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# REPAIRS AND REMODELLING OF RASUL WEIR, 1929-1931.

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## Preliminary.

On the 28th August, 1929 the river Jhelum came down in high flood owing to heavy rain throughout the Jhelum valley. This flood caused extensive damage to Rasul weir and it is the purpose of this paper to give the history of the flood and of the consequent repairs; these repairs led to the remodelling work which is also described.

The following are the sections in this paper and explain its scope :—

(1) Description of weir.

(2) History of flood.

(3) Summary of damage.

(4) Programme of repairs.

(5) Detailed description of the repairs bay by bay.

(6) Description of flood of April 1930 which interrupted the repair work.

(7) History of remodelling proposals.

(8) Details of remodelling work done in 1930-31.

(9) Statement of works still considered necessary for the complete safety of the weir.

## Description of weir existing prior to 1929.

Rasul weir, prior to the repairs and remodelling work described below, consisted of 12 bays of under-sluices of 20′ span and 8 bays of weir proper of 500′ clear span each.

The weir was divided from the under-slucies by a stone-pitched divide groyne upstream and a short stone masonry continuation of the abutments downstream. The Lower Jhelum Canal regulator took off on the left bank above the under-sluices.

The weir was provided with upstream guide banks on the old fashioned Bell's bund pattern : the right guide bank was stone-pitched for 4,500 feet and thereafter consisted of an earthen bank. On the downstream side on the right flank there was the stone-pitched Dilawar bund gapped to permit the Darapur torrent to pass through it; 1,800 feet downstream of the weir line there were two T spurs which constricted the waterway to 3,500 feet. The weir was built at a skew of 16° to the nominal river axis. In practice this skew is accentuated to about 26° to the true flood axis.

The weir section, as is shown on plate I, consisted of a flat upstream floor 30 ft. wide laid at the comparatively high level of 707·2 in bay 1 and stepping up ·15′ per bay. This upstream floor was protected by 25 ft. width of stone pitching laid at the same level as the floor. The downstream floor was laid with an approximately 1 in 15 glacis from the upstream floor down to R. L. 701·2, the length of the sloped portion being 90 feet with a further 6′ flat formed by line D of wells. Downstream of the glacis there was a 40 ft. width of stone masonry blocks and below that a 30 ft. width of loose stone pitching. The weir section was divided up by 4 lines of wells, A, B, C, and D. The upstream line of wells A was of shallow depth extending for 8 feet below the upstream floor and founded nominally on sand, though the sand contains an occasional admixture of small shingle. The A line of wells, though originally intended to be built as wells and sunk, was in practice built as a continuous obstruction and was in fact a drop wall 8 feet deep.

The B line of wells is under the crest and extends down to R. L. 685; it is founded on the alleged boulder bed which, we have reason to believe, consists very largely of small shingle up to 6 inches size.

The C line of wells is 58 feet from the upstream edge of the crest and goes down to R. L. 686 resting on the shingle bed.

The D line of wells is only 6 feet deep and goes down to R. L. 695·2.

The B and C line of wells have a solid capping down to R. L. 700. Below this the gaps between the wells are closed by timber piles. The timber piling is not effective in closing the gaps. The D line of wells is not piled and is in fact open below R. L. 699·1.

The thickness of the upstream floor is 2 ft. of rubble masonry in lime mortar. The floor between B and C is 4 ft. thick consisting of 2·75′ stone masonry flat with 1·25′ of stone on end. The floor between C and D consisted of dry ballast 9 inches thick, dry stone 1·83′ with stone on end course 1·17′. The stone masonry blocks downstream of the weir were 4′ × 4′ in plan and 2 ft. deep ; though built as blocks they generally act a monolith of 3 or 4 blocks. The pitched aprons both upstream and downstream of the weir were 4 ft. thick.

The weir was fitted with groynes in line with the piers. All groynes downstream were similar and consisted of rubble masonry blocks up to a distance of 144 feet from the upstream edge of the crest with 100 ft. extension portions of dry stone. The downstream groynes extended to a level of 711·2.

The upstream groynes 1, 3, 5 and 7 were dry stone groynes of the section shown extending up to R. L. 712. Their effective length was 100 ft. and they were given a flat batter upstream of this for an additional 50′. Groynes 2, 4 and 6 consisted of stone masonry groynes 100′ in advance of the weir proper and built up to R. L. 726. This portion of the groynes was founded on wells going down to R. L. 685. In advance of the masonry groyne there was a batter in dry stone extending from 712 down to the floor level in a length of 50′. All groynes both upstream and downstream were provided with a berm of 10 ft. The weir was originally fitted with shutters. In 1921, these shutters were replaced by a uniform masonry crest of ogee section 4 ft. wide on top with a uniform top level at 711·5.

**History of floods.**

The river commenced to rise from R. L. 710·3 on 27th. August, 1929 at 3·00 hours and continued to do so with minor fluctuations till 7·00 hours on the 29th. when a gauge of 723·5 downstream of the weir was attained. The subsequent fall was rapid at first and then gradual to R. L. 712 at 4 hours on the 31st.

The maximum gauges upstream of the weir were 724·2 and 724·7 on the left and right flanks. The midriver gauges at the peak of the flood were not read, but subsequently from silt and watermarks on the piers were known to have reached R. L. 728.

Plate 2 shows the profile of the river from bank to bank upstream of the weir. It also shows the waterway as enlarged through breaches of the weir.

The peak discharge was computed by formula for a drowned weir, and by river sections at 3 sites upstream and downstream. The assumptions made are considerable, but the results showed fair agreement and the flood discharge was finally accepted at 875000 cusecs.

**Summary of damage to out works.**

The Bell's bund was breached. The left bank T spur berm was scoured and a part of the side pitching destroyed. The right bank T spur was overtopped and extensive damage done to the pitching. The Dilawar bund was overtopped and levelled. The downstream right guide bank was overtopped and partially destroyed.

Upstream groyne 4 was entirely, and groynes 3 and 5 partially destroyed; groynes 2 and 6 had scour holes in the berm near the nose.

Downstream groynes 4 and 5 were entirely destroyed. The loose stone extension portion of groyne 3 was entirely, and that of groyne 6 partially eroded.

**Summary of damage to weir.**

In bay 2, 100′ of the upstream floor settled together with a corresponding amount of the A line of wells, the downstream stone apron being partially damaged.

In bay 3, 218′ of the crest failed and an equivalent amount of the upstream floor, line A of wells and the stone apron were missing. On the downstream side the damage consisted of a semi-elliptical scour hole between well lines B and C. A portion of the downstream blocks and stone in the right half of the bay were eroded.

In bay 4 the entire section was removed over about 250′ of the bay adjacent to groyne 4, the only traces left being the occasional fragments of titled wells in lines B and C.

In bay 5,110′ of the crest adjacent to groyne 4 was removed together with an equal length of the upstream apron. A line of wells, and the upstream floor, and of the B to C downstream floor, 2 wells from B line were not found. In addition the entire section of the weir downstream of the C line of wells was removed throughout the bay, except for a portion adjacent to groyne 4. The portion of the B to C floor, which remained was blistered and damaged.

In bay 6 there was no damage on the upstream side but on the downstream side the entire section was removed downstream of the C line of wells with the exception of about 1 chain of the C to D floor and blocks near groyne 6. The B to C floor was blistered and damaged.

**Programme of the repairs and sluicing capacity provided for winter floods.**

The Jhelum river rises early in the year and is at all times subject to heavy winter freshets. The repairs programme was devised to cope with this as far as possible. Also we were at first tied by the necessity of getting our earth supplies for the ring bunds largely from the right bank and our concrete materials and stone from the left bank.

The discharge records of the previous 11 years were examined and it was decided that we should have to be prepared to pass a winter flood of 150,000 cusecs. To do so the raised crest was removed in bays 7 and 8. An upstream ring bund was constructed throughout the weir, a downstream ring bund being constructed in bays 1 to 6. Cross bunds were made in bay 3 adjacent to groyne 2 and in the middle of bay 5, the downstream ring bund being tucked in at groyne 6 to avoid an additional bund here. The sluicing programme was :—

Up to 20,000 cusecs Through undersluices only.

From 20,000 to 100,000 Cut upstream ring bund in bays 7 and 8, and bring these bays into play.

From 100,000 to 120,000 Cut upstream and downstream ring bund in bay 6 and bring this bay into use.

From 120,000 to 150,000 Cut the upstream and downstream ring bunds in bays 1 and 2.

It is worthy of note that if the records had been traced further back, we would have realized that we might have had to cope with a higher discharge than 150,000. As however the weir in bays 7 and 8 was sufficiently strained with the flood of 250,000 in April 1930, which obtained relief by bursting the bunds in bays 4 and 5, it is providential that the bunds were not raised higher.

In practice a freshet of 30,000 was passed through the undersluices.

The works programme to accord with the sluicing programme was :

(*a*) Construction of a stone barrier across the breached sections of weir.

(*b*) Construction of the earthen ring bunds.

(*c*) Lowering the crest in bays 7 and 8.

(*d*) Completion of repairs in bay 6 and part bay 5.

(*e*) Completion of repairs in bays 3, 4 and part bay 5.

(*f*) Repairs in bay 2 and to outworks were carried on independently and simultaneously.

Before proceeding with a description of repairs bay by bay, it is advisable to state briefly the general principles on which these repairs were to be carried out.

In the absence of any previous criticism of the weir it was decided to restore it to the same general section as before. An upstream floor of 2 feet stone masonry was to be replaced, where it had been damaged, by a flat floor 1·5′ thick of reinforced concrete 30 ft. wide. The upstream edge of this floor was to rest on a line of piles taken down to the bottom of the scour hole and, where the weir had not been damaged, to a level of 686. In advance of the reinforced concrete floor the specifications called for a 20 ft. width of 4 × 2 × 4 concrete blocks and a 30 ft. width of 4 feet deep stone pitching depressed wherever practicable. On the downstream side the replacement was to consist of 2·75 feet of concrete with 1·25′ stone on end between well lines B to C. Between well lines C and D the floor was to be as above except that 1·75 feet thickness of concrete was to be provided. Below line D of wells a 40 ft. width of blocks 4 × 2 × 4 with a further 30 ft. of 5 ft. thick pitching stone was called for.

As seen above the A line of wells was, where destroyed, to be replaced by a line of piles, B, C and D lines of wells were to be replaced by concrete core walls, to be described later, in the deep scour hole in bay 4. In bays 5 and 6 where the scour hole had been silted up, the D line of wells was replaced by wells sunk as low as possible and in general down to R. L. 693. The solid crest was to be replaced by 6 ft. shutters in bays 3 and 4. The downstream groynes were to be replaced. The question of the upstream groynes was never generally decided. Groyne 3 was rebuilt up to the edge of the pacca floor only. Groyne 4 was rebuilt up to 712 in stone masonry blocks for the 100 feet upstream of the apron in which wells existed and was further connected up with the loose stone extension built for protecting the ring bund.

**Detailed description of repairs.**

The first essential was to close off the gaps in the weir and to turn the river through the undersluices. It was decided that this should be done by a stone barrier. Accordingly boats were collected and the work commenced. Plan No. 3 shows the alignment chosen for the barrier. Commencing at a point in bay 3, 370 feet from groyne 3 the barrier ran out at 45 degrees until it reached its general alignment 90 feet upstream of the crest in bay 3, from whence it was continued upto groyne 3. The velocities in bay 3 were not very considerable and this portion of the work presented no particular difficulty.

In bays 4 and 5 the enormous velocities through the breached section rendered the task extremely difficult. An alignment on the crest line direct across the gap was considered and rejected as we did not want to throw loose stone on to a position where the weir was to be rebuilt. The alignment finally chosen was selected to give the least reaction against the current which was approximately as shown on the plan. We were further influenced by the existence of small remnant of the berm of groyne 4 at point A. Accordingly starting at a point, 223 feet from the centre line of groyne 4 and in bay 5, the bund was run out directly to A, edging off the current as it went. This minimized scour in this bay. On the bay 4 side of groyne 3 there was originally a silt island as shown on plan. From point B on this island 95 feet upstream of the crest and 60 feet from centre line of groyne 3, the alignment A, B was chosen and work was done from both ends. Owing to the enormous velocities it was not possible to lay a mattress in the final closing section which was at about the point C. An attempt was made by anchoring a boat upstream of C to drift in the stone boats into the gap and so establish a layer of stone on the bed before the final erosion started as the gap was closed. This was only very partially successful and its chief advantage was that it provided an additional working face for the handling of stone. Through good working arrangements a very high speed of adding the stone was attained and the bund satisfactorily closed.

Although the bund was given an abutment at point B, this abutment was outflanked and the silt island eroded. Accordingly the bund had to be rapidly continued to meet the bay 3 bund at groyne 3.

Scour took place in front of the advancing bund, the maximum depth sounded in the closing section being 35 fee tat R. L. 674.

The bund was intended to be made top R. L. 711·5 and top width 5 feet and the stone to be laid at as steep a slope as possible. In practice the upstream face of the stone took a slope of approximately $\frac{1}{2}$ to 1. The downstream slope of the bund below a certain level at approximately 705 took a very flat slope of 2 to 1 owing to the velocity of the stream. Further it was found that a top level of 713 was necessary to enable the bund to stand slight variations in the river level and to afford safety against the settlements which were continuously taking place both during the construction and in the first fortnight after the bund was completed. The day after the bund was completed, the settlements were particularly dangerous and caused the bund to be overtopped and the top 3 ft. of it whipped off twice during the day on a width of a chain; a total of 13000 c.ft. of stone was added in maintenance during that day alone, All stone had to come from the left bank and pass over the powerful stream flowing through the undersluices. To enable the stone boats to work, both from the point of view of checking this velocity and to give them sufficient depth of water to work in, it was necessary partially to close the undersluices. This, of course, added to our difficulty in constructing the bund. It is intended that this particular difficulty shall not occur again as we are keeping a reserve of $1\frac{1}{2}$ lacs of stone on the right bank.

The bund was closed on the 30th. of October, work having been started about the third week of September. The discharge in the river below Rasul at the time of closing was about 12,000 cusecs. The afflux measured between gauge No. 2 and No. 4 was 3·4 feet. The true afflux across the gap was proximately one foot higher.

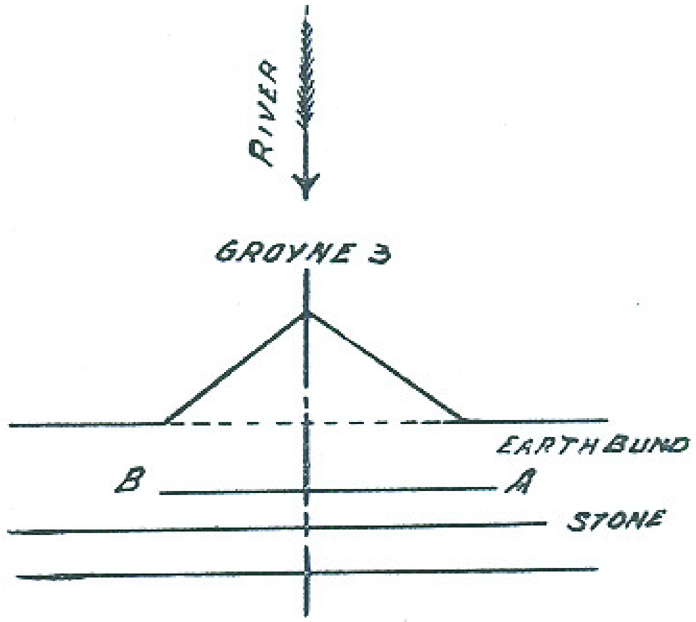
The stone barrier was, of course, extremely porous and before it could be staunched with an earthern bund, it was necessary to partially staunch it with a shingle and spawl facing. It was considered that 1 ft. thickness of this material would be sufficient. Unfortunately owing to the fact that the stone barrier had a $\frac{1}{2}$ to 1 slope, and as the shingle took up a 1 : 1 slope, the quantities of shingle required were considerably more than anticipated. They would have been very much higher still but for the fact that a certain amount of silting in the deeper levels upstream of the stone barrier had already occurred.

It was very necessary to add the shingle facing as quickly as possible to limit the underscour occurring on the stone barrier, Shingle and ballast being difficult materials to handle, country boats were fitted with tip wagons ; 6 tip wagons per boat. This secured rapid progress, but care had to be taken to tip the wagons alternately to avoid upsetting the trim of the boat.

The completion of the stone barrier on 30th. October just enabled water to be given for average *rabi* sowings on the Lower Jhelum canal and thereby prevented a wide-spread catastrophe.

The general alignment of bunds calls for no particular comments except in the large quantities of earthwork handled and the long leads from which it was necessary to get it. The bunds were designed for a 5 to 1 H. G. under flood conditions.

In bays, 3, 4 and 6, the earthen bund was placed outside the stone barrier to enable a staunch bund to be built. This alignment crossed the remnants of groynes 3 and 4. At both these junctions of the groynes with the stone barrier difficulty was experienced in getting a staunch bund. The first attempt was by thickening up the corner at the junction of groyne 3 as shown on the sketch. When this was done a trench was made on line A B and this was puddled with clay and sand. This was moderately successful in the case of groyne 3.




It was a total failure in the case of groyne 4. The leakage entering through groyne 4 found its way along the stone barrier and forced an exit at point C on the stone barrier, plate 3.

The next attempt was to build an earthen bund inside the stone barrier to within 50 feet on each side of point C and adding a reverse filter of small stone on the inside of the stone bund over this 100 feet. This reduced the discharge considerably but it was still greater than could be coped with by the pumps.

The next step was to continue the ends of the inside earth bund, referred to above to complete the earthen bund inside the stone barrier. This still further reduced the discharge but the water level of the water inside the stone barrier rose to the river level and breached the inside bund. During this time the stone groyne extensions, referred to subsequently, had been filled in advance of the outside earthen bund. By the addition of sand all round the outside of this stone extension groyne, the flow was finally reduced to a very small quantity, but never entirely ceased and was always a source of anxiety.

In bays No. 1 and 2 it was anticipated that there would be no flow and that the bunds were required only to be protected against wave action. It was thought that 1 ft. thickness of engine ashes would be sufficient to do this. This was done, but experience on April 9th, when there was a high river and much wind, showed that these were insufficient and that nothing less than 1′ thickness of spawls or ballast or shingle is a sufficient protection against wave action in the open river.

The upstream bunds in bays 3, 4, and 5 which were open to river action was protected by pilchi mattresses. The protection was perfectly satisfactory.

The bunds in bays 6, 7, and 8 were not protected as it was intended to cut these bunds very early in the season.

The downstream bunds were not protected against wave action. To keep the flow off them two spurs were built out to local islands in the river. The spur protection was perfectly satisfactory in preventing flow except just near the right flank of the downstream bunds, but considerable anxiety was occasioned during several freshets by erosion due to waves.

In addition to the pilchi protection, the upstream bunds were protected by extending groynes 2, 3, 4 and 5, a distance of one chain with top R. L. 718. These groyne extensions were very serviceable and that at groyne 2 has been allowed to remain as a part of the permanent works of the weir.

The damage in bay 2 is best seen by reference to the plan and sections of the repairs attached as plate No. 4. It will be seen that the upstream floor and apron were scoured on a length of 100 feet distant 55 feet from groyne 2. Settled portions of the floor were found at R. L. 697, *i.e.*, 10 feet below the level of the undamaged floor. The A line of wells settled in conformity with the general damage as also did the upstream apron although stones from the upstream apron were removed and were found heaped up against groyne 2 and against he raised crest. The reason for the failure is clearly attributable to the action set up by the groyne. The length of the groyne was obviously insufficient to enable this action to die out before the eddies reached the weir proper. The actual failure may have been caused by the deep scour in front of the upstream apron, or by blowing up of this thin floor ; the pressure under the floor would be approximately uniform, whereas where the eddy occurred the water surface level above the floor might be as much as 6 ft. below the general water surface level.

To guard against this action occurring in future, the groyne has been extended by one chain of dry stone hand-packed and built to R. L. 717.

The repairs to the floor were carried out by driving a 10 ft. line of piles from R. L. 706 down to 696 one foot in advance of the original alignment of the A line of wells. The floor was replaced by a 2 ft. thick plain cement concrete floor extending from the crest and overlapping the line of piles by one foot. On the upstream side of the line of piles the floor was made 3 ft. deep to get a proper grip of the piles. In some cases the piles came against the submerged wells which had been tilted outwards. The A line of wells was connected up with the floor in mass concrete. Wherever the stone masonry floor was damaged, it was cut back to a point where no damage existed and the old stone floor rested solid on its underlying sand.

The concrete used was 1 : 2 : 4 machine mixed, the aggregate being graded to give a dense concrete.

Repairs in bay 3 are typical of the repairs over the remaining of the weir. They are described in detail for this bay, and shown on plate 5.

The upstream stone apron is straightforward and calls for no comment.

The upstream line of concrete blocks 4′×2′×4′ were made of 1 : 3 : 6 cement concrete machine mixed. The blocks are separated by .4′ dry brick boxing and are stepped down from R.L. 707.4 to R. L. 706. Their construction calls for no particular comment.

Before commencing work in this bay, a line of cross piles was driven from the upstream pile alignment up to the C line of wells alongside groyne 3 to separate the damaged portion subsequently to be dismantled from the intact portion near the groyne. It is doubtful whether this cross piling was absolutely essential, but it was considered advisable to put it in as we have on this side the heavy masonry of the downstream groyne, which necessitated that there should be no withdrawal of the underlying sand foundation. On the opposite side piling was not resorted to, the damaged work was dismantled until an absolutely intact portion was reached.

The driving of the main line of piles replacing well line A presented no particular difficulties. Where the piles encountered stone, progress was naturally very much retarded, but the comparative straightness and verticality of piling would seem to show that none of the piles have sprung their interlocking arrangements.

The upstream reinforced concrete floor was made of 1 : 2 : 4 cement concrete machine mixed. The reinforcement consisted of ½ inch bars spaced 6 inches apart normal to the weir and one foot apart along the weir. The work was divided up by compartment walls into portions suitable for one day's work. The compartment wall consisted of a small dwarf wall 3·5 feet wide and 1 ft. deep just below the bottom level of the floor. The day's task was completed on a compartment wall, and before the commencement of the pouring of the next day's concrete, old concrete was stepped back. This arrangement has been successful in preventing through cracks due to temperature or setting contraction running out through the entire thickness. The concrete was mixed fairly wet and worked into place with rods.

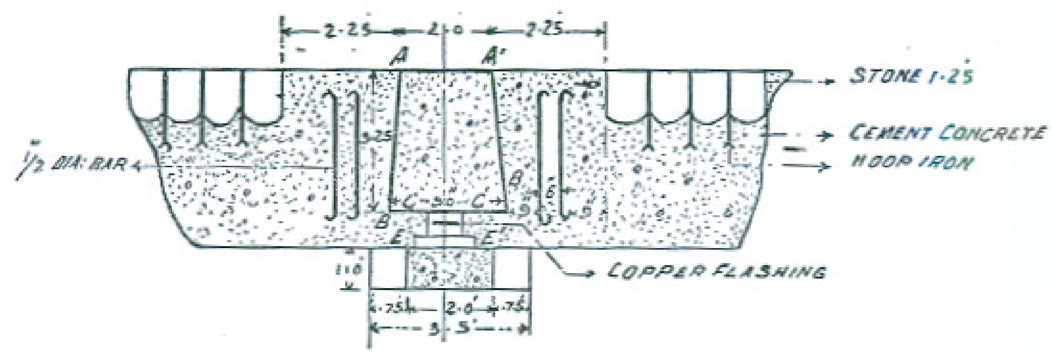
At the commenement of work it was considered that all wells in B line were intact as the capping of the wells, which for this line consists of the thickness of 6 ft. of brick masonry, was everywhere intact.

Detailed examination showed, however, that five wells were displaced, 3 of which were found very seriously tilted and two of which were not found at all. The brick masonry capping was spanning the gap in a flat arch of 70 ft. span. The brick capping was first removed and three new wells were sunk marked 1, 2, 3 on plate 5 ; the old well corresponding to well No. 1 was not discovered until sinking operations had been considerably advanced. This well eventually stuck on the old tilted well and itself tilted outwards.

Wells No. 2 and 3 were sunk satisfactorily to R. L. 685. In the case of wells 4 and 5, which had not been so badly tilted, a line of 10 ft. longsheet piles was driven with their tops at R. L. 700. The sand between the piles and the old tilted wells was excavated down to R. L 698 and a concrete core wall given up to this level. This wall therefore rests on a sand foundation boxed in on the upstream side by a line of piles and on the downstream side by the tilted well and in addition receives support from both of these points. The plan and section on plate 5 illustrate the work done.

The floor from B to C was replaced by a 2·75′ thick concrete floor of 1 : 3: 6 concrete on the top of which was laid a 1·25′ course of stone on end masonry. The stone on end masonry was bonded to the concrete by hoop iron reinforcement, 1 inch wide and 1/8 inch thick.

The work was divided up into portions suitable for one day's task and the concrete was poured in one unit, *i.e.*, not in layers, and worked with rods. Each day's work was separated from the next by an expansion joint. The construction of these is clear from the sketch below.




A compartment wall, 3·5 feet wide and one foot deep below the bottom level of the floor, was first constructed. On this was built ·75′ of brick masonry to house the copper flashing and a further seal above the copper flashing was given by working in puddled clay in the one inch gap between the bricks. The concrete of the floor was then poured up to the line ABCDE, being held by timber false work. The following day's work was similarly finished off and some days after the concrete wedge shaped and seal ABCC′ B′A′ was poured.

These expansion joints were examined the following year. There are always bound to be contraction cracks in concrete due to the setting contraction. These joints by providing a plane of weakness gave a definite line instead of an irregular crack. The joints were obviously working as contraction joints. In the morning when the temperatures were low, there was a distinct film of moisture all along the joint. As the temperature increased, this tended to disappear until by afternoon no moisture was visible. The trapezoidal section of the concrete sealing block effectively prevented any possibility of uplift.

No repairs were required in the C to D floor in this bay.

The weir had originally been provided on the downstream side with a 40 ft. width of 2 ft. thick stone masonry blocks. These had been settled by the flood of 1905, the bed being brought back after this to R. L. 790, by pitching stone dumped in on to the blocks and silt.

The flood of 1929 removed this pitching stone and probably further settled some of the blocks. During these repairs these blocks where they existed were brought up to R. L. 701 by 1 : 3 : 6 cement concrete blocks. Dry stone form work was used for these concrete blocks which were made 4 × 4 in plan as were the original blocks. Where no old blocks could be traced, the new blocks were made 4 feet deep throughout bay 3. The old blocks were traced up to R. L. 698 and the new blocks founded on them.

In the right hand downstream corner an alternative method of construction was followed. Wire trangars 4 feet deep and 6·5 × 16 ft. long were made and filled with stone for a depth of $3\frac{1}{2}$ feet. The trangar was then closed and concrete was poured 1 ft. thick over the trangar, the top of which was thus embedded in concrete. After some work had been done on these lines, this method of repairs was not considered as satisfactory as individual blocks and was accordingly discontinued.

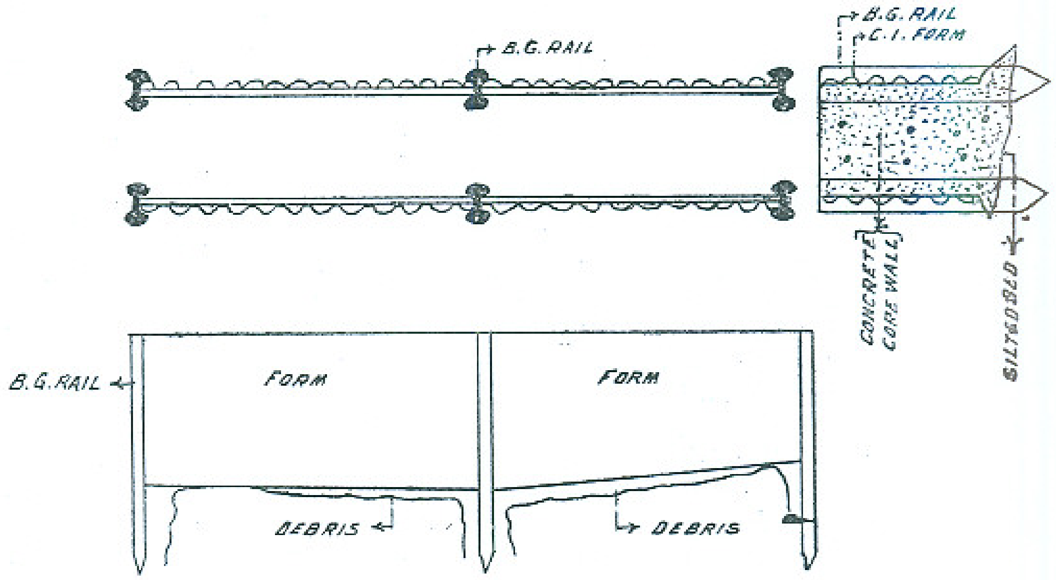
The downstream stone apron throughout the bay was examined and was found to be dangerously deficient in many places besides those where it had been entirely removed by the flood. It was accordingly entirely excavated and replaced with a 5 ft. thickness of new stone 30 ft. wide. Twenty feet downstream of the alignment of the stone apron there existed an old stone island made up of debris washed by this flood. This island was levelled down to R. L. 699·2 and connected up with the existing stone apron of the weir by a 2ft. thickness of stone laid on a 1 in 10 slope.

Bays 3 and 4 are shutter bays. During February 1930 the question of the additional velocities which will be induced in these by owing to their low crest was investigated; velocities were found to be extremely high on the upstream stone apron. The stone barrier which had owing to the scour reached a minimum level of 695 formed a protection against scour over half the bay. In this half of the bay accordingly it is only a question of protecting the large 4 × 2 × 4 blocks by something which will not be picked up but which has a certain freedom of settlement.

Accordingly instead of a loose stone apron in this part of the bay protection was given by means of 1 × 1·5 × 2 ft.(deep) blocklets. The top of these was sloped down 1 in 10 to R. L. 704·9 and they were finished off on the stone barrier. One foot thickness of spawls and small pitching stone was given underneath the blocks.

For the remaining half of the bay there is no stone barrier providing protection. Here the blocks as described before were made and beneath them a 2 ft. thickness of pitching stone was given. The function of the blocklets is to permit gradual settlement and it is hoped by their size and smoothness that they will not be picked up by the velocities prevailing.

The repairs in bay 4 were the heaviest as the entire weir section was wiped out on approximately half the bay, see plates 6 & 7. The principal difficulty was the replacement of the lines of wells. These had been washed away but the debris and in places tilted wells existed at varying levels. Piling and sinking new wells were considered as a method of repair but were rejected owing to the mass of debris which would have had to be pierced. The alternative adopted was a concrete core wall. By careful probings and verification of these by divers, the main blocks of debris and the tilted wells were located. Broad gauge rails were sharpened and driven with a monkey into these gaps, the long axis of the rails being on the river axis. The rails having been driven, corrugated iron sheets were cut to the exact shape to fit the bottom and stiffened with angle iron. The sketch below shows the method adopted :—




These sheets were slid into the grooves formed by the heads of each pair of rails and formed a false work for the concrete core wall. This core wall was then placed by skipping concrete to fill the cavity between the forms.

As the form work did not touch the debris along its entire length but was held on the highest point of debris, it permitted the concrete to fan out at the bottom which considerably increased the strength of the wall. The wall was brought up to R. L. 704 by skipped concrete and was here bonded with bent tram rails of 14 lb. section. The reason for this is that we were not ready at that stage to proceed with the further work.

Plate 6 shows the exact R. L. to which the concrete was poured. B, C, and D lines of wells were treated in this way and were replaced by a mass concrete wall. The maximum depth attained was about 689 on the B line, 683 on the C line, and 686 on the D line. The width of the concrete core wall was 8′-6″ on the B line, 7′-6″ on the C line, and and 6′-6″ on the D line. The concrete used was 1 : 2 : 4 to allow for the loss of cement in skipping.

The well lines having been replaced, repairs proceeded as described for bay 3.

**Stone aprons.**

Where, owing to the scour, depth was obtainable a small profile of solid stone was constructed at the upstream and downstream edge of the upstream and downstream stone apron respectively. Sand filling was carried out between these two profile walls and the normal weir repair procedure followed.

In most of the bays the upstream stone apron was depressed to R. L. 702 but in the 125′ adjacent to groyne 3 this was not possible and here concrete blocklets were given as in bay 3.

On the extreme right of the bay where the pile line encountered the debris of groyne 4, its alignment had to be curved to take advantage of gaps in the debris. The groyne had been broken into large solid pieces of complete section which had been overturned and in consequence a gap between the two adjacent sections had to be found. The new upstream blocks naturally followed the curvings of the pile line. The upstream reinforced concrete floor was similar to that made in bay 3.

The repairs of the B to C floor and the C to D floor were similar.

The fracture in the middle of the bay was not regular so that the lengths of floor replaced vary between the different lines ; that between lines A to B is 324′, that between B to C is 303′, and C to D 255′.

A certain proportion of the old downstream masonry blocks of the weir were found intact and others had settled irregularly. Where these blocks were intact, they were left and where settled they were brought up in concrete with dry stone masonry boxing up to R. L. 701. Where the blocks were missing they were replaced by blocks 4 feet deep and 4×2 in plan.

**Pressure grouting.**

At the time of the flood of April 9th. the upstream reinforced concrete floor had not been started, the B to C and C to D floors had been completed except for the last junction between the drop wall and the undamaged work. This was done after the flood. In the B to C floor it represented no particular difficulty, levels being comparatively high, but in the C to D floor great difficulty was experienced owing to the springs in the narrow trench left between the old work and the completed new work.

The method followed was to pour concrete mixed with 5% of soda to ensure rapid setting into the trench. Grouting pipes were left at intervals and then this concrete had set, pressure grouting was applied with a grouting machine. It is of interest that during the remodelling we subsequently examined and picked up the concrete so laid. On examination it proved impervious but somewhat soft, and I would not recommend the use of so much soda in concrete under similar circumstances. The grouting on the other hand was seen to have been extremely successful and layers of grout were found to force themselves through the weak points in the concrete and even under the concrete.

In bay 5 there is the boundary between the two units into which the repair work was divided for sluicing purposes referred to previously. Along this boundary a pile line was driven 188 feet from groyne 4 from the B line of wells to the D line. The work on the right of the bay was done at the same time as the work of bay 6 and that on the left with bay 4.

The pile line was continued from bay 4 up to a point in the centre of bay 5, beyond which it was not taken during the season 1929-30 owing to the proximity to the upstream ring bund. The pile line was picked up at this point in 1930-31 and continued right across the bay.

Repair works were carried out exactly as detailed for bays 3 and 4. The two wells of the B line of wells adjacent to groyne 4 were found tilted. These were repaired as detailed for wells 4 and 5 in bay 3.

The D line of wells, where missing in this bay, was replaced by new wells sunk down to approximately 687 R. L., where they stuck on the old stone and shingle.

In this bay in the B to C floor there were three examples of the failure by the uplift of the khoranja (stone on end course), the underlying courses being intact. These were repaired by straightforward replacement of the stone on end course in 1:1 cement mortar. The joints were left one inch wide and grouted with the same mortar.

Against pier 5, the failure of the C to D floor was complete and involved the complete destruction of the downstream groyne including the pacca masonry steps leading up to the pier. The repairs here followed standard designs but expansion joints were given to adjust differential settlement of the heavy masonry wall of the steps. The groyne was not rebuilt but a dry stone temporary groyne was given to protect the earthen cross bund in the middle of the bay. This dry stone temporary groyne was subsequently removed.

No repairs were required on the upstream side of bay 6.

Between B and C lines of wells there was a considerable uplift of the khoranja course, which was treated as noted for bay 5. The destruction of the B to C floor near pier 5 extended into this bay also and was treated as for bay 5. There was a very perfect example of the blow up of the stone on end top course in this bay ; in this case the destruction had not reached the stage of complete removal of the stone on end course, which was lifted up into a pimple, the maximum uplift being 3 ft. The gap between the stone on end course and the underlying courses was completely filled with sand. The underlying courses were comparatively intact.

One well of the C line of wells was missing, the failure being part of the intense action round pier 5. This well was replaced.

The remaining repairs were as already detailed. One chain of blocks was replaced with the trangars with concrete on top as already described for bay 3.

It is noteworthy that the B to C floor was damaged and C to D floor entirely eroded whereas over a considerable length of the bay, the old blocks downstream of the D line of wells were intact. This fairly proves damage owing to the standing wave although no wave was reported in these bays.

No repairs were required in bays 7 and 8. The only work done was the removal of the crest already referred to.

**Repairs to groynes.**

Groyne 3 upstream was replaced by a stone masonry groyne up to R. L. 712 extending only to the upstream floor.

The wells on which the upstream end of groyne No. 4 high groyne was originally founded had been tilted and split. They were repaired and the groyne rebuilt to R. L. 712 for a length of 140 feet upstream of the crest. The loose stone extension which had originally been carried to R. L. 718 was reduced to R. L. 712 and connected up with stones with the groyne, so that this groyne is now 405 feet long.

Groyne 4 was built as a solid wall except for the upstream 21 feet which were built as blocks to allow a slight settlement, the wells not being trustworthy in this length. The groyne was protected by a berm similar to that done to the downstream groynes.

A standard section was laid down for the downstream groynes. The groynes were to be taken up to R. L. 713, which enables them to control the river for discharges of 100000 cusecs which is the maximum supply of the river apart from floods of comparatively short duration. The groynes consist of concrete blocks with a stone facing built in three layers. The bottom layer is 10 ft. wide and extends from R.L. 696 to R. L. 701. The middle layer is 7 feet wide and extends from R. L. 701 to R. L. 707. The top block is 5 ft. wide and extends from R. L. 707 to R. L. 713.

The groyne is protected by a 20 ft. berm at R. L. 701 consisting of 10 ft. width of $4' \times 2' \times 4'$ blocks and a 10 ft. width of 4ft. deep wire trangars. Groyne 2 which was remodelled to this section in 1930-31 was given an additional 10 ft. of loose stone. It was orginally intended that the groyne should extend 100 ft. downstream of the loose stone apron of the weir, *i.e.*, 274 feet from the crest. Owing to the position of the downstream ring bund it was not possible to do this and groyne 3 was built to a length of 224 ft. from the crest.

Groyne 4 downstream was repaired to the standard section to a length of 249 feet.

**Repairs to outworks.**

The left bank T Spur was repaired to the original design. The berm, where destroyed, was given a shorter width on account of the additional depth into which the stone was thrown.

The right bank T spur was abandoned for the year 1929-30 pending a decision on the policy to be adopted. During 1930-31 it was repaired. The scour hole in the shank was also repaired and the shank extended back to meet the new right retired embankment. The shank was protected against the Darapur torrent by repairing a portion of the old Dilawar bund up to the stone pitched gap which existed in this bund.

The Dilawar bund was definitely abandoned.

The Weir was given a proper right retired embankment extending from the right abutment on the same alignment as the weir, and connecting up with the high land on the right bank. Where this retired embankment is liable to attack by the Darapur torrent, it has been pitched and has been given one spur.

The Bell's bund on the right bank was converted into a true right guide bank by giving it an armoured head at R. D. 4500. It was also widened to top width 30 ft. and raised to R. L. 730 to ensure a proper freeboard.

The canal had been protected by its spoil banks in the reach from Rasul to R. D. 70000. The gaps between the spoil had been connected up by light bunds. This was overhauled and a flood embankment made to R. D. 70000 to suitable levels allowing 5 ft. of freeboard over the flood levels.

**Description of flood of April 1930.**

The repairs were within one week of completion when a record winter flood was experienced.

The river started to rise at 18 hours on the 7th. The situation at that time was that the bays 7 and 8 were open and the bunds were still existing in bays 1 to 6 both upstream and downstream. At 3 hours on the 8th. as the flood was rising, the bunds in bay 6 were cut to bring this bay into action. At about 6 hours on the 8th. morning owing to a high wind extremely serious wave action was set up which eroded half the width of the upstream ring bund in bays 1 and 2. This action was counteracted by throwing in ballast, spawls, and broken bricks to face the bund. The river still continued to rise and at about 15 hours on the 8th. it was decided to cut upstream and downstream ring bunds in bays 1 and 2.

Three cuts were made in each of the bays. The upstream cuts eroded much faster than the downstream with the result that the water level between the crest and downstream ring bund rose to a considerable height and overtopped the downstream groyne 2 which was protected against hydraulic gradient by a cross bund. The cross bund was at R. L. 716 but was overtopped. Nevertheless apart from the damage done to the downstream groyne 2, and the working area being flooded, the situation was not desperate at that time.

During the night of 8th—9th. the gauge on the right flank rose to 719·95. The levels in mid-river probably were somewhat higher, but in any case as the bunds were only made with top R. L. 720, a breach occurred in bay 5 upstream bund and spread rapidly eroding the entire upstream bund in bay 4 and the downstream bund in bay 4 and most of bay 3.

The situation with regard to the repair works was that the upstream reinforced concrete floor had not been done in bays 4 and 5. The reinforcement was in position. On the downstream side the only work left was the sealing plug of the last contraction joint between the well lines B and C and also between C and D. A small amount of the stone on end course between well lines C and D was also missing. In bay 3 a certain amount of the upstream blocklet work remained to be done.

The upstream stone apron in bay 4 had not been completed.

The chief difficulty was the restoration of the bunds, which was rendered additionally difficult by the fact that owing to the high river there was no sand available in the weir area and all the sand and earth had to be brought from the left bank with 30 chains lead.

Connection was first restored with the left bank by an upstream bund in bays 1 and 2. While this was going on a gunny bag bund was built along the alignment of the old stone barrier in bay 5 to choke off the velocities which were too great for an earthen bund. An upstream ring bund was restored in advance of the gunny bag bund. Downstream ring bunds were also restored and the repair works recommenced. The repair works were completed on the 31st. of May.

The flood entailed very heavy loss of stock and plant and machinery. The loss of the latter was, however, only temporary, as after the flood, four of the portables were recovered from the silt in which they had been buried. The remainder of the portables and pumps were recovered during the working season 1930-31 and had suffered no particular damage despite being submerged throughout the hot weather.

This flood caused certain damage in bays 7 and 8, which were not discovered until the following working season. In bay 8 the downstream velocities were just sufficient to start shifting the downstream stone apron. It is calculated that the velocity was 9·6 feet per second and the depth on stone 13 feet. In bay 7 certain of the weir masonry blocks downstream were settled. This damage was repaired in 1930-31.

### History of Remodelling Proposals.

The repair design and programme had been framed to bring the weir into operation before the 1930 floods, subsequent remodelling being left over for further consideration.

While there is no absolute certainty, the Rasul breakdown may be attributed to the following :—

(*a*) The upstream floor and stone apron was laid at too high a level to permit the loose stone to stand the high velocities as in bay 2. The well line A was also too shallow to prevent sucking out of sand if the upstream stone apron failed.

(*b*) The upstream groynes inevitably caused swirls, and the length of the groynes was insufficient to permit these to die out before reaching the stone apron. The swirls and consequent scour besides destroying the groynes themselves damaged the weir as was found in bay 4.

(*c*) The high uniform solid crest had worsened conditions by the slight contraction of the waterway, but mainly by the loss of control for training the river channels.

(*d*) The crest section was weak and sheared off thus causing very high discharges and velocities in these sheared sections. These high discharges and velocities wrecked the downstream apron, blocks, and possibly the C to D floor as in bay 3.

(*e*) The uplift of the stone on end (khoranja) course in bay 9 demonstrates the action of the standing wave which possibly was the cause of failure of the C to D floor in this bay and also in bay 5.

The repair programme had catered for (*a*) in the bays actually damaged. It was decided to strengthen the other bays as well, and this forms the main item of the remodelling (see plate 8). It was originally decided to lower the apron to R. L. 704, and this was done in bay 8. With the experience gained it was found possible to lower the upstream stone apron to 702 instead of 704 without incurring additional expense and this was done in bays 1, 2, 5, 6, 7.

The usefulness of the upstream groynes occasioned much discussion. They do undoubtedly cause swirl action. Equally, if long enough they compel flow normal to the weir. The balance of opinion decided that the danger outweighed their usefulness. Accordingly groynes 1, 5, 7 were removed. Groynes 2, 4, 6 are founded on wells and with the stone added, much of which has gone to a considerable depth, were difficult to remove completely so that here it was considered advisable to lengthen the groynes by the addition of 100′ of pitched stone groyne at R. L. 717.

The waterway and control had been increased by the provision of shutters in bays 3 and 4 during the repairs of these bays. On further consideration bays 5 and 6 were fitted with shutters to increase control and reduce somewhat the high selective velocity which would otherwise have occurred in bays 3 and 4. To counter these higher velocities the top 2′ of the downstream stone apron was replaced by stone blocks and small concrete blocks 2′ × 1·5′ × 2′ deep.

The crest section replaced in bays 7 and 8 was made homogeneous with the floor and was strengthened by the 2 : 1 sloped upstream fillet. This fillet was put in in bays 1 and 2.

The downstream side of the crest may still be considered by some as weak and undesirable. Experiments are being carried out in the Research Laboratory to determine whether these defects are sufficient to necessitate its replacement.

The uplift of the stone on end (khoranja) course has been countered in the repaired downstream portions by tying it in with hoop iron reinforcement to the underlying concerte. This can be seen in the sketch of the expansion joint (page 117). The jet action on the hollow C to D floors has been met by making these floors solid (1·75′ concrete and 1·25′ stone masonry). In 1930-31 the remainder of bay 4 was thus treated so that the original underlying dry floor still remains in bays 1, 2, 3, 7, 8 only.

The methods of calculating the velocities on stone are shown in Appendices B & C attached.

The sections of the weir in the various bays as finally adopted may be seen by reference to plates 5, 7, 8.

The total expenditure incurred on the weir repairs and remodelling works was Rs. 33,90,000. A detailed statement of the cost of various works is attached.

Works described above may be said to have rendered the weir moderately safe for a flood of 9,00,000 cusecs.

There is still doubt whether the regulator is safe against creep and whether it has sufficient freeboard ; both these points are under consideration as is also the security of the undersluice floor downstream.

**Statement of costs.**

## (A) REPAIRS.

| | Rs. |
|---|---|
| (*a*) Cost of railway repairs .. .. .. | 2,03,252 |
| (*b*) Total expenditure on new tools and plants .. | 2,53,668 |
| (*c*) Expenditure on stone barrier.. .. .. | 1,28,226 |
| (*d*) Bunds .. .. .. .. | 2,97,656 |
| (*e*) Expenditure on weir works .. .. .. | 13,95,067 |
| (*f*) Total cost of flood embankment .. .. | 60,440 |
| (*g*) Total cost of right bank T spur repairs .. .. | 25,355 |
| (*h*) Total cost of left bank T spur repairs .. .. | 17,855 |
| (*i*) Total cost of right retired embankment .. .. | 22,738 |
| (*j*) Total cost of right guide bank .. .. | 53,305 |
| Total .. | 24,57,559 |

## (B) REMODELLING.

| | Rs. |
|---|---|
| (1) Bunds .. .. .. .. | 1,34,243 |
| (2) Upstream floor .. .. .. .. | 3,03,984 |
| (3) Downstream floor and groynes .. .. | 37,877 |
| (4) Piling .. .. .. .. | 1,70,035 |
| (5) Shutters .. .. .. .. | 92,880 |
| (6) Downstream apron .. .. .. | 57,629 |
| (7) Pumping .. .. .. .. | 1,03,437 |
| (8) Miscellaneous .. .. .. .. | 32,371 |
| Total .. | 9,32,456 |

## APPENDIX A.

DISCHARGE OF WEIR AND UNDERSLUICES FOR VARYING UPSTREAM T. E. LEVELS.

| | | | | | | | | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| U. S. T. E. R. Ls. .. .. | 713·0 | 715·0 | 717·0 | 719·0 | 721·0 | 723·0 | 725·0 | 725·6 | 727·0 | Discharge in lacs. |
| 4 No. Crest bays .. | 0·12 | 0·43 | 0·85 | 1·36 | 1·94 | 2·57 | 3·24 | 3·49 | 4·03 | |
| 4 No. Shutter bays .. | 0·78 | 1·28 | 1·74 | 2·34 | 2·98 | 3·72 | 4·38 | 4·61 | 5·16 | |
| Undersluices .. .. | 0·30 | 0·37 | 0·46 | 0·55 | 0·65 | 0·75 | 0·84 | 0·88 | 0·96 | |
| Total discharge, weir and undersluices. | 1·20 | 2·08 | 3·05 | 4·25 | 5·57 | 7·04 | 8·49 | 8·98 | 10·15 | |
| Discharge (normal distribution) per foot run. | | | | | | | | | | |
| (a) Crest bays .. | 6·0 | 21·5 | 42·5 | 68 | 97 | 128·5 | 163·5 | 174·5 | 201·5 | |
| (b) Shutter bays .. | 39·0 | 64·0 | 87·0 | 117.0 | 149·0 | 186·0 | 219·0 | 230·5 | 258·0 | Discharge in |
| (c) Undersluices .. | 125 | 154 | 192 | 229 | 271 | 312 | 350 | 367 | 400 | cusecs. |

## APPENDIX B

VELOCITIES ON UPSTREAM FLOOR FOR 9 LAC FLOOD.

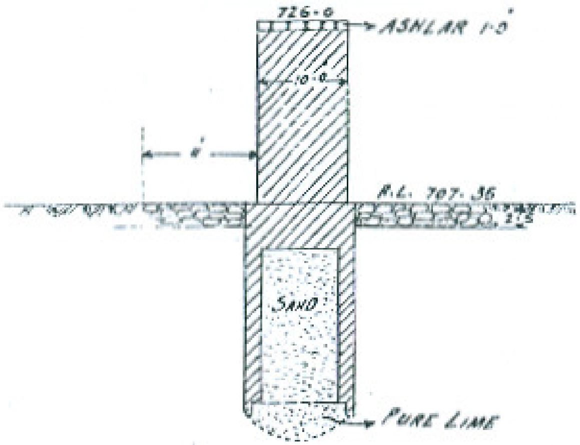
| | q for normal distribution. | Add 20% for excess. | q′ to be designed for. | U.S, T. E. R. L. to pass q′. | Correction factor for piers, etc. | Net discharge per foot run over stone. | W. S. R. L. Actual. | Stone R. Ls. | d. | v. | Critical velocity depth on sand. | R. L. of sandy bed. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crest bays | 174·5 | 34·9 | 209·4 | 711·5 + 17·0 = 728·5 | 500/510 | 205·3 | 727·3 | 704 | 23·3 | 8·8 | 29 | 699 |
| Shutter bays | 230·5 | 46·1 | 276·6 | 707·7 + 20·4 = 728·1 | Do. | 271·2 | 726·2 | 702 | 24·2 | 11·2 | 34 | 693 |
| Under suices flume upstream. | 367 | 73·4 | 440·4 | 701 + 27·7 = 728·7 | 240/335 | 315·5 | 726·4 | 701 | 25·4 | 12·4 | 37 | 698 |

## APPENDIX C.

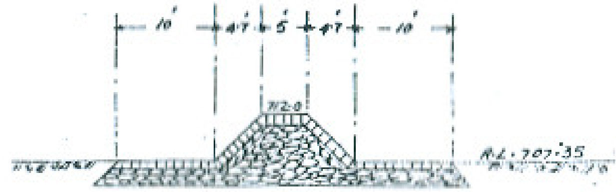
VELOCITIES ON DOWNSTREAM FLOOR FOR 9 LAC FLOOD.

| | q to be designed for. | Correction factor. | Discharge over stone. | D.S.W.S. R. L. at Gauge. | Critical depth. | R. L. of bed. | Critical velocity. | $h_a$ | D. S. T. E. R. L. | W. S. L. on stone. | V on stone. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Crest bays .. | 209·4 | $\frac{500}{510}$ | 205·3 | 722·3 | 29 | 693·3 | 7·1 | 0·8 | 723·1 | 720·8 | 9·8 |
| Shutter bays .. | 276·6 | Do. | 271·2 | 722·3 | 34 | 688·3 | 8·0 | 1·0 | 723·3 | 720·1 | 14·1 |
| Undersluice bays .. | 440·4 | $\frac{244}{316}$ | 335 | 722·3 | 37 | 685·3 | 9·0 | 1·2 | 723·5 | .. | .. |

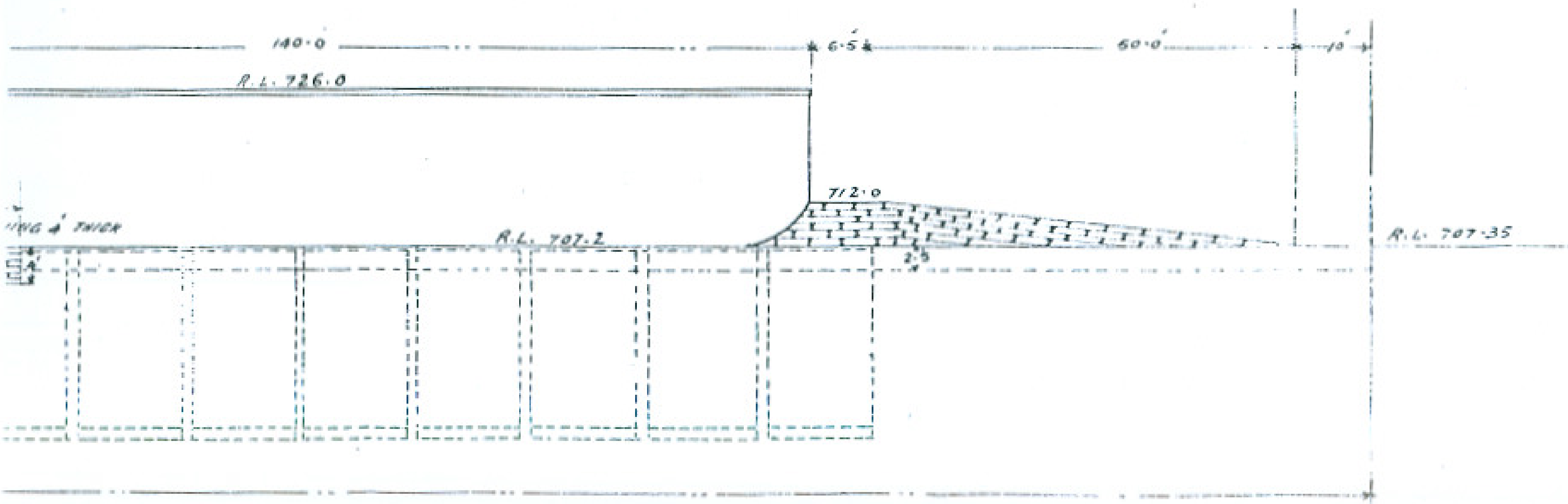
PLATE No. I




SECTION OF LARGE GROYNE



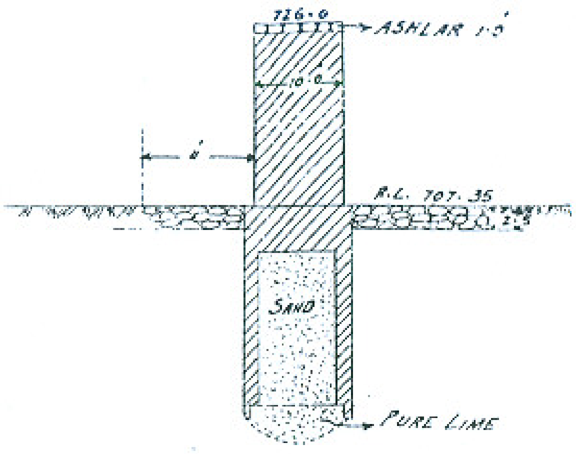

SECTION OF SMALL GROYNE



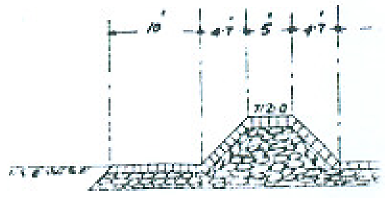
# RASUL WEIR AND GROYNE

BEFORE 1929

SCALE 1/200

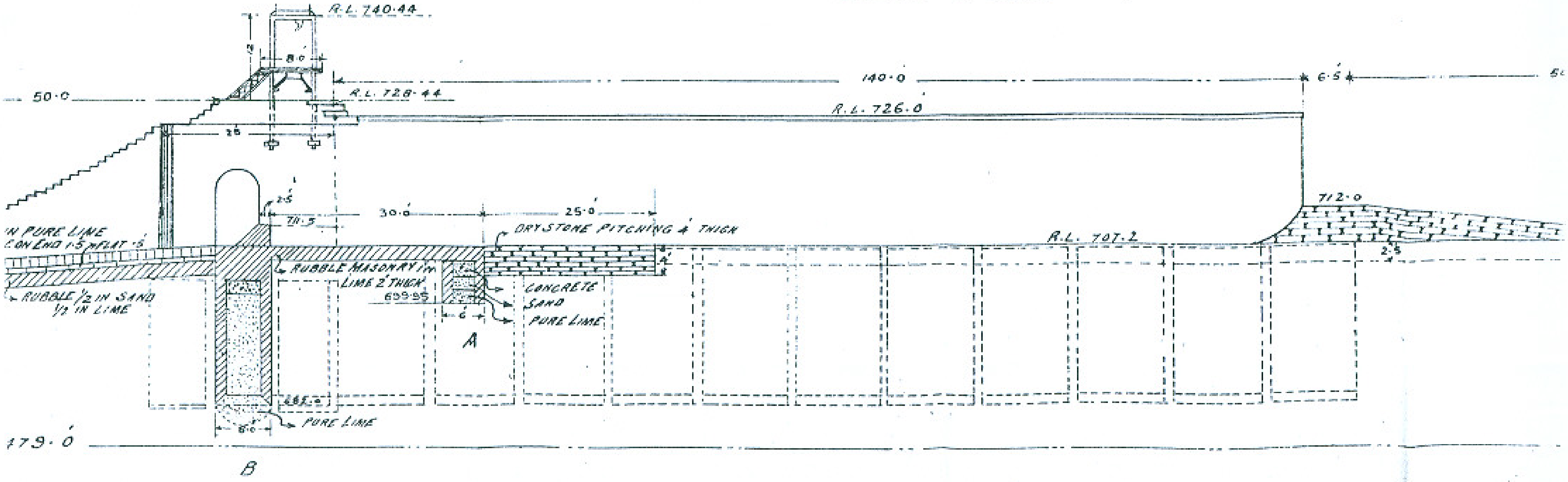


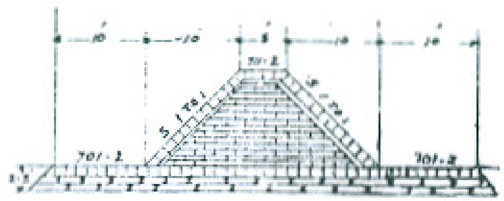

SECTION OF LARGE GROYNE



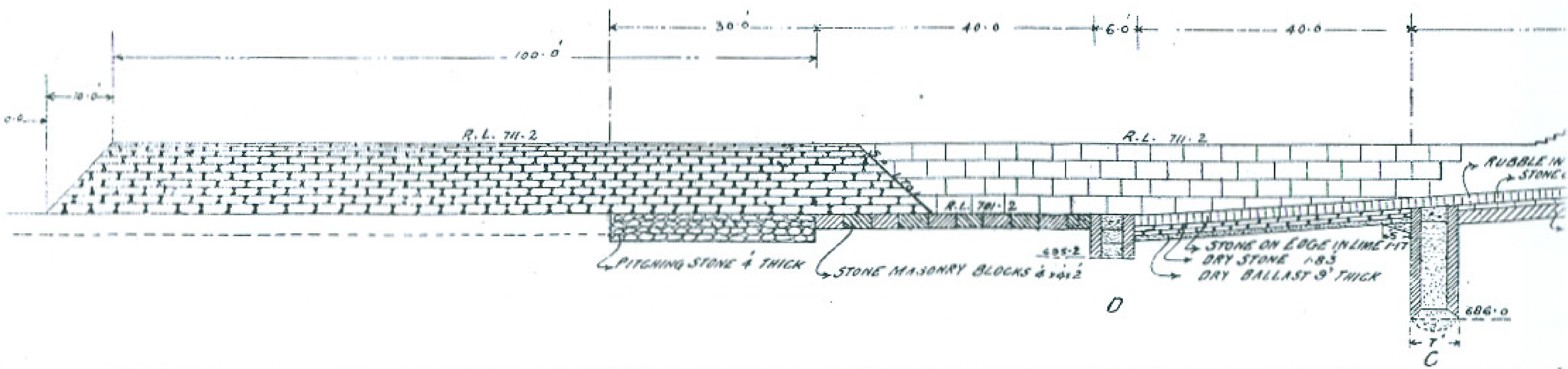

SECTION OF SMAL

CROSS SECTION OF WEIR






SECTION OF DOWN STREAM GROYNE



# RASUL WEIR DIAGRAMATIC SECTION

## SHOWING FLOOD WATERWAY 29·8·29

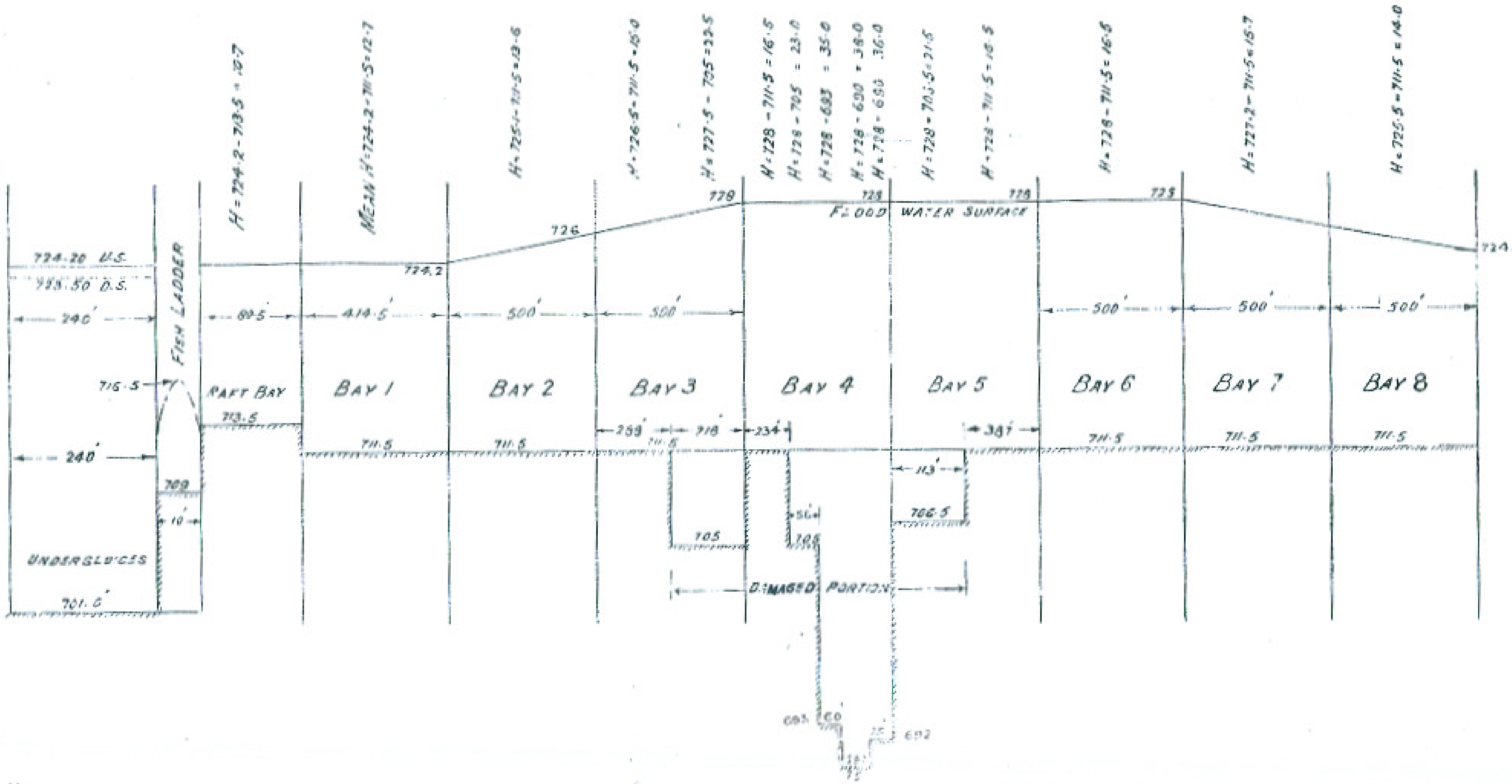


PLATE 3

# RASUL WEIR
## PLAN SHOWING ALIGNMENT
### OF STONE BARRIER
MADE FOR CLOSING GAP IN WEIR 1929

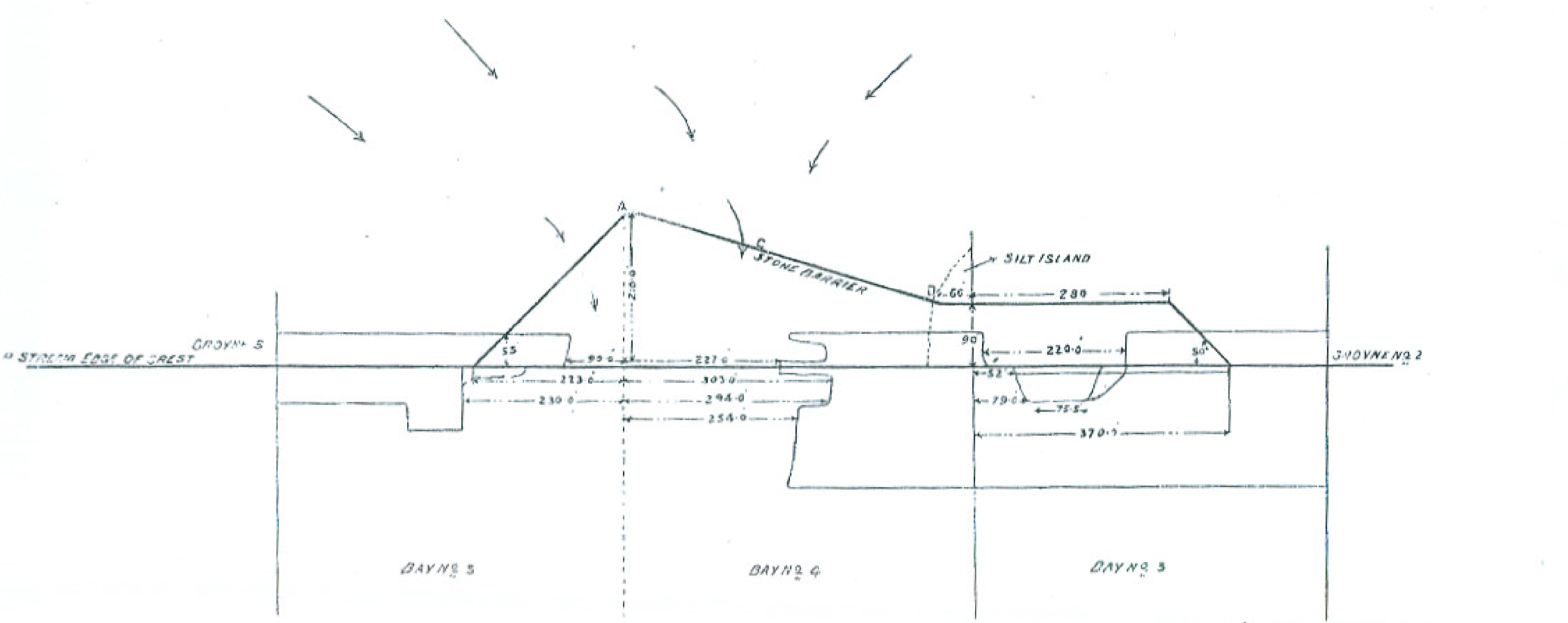
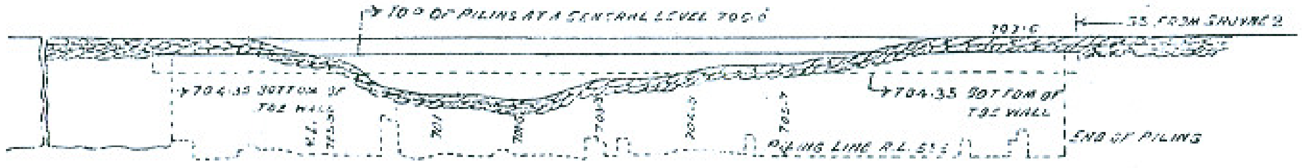


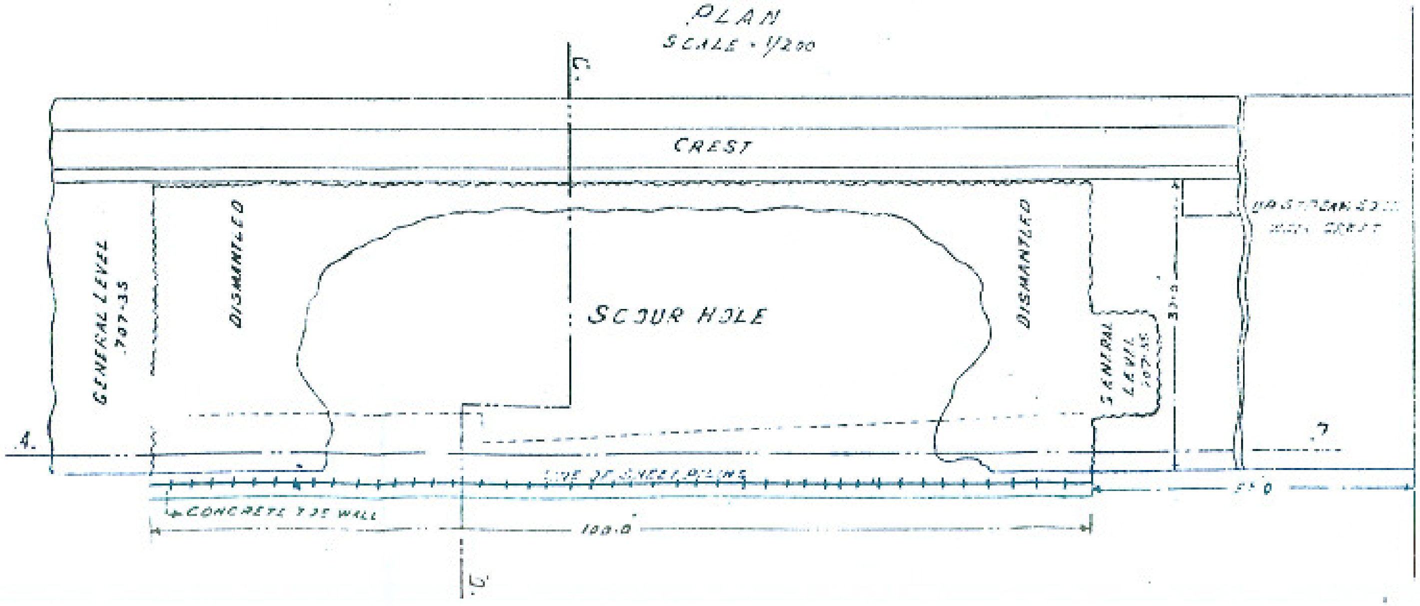
PLATE 4

# RASUL WEIR
## REPAIRS IN BAY No. 2
SCALE 1/200

SECTIONAL ELEVATION AT A.B.




PLAN
SCALE 1/200




CROSS SECTION AT C.D.
SCALE 1/100

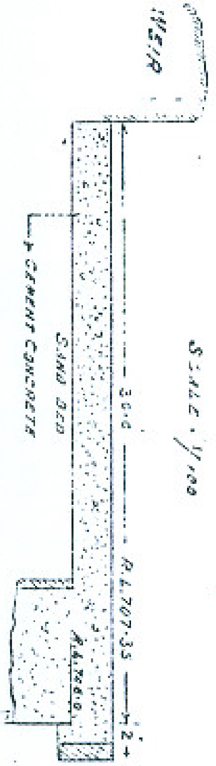
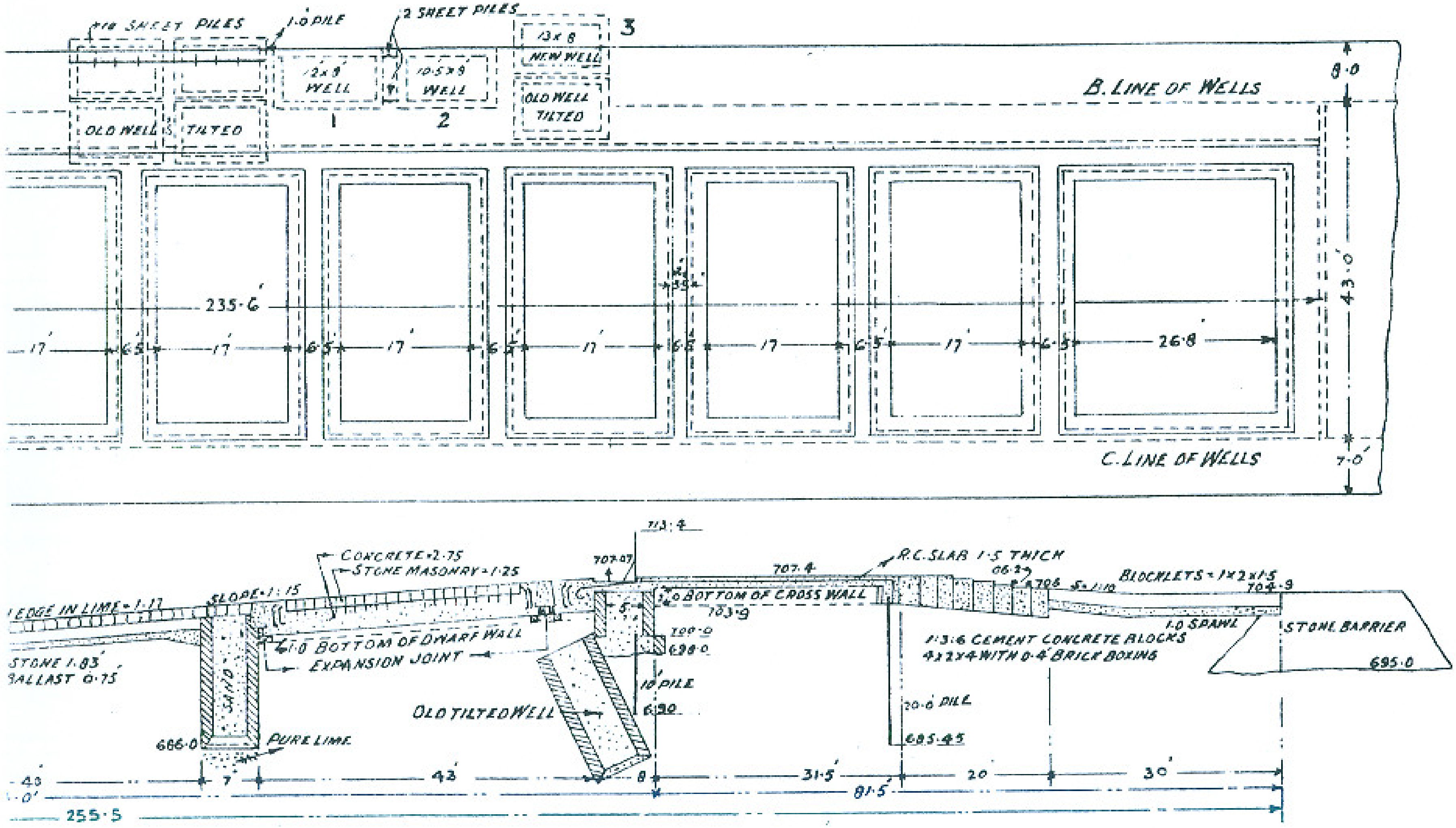


PLATE 5

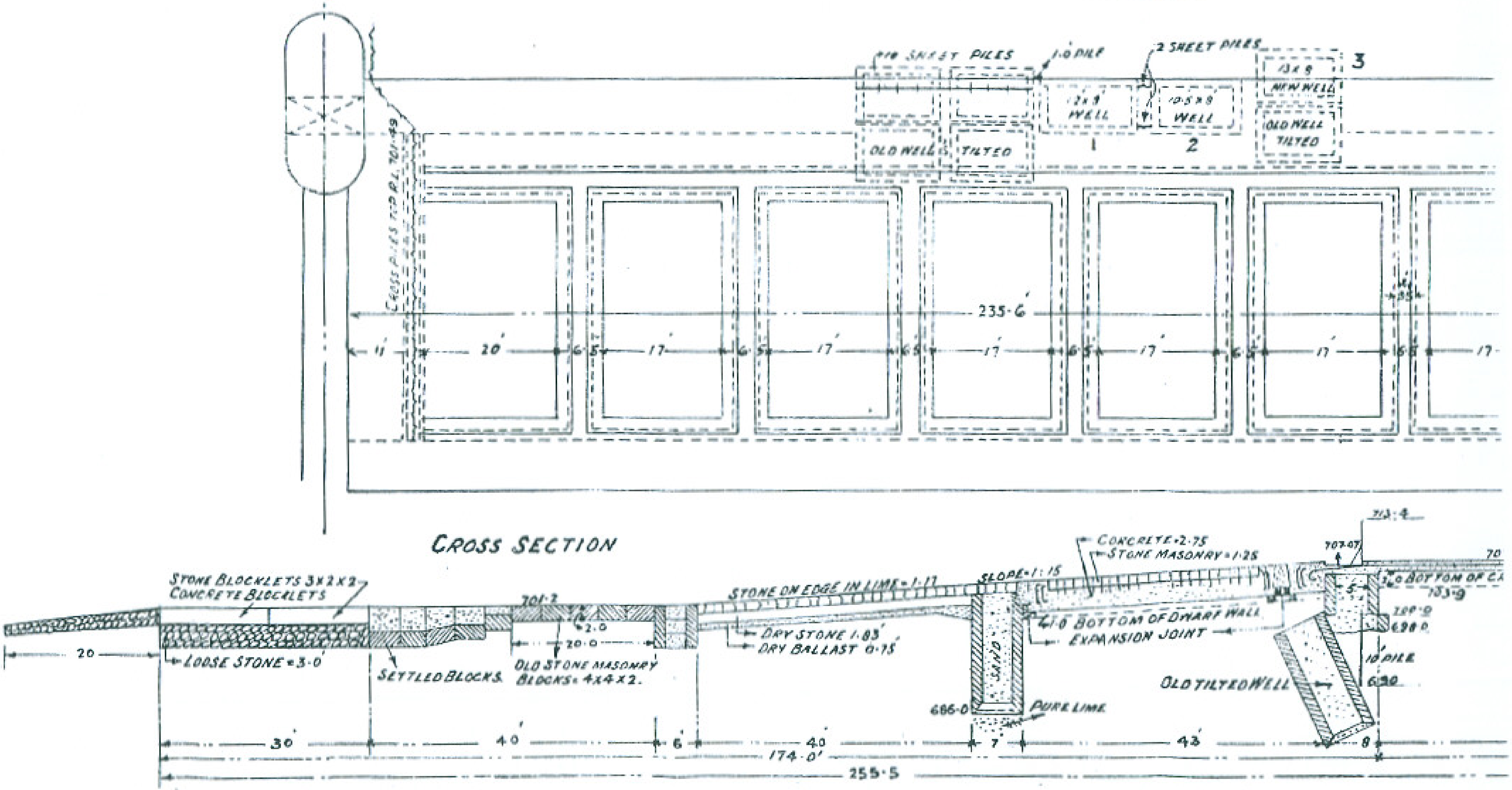
# RASUL WEIR
## PLAN SHOWING TILTED WELLS BAY 3

SCALE 1/200



## RASUL WEIR
## PLAN SHOWING TILTED WELLS BAY 3

SCALE 1/200



# RASUL WEIR

## LONGITUDINAL SECTION OF B. LINE OF WELLS BAY 4

SCALE=1/200

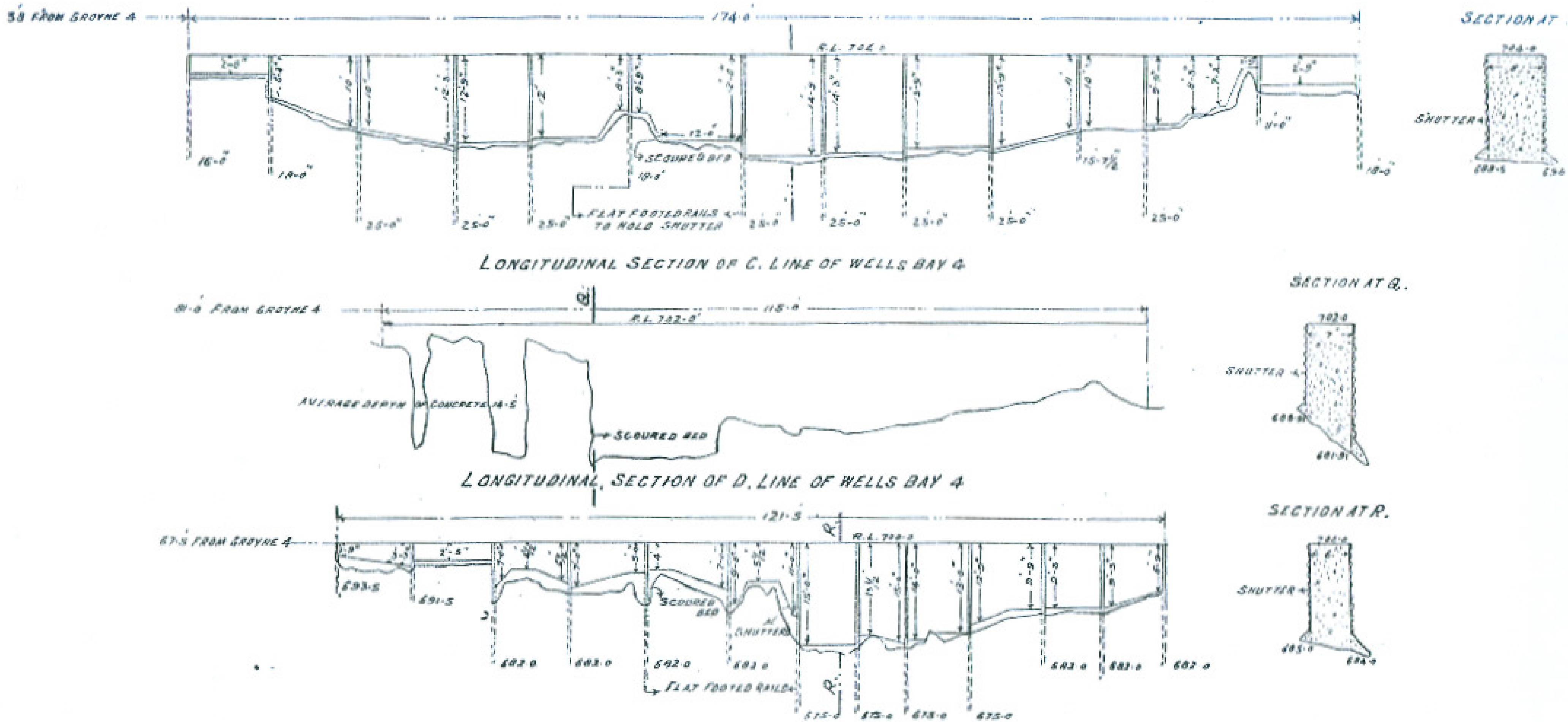
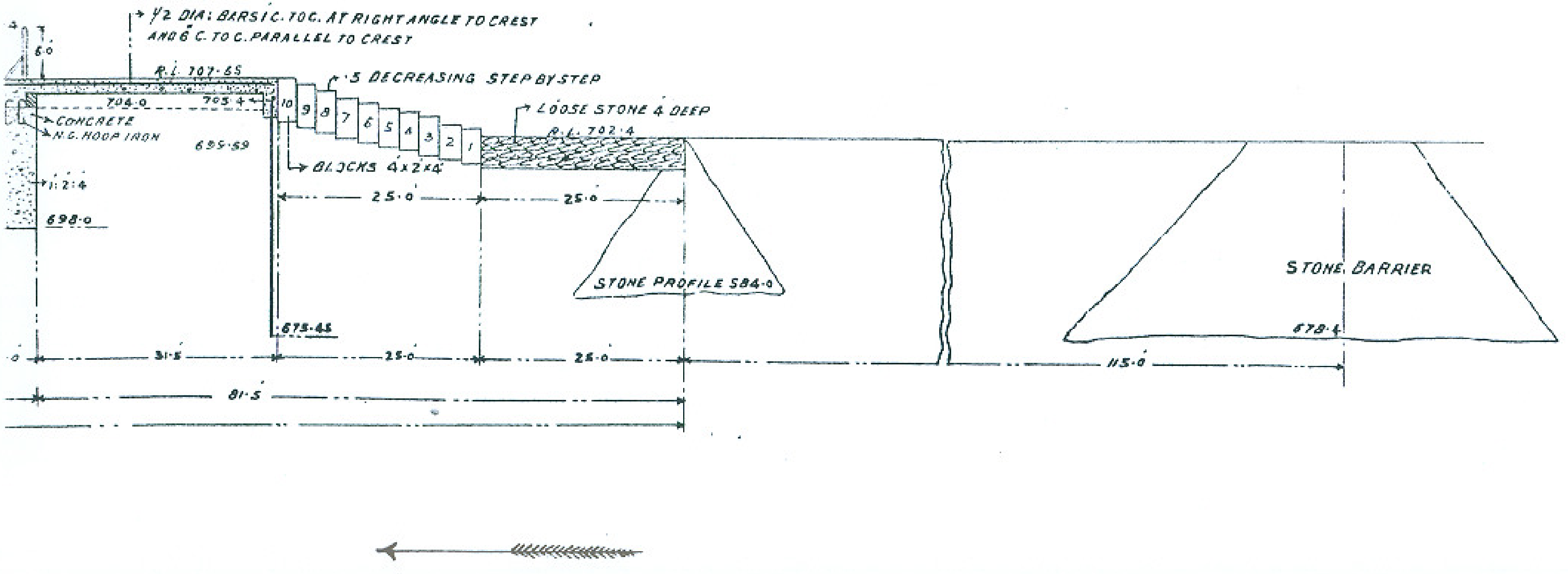


PLATE 7

SUL WEIR

CTION OF BAY No. 4

SCALE = 1/200



RASUL WEIR

CROSS SECTION OF L

SCALE=1/20

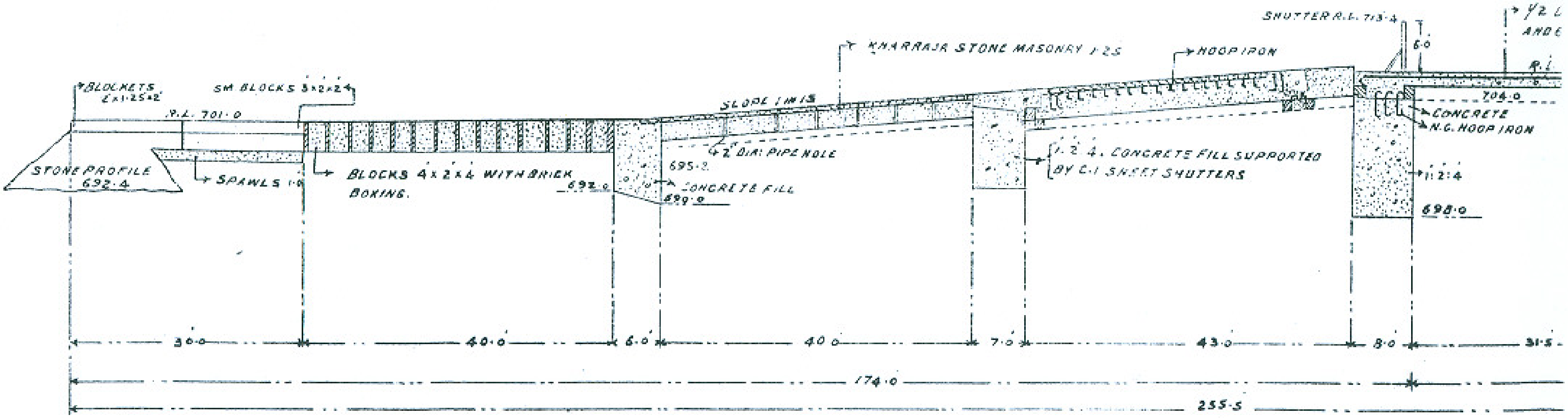
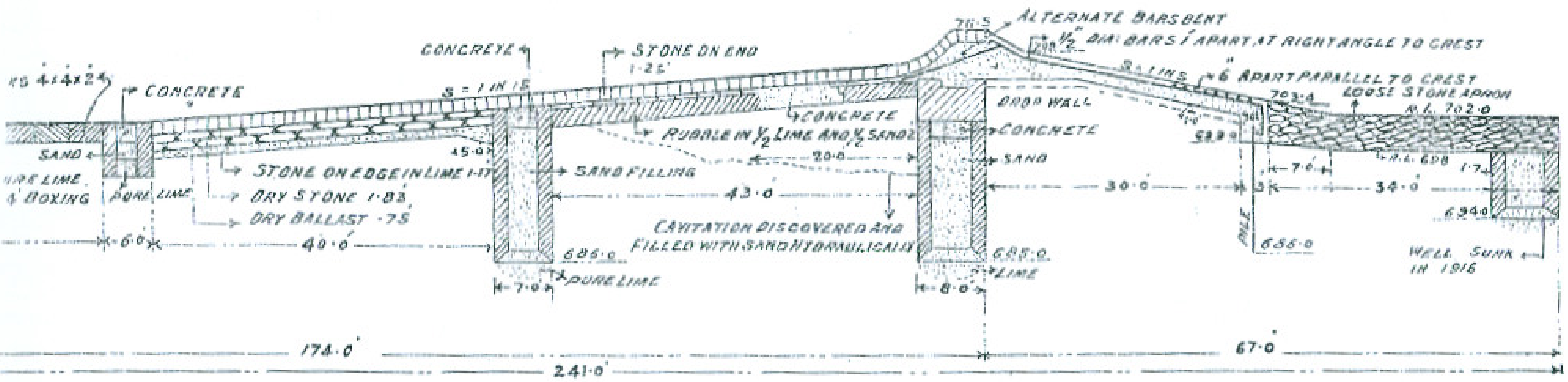


PLATE No. 8

RASUL WEIR

CROSS SECTION BAY 7

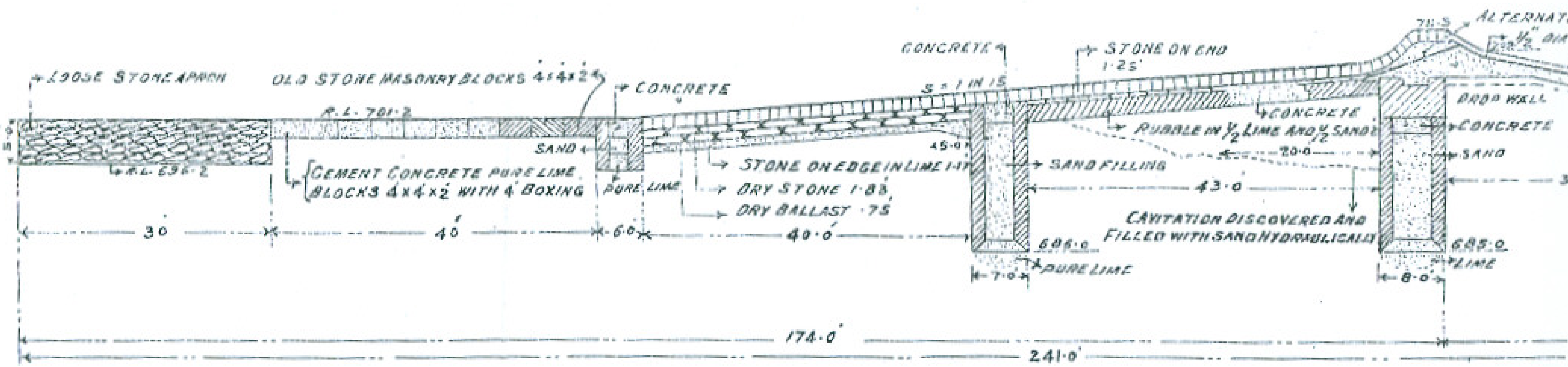
SCALE = 1/200



RASUL WEIR

# CROSS SECTION BAY 7

SCALE = 1/200



MR. FOY introduced his paper and remarked that it was with considerable diffidence that he undertook the writing of this paper as he realised that there was little of novelty about either the design or the methods adopted.

There were three underlying considerations which governed the entire operations and which should be borne in mind when considering the paper :—

1. The necessity for feeding the Lower Jhelum Canal as soon as possible and keeping the supply free from interruption.

2. The fact that the Jhelum rises very early in the year thus affording a rather short working season.

3. The frequency and intensity of the Jhelum winter freshets.

With regard to the details mentioned in the paper it would be useful if consideration might be given in the discussion to two points.

1. The method adopted of turning the river by means of a stone bund. This was the only feasible method at Rasul, but its comparative cheapness merits consideration even where other alternatives are feasible. The pile regulators adopted at some of the Sutlej Weirs proved considerably more expensive.

2. The expansion joint sketched at page 119. This was a cheap type and, if doing it again, he would be in favour of cheapening it still further by omission of the copper flashing on weirs not carrying a railway.

MR. COLYER enquired whether in the design of these repairs Bligh's theory of creep, or any application of it, was taken into consideration, and if so, what was eventually decided, because he had seen for almost the last 30 years these weirs being destroyed and built up again. He had pointed out the need of examining this question in one of the first Congresses when he had put up a paper urging the necessity for an Investigation and Research Circle. This was about 20 years ago, but this matter does not appear to have been properly investigated yet. He further remarked that when these weirs were destroyed something was always done on a rule of thumb-method and not in a sufficiently scientific way. He pointed this out to the younger engineers and requested them to carry out experiments both in the laboratory and on all headworks so as to reach some definite conclusion.

MR. BEDFORD said he wished to invite consideration to a few points that struck him on going through this paper. This smash was not the first of its kind. It was the third big smash, two big smashes occurred before the shutters were removed. A third small smash after the shutters had been removed, and now we had the fourth and biggest smash.

The fact that we had these smashes both with the shutters and without them went to show that the main reason was not in connection with the wall that had been built across the river. Therefore these smashes must have been due to something wrong in the design of the floor upstream and downstream. It appeared to him that the matter of a correct design was not given sufficient attention, for if we look into the details of the design, we find that the 4 central bays have had the wall removed and shutters replaced, *i.e.*, the crest level in the centre of the river had been lowered and to all intents a cunette made in the river. Now, as far as memory goes, all the smashes were located principally in the 4 centre bays.

This indicated that in high flood the river had a spear point of attack at the centre. Now in dealing with this problem it appeared to him that we should so design our weir that we would dissipate this spear point of attack. But what had been done. The high wall in the two bays on each sides had been left and by lowering crest at the centre a bigger amount of water passes down the centre in high floods and increases the intensity of attack at the centre. It seems that as we have had so many smashes it was up to us to consider very carefully the cause of these smashes and try to discover what the real reason was and then to start our repairs accordingly in order to make this weir safe.

If shutters were necessary, it was a mistake to put them in the 4 centre bays only leaving the 4 side bays with a high crest and concentrating the river at the centre. Shutters should have been put in all 8 bays and if the money was insufficient it was a matter for consideration whether shutters would not have been of more use in the side bays or in alternate bays. The effect of these shutters in high floods has been considered. Now let us see what is likely to happen in normal working.

What section of river is one to expect with such a weir ? Surely we will have a deep section at the centre with shoaling at the side. In fact we have now introduced a device by which we shall neutralize the effects of the undersluices. It seems strange to build under-sluiçes and then spend much money to build a neutralizer. The centre shutter does not increase our control over the river, but lessens the control, because the more we drop the shutters the more the sides shoal and although the tops of shutters are somehwat higher than the top of crest of side spans we cannot expect to get any scour at the sides.

The speaker would expect to see a tendency for the under-slucies to shoal. Perhaps the Executive Engineer in charge could give some information on this subject. Another effect will be to cause the canal to silt. This effect will not be apparent immediately, but it will be interesting to see if silt troubles increase in the Lower Jhelum Canal in the years to come. To sum up then, the effect of the shutters in 4 centre bays will be in floods, a concentration of river attack at a point where under ordinary circumstances the attack is greatest; in ordinary supplies a rise of river bed towards the sides, a shoaling up of the under-sluices and silting of the canal.

One more point. An experiment was being carried out in the laboratory. He understood that the section was 2′ and the discharge of 1 or 2 cusecs was being tried. It was hard for him to believe that any results that will be got as regards pressures on the floor could in any way be comparable with the pounding effect of a big river in flood.

In conclusion, he suggested that in cases where there was a large amount of money at stake there should be an advisory board from among the canal engineers of the Province, not necessarily merely from among the men who were directly dealing with the problem. Such a committee should consist of men of different schools of thought.

MR. M. C. SHARMA pointed out that the cost of the whole of the Lower Jhelum Canal system was 162 lakhs out of which 34 lakhs was the cost of headworks and weir. The cost of the repairs of the damage done to the weir of one-fourth of its length is 34 lakhs, and if we add Establishment charges, it will go beyond 40 lakhs. By doing ordinary restoration to the weir, and making a fall at about R. D. 245,000 of Upper Jhelum Canal, of well type as is on the Randhir Canal at Jammu and also increase the supply of Upper Jhelum Canal above that point from 8,500 cusecs to 12,500 cusces, partly by scouring bed above regulator at R. D. 255,000 and partly by raising banks which are high enough for more than half the length, the cost of all the above would not have been more than 20 lakhs which is half the cost of the repairs. The percolation of Jhelum River is 7 cusecs per mile, and it would yield in 50 miles above Rasul during winter a supply of 350 cusecs which could either be utilised in the Havelian Project, or pumped into the Lower Jhelum Canal by utilising 1-20th of the power that could be generated at Rasul.

MR. FOY in replying dealt first with the questions raised by Mr. Mool Chand Sharma, who pointed out that the total expenditure on repairs were 24 lakhs. Out of this sum a sum of 2 lakhs is to be deducted on account of the cost of repairs to railway. In comparing a repair with a new work one has to remember that the former is always a good deal more expensive because the conditions are already prejudiced. When Mr. Sharma remarks about the additional expenditure on establishment he makes a slip. Extra establishment was for 2 sub-divisions for a matter of 18 months and one for 5 months, and a sub-division costs about Rs. 4,000 a month. His other suggestion was that Rasul should be abandoned and that the Lower Jhelum Canal should be fed from the Upper Jhelum. Needless to say this possibility was considered, but was rejected. Five hundred cusecs would have been lost if this had been done, and the Haveli Project is still in the air for which in any case fresh supplies will have to be found. It was also not to be thought of as the Upper Jhelum could not carry the extra supply required for the Lower Jhelum without expensive reconstruction.

Mr. Bedford regarded the natural concentration of the river as a spear head of attack and suggested that the best method of remodelling would have been to have found some method of dispersing this spear head. This matter had received a good deal of consideration and if Mr. Bedford would suggest a method it would be of considerable help not only at Rasul but on all other weirs. Nothing had been yet evolved for bringing the river uniformly on to a weir. At Rasul the alternative was adopted of removing the obstructions of the crest where this spear head of attack occurs. It does undoubtedly concentrate the velocities, but it would be cheaper if it was found necessary to do so to provide additional protection on the downstream side to cater for this velocity and to take your protection to greater depths, on 2,000′ of weir than on 4,000.′

The reason for the different proportions in which the cement concrete was mixed was generally speaking, where you are mixing a small thickness you make a richer mixture while for the mass concrete you naturally could have a leaner mixture, because you are utilising the weight. A richer mixture was used for R. C. concrete to get the grip strength.

They started conservatively using 1 : 3 : 6 with 16 per cent. of plum and in the remodelling work for such blocks 4′ deep as were built they went in for 1 : 4 : 8.

Unfortunately no pressure pipes were put in. There was no suitable place for putting these in. Mr. Coyler enquired about Bligh's theory being applied. Examination of the section of the original weir or the weir as remodelled he would see that the weir even as originally constructed was amply safe against creep gradient or blow up, whatever theory might be adopted, that is whether you follow Bligh's theory or Mr. Khosla's revised one.

THE PRESIDENT is summing up remarked that he thought that in the discussion of this paper due consideration should have been given to the fact that time was a big factor. This point had been lost sight of by each one of the speakers in turn. Mr. Sharma wanted a new canal practically to be made *via* the Upper Jhelum to the Lower Jhelum. If he had only considered for a moment that you can not make the Upper Jhelum to carry nearly 66 per cent. of extra supply in a period of about 7 months—November to June.

Mr. Bedford pointed out that no pains had been taken to ascertain the cause of the smash. It is very difficult when there is a smash like that to determine from the conditions which one finds on inspection what the cause of the smash was. We had many theories and had ultimately come to the conclusion that the cause was as stated by the author in this paper. This was confirmed when the depth was calculated at which it was necessary to place all protection both upstream and downstream. And by observing what we saw at the site, and there was distinct evidence—thought I was disinclined to accept it at first—that the stone pitching had been picked up from upstream of the floor and deposited right against the crest of the weir.

Regarding Mr. Bedford's remarks about the advisory board. The fact was not given in the paper, but we had sought the advice of 4 or 5 other officers of the department who were not connected with the work and therefore could bring a distant vision to bear upon it and the decision that we ultimatey arrived at for the repairs or for the subsequent remodelling were carried out on the advice of this council which we had called. He remarked that if Mr. Bedford could enlighten us as to what was the cause of the smash he would be doing a very great service not only to engineers entrusted with the repair work, but to the general advantage of the engineering profession. He expressed his thanks and obligation to the author for writing this paper. The author was intimately connected with the work from immediately after failure till well on to its completion and he had had most extraordinary bad luck, when finishing the first season's work—when the river came down in an unprecedented freshet in April and set the work back many days.