly under the Chief Engineer. This relieved much of the strain on the local officers and gave them more time for attending to the actual construction work.

Design.—In point of design, this was the first weir which had been designed in almost every major detail in accordance with the latest "Theory of Design of Weirs on Permeable Foundations" as embodied in the Central Board of Irrigation Publication No. 12 (1936). This theory had its beginning on the remodelling of the Syphons on the Upper Chenab Canal in 1926-27, its first large-scale application and further elaboration on the Annexe of the Panjnad Weir in 1929-30 and its development in final form on the Remodelling of the Khanki Weir in 1934-35. Its perfection was made possible by the subsequent close collaboration between field and laboratory research.

This Barrage had been designed for heads of 24 ft. for the weir and 28 ft. for the undersluices. These heads were much in excess of those for which the other major weirs in the Punjab and the Sukkur Barrage in Sind had been designed.

The exceptionally high heads for which this structure had to be designed introduced a serious problem in pumping, both in point of soundness of construction and its speed. This was solved by constructing the floor of reinforced concrete in the shape of a relatively thin continuous raft held down by the weight of piers and superstrucuture. In this way the depth of excavation and, therefore, the magnitude of pumping was materially reduced. The pier foundations were, however, taken somewhat deeper for constructional reasons, that is, to prevent its movement from a completed bay to the adjoining one under construction, which would inevitably occur if there were no cut-off separating the two. For the same reason, the weir floor as a whole, was divided into five independent compartments by means of deep lines of piles driven at right angles to the length of the weir and linked on to the upstream and downstream pile lines.

The raft design was a special contribution of Mr. Kanwar Sain then Director of Central Designs Office. The reinforced concrete road bridge of the double cantilever type designed for the Indian Roads Congress heavy loading, was another of his contributions.

Programme.—The Barrage was located some two miles below the junction of the Chenab and Jhelum rivers at Trimmu, at a site where the set of the river was most favourable for the construction of the Barrage and for the subsequent diversion of the river over it. The main channel of the river was on the right. There was ample and high lying area of the river bed on the left which would fully accommodate the whole length of the weir and the necessary protection works and yet leave sufficient water-way on the right for the passage of an abnormal flood without causing undue afflux.

In view of the necessity of completing the river diversion in the second winter when supplies were lowest (not later than the third week of December) and, therefore, a few months ahead of the completion of the weir, undersluices and allied works, it was decided to start construction on and complete the right pocket and right half of the weir first, so that the river could be finally diverted over these and work continued in the left undersluices and the remaining part of the weir. This was the determining factor in the entire programme which consequently worked in the following sequence :

Completion of right pocket, right half of weir and all deep foundations; relative part of the road bridge and of steel work and sustained progress on the left half of the weir and left pocket. Final diversion of the river by 3rd week of December, 1938, and final completion of the weir, right and left pockets roadway and all steel work and opening of the weir by end of March or early April of 1939.

The programme of actual construction closely followed these dates which had been visualised in 1937. Excavation in the weir started in September, 1937, the first basket of concrete was laid in the weir floor on January 25, 1938, the foundation-stone laid on February 10th, 1938, and by the 14th September the entire floor concreting of the weir and undersluices had been completed and work on the piers well advanced. The river was diverted over the completed right pocket and right half of weir by the 18th December, 1938 or within one year and three months after the first sod was turned in, the weir.

The Barrage was opened by His Excellency the Governor of the Punjab on the 2nd April, 1939, or a fortnight less than two years from the opening of the Trimmu Division and that in spite of the very serious setback caused by the record winter flood of 3rd March (1939) of fully 200,000 cusecs in discharge with an afflux level 1·8 ft. higher than the record flood-level of September, 1929.

Construction.—The special features of construction may be briefly summed up as (*a*) opening up the entire weir all at once with a view to speed up construction and consequent economy in cost; (*b*) special care in the planning and control of pumping; (*c*) definite prevention of sand movement from beneath the floor during construction by judicious sequence of pouring of concrete and special precautions in local pumping; (*d*) reinforced concrete raft floor and provision of a 9 in. under-layer of 1:3:6 concrete; (*e*) rigid control of concrete mixing and water cement ratio; (*f*) introduction of mechanical vibrators; (*g*) the use of precast face blocks for piers and walls with resulting speed and economy; (*h*) prolonged curing of the finished work; and above all (*j*) presence of officers on the spot throughout the period when any concreting of the Barrage floor was in progress.

Great difficulty was experienced in laying the floor concrete after the piling had been completed. The pressure level of water inside the pile box stood considerably higher than the open pumping level outside, with the result that local pumping had to be done in each compartment to enable laying of the concrete to be done in the dry. This pumping had to be continued till the full thickness of concrete was laid, as otherwise the high uplift pressures developing in the area enclosed by the pile lines would lift up the 9 ins. underlayer of concrete. To make sure that no sand movement took place during laying of the underlayer and the raft floor, removable Tej Strainers were sunk in the sloping glacis and water pumped from these. On the horizontal floor inverted Bajri filters were laid suitably spaced and the water under pressure led out by gravity through $1\frac{1}{2}$ in. pipes outside the sheet piles. The relief pipes were later used as grout pipes. Each of these bajri strainers took no more than a few bags of cement for final grouting.

The erection of steel work had some novel features in the design of slipways for stacking of gates and trestles and in that of road gantries for erection. This arrangement was very convenient and quick. This was planned by Mr. W. G. Wheatley, Superintendent of the Central Workshops.

Pressure pipes had been fixed at suitable intervals in the undersluices, the weir and along flanks and the divide-walls. The observations on these showed that the results agreed with the theoretical assumptions. A critical study of these results helped to lay at rest the alarmist rumours set afloat in this connection which were designed directly or indirectly to question the stability of the structure.

Silt Exclusion.—Silt Exclusion was a special feature of this barrage. Silt excluders had been provided in the left as well as the right undersluices; the former commonly known as the Kalabagh type (suggested by Mr. Kanwar Sain) and the latter, the Khanki type. The relative efficiencies of these were being studied.

In the Canal two silt extractors, designed by Mr. F. F. Haigh, had been put in with a view to further exclusion of silt.

The Barrage had cost just under one and a half crore of rupees.

Mr. F. F. Haigh said that Mr. Kapur had put up a very interesting and detailed paper and it was difficult to find anything to add to it. However, there were one or two points where he would like to supplement what the author had said.

Firstly, as regards the alignment of the left marginal bund, discussed by Mr. Kapur on page 71, a more economical alignment would have been rather further from the river, but the actual alignment was fixed where it was in order to protect the Jhang-Bhakkar road from flooding by the river.

Reference to page 79, Readers may wonder why the fish ladder on the right was one foot wider than that on the left. This was not the original intention but was adopted to set right a discrepancy in the setting out due to the inaccuracy of the steel tapes, which had been mentioned by Mr. Kapur.

Mr. Kapur had said on page 82 that the uplift pressures under the trough of the wave were found to be small in comparison with the pressure occurring when the barrage was closed. In this connection the Research Institute carried out experiments which showed that the actual pressures under the trough of the wave were much greater than static, the reasons apparently being that they were increased by the dynamic action of the jet turning from the sloping glacis to the horizontal floor.

As regards the silt ejectors Mr. Kapur noted on page 110 that they could operate with river levels between 475·0 and 484·0. This was with their full supply discharge of 2,200 cusecs, and a head of 5 feet. With a head of only one foot, however, they would take a discharge of about 1,000 cusecs with little loss of efficiency, and could consequently work with high river levels provided the canal were running full supply.

In reading through the paper the speaker had endeavoured to note any points on which, for the same conditions they had been able to improve on Trimmu practice at Kalabagh and he said, he must confess they were very few.

In the type designs of buildings at Kalabagh various small improvements had been made, without appreciably increasing the cost. Much cheaper types were used, with mud floors and sirki sarkanda roofs for the lower class of quarters. In this way it had been possible to construct more quarters for the same money. For instance, 280 coolies' quarters had been constructed at Kalabagh instead of 108 at Trimmu. This had obviated almost entirely the frightful congestion experience at Trimmu.

Mr. Kapur had mentioned on page 79 that a glacis slope of 1 in 4 was adopted although experiments showed a 1 in 3 slope to be preferable as it was thought that this was the greatest slope which would not give difficulty in construction. Actually these difficulties were found to be largely imaginery as a 1 in 3 slope had since been laid without trouble at Kalabagh.

Trouble had occasionally been experienced at Trimmu where owing to high supply in the river and low supply in the canal the silt extractors had not been able to work. Although the designs of the Kalabagh extractors had not yet been settled it was intended to provide a regulator in the canal downstream of the extractors capable of heading up supply in the head reach to pond level and thus enabling the full head across the barrage to be used in the extractors.

There were many points, of course, where different conditions at Kalabagh required different methods of design and construction to be used, but these must, he thought, be left for a paper on the Kalabagh Barrage which he hoped one of the Executive Engineers would produce next year.

Dr. J. K. Malhotra congratulated the author on his very lucid chronical of a very great project.

There were three points which he wished to raise in regard to this paper. The first of these was connected with the utility of the upstream and downstream pile lines, the second with the layout of the pressure pipes, and the third with the surface profiles of the Haveli and Rangpur Canal Regulators.

1. *Utility of the Upstream Pile Line.*—On page 80 the author had stated that a pile line was introduced on the upstream and to kill the pressure but its depth was determined from scour considerations. Earlier, on page 77, it was stated that the design of the weir was in conformity with the general principles laid down by Mr. Khosla in the C. B. I. Publication No. 12, "Design of Weirs on Permeable Foundations."

On page 133-134 of the "Design of Weirs," Mr. Khosla has stated, however, that the upstream pile line has little influence on the uplift pressures under the downstream floor, and that all it does is to effect a reduction of pressures under the upstream floor, which is of no consequence in case of weirs, where the head of water on top of the upstream floor is much in excess or the uplift pressure ; though it is of very great importance in the case of high dams, as it might effect great economies in the mass of the structure.

It would, therefore, seem that the upstream pile was introduced not to kill the pressure, but to prevent failure of the upstream floor through slipping or the subsoil into the scour holes by simple earth pressure.

Mr. Khosla, however, states that in the case of a scour hole at the upstream end the flow of seepage water will tend to keep the soil in position as its force will oppose slipping due to earth pressure and that after a deep scour hole had been formed during floods the failure at the upstream and will generally occur at low heads when the restraint exercised by seepage flow is reduced. This really means that the failure is likely to occur during months with high supplies.

Dr. Malhotra said that while he would not go so far as to say that an upstream pile is totally unnecessary he would suggest that the author and Mr. Khosla might go more deeply into the question. It was of some importance to know if this likelihood of scour at certain periods of the year, which may be partly met by the loose protection upstream or the pacca floor was such as to justify the cost of the upstream pile. Was there any instance, for example, where the failure of the weir, partial or total was due to upstream scour alone.

Under these circumstances the additional pile line at the toe of the upstream glacis in the undersluices would seem to need somewhat more justification than was given by the author.

2. *Utility of the Downstream Pile Line.*—The author stated, another pile line was introduced at the downstream and was taken deep enough to permit a safe exit gradient which was given a factor of safety of about 4·5.

On page 98 of the "Design of Weirs" Mr. Khosla stated : "It is proposed to apply the following factors of safety to critical values of exit gradients :—

Shingle	.. 4 to 5
Coarse sand	.. 5 to 6
Fine sand	.. 6 to 7"

The factor, consequently, applied for the Trimmu Barrage is appropriate to a shingle foundation. Actually the foundation material is perhaps best defined as a mixture of coarse and fine sands, for which the safety factor would be nearly 6.

He had found by calculation that this would have involved increasing the depth of the downstream pile from 27 ft. to nearly 48 ft. The conclusion, therefore, was that either the depth of the pile line was fixed not by any considerations of safe gradients, but because this was the maximum scour expected or that Mr. Khosla had changed his safety factors.

In this connection he would like to draw Mr. Khosla's attention to the necessity of putting these safety factors on a more satisfactory basis. From a rough formula which he had derived, it seems that doubling the safety factor increases the pile depth nearly four-fold ;

so that where high heads, as at Trimmu, were operating it might mean a considerable difference in pile depth according as they used one value of the safety factor or another.

He was inclined to think that the lower safety factor was used at Trimmu, because the value indicated by Mr. Khosla in the C. B. I. Publication No. 12, seemed impractical.

3. *Layout of Pressure Pipes.*—Turning to page 81 Dr. Malhotra wanted to know if the complete sets of pipes shown in the weir and undersluices sections in Plate IV were inserted in everyone of the weir or undersluice bays. On page 33 of "Design of Weirs" it is stated that "such a large number of pressure points need only be placed at either flank and at a few lines in the body of the weir, depending on its size."

The placing of the horizontal pipe connections at a slightly upward incline to avoid the possibility of air locks may be copied elsewhere with advantage.

It would have been better if one more pipe had been inserted between No. 8 to 11, as the threat to a work was in general, more likely to arise on the side downstream of the crest than on the upstream side and consequently the pressure points under the floor should be spaced more closely on the downstream side so as to make the location of any defect comparatively easier.

A few months back he was asked to suggest a layout of pressure pipes for the depressed bays of Islam weir. The principles laid down by Mr. Khosla were studied by me in this connection and the following additional points noted as a result of this study, and earlier mathematical research.

(*i*) The rate of fall of head along the horizontal (or nearly so) portions of the profile was usually uniform and smaller than the rate of fall along the vertical cut-offs. It was, therefore, possible to place fewer pipes per unit length or creep under the horizontal floor than along the cut-offs.

(*ii*) The % residual heads evacuated by the method of Independent variables had a certain range of variation, partly due to the approximation implicit in the method and partly to the uncertainty involved in the assumption of a homogeneous foundation material. This range might be put as $+1\frac{1}{2}\%$ *of total head*, and it was therefore advisable to space the pressure pipes so that the estimated % heads at any two neighbouring pipes differ by more than 3% of total head. Usually it would be advisable to space them at intervals of 8—10% of total head, so that any ordinary variations might not be misinterpreted.

(*iii*) The residual heads declined rather more slowly with depth near the central part of the work than near its ends. If any pipes were to be placed in the subsoil, it would be possible to give greater vertical spacing near the centre than near the ends.

To sum up: The pressure pipes should be placed—

(*i*) At larger intervals under the horizontal floors than along the vertical cut-offs.

(*ii*) At points, the % residual heads at which were estimated to differ by 8—10% of total head, at least.

(*iii*) More closely near the toe of the work than upstream of the crest.

(*iv*) At closer vertical intervals at the ends of the work that at the centre, if any pipes were to be placed in the subsoil.

4. *Profile of Canal Regulators.*—On page 104 the author stated that the profile dimensions were worked out from the formula

$$X = y + \frac{U\sqrt{4y}}{9}$$

where U was the maximum velocity and X and Y the profile co-ordinates. This formula was first given by Mr. Montagu in 1935 in the C. B. I. Publication No. 10 "Irrigation Canal falls" on page 40, Appendix VI A, and had been since used by the designers, apparently without any examination of the reasoning on which it was based.

The primary object of Mr. Montagu was to design a profile which would reduce the vertical velocity of the jet leaving the crest. This he assumed is not changed. This vertical component it was assumed, was responsible for the scour downstream of the fall. To this end he tried to evolve a profile which would give the maximum horizontal acceleration to the jet at all points, the idea being that if the horizontal velocity was thus increased, the vertical velocity would go down.

Dr. Malhotra had examined this profile in some details in a note, a copy of which was sent to the Central Designs Office. Briefly, the findings were that—

(*i*) There was a fallacy in the logic leading to this formula.

(*ii*) Apart from its mathematical invalidity, this profile while giving a high horizontal acceleration to the jet would give it, if anything, a higher vertical acceleration at the same time.

This profile did not, therefore, theoretically at any rate, fulfil the object for which it was designed. Whatever its actual performance may be—on which point more information would be welcomed —it would have perhaps been more appropriate if the designers of these regulators had verified the accuracy of the formula before they started using it.

Mr. M. R. Chopra remarked that the author had dealt with all the major points in great detail and given a very lucid description of the whole construction. He would, however, deal with some of the points which had not been given the detailed mention that they deserved.

Mention had been made of the whole scheme being based on diversion of the river through the right when the work elsewhere would continue. This necessitated bunds across the weir for purposes of segregation. To make this effective, deep walls were constructed right through, the apron and the Block portion in between thoroughly sand grouted and this supported a bund on leak proof foundation. The author would have done well to mention all such works which though of small magnitude were of fundamental importance. The speaker was of the opinion that there should be at least four or five such divide-walls in the apron and weir, so as to enable the weir to be divided into compartments for purposes of repairs to any one or more compartments. These divide walls, below floor level, would form core walls for the ring bunds needed subsequently. This was a point of considerable importance which should be borne in mind in future constructions.

Mr. Chopra then referred to some surface cracks which had appeared during constructions in the concrete of the weir and requested the author to state how these had behaved subsequently. These cracks though a perfectly normal occurrence in cement concrete of this nature had frightened some people who found something to criticise. Actually, all concrete must crack. Temperature reinforcement would distribute cracks to such dimensions as would render them harmless. But that reinforcement would be very heavy indeed to be really effective in the massive floor. The temperature reinforcement actually given was in the nature of a compromise. The cracks were all opened out and grouted but they did not take any appreciable amount of cement. These cracks were caulked with leadwool at surface to prevent escape of mortar. Part of the grout, no doubt, passed below the floor and filled the pores of the underlying sand.

In the case of bridge, the intricate framework and problem of concreting at higher level had already been stated. He wished to make a remark on the wheelguards which were formed of hollow light sets. Their construction was rendered easy by precasting the sets in advance and laying them at site. The back support was of course put in with timber shuttering.

In conclusion he wished to emphasize that this construction had brought out one important point and that is the great speed of construction possible with the use of recast concrete units.

At one time it was contemplated to use precast troughs for the bridge T beams as well, but as the other organization of concreting in situ had started satisfactorily the idea was not pursued, but this was a point which could be considered with advantage for future.

The speaker wanted to know of any damage that had occurred to the apron, the configuration of the river and of the behaviour of fish ladders.

Mr. A. R. Khanna, considered the paper as very interesting with its wealth of constructional details so clearly depicted.

He had just to make a few remarks about the constructional details of the ejectors on the Left Canal with the hope that this information may be useful to Engineers engaged on a similar work.

The downstream level floor of the ejectors is a combined pervious and impervious floor in as much as pressure relief has been afforded in the impervious floor. The floor consists of 18 inches of cement concrete 1 : 4 : 8 laid on 21 inches deep inverted filter consisting of sand, graded ballast and dry brick soling. A pile line has been provided at the toe of the glacis under the flanks and going along the Returns.

As stated in the paper, pressure relief has been afforded by means of relief pipes. 32 No., three inches diameter pipes have been provided and the pipes have been placed in groups of four each discharging in a silt trap.

As the floor was being covered over with concrete the area through which the filter could discharge was naturally being restricted. As soon as the entire area was covered over, there was no place left for the pressure to find relief except through the pressure relief pipes. The pipes therefore started to flow when concrete was still fresh. This happened in spite of the fact that water level in the sump well lower down from which open pumping was being done was at a level lower than the bottom of the concrete. A small toe-wall 2·5 ft. deep had been provided at the downstream end of the floor.

Armoured suction hoses used on small pumps came in handy at this time. They were made to work as syphons discharging into the seepage water outside the floor area. With this arrangement, relief was afforded to the floor without interfering with the fresh concrete on the floor.

2. One word regarding the strain on "Power" at Trimmu. It is very well to open the entire weir as was done at Trimmu in order to have a large working area but the experience at Trimmu showed that it should not be attempted unless there is plenty of power available. The Power House plant being old (the new set did not arrive till the work was nearing completion and was not installed) there were several break-downs on account of the heavy strain on Power. This was felt most on the left side of the Barrage as on account of the programme for Diversion no chances could be taken on the Right. This meant rationing of Power practically all along. He understood from Mr. Handa that two new sets had been installed at Kalabagh.

3. On a work of this magnitude it is of the utmost importance to plan all the details beforehand like fixing the position of mixers and bins. Constant shifting of mixers is both troublesome and expensive. On the left the mixers as originally installed served til the end and from four mixers shown on Plate V they could feed th

Pocket both upstream and downstream, both the Divide-walls, Left Regulators and four bays of the weir on the left.

Mr. C. L. Handa said that he was tempted to speak on this paper from two considerations. Firstly, because the author in his opening remarks had alluded to the subject of pumping in rather general terms and secondly because the speaker had been associated with the construction of the Emerson Barrage in an intimate capacity.

As, however, almost all the engineers connected with the construction of the Trimmu Barrage had already spoken and exceeded the time limit imposed by the President, the speaker would only say a few words with regard to pumping arrangements, of which he was now in charge, at the Kalabagh Headworks construction.

The rules and procedure of pumping in connection with executing open foundations much below the subsoil should not and could not be standardised. The engineer has to study the local conditions and the profile and situation of the work under execution. The speaker had had personal knowledge and experience of reconstruction or original construction works at Khanki, Marala, Deg Fall, Trimmu, Sidhnai and Kalabagh Headworks and at each of these places, pumping had to be arranged differently. At the Deg Fall the pumping was mostly from a system of shallow tube-wells which were interconnected and which served to depress the Spring Level at the immediate site of the deep foundations. At Kalabagh Headworks there were practically no tube-wells and pumping was being carried out from open sumps situated outside the section or from local sumps situated within the floor at the site of the deepest pier foundations. At Marala Headworks the scour pits immediately downstream of the groynes were made use of to instal large pumps and the entire water-level below the crest was depressed deep enough so as to obviate the necessity of any local pumping from within the section of the floor concrete. As this work had to be carried out against a big pressure head due to the necessity of escapage through a portion of the weir, difficulty was experienced in bay No. 5 and working conditions could not be secured on account of springs although the downstream water level within the Ring Bunds was sufficiently low. Hence it became necessary to adopt tube-well pumping and this gave excellent working conditions. The tube-well consisted of just one strainer length 8 inches diameter and 10 feet deep which was sunk and provided with a short length, of blind pipe to suit the depression head. The concrete was thus poured in the dry due to the tube-well producing a cone of depression with a discharge of about one cusec for an area of roughly 2,000 square feet. This idea of tube-wells supplementing open pumping needs a judicious combination and is most suitable.

The problem of pumping at the Kalabagh Headworks is more complicated. The first difficulty is due to too much inflow as compared with the plant available. The second is due to the gravity section wherein the pier foundations are 4 feet deeper than the deepest foundations of the pile line curtain-wall on the extreme downstream and of the section. The remarks made by Mr. Kapur in opening his paper apply to the sumps that have been made on the downstream side of the piers to enable the concreting of the deep pier foundations. I agree with the author that in case uncontrolled open pumping is allowed from internal sumps there is a great risk of cavitation due to sand being sucked out from the sub-formation below the floor concrete. In order to get over this trouble these sumps are being tackled in a special manner at Kalabagh Headworks and the arrangement is as effective as it is simple. On account of the shingle strata in the soil it is impossible to sink tube-wells as normally understood. And still a large amount of inflow has to be dealt with and provided for to enable the unwatering of the sump in the first instance and then its subsequent control while concreting of the neighbouring compartments or the sump itself is in progress. This has been achieved by the speaker by having a perforated conical bell-mouthed metal strainer of about 5 sq. feet surface area which is embedded in the shingle below the bottom level of the floor concrete. The perforations are 5 inch in diameter and spaced one inch clear. This strainer is shrouded with an inverted filter of bajri so as to prevent withdrawal of sand. A casing pipe of about 10 inches diameter is riveted to this strainer and this constitutes the equivalent of the tube-well from which pumping is arranged by means of an electric pump of 8 inches size. The suction pipe of this pump is unscrewed from the conical strainer after the concreting has been done. As the members of this Congress are visiting Kalabagh Headworks, the speaker would not mention further details of this arrangement which will be shown to the members at the Headworks.

As an instance of rapid construction the speaker was of opinion that the work at Marala Headworks set the pace as the entire reconstruction of the weir together with the remodelling of the Canal Head Regulator were accomplished in less than 6 months against a big, furious and uncertain river. This achievement had been followed up at Trimmu where the colossal work of the new construction of the whole headworks had been achieved in two years.

Rai Bahadur Kanwar Sain remarked that so much had been said for and against the Haveli Project—some might say by way of propaganda and anti-propaganda—that one might feel somewhat hesitant in offering a frank criticism on the valuable paper of Mr. Kapur, under discussion. It was almost an encyclopædia of Trimmu. It was a record of the latest methods of construction of a barrage, of the difficulties encountered during the construction and the special steps taken to overcome them.

The paper was rather voluminous and even then the reader remained unsatiated so far as the design part of the Headworks was concerned. If Mr. Kapur had confined himself in this paper only to the organization and construction of the headworks, the paper would have been of more manageable dimensions and he would have done more justice to his readers.

There were points concerning the designs which had to be skimmed obviously on account of the sheer volume of the paper—points which gave them in the Central Designs several sleepless nights.

The design of the Trimmu Headworks had some bold departures from the past practice. The main differences might be stated to be—

(a) The design of the raft in the floor of the weir and the undersluice bays.

(b) The arrangement of the undersluice bays and the provision of the silt excluding device on the left side.

(c) The design of the cantilever type reinforced concrete girder bridge for the arterial road over the river.

Each of these subjects was important enough to justify a separate paper for the Congress. In the time at his disposal he could only draw attention to the salient features in a most general manner.

The design of the raft foundations was necessitated by the conditions arising at Trimmu. The upward hydrostatic pressures were calculated in accordance with Mr. Khosla's theory. The downstream floor levels were fixed by considerations of standing wave. The pressures that resulted were of the order of 12 feet static head of water. A concrete gravity section would have entailed not only very heavy pumping but could not be done monolithic, a point on which they had a very heated discussion at various stages. Also deep wells had then to be provided under the piers and the join of the floor with the pier foundation would have been a plane of weakness.

A reinforced concrete slab appeared to be a possible way out of the difficulties. The usual method of raft design was to assume the earth pressure under the floor to be uniform throughout and then to calculate moments at any section taking into account spreading moments of 50 to 100 million inch-pounds. In some cases this was financially out of question. In average raft beams moments of the order mentioned should produce deflections of 1 inch to 3 inches but these deflections did not usually occur and it must be concluded that such big moments did not occur, but were counteracted partly by variations in the soil pressure and partly by variations of the pier loads due to the supports not remaining exactly at the same level. Hence to provide reinforcement for such movements, without investigating the deflections and variation in soil pressure was both extremely wasteful and irrational, since if the moments occurred, they would often produce deflections large enough to cause failure of the superstructure.

Often it was not realised how big the changes in bending moments could be if the distribution of earth pressure was even slightly altered.

On the basis that the earth pressure at all points was equal to a constant (K) times the settlement of ends plus the deflection at the point, Dr. Hayashi and others had investigated actually the moments occurring at various points, but the calculations involved were very long and too tedious.

The soil-line method followed in the case of raft design at Trimmu was developed by A. L. L. Baker in 1936-37. Details were published by the British Concrete Journal. This method took account of variation in soil pressure and its relation to deflection, but in order to simplify the calculations it was assumed that the earth pressure varied throughout according to a straight line law. In order to cover the worst possible case, limits, between which the soil pressure variations for Trimmu must lie, were found from actual settlement experiments. The details involved in the design would be too cumbersome to detail in this discussion.

With regard to the arrangement of undersluice bays on the left bank, this was guided by model investigations carried out by Mr. Inglis some years ago in connection with silt exclusion. The silt excluding device in the four bays nearest to Regulator was based fundamentally on something suggested in early 'twenties by Mr. Elsdon, though the details were different. In the design of the silt skimmer platform, the safe stress for concrete was taken as high as 1,100 lbs. per square inch and this, was a very bold departure from the usual practice. The speaker was criticised only in 1937 for taking 750 lbs. as safe compression stress for concrete in place of the usual 600 lbs. per sq. inch. Actually the field tests of concrete used for the silt skimmer justified the assumption made in the design.

Actual observations made on the efficiency of the silt exclusion were not sufficiently conclusive to prove or disprove the claims made for this arrangement. The main reason was that sufficiently systematic observations had not been made as yet. He understood from Dr. Bose that more systematic observations would be made in the coming summer and it would then be possible to get some definite information on some of the important points which had been in the debating box for a considerable time.

In the design of the reinforced concrete cantilever bridge the most important item was the bearing plate on the piers, but the speaker failed to find any details of the bearing plate in the drawings attached to the paper. It was hoped that author would make up this deficiency when submitting his final comments.

Dr. N. K. Bose contested the claim of R. B. Kanwar Sain that the Silt Excludes in the left pocket was the most efficient, and stated that apart from the silt tests carried out on the model of the Haveli undersluices the analyses of the data of silt observations carried out at the Trimmu Headworks during the summer of 1939 and the comparison of similar observations carried out at Khanki Headworks, during the period 1939-40, led him to believe that the efficiency of the Khanki type silt excluder was, on the data so far obtained, as high as that of the left-hand silt excluder at Trimmu.

He said that a note on this subject was being written and would be submitted to the Chief Engineers. From the analysis it appeared that as the discharge ratio (the ratio between the discharge that is going through the tunnels over the discharge which is going into the canals) increased from about 120 to 300% the efficiency of the left-hand silt excluder at Trimmu also increased from a value of about 10 to 12% to 75%. The efficiencies had been calculated on the lines as suggested by Mr. Haigh in his Punjab Engineering Congress Paper No. 211 on Silt Excluders. If the discharge was below 100,000 cusecs the above relation was found to hold satisfactorily. When the river discharge went above this limit the efficiencies became very small, of the order of 7 or 8%. It was easy to understand this sudden drop in the efficiency of the silt excluder for river discharges above 100,000 cusecs. At that stage whether the river was rising or falling, all the silt carried by the river was churned up and the vertical distribution of silt at any point, even inside the pocket was more or less uniform. This had been verified by a number of bottle samplings taken in the pocket. Under these circumstances the slab of the silt ejector would not be able to separate the more heavily laden water from the less heavily laden water and in consequence the efficiency would come down.

Similar analysis was carried out of the silt observations at Khanki Headworks. The discharge ratio for Khanki had been maintained more or less at the same level, that is 8 to 12 per cent., and the efficiency varied between 35 to 40 per cent. The corresponding efficiency in the case of Trimmu was very small. In the case of Trimmu it would be necessary to have a discharge ratio of about 200 per cent. to attain the same efficiency as at Khanki. It was proposed to carry out a series of experiments varying the discharge ratios with different river conditions and to work out the efficiencies. It was expected that some more interesting results would be obtained during the course of next year. All the analysis that had been so far carried out on efficiency related to coarse silt, that is silt with diameter coarser than .2 mm.

It must be pointed out here that there was a great difference between the silt to be obtained in the river Chenab at Khanki and at Trimmu. At Khanki the percentage of coarse silt was very great. Silts of diameter even coarser than .6 mm. were contained to the extent of 10 to 15 per cent. in the river water. Whereas at Trimmu the percentage of coarse silt was very small and no particles coarser than .6 mm. were ever come across in the river water. This point would make it clear why such an elaborate arrangement of silt excluder at Trimmu was necessary, whereas at Khanki a much simpler type has been able to serve equally well. This point was worth remembering whenever any proposal on silt excluders were taken into consideration.

Rai Bahadur A. N. Khosla made the following remarks in reply to Dr. J. K. Malhotra's criticism on design:

(1) *The Upstream Pile Line.*—This was fully dealt with in the C. B. I. Publication No. 12. Its primary function was to safeguard against upstream scour. Failures on this account were known to have occurred at the Narora, Khanki and Rasul weirs.

(2) *The Downstream Pile Line.*—The downstream pile line at Trimmu was designed with due regard to the factors of safety in exit gradient recommended in the C. B. I. Publication No. 12, and to the likely depth of scour. Slight modifications in length were made to suit the lengths of piles available at the time. The factor of safety was considered in conjunction with the extent of the heavy block protection and loose stone apron at the downstream end. Engineering judgment would in all cases decide as to whether the upper or the lower limit of factor of safety should be taken in any particular design and the choice would be governed by the type of soil, the main features of design and the disposition and extent of semi-permanent and loose protections.

(3) *Layout of pressure Pipes.*—The number and location of pipes at the Timmu Weir were fully adequate and satisfactory. A closer spacing at the downstream end would be of no additional help but would unnecessarily add to the cost. The treatment of this aspect of the problem, as outlined in the C. B. I. Publication No. 12, was comprehensive. Dr. Malhotra's suggestions were, however, sound. Regarding foundation-soils composed of mixtures of sand and shingle, the usual principles of design relating to pure sands would fully apply provided that the mix was sensibly uniform throughout a section and—this is most essential—the sand volume was enough to completely fill the voids in the shingle. If the latter condition were not fulfilled, pipe flow would occur and the theory of uplift pressure relating to sand foundations would not apply. The word homogeneous, in the case of soil formations had a wider meaning and included soil mixtures of various grades provided these mixtures were uniform and contained enough fines to obviate the possibility of pipe flow.

Rai Bahadur Khosla sounded a note of warning in respect of the interpretation of uplift pressures by means of contours as proposed by the author. This method was misleading and could be dangerous in its application. The pressures along each line of pressure-pipes must be dealt with and interpreted independently as the extent and nature of silt blanket on the upstream and downstream floors would differ from line to line, and would affect the uplift pressures differently on different lines. To link pressures on different lines by contours would be utterly wrong.

The Author in replying to the discussion, thanked Mr. Khosla for his amplification of the subject and the addition of fresh valuable matter.

According to Mr. Haigh, the alignment of Left Marginal Bund had to follow the Jhang-Bhakkar Road. This alignment of the road was, however, unsuitable as due to constant ponding inside the bund the road would tend to get waterlogged. This alignment was ultimately abandoned in favour of the alignment along the Jhang Shorkot Road which was at about the same level as the pond. If the B. & R. Branch had selected this alignment from the very beginning the Left Marginal Bund could have been better aligned.

As to the discharge through the silt ejectors, subsequent experience had shown that there was no difficulty in working them.

The author agreed that the design of menial quarters at Kalabagh was an improvement in point of economy. These quarters were meant to last a few years only.

Referring to Dr. Malhotra's remarks about the utility of U/S and D/S Pile Lines the author referred him to Mr. Khosla's further remarks.

Mr. Khosla had also dealt with the remarks regarding the number and location of pressure pipes.

As to Dr. Malhotra's remarks regarding the profile of regulators; the matter was still under investigation in the field and the laboratory and the mathematics of it was being subjected to critical study. But the engineers could not hold up construction pending a conclusive proof of the underlying theories. The principle underlying Mr. Montagu's formula—on which the regulator profiles were based—was to give the maximum horizontal acceleration at every point on the profile and so to secure the most economical length of masonry work. Since a profile cannot be altered with a varying discharge, such profile must be calculated for full supply conditions. Dr. Malhotra's statement in regard to vertical component of velocity and of acceleration seems to be open to question.

Any fallacy in Mr. Montagu's treatment would naturally show up if there should be any sign of failure of works designed in accordance therewith.

Referring to Mr. Chopra's remarks the author agreed that the additional cross walls suggested by him would be an advantage. During construction, cut-offs were provided at the upstream right guide bank where it was joined by the second upper ring bund (Plate IX). Similar cut-off was provided for segregating the right pocket from the rest of the work. The latter bund came into action after river diversion. At both sides two cut-off walls were constructed about 100 ft. apart with foundations about 2 ft. below the apron and slope pitching. The apron and slope pitchings in between the walls were carefully sand-grouted and the bund constructed on the grouted stone.

After the river diversion the Right Half of the weir was to be used for passing the river discharge while work had to proceed in the Left Half. Similar cut-off walls, both on U/S and D/S floors, were constructed between bays 19 and 23 and aprons sand-grouted. The cut-off walls were taken well beyond the apron edge so as to be embedded well in the sand embankment to avoid piping round the wall.

As to the surface cracks, they were most prominent during the construction period. Later, as anticipated, due to lesser temperature variations they were never found to be so marked. A careful record was maintained of these cracks and checked every year. These had given no cause for anxiety whatsoever.

The mass concrete laid at Islam and Panjnad had been found to be spongy below the surface and it was suggested that the Trimmu concrete would be found to be similarly spongy. To test this 3 feet deep holes were bored in the weir profile at Trimmu but the concrete was found to be dense and completely homogeneous as a result, obviously of thorough and efficient wriggling and vibrating.

As to Mr. Chopra's enquiries regarding the water way, a plan attached showing developments each year would avoid lengthy narration. Naturally the barrage having been constructed outside the river course, the entry was oblique. On the D/S side it again swung back to old course leaving at an angle. The obliquity of flow both on the U/S and D/S caused some settlement of aprons, but it was nowhere big. The river entered through a very tight section and unless there was a big flood this would not scour the bela on the left. It evidently meant strain on the Right Guide Bank apron at nose which was made up every year. The Apron on D/S Left Guide Bank and Right Guide Bank were laid higher than floor and were bound to settle. The statement on plan gives the figure for maximum flood and stone dumped to make up the aprons each year.

With bigger floods the waterway could clear out further but even at present it had opened out sufficiently and there was no cause for anxiety.

The fish ladders were worked each year but fish had not yet been attracted. Probably the entry did not advertise itself too well.

As regards Mr. Khanna's remarks that the pipes started to flow in spite of low pumping level in the sump this would naturally be expected. The pile line cut off communication to the sumps. This point had already been brought out in opening remarks on the subject of pumping.

As regards Mr. Khanna's remarks regarding the strain on power there is no doubt that the greater the power capacity the more efficient the working would be, but no matter how new the plant be, breakdowns cannot be avoided—and these were rare at Trimmu. Even at Kalabagh where, new power-sets were installed, breakdowns had been occurring. The author was still of the opinion that it was best to open up the entire area. The programme should, however, take account of possible dislocations and breakdowns.

Regarding Mr. Handa's remarks on pumping, although local conditions would determine the detailed organizations, the author had prominently brought out the general principles which must not be lost sight of and which presented a test which every pumping scheme ought to satisfy. Mr. Handa's narration of the pumping schemes at various places might be correct as a statement but could not be the last word on efficiency of the scheme. At Sidhnai there was no pumping as the subsoil was lower than the foundation of work. Pumping from scour pits cannot be carried too far as it may as well bring sand from under the floor. Besides, pumping schemes for remodelling of an existing work would have to be differently organized as the problems are different. The author had advocated for new construction sump pumping outside and only tube-well pumping inside and this was supported by what had to be done at Marala as the ultimate solution.

As to the merits and efficiency of the pumping scheme at Kalabagh, the author would have preferred to leave it to the judgment of the members who were visiting this work but as the matter had been brought in, he would state that the pumping scheme as originally existing at Kalabagh was not a happy one. Due to shallower and high-level works having been rushed, the outside sumps had become ineffective and heavy pumping under the floor area was causing heavy cavitation. This was exactly what was to be avoided and the author was glad that eventually the pumping scheme at Kalabagh in the left undersluices had been modified to conform to the requirements as in the opening remarks.

At Kalabagh heavy cavitation had occurred under the floor due to greater area getting blinded, resulting in heavier seepage and, therefore, heavier pumping required as the work proceeded.

As a further improvement it was suggested that if a series of tube-wells had been left in the main floor, part of the supply that was pumped at the last stage could have been diverted and the discharge available at the last stage would not have been too much to cause heavy cavitation. In fact by multiplying pump sites, the resultant lesser discharge may have caused very small cavitation, if at all.

As to R. B. Kanwar Sain's remarks the author admitted that the volume of the paper was big and he had of necessity to be unduly terse in places. As to the design probably each matter deserved considerable amplification. He, however, only gave the bare outlines and the factors considered on which design was based.

As to R. B. Kanwar Sain's remarks regarding the bearing plates of the bridge probably the late printing of drawings was responsible for the misunderstanding. These details were shown on the plate VII.

The author further thanked R. B. Kanwar Sain for amplification of the design part of the subject, on which he was the right man to speak with authority.

Referring to Dr. Bose's remarks about experiments at Malikpur, the author stressed that it was not advisable to place too much reliance on results of model experiments unless some of these were borne out in actual practice. As to the aligments of Guide Banks the author could state that what results Dr. Bose had reported with a different alignment were being found with the alignment as constructed. In the opinion of the author the results were due to the configuration of entry and had nothing to do with the alignment.

Similarly the diversion-cuts as proposed by Dr. Bose were not excavated and the one actually excavated gave more satisfactory results.

The author had supplied the data relating to observations on silt excluders both to Dr. Bose and R.B. Kanwar Sain and had clearly stated that the data so far collected were insufficient and due to peculiar circumstances, might take some time to complete. As such, it would not be advisable to base any conclusions on these. He was, however, surprised to find that by rejecting inconvenient data, strange conclusions had been arrived at. No conclusive opinion as to the relative efficiency of one or the other type of silt excluders could be given unless considerable data of their behaviour under various conditions were available.

It might further be mentioned that different methods of regulations for left excluder were being tried and this experiment might take 3 years before coming to a conclusion.

Dr. Bose's figure of 100,000 cusecs of discharge was arbitrary at this stage, the river was not in flood and silt charge not heavy. What was wanted was to determine the efficiency when silt charge was heavy. It may also be mentioned that regulation on right side (with Khanki type excluder) was not being done with the object of excluding silt and therefore the comparison of the results of two would be futile.

In view of the above statements and the inadequacy of data Dr. Bose's conclusions appeared to be premature.

The author finally thanked the members who had contributed to the discussion.