PAPER No. 229.

RIVER DIVERSION AT TRIMMU.

By Som Nath Kapur, I.S.E.

The Emerson Barrage is situated about 2 miles below the junction of the Jhelum and Chenab rivers at Trimmu. This particular site was selected with a view to the favourable lay-out of river channels which permitted the headworks to be located in such a way that the construction area could be completely enclosed within ring bunds and still leave plenty of waterway on the right, for the floods to pass through, without involving serious risk of damage. (See Plate I). The river at this place ran in three different channels, the right, main and left which discharged 35, 45 and 20 p.c. respectively. The course of extreme left channel determined the exact lay-out of the headworks as it offered a natural sump for unwatering which enabled the weir excavation to be started much earlier than would have otherwise been the case. Further, this offered a natural outfall for the river after its diversion through the completed works. The existence of this natural arm of the river also determined the programme of works.

The Emerson Barrage as constructed consists of 37 weir bays each of 60 ft. span in the middle, 8 sluices each of 30 ft. on the left and 6 sluices each of 30 ft. on the right, the two sets of undersluices being divided from the weir bays by long divide walls. The crest of the undersluices is at R. L. 472·0 and is 5·5 ft. lower than the crest of the weir. A fish ladder is built alongside each of the divide walls. The Main Line Left, with a discharge of 5170 cusecs takes off on the left flank, its regulator having five spans of 24 ft. each. The Rangpur Canal with a discharge of 2710 cusecs takes off on the right flank through a regulator of three spans of 24 ft. each. Both these canal regulators are fitted with silt excluders of suitable design.

River Diversion Scheme determined Programme of Works.

As this barrage was to be equipped with sets of undersluices at the two ends, the diversion of the river had obviously to be done through one or the other or both of these sets. In view of the rushed programme of construction, which aimed at completing the entire Headworks in less than two years, it was necessary to have the final river diversion a few months in advance of the final completion of works. It was therefore not possible to wait for the completion of two sets of undersluices before the river could be diverted. The choice lay between diverting through the left or the right undersluices. The diversion through the left undersluices had the serious drawback of having to carry all materials over a temporary railway bridge (across the left undersluices) which would have meant unnecessary expense in its construction and also considerable delays due to congestion of traffic over the single track on this bridge. It would have further meant considerably increased pumping and the possible risk of segregation and therefore interruption of works on the right side in case of any sudden big rise in the river. In view of these considerations and the fact that one of the major arms of the river traversed the right undersluices and the right group of the weir it was decided to divert the river through the right undersluices. This permitted the river, now entirely on the right, to be gradullay pushed on to the barrage.

This decision determined the sequence of construction of the various units of the barrage. The first work to be undertaken was the Upstream Right Guide Bank which had to be completed before the monsoon of 1938, so that its armoured nose would protect the right ring bund of the weir area. Simultaneously but next in order came the construction of the right pocket, downstream Right Guide Bank, regulator of Rangpur Canal, right divide wall and the right group of the weir. Next in order came the left undersluices not because it was to be requisitioned in that order but because its construction involved deeper founds and heavier pumping. Last in sequence came the left half of the weir.

Protection Works as related to Diversion Scheme.

Plate III shows the main ring bund round the weir works. These ring bunds were made sufficiently heavy for the maximum flood of 6,50,000 cusecs, with a possible afflux level of 493·5 due to destruction of waterway. The top of the main ring bund was made at R. L. 500 and at the deepest section across the creek the bund was made strong enough for a hydraulic gradient of 1 in 15. Upstream of this ring bund a subsidiary ring bund was laid joining the two guide banks. This latter was constructed as a further line of defence as the area between this and the main ring bund contained all the railway sidings which carried materials for the two guide banks, right pocket and the entire weir upstream. Also in this area it was necessary to preserve the existing arm of the river. Further this offered facilities for excavating the upstream diversion cuts during the hot weather 1938 much in advance of actual river diversion—a procedure which eventually resulted in considerable saving of time and in the river diversion being completed at the right moment in December 1938. A portion of the above river arm between this upper bund and the guide bank nose had to be preserved and protected against silting up with heavy slush and for this reason a subsidiary ring bund, named the first line of defence, was constructed as shown in Plate III. The first line of defence generally and a small portion of the second line withstood all the floods.

Below the downstream ring bund, this river arm was protected from silting up by a small marginal bund about three miles in length. The bund proved most effective not only in preserving this arm of the river but also in obviating the necessityf or double stage pumping by keeping the direct flow of the river three miles further down.

Diversion Cuts.

To begin with, it was decided to make three approach cuts and three outfall cuts leading to one common main outfall, as shown in Plate II. The dimensions of these were, Left cut 150 ft., Centre 100 ft,, and Right 125ft. wide. Bed levels of the Left and Centre were kept at R.L. [illegible]5·0—general subsoil water level in winter; but the Right which was to come in operation first of all was taken down to R. L. 472·0—the crest of undersluices. The conditions at this headworks are, however, somewhat peculiar. Firstly, the N. S. level of the excavated area is very high and consequently its removal and that of the enormous mounds of earthwork formed from the weir excavation will offer great obstruction to the development of any reasonable size of channel for the river during floods. Undue restriction of waterway would lead to unnecessary heading up and consequent risks to the marginal bunds and guide banks during floods. If the river were to rise gradually and afford an opportunity for progressive widening of the cuts, so that sufficient waterway could be made available for passage of floods, there would be no cause for anxiety. But the river can rise erratically; it may remain low during the early hot weather and rise suddenly later on. Under such conditions the cuts would not get any chance of developing and there would be a risk of serious heading-up. In view of these considerations and to provide for freshets, it was decided to add a fourth cut and to widen the outfalls of the middle and the left cuts. This will be discussed in detail later.

Right Cut.

For the original diversion of the river the middle and left cuts must obviously remain out of action and the entire supply must be passed through the right cut. This cut had therefore to be designed and excavated to suit the river discharges at the time of diversion. As this was to come into operation when the total waterway would be very small its alignment followed the creek so as to give relief in case of a freshet.

Most Suitable Time for Diversion.

Hydrographs and their warnings. A study of the hydrographs of the Chenab at Trimmu for the past several years indicated one peculiarity from other rivers, *viz.*, that the range of discharge was greater and the rise started earlier. Statement I shows the maximum discharge for the months November to March for the last 11 years. It will be noticed that the river at Trimmu had generally been lowest in December.

It will be remembered that in winter the water received at Trimmu is the seepage inflow below Rasul in the Jhelum and below Khanki in the Chenab, because the regulation of the Triple Canal System does not permit any escapage below these two weirs in the cold weather. By the last week of December however, winter rains set in and freshets have to be passed below these weirs. The fact that the considerations of the two rivers had to be dealt with and the number of chances in respect of duration, intensity and repetition of freshets were greater, made it necessary for the final diversion of the river to be completed before Christmas week.

The completion of diversion operations during the freshet period was accompanied with grave risks. With the restricted waterway of the undeveloped diversion cuts a freshet might easily lead to failure of the Diversion Bund and carry the reconstruction of it into a zone of heavier and more frequent freshets. Besides, the cost would go up considerably. Not only this but with the heavier discharges coming, a situation might arise making diversion in 1938-39 impossible and necessitating postponement to the cold weather of 1939-40—an extremely unsatisfactory and dangerous state of affairs, because the works would have to be protected for another flood season and the bulk of the establishment kept on—the expenditure on which account would run into several lakhs.

Risks of a late diversion were also great. With the cuts not fully developed and with a big unscoured *bela* restricting the waterways, heavy discharges were likely to result in excessive heading up and consequent overtopping of guide banks and marginal bunds in the ensuing flood season.

It may be stated as a general principle that where weirs are constructed in high *belas* the diversion must take place as early as possible to enable the *belas* to be scoured out in any case when the river is at its lowest, *i.e.*, before winter rains set in.

These limitations and risks were fully visualized and works were organized so as to complete all operations by the end of December. The design of the Diversion Bund was also to have ample margin of safety against possible unfavourable river conditions.

Design of Cuts.

It was anticipated that the discharge to be finally diverted would be of the order of 2000 to 3000 cusecs. For this the river water level was expected to be about 474·75 at the guide bank nose and about 473·0 at the tail of the diversion cut.

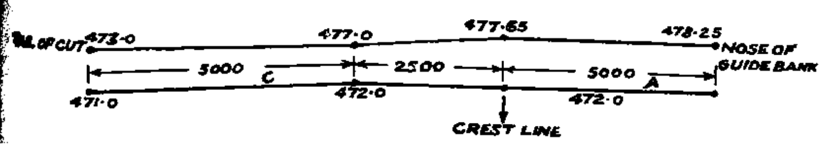
In this connection the model experiments carried out by Dr. N. K. Bose at Malikpur provided useful information. Various diversion runs were tried in the model and the effects of putting the cuts in different positions were studied with a view to gaining information about the probable river water levels for different discharges at the time of diversion.

An ideal channel to carry 2000 cusecs discharge would have a wetted perimeter of $2{\cdot}67\sqrt{2000}=120$ ft.

Velocity is given by $\left(\frac{Q.f^2}{3.8}\right)^{\frac{1}{6}}$. Take $f=1$, hence velocity

$$=\left(\frac{2000}{3{\cdot}8}\right)^{\frac{1}{6}}=2.8 \text{ ft./sec. Waterway}=\frac{\text{Discharge}}{\text{Velocity}}=\frac{2000}{2{\cdot}8}=715 \text{ sq. ft.}$$

This required a bed width of 100 ft. and depth of 7 ft. If it were possible to dig to these dimensions the river water could be diverted without any material heading up. This not being possible the right cut had to be designed to give a scouring velocity so as to develop its own section. It was decided to have the main cut 150 ft. wide with a bed level of 472·0—the same as the crest of the undersluices. The necessary head was worked out. Excavation to a level lower than 472·0, which meant 5 to 6 ft. excavation under water, was not possible owing to the abnormal pumping involved. Considering the time at our disposal and the labour available, the widening of cuts beyond 100—150 ft. would have been impossible by the end of November and corresponding head had therefore to be accepted as inevitable. On account of the high bed level of the downstream cuts no standing wave would form below the undersluice crest and therefore no discharge formula could be applied. The pocket was therefore to function as a tank. The excavation from practical pumping and labour points of view was done to the following levels:—



In order to pass a discharge of 2000 cusecs with a tail water level of 473·0 and tail bed level of 471·0, consider a slope of 1 in 2000. This would mean an average depth of $2{\cdot}0+1{\cdot}25-0{\cdot}5=2{\cdot}75$ ft. for reach C.

Sectional area $=2{\cdot}75\times150$,

$$\text{Hence } V=\frac{2000}{150\times2{\cdot}75}=4 \text{ ft./sec.}$$

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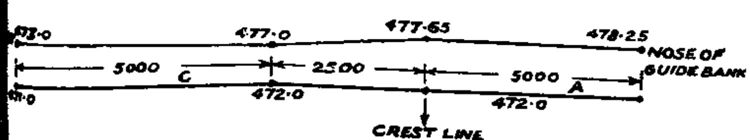

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From Kennedy's Diagrams, for R=2·75, slope 1 in N=0·025, the velocity works out to 2·6ft./sec., against 4 ft./sec. which indicates that the slope will have to be steepened to pass charge of 2000 cusecs.

Next try a slope of 1 in 1000.

$$\text{Depth at middle section}=2.0+\frac{2500}{1000}-\frac{2500}{5000}=4.0 \text{ ft.}$$

The velocity required to pass a discharge of 2000 cusecs $\frac{2000}{150 \times 4}=3{\cdot}33$ ft./sec.

From Kennedy's Diagrams for R=4·0, S=1/1000, V=4·8

Thus the slope will lie between 1/1000 and 1/2000. By trial error it will be found that a slope of 1 in 1250 will pass the discharge and this will mean a water level of 477·0 at R. D. 2500 the undersluice crest.

Consider reach (B).

R=4·0 generally.

Bed width=125 ft. V required is $\frac{2000}{5 \times 1{\cdot}25}=3{\cdot}2$ ft. This slope of 1 in 3000, making average depth 5·4. With second velocity works out at $\frac{2000}{5{\cdot}4 \times 125}=3$ ft./sec. and slope 1 in 4000, water level at crest of pocket of 77·65.

Consider the first reach (A)
Depth will be of the order of 6 ft. Average bed width is 150

Hence velocity$=\frac{2000}{150 \times 6}=2{\cdot}2$.

This needs a slope of 1 in 8000 giving a water level of 478·25 Guide Bank nose.

It was decided to keep cunettes that were below R. L. 475·0 wide and to depend on the development to full width during the of diversion.

At the time of actual diversion however, the discharge 1245 cusecs; the lower cunettes had to be left a few inches too

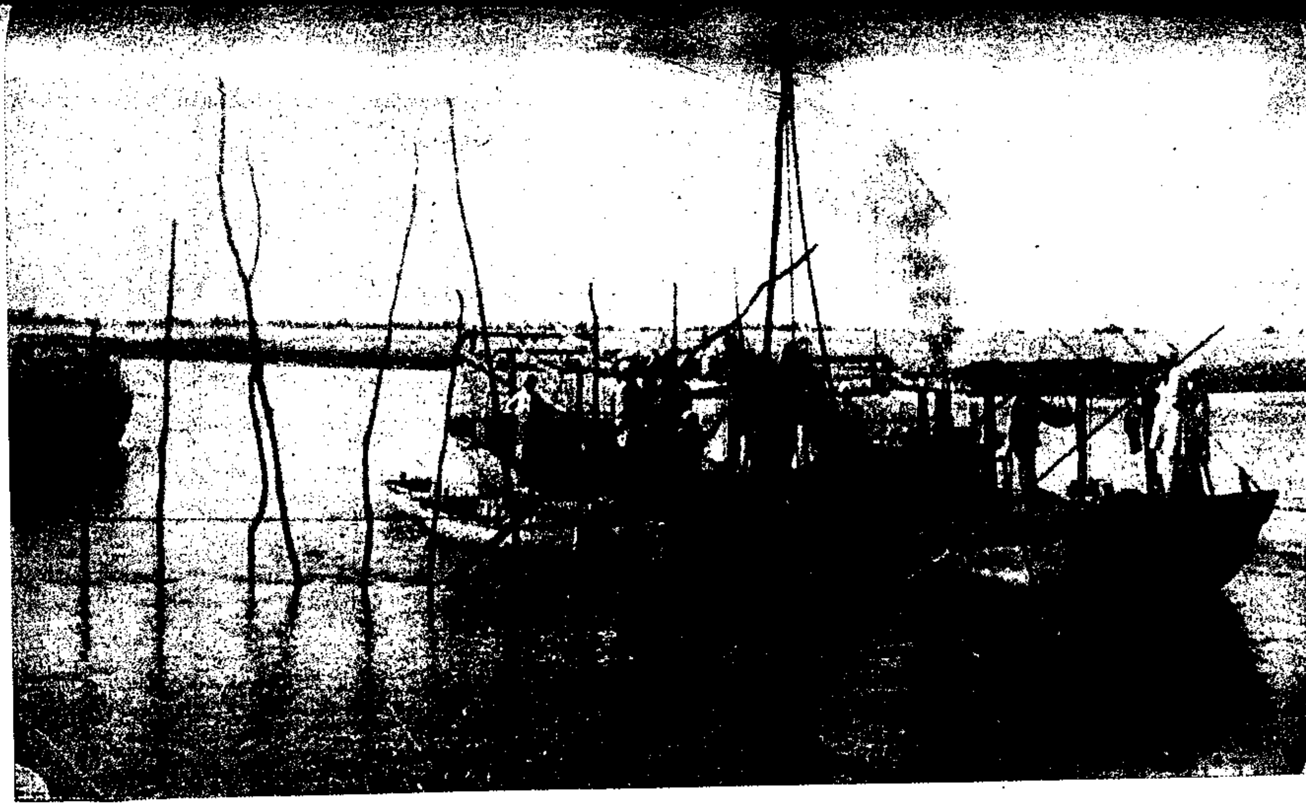

Photo No. 1. Sinking sal ballis with a jet.
Note the engine on one boat and lifting arrangements for pipe and balli on another.

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reach B the width of cunette had to be left at 50 ft. Under itions the water level at the guide bank nose rose to 478·35, pocket and 473·13 at the tail. This agreed well with the ked out above for 2000 cusecs discharge and excavation done dths. The cunette widths however excavated were 66 p.c. of n for the calculations and the discharge passed was 62 p. c. cipated 2000 cusecs, which is a fairly close agreement.

rally speaking on the upstream side a relatively wider cut is but on the downstream side a deeper one would be better than ne. Of course the design would depend on the limiting head e factor limiting the excavation. Statement VI and Plate VIII width of diversion cut as it developed and the long section of e and after and tends to show the above conclusions.

hannels before Diversion.

e II shows the river conditions after floods of 1938. The river flowing in three distinct channels—the right (known as), the central and the left of which was the main creek. In the relative magnitude of these three creeks the best course d to be to close off the central crest first of all and protect it by arthern bund at its head, then to divert the right creek into the the main river, and to protect the former also by a bund. diverted all the water into one channel. the next course was to e river into the right undersluices through the diversion cut. ide the work on the Marginal Bund was to start as soon as river s permitted and with the closing of the middle and the right e work was to advance in these leaving only the gap in the main final closure.

n of Central and Right Creek.

closing of the central creek did not present any great difficulty. e driven in the bed 5 ft. apart. *Pilchi* rolls about 2 ft. diameter pared and placed in front of these pegs which obstructed the discharge. The water in attempting to find its way undermined s and thus scoured out sand from below them. The discharge and the section being shallow and wide this scoured sand was y water downstream of this *pilchi* bar and the channel was f. With the depth thus decreased the creek was finally closed n earthen bund on 5th October 1938.

reek.

work of diversion of the right (Malkana) creek into river was started by the end of September and it was o choke it off by means of permeable spurs and attempt the ng when the discharge had been reduced considerably.

This creek as will be apparent from the plan is fed mostly f main river but another creek from the Jhelum also comes and It was therefore decided to put three permeable spurs below the of this creek from the Jhelum River. Subsequently spurs Nos. were put in at shallow sections, the first 50 ft. below the head creek and the second 200 ft. below the first (See Plate II).

Permeable Spurs.

These consist of a line of *sal ballis* driven nearly 5 ft. ap tied across by strands of G. I. wire No. 12, above and below wate To these wires is attached a vertical *pilchi* or other brushwood with its bottom touching the river bed or just above it. An alte method is to have long *pilchi* rolls spanning the *ballis* and plac above the other till they appear above water (Fig. 2 and 4) Pl The function of the two types is the same, namely forcing the hig city filaments of water from the surface to below the bottom of screens, scouring out sand from there and depositing it lower do form a progressive bar across the channel bed thus causing aut and progressive choking of the channel.

Sal ballis were sunk by means of a water jet fed from a M weather fire engine. (See Photograph 1). This pump (Merryw engine) was placed on a boat and by means of an armoured rubber delivered water under pressure to a $1\frac{1}{4}''$ dia. pipe about 20 ft. long e in a nozzle (See fig. 1 Plate IX). This pipe was tied by loose to the *balli* to be driven and had its nozzle discharging just at the b of the *balli*. The water jet forced a hole through the soil alongsi *balli* carrying the latter down with it. The *ballis* were sunk 10 below bed in shallow water and 15 ft. in deep water. The jetting and the *balli* to be driven were lifted up vertically and then la in position on the river bed when the pump would start workin supplying water under pressure from the jet. The bottom of the was pointed to facilitate penetration. The process was accelerat men shaking the *balli* with the jet working. When the *balli* was to proper depth the jet pipe was pulled out by a string over a p The jet pipe and the *balli* are loosely tied to facilitate the withd of the former. The spacing of *ballis* depends on the depth. I kept at 5 ft. in shallow water but as close as 3 ft. in deep water. the *ballis* were sunk they were stranded by G. I. wires and *pilchi* 6" diameter, hung from the top strand so as to give a pervious scr

The action downstream of the spurs is progressive both in and height and finally a stage is reached when the water is so s that the channel can be closed with a small rush and at small cost. action is slow and time factor helps it. In cases where the *ball* not driven deep enough and there is concentration of flow, the and the *pilchi* screens will continue to sink bodily together as the s ing of sand underneath advances. The screen is continuously m

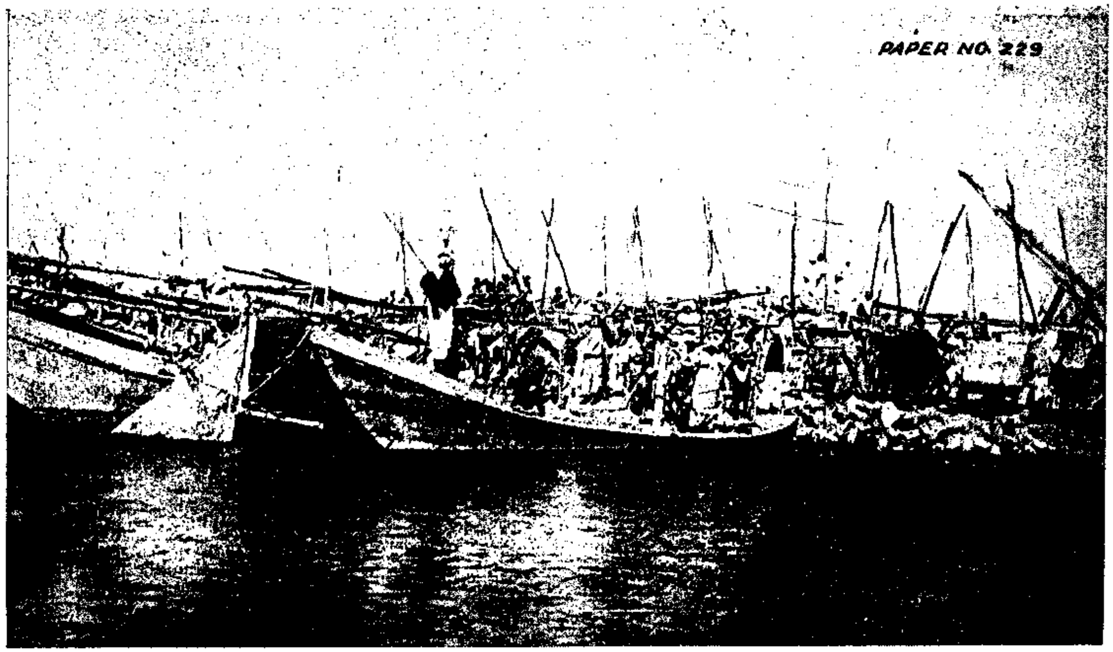

Photo No. 3. Sheet Pile regulator at Suleimanki with one mattress being rolled on the bank and another mattress being floated up towards the pile regulator by means of rope attached to a crab winch mounted on a boat alongside the regulator.

ove water level as fast as the sinking proceeds. In this way the continues to function. Flow of water over the *pilchi* must not mitted as not only will it reduce action at bed but also generate and may remove existing sand deposits downstream.

sion of the Right Creek.

The efficiency of permeable spurs is a maximum when they are the head of a channel whence water can be easily diverted into adjoining channel. In the right creek, spurs Nos. 3, 4 and 5 were screen type but spurs Nos. 1 and 2 were made up of rolls placed above the other. *Pilchi* was tied in small 6" diameter rolls and made a mattress which was then rolled into thick rolls about 16—18 ft. and 3 ft. diameter. These rolls were towed across in water and ed in front of these *ballis*. Rolls were placed one above the other they appeared above water level. This gave a thick screen for water ss through and diverted the balance into the main river (left creek). to water pressure against the *ballis* the latter gave way and had to eplaced and supplemented by intermediate stakes. The arrival of shet while these operations were in progress proved to be very ul on account of increased concentration at the spur sites. The tence of the first spur resulted in the river bed getting a definite d at this site but too close to the spur. The bend was useful as it ged the direction of the main current upstream but its proximity atened to destroy the spur. So consequently slanting spurs with were put in with the result that the deep bend shifted further up-m and out in the river. Photograph 2 show the general me. The reduction in discharge and silting up of the creek had so advanced that it was decided to close off the creek on 19th October, . Before the final closure, earthen bunds were advanced on both s to avoid out-flanking. The final closure was done above spur 3. The small discharge coming from the Jhelum River was dealt the following day and a bund was put across it at the head, and her bund put below spur 3—the junction of the two.

It may be mentioned that the spurs should not be placed too close e silt thrown by one may be influenced by the sucking action of the r.

l Diversion Sites.

With the right arm closed all the water was flowing through the creek, work on the closing of which was now to be started.

Two sites were considered for the final diversion ; one at the nose e Right Guide Bank and the other between the canal and Right ed Embankment. The channel was shallower but wider at the r place and narrower but very much deeper at the former. In the of the Guide Bank the advantage was that the head of the diversion

cut was closer but as the depletion down-stream would have been grea
here on account of the greater distance from the tail of the diversion c
the head against the diversion bund would have remained the same i
both cases, the head really being the fall in the diversion channel.

If the diversion had been done at the Right Guide Bank nose, a
additional bund would have been necessary on its right to linkit to th
highland to avoid outflanking. But all this earthwork would serve n
purpose later on and would, besides meaning extra expense, take o
some labour from the cuts and the Right Retired Embankment. If th
site was at the Right Retired Embankment the marginal bund complete
from both sides would require no further protective embankment an
the earthwork done in the diversion bund would be partly utilized in th
Right Retired Embankment. Again at the higher site (nose of Righ
Guide bank) a leak-proof abutment might have been built on the righ
side but the ungrouted stone apron of the guide bank would alway
have remained a source of leakage and, as such, of anxiety. Th
diversion work involves diving operations, laying of mattresses an
cribs, etc. These are much easier done in shallow water.

Another advantage of the lower site was that the attack on the riv
could be made at two points. Choking and partial diversion of riv
supplies by permeable spurs could be done at the guide bank nose an
this would reduce the discharge for the final diversion bund. Also th
permeable spurs would cause some heading up, relieving the diversio
bund of the strain to that extent. In short, a retarded line of fin
blockage permitted an attempt at partial blocking in front of it whic
advantage the upper site could not possess. In view of all these conside
ations it was decided to do the diversion at the lower site.

Type of Diversion Bund.

There are two main factors to be considered in river diversion
the discharge which may vary between wide limits and the probab
head across the diversion bund. The head is a factor to be determin
by the river discharge and the dimensions of the cuts. Concentratio
of surface flow will lead to deep scour holes and excessive head may le
to failure by undermining. These two contingencies must be fully pro
vided for in the design of the diversion bund and in the programme
its construction. The cheapest and most satisfactory form of bed pro
tection to withstand high velocities without erosion is afforded by
covering of *pilchi* mattress. If this mattress is of suitable constructi
and is adequately weighted down, it will to a large extent prevent und
mining as a result of high head. The mattress should be long enou
to kill the head completely. Different methods best suited to ea
locality have been devised to do the heading up which is essential bef
a diversion can take place.

In 1915 the main channel at Khanki had to be diverted and the [...]d employed was to lay *pilchi* mattresses on the river bed, then wooden cribs on these and gradually raise the water by placing stone and *pilchi* in alternate layers. After this was raised above water, earth was advanced in front of it.

At Islam and Ferozepur the river diversion was done by mattressing the river bed, then advancing a stone bund on it sothat water passed through the voids. In front of it tarred gunny-bag tarpaulins were laid over the stone so as to prevent wastage of earth which was advanced on both sides.

Ample freeboard is generally necessary to provide for sudden rises in the river before the diversion is complete. At Islam the small allowance for freeboard (insufficient to withstand freshets) was responsible for failure and each failure meant additional expenditure and delay.

At Suleimanki a pile regulator was constructed. This consisted of rows of piles across the river bed forming 30 openings of 9 ft. separated by piers of piles and 40 ft. length of abutment on either side. (See [...]3 Plate IX and Photo 3). The bed downstream of the piles was protected with *pilchi* mattresses suitably weighted with stone. The piles were given a backing of stone on the downstream to avoid scour and also to give stability. After this was done *karries* were put which did the heading up and the earthwork was then advanced. The piles were about 20 to 35 ft. long, depending on the depth of scour. These were taken well below the bed.

The diversion at Panjnad was done in two stages. A masonry diversion regulator was constructed close to the main river with leading channels from and back to the river. The river was first diverted through the regulator and then gradually through the completed weir. The gap portion was closed by mattressing the bed, then laying cribs which were filled with sand bags. This permitted some leakage which was checked by spreading juting in front of the cribs. The earthwork was advanced on this juting. Later, heading up was done at the diversion regulator by means of *karries* and thus the original weir channel was finally closed off.

The heads across the diversion bunds and at various places were as follows :—

Khanki	..	Not traceable.
Ferozepur	..	2 feet.
Islam	..	Probably above 4 feet.
Suleimanki	..	5-6 feet.
Panjnad	..	3 feet.
Trimmu	..	4·9 feet.

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The comparative costs, as far as can be ascertained from the files are :—

	Rs.	
Ferozepur ..	1,62,000	
Islam ..	3,90,000	
Suleimanki ..	1,67,800	
Panjnad bund and regulator	3,50,000	
Trimmu (estimated amount)	70,000	(actual cost in appendix).

Diversion Bund at Trimmu.

The diversion bund at Trimmu as explained in the paragraph o the design of cuts was designed for a head of 4 to 6 ft. and a discharg of nearly 2000 cusecs. As explained therein, further deepening widening of cuts to afford substantial relief was not possible in the tim available. For this unavoidably high head, a pile regulator would hav been the most suitable, but as piles were not available in the countr the idea was given up, and a stone-cum-crib bund overlying a suitab length of *pilchi* mattresses was selected. In deeper sections a doub line of cribs was provided. A section through the diversion bund, executed, is shown on Plate V. Its site relative to the left bank of can and Right Retired Embankment was fixed in such a way that the ma embankment in no case came on to the *pilchi* mattresses.

General Scheme of Works.

The plan and section of diversion bunds (Plates IV and V) show mooring posts sunk 25 feet apart and 115 ft. upstream of central line bund. 15"—diameter iron rings were slid round these posts and 7 G. I. wire passed through rings to anchor *pilchi* mattresses which we 60, 80 and 100 ft. long, according to the depth of water. Cribs we placed on these mattresses, the smaller ones in shallow water but t bigger ones in deeper water and in double rows. Stone was dump both upstream and downstream of the cribs and when this had reach above water, heading-up was done by filling cribs with sand bags. Th permitted leakage through stone, which was reduced by throw ballast on the upstream stone slope. Further leakage was stopped tarred gunny-bag sheets spread over the upstream face of the ba These sheets projected beyond the upstream end of the pil mattress. After tamping the leakage earth was advanced.

Photo No. 4. Rolling mattress to river bed.

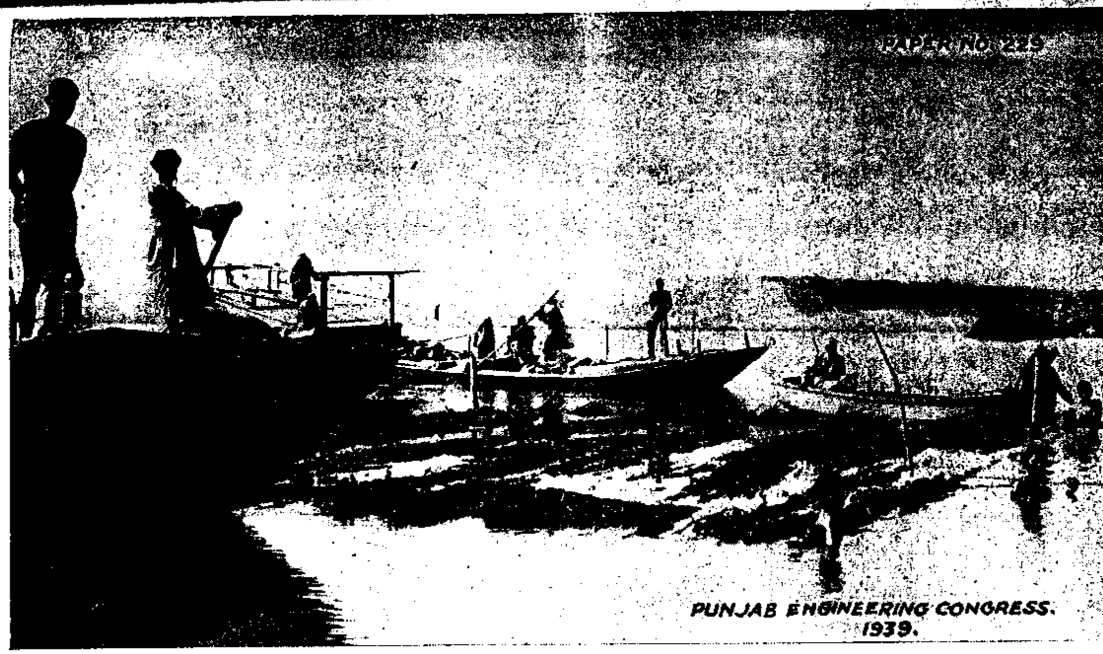


Photo No. 5. Launching of mattresses. Note the fixed end of anchoring 7/14 wire and the other end tied to bamboo. Boats ready for weighting with bags and stone.

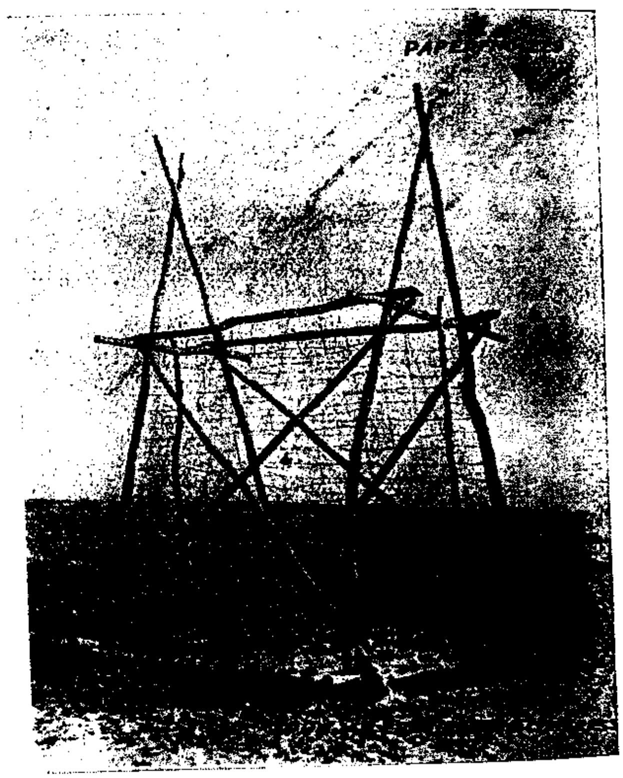


Photo No. 6. Completed cribs.

oring Posts.

These posts were 30 ft. long *sal ballas* and 15" diameter (minimum). he sinking which took 8 days was started on 6th November 1938 and s done with a Merryweather fire engine pump. The process was the ne as for smaller *ballis*, except that, as the hole to be made was bigger, o jets were worked simultaneously to give greater displacement. The ts being heavy had to be lifted by means of a pulley block. It was nded to sink them 10 ft. below bed in shallow water and 15 ft. in deep ter. Actually however the posts did not go more than 12 ft. in deep ter due to the existence of clay. In clay the water jet is ineffective opening up a hole big enough for the post to go down. (See Fig. 5 te IX).

chi Mattressing.

Pilchi was not available in the locality and had to be carried by ts from a distance of about 12 to 14 miles. The collection was there- e started in October so as to set the boats free for other works by the ne the actual diversion started.

G. I. wire netting, 6" mesh, was first woven to the exact size of ttresses which were of three dimensions 30×60, 30×80 and 30×100. re netting was manufactured on 30 ft. long wooden boards with nails ed as shown in Figure 6 Plate IX.

Simultaneously, *pilchi* rolls 9" diameter were prepared in lengths htly over 30 ft. The binding was done by G. I. wire No. 20 and to re proper thickness standard perimeter measures were given. One n compressed the roll and checked with this standard measure and other followed with No.20 wire to do the binding.

The wire netting was then spread out on the ground and rolls ely tied to it. The mesh was 8" across the diagonal. The 9-inch meter rolls were pressed one against the other to such an extent that roll covered one mesh. Further G. I. wire No. 12 was roped in each sh. It went under one mesh, came out through one end of the ad- ent mesh roped in the roll and passed through the other end of the e mesh and so on, as shown in figs. 7 and 8, Plate IX. The second e passing along the central line of adjacent sideways mesh roped in alternate roll and thus each mesh had a roll roped into it and no nces were left for any roll separating from the wire netting when the tress was fully woven. Two *ballis*, 30 ft. long, with their thick and n ends opposing, were placed on the upstream end of the mattress. se *ballis* were carefully tied into the mattress by G. I. wire No. 12. e Fig. 9, Plate IX). The mattress was then rolled up and the free s tied to the wire netting to prevent accidental unrolling.

The rolling was usually done by placing *ballis* underneath the mattress in the direction of rolling and also by tying down ropes to place on the mattress, carrying it round and then by exerting a pull to this rope. (See Fig. 10, Plate IX). In addition to this, men were employed on pushing it from behind. About 50 men were needed for a 60 ft. mattress, about 80 men for 80 ft. and 110 men for a 100ft. mattress. (See Photograph 4.)

It is necessary to roll the mattress into the water straight, but due to limited space it may be possible to build it up in the direction in which it is to be rolled. Effort was made to make as many mattresses as possible on the river edge and perpendicular to the direction of flow but some had to be made further out. In order to bring them to the river properly [illegible]ed a spiral form of rolling was resorted to, by adding loose *pilchi* on one side. In this way it would roll into a spiral, with one end thicker than the other so that with equal number of turns, one side would travel more than the other and thus get a circular motion which would change the direction. Of all the methods tried this was the simplest and most successful.

Launching Mattress. (See Photograph 5.)

The mattress was rolled sufficiently far out in the water so that its nearer end could float when the mattress was unrolled (Fig. 11, Plate IX.) It was thus rolled into water, then unrolled and floated. The *ballis* were now floating at the far end. On one side of it which was to lead in water 200 ft. of G. I. wire 7/14 was passed round *balli*, [illegible] and wire netting and given 8 turns, and the free end tied down to the longer one by G. I. wire No. 20 as shown in Fig. 12, Palte IX, so that there was no possibility of its getting loose. Generally the free end of the wire was kept about 3 ft. from the extreme end of mattress. The *balli* was then tied by means of ropes to a country boat which was floated down to site. The boat was anchored down to the mooring posts and the ropes were manipulated in such a way that with the help of divers the mattress was brought to the position it had to be laid in. After this the free end of the anchoring 7/14 wire was passed through the 15" diameter iron ring slid round the mooring post, knotted and tied, brought back to the mattress and tied on to a bamboo fixed 5 ft. from the outer edge of the mattress (Fig. 13).

The mattress was then sunk into position by divers starting from one upstream corner and weighting the edges by sand bags. Bags and stone were also thrown all over the mattress to sink it completely. The next mattress had to be given a 5 ft. overlap and therefore pegs were driven through the mattress 5 ft. from its outer edge. The next mattress was then laid with its edge touching these pegs and the free end of the 7/14 wire of the previous mattress was tied on to the *balli* of the new one, given 8 turns round it and tied as at the other end.

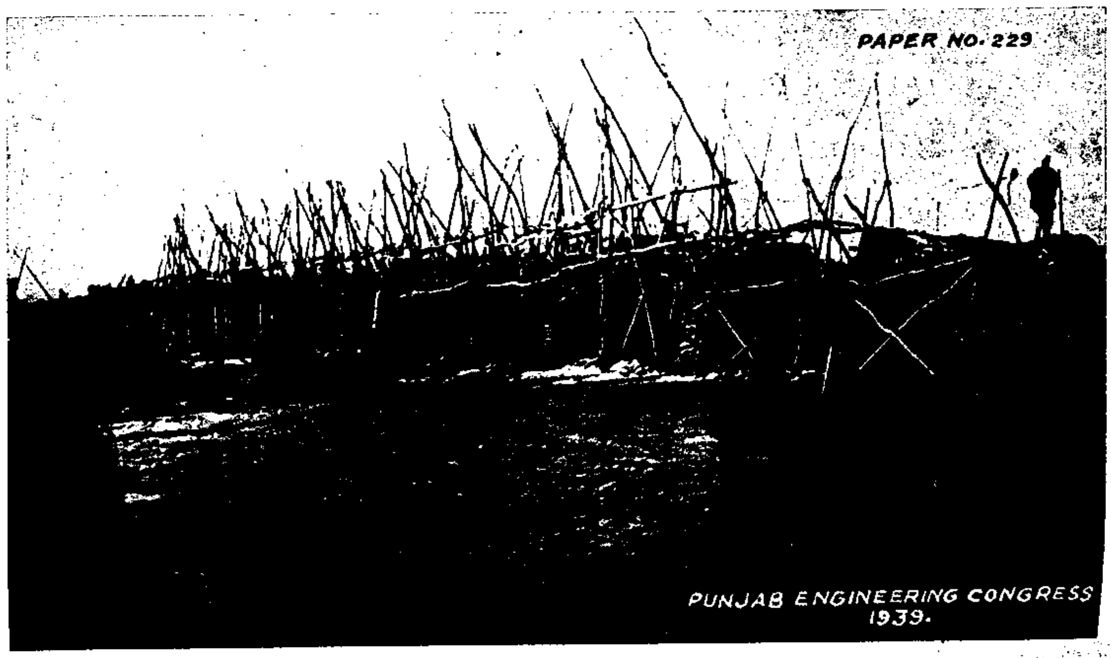


Photo No. 7. Gaps between cribs converted into piers. **Note the tilting of cribs.**

The joint would be as shown in Fig. 14. In this way all the mattresses tied to each other in succession through the rings in mooring posts. ensured that in case one mattress lifted or something happened it ld not flow away unless the ring or mooring post gave way, in which the other end of mattress would still be safe; but such chances ld be remote. It is very important to note that each mattress must adequately weighted down as if any portion remains lifted up, ies will form underneath due to under-flow and, if of any consider- size, may damage the mattress. To avoid this the ends were all ghted with bags side by side and stone dumped all over. Care was ever taken that the portion where the cribs were to come was covered with stone or bags. The placing of the last few mattresses ally gives trouble particularly if the final linking is done in deep r. To get over the difficulty the deep portions were mattressed and shallow portions afterwards. The mattressing of the bed was ed on 12th November, 1938 and completed on 26th November, . In all 23 mattresses covering 575 ft. of river width and 54,600 feet of bed were laid. In passing, it might be mentioned that a mat- should not be left in water for any length of time. Once it is brought ater it must be launched in position, otherwise *pilchi* gets heavy, to soakage in water, and on account of its own weight the mattress sunk in sand from which it is very difficult to extricate.

tments.

Plate V (Fig. 1) shows the details of abutments as constructed. se were laid on *pilchi* mattresses and consisted of a central core of bags with a backing of stone on both sides. The entire section one and sand bags was grouted with sand to make it leak-proof. The s were similarly laid on the mattress as a further precaution. The bag core was raised to R.L. 482·0, approximately 3·5ft. above anti- ted water level. An earthen bank was made on the upstream face of abutment and wings and linked on to the marginal bund at either The work on these abutments was started simultaneously with mattressing and continued till 3rd December, 1938.

s.

The launching of cribs followed the laying of mattresses in the bed. Photograph No. 6 and Plate No. V (Figs. 5 and 4) show the s of a crib. The object of a crib is to have a framework of a large which when filled with bags and stone would form a sufficiently barrier against dislocation by any local concentration of flow. the stone backing in front and behind such a barrier becomes against all contingencies. As the photograph shows it is a oidal framework of *sal ballis* diagonally strutted across the ion of flow. The joints are nailed by ½" bars and are further thened by G. I. No. 10 wire and twine finally all the member together at the joint. G. I. wire is then carried all round the and attached to the various members by means of U-staples. affords a wire net round the crib which prevents stone and bags being carried with the current. The bottom is floored with with a maximum spacing of 9", centre to centre. The cribs are open at the top to permit bags or stone being thrown in.

The floating and launching was done in two ways. The smaller cribs were lifted by diver gangs and carried in water and placed on rafts of 40-gallon empty barrels. These were floated and the cribs then slid into position. With the bigger cribs a different method was adopted. After construction all the cribs were placed along a narrow gauge track which was laid at such a low level that the frame of platform trucks came almost at ground level. Two N. G. truck platforms were placed one behind the other and the crib slid on to them and laid flat. The truck platform had ten feet sleepers attached to their top so as not to let the cribs overhang (See Fig. 15) Plate IX.

These were then pushed on a track extending well into the river where a raft of empty barrels was kept in readiness. The crib was transferred from platform trucks to this raft which was then tied on to a boat and floated close to the site. Here a gantry was erected on a boat which was anchored to an aerial ropeway on the upstream side. This ropeway was kept high enough to permit boats passing under it.

The crib was loosened from the raft and the gantry lifted it up. Men had to be employed to disengage the raft, which was then pulled out by ropes, worked from another boat anchored to the mooring posts. After the crib had been lifted by the gantry, the gantry boat took it to its proper position.

The divers were then sent under water to level up the ground by removing any sand bags or stone that may have been dumped to weigh the mattress. The crib was aligned and lowered in position, and adjustment necessary being made by pulling or easing ropes tied to its corners. After it was lowered and properly placed one layer of sand bags was placed at the bottom of cribs, well packed. This was done by divers. In addition, precaution was taken that no water passed between the crib and mattress and undermine the latter. It is very essential to see that there are no projections and obstructions under the crib. A further safeguard was to line up sand bags upstream and in front of the cribs (Fig. 16) Plate IX so that the level of the bags inside and outside would be the same and fill up any openings that were left.

It was very essential not to restrict the waterway too much as this would lead to high velocities at local sections. Only the minimum obstruction was placed over the bed and that too gradually, to avoid undesirable heading up. Where the double row of cribs came in the lower was placed first and then the upper one but both were advanced togeth

Photo No. 8. Gangway on cribs. Note downstream line of cribs tilted and anchoring arrangements of boats from aerial ropeways.

Photo No. 9. Ideal conditions for stone [illegible]

Photo No. 10. Concentrated flow on *right partially controlled.*
Note tilting of cribs and top members of side cuts sloping towards the fall.

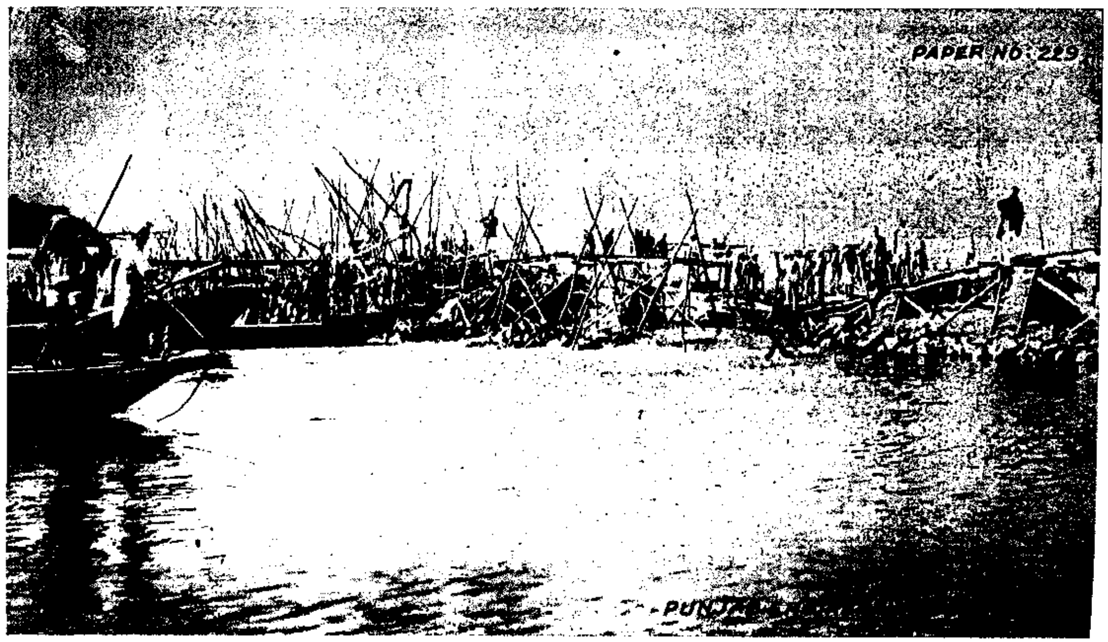


Photo No. 11. Concentrated flow on left bank, not fully controlled. *Mark the settlement* **of criband gangway at X and also breaking up of cribs of lower line.**

hen the cribs were placed in position a gap of about 2 to 3 ft. was ween the adjacent ones. This could not be helped because of ection of *ballis* needed for strength. These gaps were closed s of gunny bags which were held in position by means of re running at 6" intervals and tying the adjacent cribs together. g. 7 Plate IX). These gaps filled with gunny bags made good (Photograph 7).

is had not only the advantage of converting the gap into piers tying one crib to the other and thus keeping up continuity and dditional strength. As was experienced later the effect was that ribs settled the *ballis* failed at joints, but the position of the crib materially alter. This meant that cribs adjusted their form to nt. Where there was any serious settlement, cribs were built the original level by additional *ballis* carefully joined and strutted.

he work of placing cribs was advanced from both sides but the as rushed more than the left to enable the last crib being laid in water.

he last crib would have to be specially constructed to suit the gap but this was managed by adjusting the spacing between the r cribs. Before putting the last crib, the boats required for g stone were passed downstream. The laying of cribs was on 20th November, 1938 and completed on 1st December,

the river had not yet been opened into the right undersluices it ential not to do any heading up at the diversion bund and at the me till then to ensure that whatever work could be done was done t to lose time.

was decided to lay one layer of stone on the mattress on the ream side and to build up gaps between adjacent cribs by sand above water level, because this would restrict the waterway by p.c. which could be risked in view of the river discharge also gone down. This gave a framework of a temporary regulator 0 ft. bays (See photograph 7 opposite). The river was opened e right pocket on 6th December, 1938 and it was not till then e real rush started.

Ropeways.

e aerial ropeway erected upstream to anchor the gantry boat and ching of cribs having done its job, was removed and fixed down- To speed up work, dumping of stone downstream had been d by boats. One main principle kept in view was to advance uni- on the full front to avoid dangerous rush and scour at the clos- For this uniform dumping, boats had to be anchored all along and this was arranged by the aerial ropeway about 5 ft. downstream the central line of second crib line. 16 pulleys each with a chain and to which boats could be anchored against flow of water, were placed on this ropeway (See Fig. 18, Plate IX).

Permeable spurs on guide bank.

The selection of the lower site for the final diversion bund permitted further measures to be adopted to obstruct the river and it into the pocket as far as possible. With this end in view eight lines of permeable spurs were put in at the nose of the guide bank as shown on plate II.

The main choking and diversion had to be done by the first line. A double row of *ballis* was therefore driven on the first line which was just below the head of the diversion cut. It was proposed to have 5 ft. diameter *pilchi* rolls put at this site and to supplement its action the second row was also to have *pilchi* rolls. The others were to have hanging *pilchi*. It was not possible to drive *ballis* where water was deeper than 10—12 ft. Such gaps were left out from the lines and trees were thrown and anchored down by stone in *trangers* at these places. The surface anchoring was done by tying trees to empty drums (floated) which were then tied to *ballis*. All *pilchi* rolls and *pilchi* mattresses for hanging were got ready earlier, all lines were stranded with G. I. wire and further necessary material collected in front of each line. The day the cut was opened, a rush was made on all these lines and they were completed. After that, maintenance was carried on during the day.

The difference between the action of permeable spurs at the Malkana (right) creek and this site was that in the former the water was to be diverted from shallower to a deeper channel and in the latter from a deeper to a shallower cut which had yet to develop. The efficiency of these spurs at this site was therefore small as no considerable heading up was possible with these, but as a source of obstruction in the river they were useful and helped the cut to take more discharge.

Stone.

Work was started on the diversion bund on 7th December with full rush. An attempt was made to close the side cribs by bags and advance earth in front of them. This was found risky as with the increase in head cribs began to settle rapidly. It was therefore decided not to take any further risks and to go ahead with the stone dumping in full section. This was done uniformly. As the stone dumping advanced, cribs also started showing signs of settlement in the downstream side. Photograph 8 shows the general tilting of cribs of downstream line. To stop further damage it was very essential to destroy

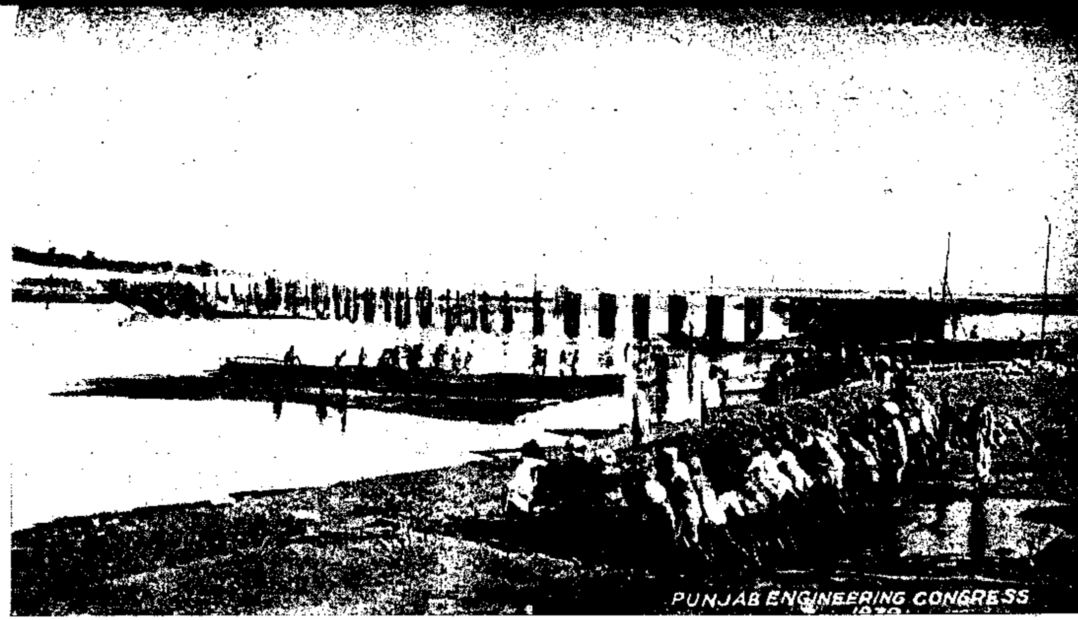


Photo No. 12. Dumping by boats and tram trucks.

Photo No. 13. Tarpaulins stretched and being sewn to cribs with gunny bags. Note diver taking down sand bag to weight its end.

Photo No. 14. Tarpaulins being stretched out of water by boats.

Photo No. 15. Boats moving away after stretching tarpaulin on water. Note the ropes stretching it in all directions.

which was being created. On the right end the current was so at stone dumped was also being carried away. Two cribs were to the downstream line and loaded with stone. Stone was also round the cribs and the situation was thus brought under con- about 10 hours struggle during the night. Conditions became erever free falls existed and there were about 5 of these. Photo- ll shows a typical fall. After the force was half controlled by as shown in Photograph 10, cribs invariably showed settlement. the horizontal members sloping down from both sides towards . The ideal conditions were where the water emerged out of the the tail end as shown in photograph 9. The concentrated flow left bank gave greater trouble and had to be controlled by adding ore cribs on the downstream side. The settlement was very nd is apparent from Statement II. Photograph 11 also shows the nt in the gangway carried over the top horizontal members of s. It shows almost complete settlement of one crib and sideways towards concentrated flow of a new crib placed at the back. It shows how the side cross members of cribs of the lower line have n the downstream side and got broken. These settled cribs made up after concentrated flow was controlled and the gang- o raised. Uniform strengthening and raising was necessary to oncentration of flow at the low sites. The sites of concentrated ere invariably accompanied by settlement of cribs.

om the successive settlement of cribs it was clear that dumping must continue to well above the water level on the downstream When the stone had appeared above water on the downstream mping was started on the upstream side. Weighting by stone d signs of tilting of upstream line of cribs on the upstream side. ngs and examination of bed by divers showed pot holes on the m side where settlement had occurred. It was therefore decided no risks to carry on with stone dumping until the stone showed ove water level on the upstream side as well and water passed h the stone voids. The second line of cribs and the space between lines were at first intended to be filled up with sand bags but as uld block the waterway it was decided to fill them with stone . The gap between adjacent cribs had however already been p with sand bags to form piers. Whenever any portion was with stone, the cribs showed tilting towards that side and many breaking up of some members to permit the crib frame work to itself to the settlement in the mattress. This settlement was because it covered up pot holes and ensured mattresses sitting bed. As the stone dumping was in progress men were made to the downstream mattress and invariably the ends showed that tress had sunk in and had adjusted itself to the scoured bed. observations made it very clear that there was progressive under- below the mattresses due to the increasing head and it was a race the rate of undermining and the protection and consolidation stone dumping. For the first few days the river got the better of it but soon it came under control. Once the stone showed itself downstream water level N. G. track was laid and N. G. trucks used to supplement stone dumping from boats. (Photograph 12). trucks usually worked in shallow water and boats in deep water. the shoaling up of the downstream river bed due to the sand from underneath the mattress the working of boats had become d and inefficient. They could not carry the full load of stone and the lead from the stacks to boats had increased.

The water level upstream was expected to rise to R. L. 478·0, it was proposed to carry the stone to R. L. 480·0 both upstream downstream. The proposed minimum section downstream is show Plate V. Below water level stone was allowed to take its own The completion of stone to full section advanced from the two It was completed both upstream and downtream about the same After this, a covering of ballast was laid over the upstream stone give a more or less even bedding for the tarred gunny-bag tarpaulin be stretched.

After the ballest had been put in the filling up of the cribs sand bags began. It will be recalled that only a one foot layer of bags had been put in as any greater depth of sand-bag filling would caused undue obstruction and forced more water from beneath mattress with consequent danger of undermining, but this danger disappeared with the stone protection laid to full section. With rise of water upstream as a result of heading up the depth of water the upstream line of cribs was now considerable. The divers had employed to pack the cribs with sand bags to within 4 ft. below level. This was done by four divers working on each crib, two from end. Bags were handed over to each man who dived with it and it one against the other and this had to be done very carefully be on its proper execution depended the stoppage of leakage. The to 4 ft. of filling was done after the tarpaulins had been laid.

At this stage it was considered advisable to start closing up earthwork. On 12th December an attempt was made to see if earthwork could be advanced without a tarpaulin covering on the stream but though the portion well away from the crib lines sho advance there was no advance along the cribs and all earth thrown carried through the stone. This attempt was therefore given up laying of tarpaulins started on the 14th evening.

Tarpaulins.

Gunny bags had been opened out and sewn in the form of a paulin 60 ft. long and 50 ft. wide. The tarpaulins were of ample w to cover the stone face, the *pilchi* mattress upstream and extend a feet over the sand bed. Stretching straight it would have been eno

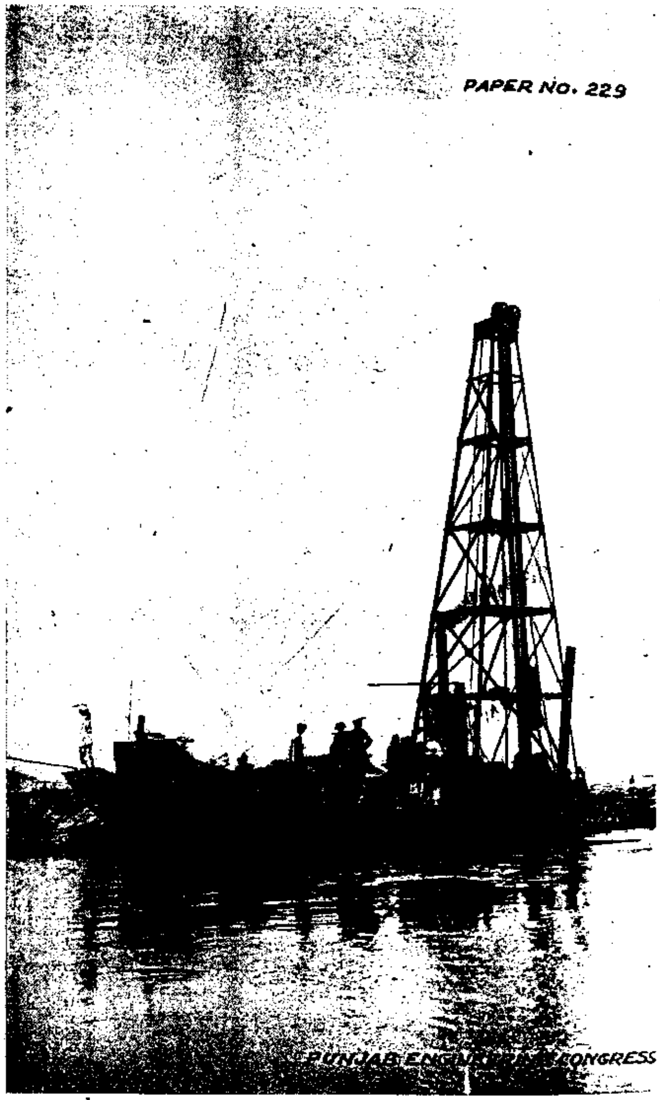


Photo No..16. Sheet pile driver mounted on a 1000 maund country boat with which piles up to 35 ft. length were driven at the sheet pile regulator at Suleimanki river division site. No. 7 hammer was used.

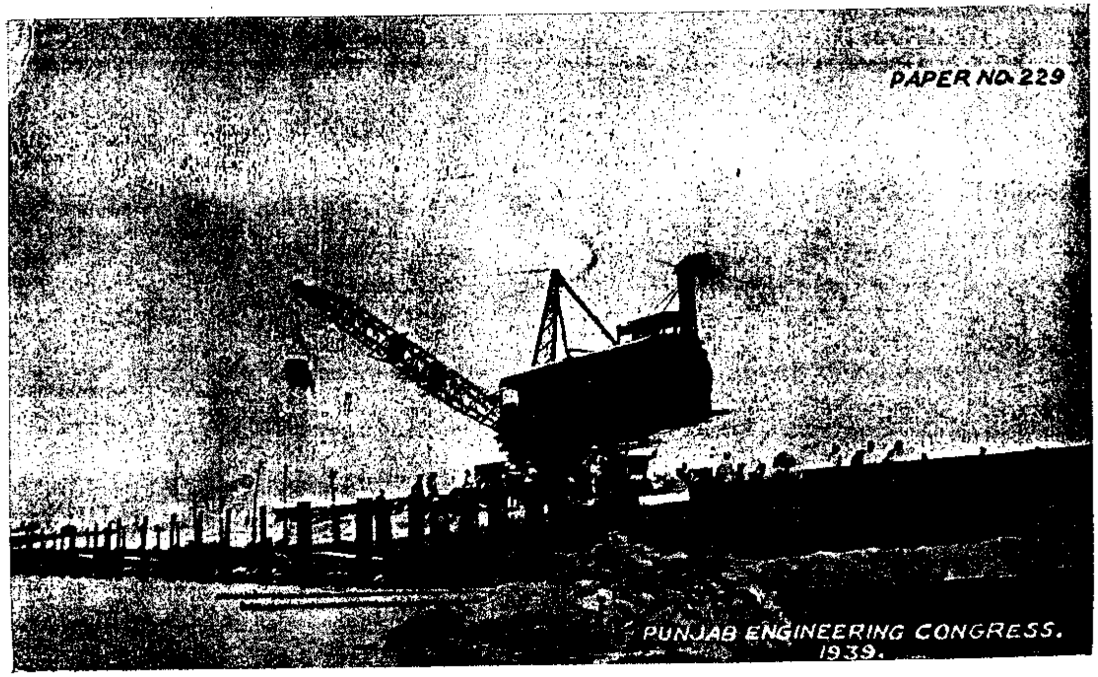


Photo No. 17. Sheet pile regulator used for diversion of the river at Suleimanki (March and April 1925). Note the pile abutment on right and the karries in the regulator spans used for gradual heading up of water.

Photo No. 17. Sheet pile regulator used for diversion of the river at Sutlej (March and April 1925). Note the pile abutment on right and the karries in the regulator spans used for gradual heading up of water.

a 40 ft. width but it is desirable to let the tarpaulin remain loose so that it does not get torn by stretching and thus permit leakage. they were sewn they were spread out. Lime and kerosene oil were in coal tar which was then applied hot by brushes. Sand was strewn on to prevent coal tar sticking when rolling. *Sal ballis* tied and sewn into that end which was to remain at the cribs and water and small thin *sal* pieces 4 ft. long to the other end which to go in water. The object of small pieces is that they permit the ulin being pulled by ropes passing round it and at the same time ake the general shape of the bed of river. The tarpaulin was then and lifted by slings and loaded on two boats joined lengthways. boats were then rowed in position alongside the cribs. The tarpaulin unrolled on the boat and the end with the long *ballis* was pulled out tied on to the cribs. Empty bags were passed round the upstream ontal member of cribs and its two ends under and above the tar- where it was sewn, thus tying the tarpaulin to the crib. (Photo- h 13). The tarpaulin was then unrolled on the boats, the boats pulled by means of ropes from heavy boats anchored with mooring and thus the tarpaulin was stretched. (Photograph 14). This done ropes were tied to the tarpaulin front at three places and pull- om boats. Two ropes on each side were also tied. Since no *ballis* be sewn on the sides and a straight pull on the tarpaulin would torn it, small stone pieces were rolled in and ropes tied round them. 19, Plate IX and Photograph 15). To make sure that the joint be- n adjacent tarpaulins was fully covered a 10 ft. overlap was given, the tarpaulin had been stretched as above the boats moved out and ulin rested completely on water as shown in the photograph.

Loading of the tarpaulin with sand bags was then started. Care taken by manipulating the pull from the seven ropes not to leave any on of the tarpaulin stretched when laid and the divers made sure it rested loose at the ends. To enable water to get out from under d to ensure satisfactory bedding the divers started loading it from ribs down to the bed and then over the mattress. Sand bags were ered to divers (see photograh 13) who went with them in water placed them side by side making sure that no sand bag thrown to the previous tarpaulin was lying under its end. Before the sand were completely laid on the front line, weighting of tarpaulin was by dumping bags from boats so as to expel any water underneath thus give it a firm bedding. In spite of all these precautions the ulin got occasionally torn by stone and these gaps had to be closed water by the divers by covering them with small tarpaulins and ng them. The existence of such gaps was indicated by the earth ng to advance. Divers were then sent in to localize the gaps. It erally not desirable to advance more than one tarpaulin at a time. g area is covered and a local breach occurs in the tarpaulin, water tart gushing out under high pressure and might suck in more and of tarpaulin thus accentuating the original breach. The pressure h is equal to the difference in upstream and downstream water levels is likely to tear the tarpaulin on stones if it is not loo... on them. As the last tarpaulin had to be put in earlier due ... sideration of advancing of earth about four big gaps were ... and two more tarpaulins 20 ft.×30 ft. had to be laid to cover th...

Final Closure.

With the tarpaulins laid the advancing of earthwork wa... on 15th December from one end and on the 16th from the o... was at first contemplated to lay all the tarpaulins and start ad... on the entire front to avoid the otherwise heavy concentration ... in the middle. Arrangements were therefore made to keep a ... bridge ready and this was borrowed from the Buildings and Roads De... partment who had dismantled Talibwala ferry in anticipation of com... pletion of the road bridge at Trimmu. The boat bridge however coul... not be brought into action till stone dumping on the upstream side wa... completed and tarpaulins laid. By then the earthwork by donkeys ha... advanced sufficiently from both ends and the full number of donke... could work on these fronts. The boat bridge was however kept rea... in case of need. The cribs in front of which the earth-work had ad... vanced had served their purpose hence their tops were sawn off and ... 5 ft. wide sand bag path covered with sand was made available for ad... vancing earthwork along the entire face. With this additional frontag... the gap was closed on the 17th night.

Head on Diversion Bund.

The maximum head across the diversion bund was 4·9 ft. on th... evening of 17th December. The perusal of the graph on plate VII show... that the gauge upstream of the diversion bund went by gradually as th... stone dumping advanced. But as a result of the final closure by means ... tarpaulins and earthwork the gauge rose rapidly between the 15th an... 17th. Statement IV gives the head across the bund and dischar... through the diversion cut for the period 6th to 17th December. Th... graph of head at diversion bund and the discharge through the cut (Pla... VI) shows that the rate of increase of discharge was greater as the hea... increased. The real development of the cut took place with the increa... in head. Statement III shows the effect on various gauges duri... diversion period.

Lighting Arrangements.

On account of the extensive area in which works were scattered a... the necessity of work being carried out at night very efficient lighti... arrangements were needed. A transmission line was carried to the bu... and two flood lights at either end were fixed to throw beams of light ... the main work. In addition to this a line carried across the river al... the mooring posts and up to the borrow pits where donkeys were wo... ing. Petromax lamps were used at places remote from the electric li... and occassionally to supplement electric lighting.

Photo No. 18. Jetting sal ballas in river bed. The fire engine is mounted on a boat on the right. Note the jetting pipe alongside the sal balla.

Photo No. 19. Sheet Pile regulator at Suleimanki with a pilchi mattress floated downstream of it in position and boats on either side of the latter to weight it down with stone.

Photo No. 20. Permeable Spurs as first tried at Suleimanki (1925).

'igures and Collection of Materials.

tion of materials started in October and all materials were well in advance. Filled sand bags were kept ready. *Pilchi* was started as soon as river conditions permitted. Mattresses got ready by the 10th November and cribs by the middle of . A reserve of *pilchi* and bags and *ballis* was arranged which ed to be very useful. Tramway lines were all laid out in ad- material kept at hand for emergencies. 46 divers had to be rom the upper reaches of Sutlej as the local boatmen were of r type who could not be trusted to work for any length of time 33 boats were employed on dumping stone and sand bags, neable spurs and four for miscellaneous jobs. A country boat ased and a gantry fitted on it. 180 N. G. trucks were brought or the carriage of stone. Four N. G. locos were kept ready ns if necessity arose. About 40 gangmen were always working lling, relaying and linking of N. G. track. Tarpaulins were well in advance. All materials for the permeable spurs at the upstream right guide bank was kept at each spur ready to be ition as the cut was opened. About 1000 donkeys and 1700 re working during the period of rush on the diversion bund in addition to the labour on cuts. Most of the work was done tally. Preparing of mattresses, part of stone dumping or sand and all earthwork were done on contract labour. For the last work continued day and night though night work was neces- er. It was only a well planned and carefully thought out on that completed the work in such a short time. The final ich was expected to be finished by Christmas week was one on the night between 17th and 18th December.

n for Freshets.

the diversion it was found that the development of the cut was and a discharge of 1245 cusecs could only be passed with a 9 ft. This meant that in case freshets came in, heading up considerable which might endanger the diversion bund. Fur- ght be beyond the capacity of the right undersluices without ading up. There would be no possibility of water passing he left undersluices before early March. The freshets had to be passed through the right undersluices and the adjoining ys which were separated from the left group by a substantial und with suitable cut-offs on grouted stone aprons. No tary bund across the ungrouted stone apron had any chances nding the head of water between river level on one side and the level on the other. Statement V of maximum discharges for ears shows that in December the maximum ranged from 69, in January 1700 to 23,700, in February 1230 to 35,365 and 10,363 to 1,05,000 cusecs.

If the waterway downstream were sufficient to permit conditions at the right pocket, considerably higher discharges passed but enough waterway to permit these did not exist. A the natural creek was to become useful and was to serve as an cut. By the end of January it was anticipated that 13 bays of weir would be able to function as the bridge would be comp erection would have well advanced. After January thεrefore had to be passed through ti e right half. This indicated the for fresh leading cuts both upstream and downstream which of the creek as far as possible.

The cross bund segregating the left half of the weir therefore designed to withstand a discharge of one lakh cusecs with a poss level of 490·0 but natural surface being at R. L. 487·0 any this will get automatic relief by spills over the *bela*. The top of bund was however fixed at 494·0 and arrangements made to spills out of the working area in the left half.

Effect of timely Closure.

The L. C. C. system was to have a closure from the 13th Till the diversion bund was completed no water could be esca Khanki and even freshets had to be absorbed as far as pos closure of the diversion bund on 18th December, 1938 however the Lower Chenab Canal closure to be fully utilized and allowed to be escaped below Khanki on 20th December, 1938 plus came well in time and helped to develop the diversion cut

Costs.

The statement of material costs and rates is attached as A. Other useful information relating to the work is also includ

Conclusions.

The diversion of a river marks the virtual compl headworks, as the original channel having been closed an longer available all rises in the river from small freshets, to have to be regulated over the completed works.

River diversion is therefore the crowning act in a head struction, and has to be very carefully planned and properl It is essentially a tricky job and to make full use of the tir an early start is extremely desirable and the successful com should be aimed at as early in the winter as possible, and d fore the winter rains set in. It should therefore be timed t the period of lowest supply in the river when chances of succ assured and at the same time allowing sufficient period fo cavation work in diversion cut or cuts.

0 *years.*

1934-1935		193.
Min.	Max.	Min.
1490	2530	1527
1331	3520	1306
1379	4506	1628
10648	31105	1161
4296	36123	26715

STATEMENT I

Maximum and minimum discharges November—March for last 10 years.

Name of the month.	1927-1928.		1928-1929.		1929-1930.		1930-1931.		1931-1932.		1932-1933.		1933-1934		1934-1935		1935-36.		1936-37.		1937-38.	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
November ..	1980	2494	1938	3472	4026	14251	1000	23956	2125	3908	1399	2240	2896	10276	1490	2530	1527	2642	1826	2928	1439	4300
December ..	1700	2802	2058	15069	2099	8169	1520	2120	1568	2512	1080	1477	2853	4518	1331	3520	1306	2001	1730	4986	1279	2390
January ..	1364	1868	2354	17000	4125	21300	1470	23700	1395	11545	974	1700	1888	5944	1379	4506	1628	4467	1944	5967	2319	17164
February ..	1477	18058	4261	16000	4366	22400	2388	15701	1520	5876	806	1230	1366	2102	10648	31105	1161	2645	1709	12688	2620	35368
March ..	7447	18667	4593	20019	7500	51000	6581	19546	1427	20072	824	33680	1300	10363	4296	36123	26715	105000	9331	31834	13094	38513

STATEMENT II

Statement showing the levels of cribs during diversion operations.

(Cribs initially fixed at R. L. 480.)

Figures in Antique show Settlement.

o. of cribs 1st line	Fixed level of crib.	SUNK CONDITON OF CRIBS DURING OPERATIONS.										
		7-12-38.	8-12-38	9-12-38.	10-12-38.	11-12-38.	12-12-38	13-12-38.	14-12-38	15-12-38.	16-12-38	17-12-38
	480·0	480·0	480·0	480·0	480·0	480·0	480·0	480·0	480·0			
	480·0	480·0	480·0	480·0	480·0	480·0	480·0	480·0	480·0			
	480·0	480·0	480·0	480·0	480·0	480·0	480·0	480·0	480·0			
	480·0	480·0	480·0	480·0	480·0	480·0	480·0	480·0	480·0			
	480·0	480 0	480·0	480·0	480·0	480·0	480·0	480·0	480·0			
	480·0	**477·7**	477·7	477.7	477·7	477·7	477·7	**476·3**	476·30			
	480·0	**474·7**	474·7	474·4	474·7	474·7	474·7	474·7	474·7	474·7		
	480·0	**474·7**	474·7	474·7	474·7	474·7	474·7	474·7	474·7	474·7		
	480·0	**477·7**	**474·7**	474·7	474·7	474·7	474·7	474·7	474·7	474·7		
	480·0	480·0	480·0	480·0	**476·3**	**476·1**	**475·8**	475·8	**475·2**	475·2		
	480·0	480·0	480·0	480·0	**479.5**	**478·1**	**477·9**	**476·6**	**476·0**	476·0		
	480·0	480·0	480·0	480·0	**479·3**	**478·6**	**477·2**	477·2	477·2	**477·10**	477·10	477·10
	480·0	480·0	480·0	480·0	**479·6**	**479·2**	**478·9**	**477·8**	**477·4**	**477·2**	**477·15**	477·15
	480·0	480·0	480·0	480·0	**479·6**	**479·2**	**478·9**	478·9	**478·2**	**478·15**	**478·05**	478·06
	480·0	480·0	480·0	480·0	**479·6**	**479·2**	**478·8**	478·0	**478·6**	**478·17**	**478·07**	478·07
	480·0	480·0	480·0	480·0	**479·0**	**478·8**	**478·6**	**478·5**	478·5	**478·0**	477·99	477·99
	480·0	480·0	480·0	480·0	480·0	**479·6**	470·6	**479·4**	479·4	**479·17**	**479·07**	479·07
	480·0	480·0	480·0	480·0	480·0	**479·6**	**479·5**	479·5	**479·17**	479·17	**479·07**	479·07
	480·0	480·0	480·0	480·0	480·0	**479·6**	**479·5**	**479·3**	479·3	**478·51**	478·51	478·51
	480·0	480·0	480·0	480·0	480·0	**479·8**	**479·7**	479·7	**479·3**	**478·97**	478·97	478·97
	480·0	480·0	480·0	480·0	480·0	**479·8**	479·8	**478·8**	478·80	478·80	478·80	478·90
	480·0	480·0	480·0	480·0	480·0	480·0	**479·6**	479·6	**479·0**	479·0	479·0	479·0
	480·0	480·0	480·0	480·0	480·0	**479·8**	**479·7**	**479·5**	**479·25**	**479·15**	**479·05**	470·06
	480·0	480·0	480·0	480·0	480·0	**479·8**	479·8	**479·7**	**479·40**	**479·25**	**479·15**	479·15
	480·0	480·0	480·0	480·0	480·0	**479·6**	**479·5**	479·5	**479·4**	**479·10**	479·10	479·10
	480·0	480·0	480·0	480·0	480·0	**479·7**	**479·3**	479·3	**478·9**			
	480·0	480·0	480·0	480·0	480·0	**479·5**	**478·9**	**478·5**	**478·3**			
	480·0	480·0	480·0	480·0	480·0	**479·5**	**479·4**	**479·1**	**477·1**			
	480·0	480·0	480·0	480·0	**478·8**	**478·7**	478·7	**478·4**	478·4			
	480·0	**478·2**	**475·80**	475·80	**475·3**	475·3	475·3	475·3	475·3			
	480·0	**475·80**	475·80	475·80	475·80	**475·3**	475·3	475 3	475·3			
	480·0	480·0	480·0	480·0	**478·4**	**478·3**	478·3	**478·0**	478·0			
	480.0	480·0	480·0	480·0	**479·0**	479·0	**478·8**	**478·0**	478·0			

The work should not be permitted to be dragged into the freshet as not only will it mean heavier discharges and therefore greater but the chances of failure will be greater and the excessive time ed for closure may bring us to discharges too heavy to be controlled sitating postponement to the next cold weather with all the dant expense and risk.

If a failure occurs it will be necessary to repair the damage done by e and thus cover the lost ground before starting the work all over . This will mean extra costs in addition to serious set-back. As takes are very heavy it will be seen that in planning or execution of sion works there is no room for taking risks. The design of di-on bund should therefore aim at making it oversafe rather than work argin. It should be strong enough to withstand any possible rise ver during operations and have ample margin of safety.

The chief controlling factor in the design of diversion bund is the across it and to reduce it to the minimum the diversion cuts should eper at the tail and wider at the head. If labour conditions permit beral a waterway on these lines should be provided in the cuts as ible.

The stakes in river diversion are so heavy that successful completion ld be the main aim and costs should be given only a secondary con-ation. There should be enough of reserve material in case of aps.

If piles are not available a stone-cum-crib bund is the only safe one e heads are likely to be excessive.

nowledgements.

The Author is indebted to the valuable guidance of R. B. Lala hia Nath Khosla, I. S. E., Executive Engineer, Trimmu Division, with his experience was always a source of inspiration and who is nsible for the design. Acknowledgements are due to the staff who ed day and night till successful completion. Thanks are also due r. A. N. Malhotra, S. D. O., Executive Subdivision and Personal tant to Executive Engineer, Trimmu, who did the photography prepared the movie film of the various operations.

STATEMENT III
GAUGES.

Date.	Head of diversion cut.	Upstream diversion bund.	Down-stream diversion bund.	Tail of diversion cut.
1-12-38	474 50	474·14	473.91	473·45
2-12-38	474·50	474·19	473.86	473·60
3-12-38	474·50	474·19	473.81	473·35
4-12-38	474·55	474·27	473.81	473·35
5-12-38	474·55	474·29	473.79	473·35
6-12-38	475·00	474·44	473.76	473·30
7-12-38	475·00	474·64	473.46	473·05
8-12-38	475·50	474·79	473.51	473·40
9-12-38	475·50	475·19	473.66	473·20
10-12-38	476·10	475·54	473.46	473·20
11-12-38	476·45	475·79	473.59	473·18
12-12-38	476·50	476·09	473.50	473·15
13-12-38	476·80	476·30	473.41	473·15
14-12-38	476·90	476·46	473.46	473·13
15-12-38	477·10	476·62	473.46	473·12
16-12-38	477·60	477·24	473.31	473·02
17-12-38	478·20	477·89	473.26	473·03
17-12-38 evening		478·10	473.20	
18-12-38	478·35	477·99	473.26	473·13
19-12-38	478·30	477·94	473.36	473·40
20-12-38	478·30	477·94	473.46	473·46
21-12-38	478·00	477·89	473.61	473·65
22-12-38	478·00	477·84	473.66	473·68
23-12-38	477·95	477·79	473.76	473·80
24-12-38	477·90	477.75	473.81	473·83
25-12-38	477·85	477.64	473.86	473·88
26-12-38	477·85	477.74	473·88	473·91
27-12-38	477·90	477.80	473·92	473·95
28-12-38	478·45	478.30	474·00	474·02
29-12-38	479·00	478.90	474·35	474·38
30-12-38	479·00	478.80	474·42	474·45
31-12-38	478·85	478.74	474·50	474·50

STATEMENT IV

Statement of discharges of diversion cut with reference to head across diversion bund.

	Morning.			*Evening.*		
…te.	Head across bund.	Discharge of diversion At head.	Discharge of diversion At tail.	Head across bund.	Discharge of diversion. At head.	Discharge of diversion. At tail.
…12-38	..	..	..	..	..	..
…12-38	1·18	256	..	1·24	..	..
…12-38	1·28	272	..	1·50	..	..
…12-38	1·53	303	..	1·90	..	..
…12-38	2·08	331	..	2.10	400	..
…12-38	2·20	405	..	2·46	427	..
…12-38	2·59	436	..	2·65	497	..
…12-38	2.89	497	..	3·10	533	..
…12-38	3·00	516	..	3·10	550	
…12-38	3·16	573	..	3·40	601	..
…12-38	3·93	699	..	4·30	750	..
…12-38	4·63	1154	..	4·90	1245	..

STATEMENT V

Statement of maximum discharges in the months of December to March for the last 10 years.

Year	December		January		February		March	
	Date.	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
1929	18-12-29	8169	31-1-29	17000	4-2-29	16000	30-3-29	20019
1930	1-12-30	2120	17-1-30	21300	3-2-30	22400	20-3-30	51000
1931	2-12-31	2512	27-1-31	23700	1-2-31	15701	8-3-31	19546
1932	1-12-32	1477	15-1-32	11545	19-2-32	5876	15-3-32	20072
1933	4-12-33	4518	1-1-33	1700	1-2-33	1230	27-3-33	33680
1934	22-12-34	3520	10-1-34	5944	23-2-34	2102	16-3-34	10363
1935	9-12-35	2001	31-1-35	4506	1-2-35	31105	31-3-35	36123
1936	26-12-36	4986	9-1-36	4467	29-2-36	2645	3-3-36	105000
1937	27-12-37	2390	4-1-37	5967	27-2-37	12688	3-3-37	31834
1938	[illegible]	[illegible]	5-1-38	17164	17-2-38	35368	29-3-38	38513

STATEMENT VI

Statement showing the width at various points in right cut.

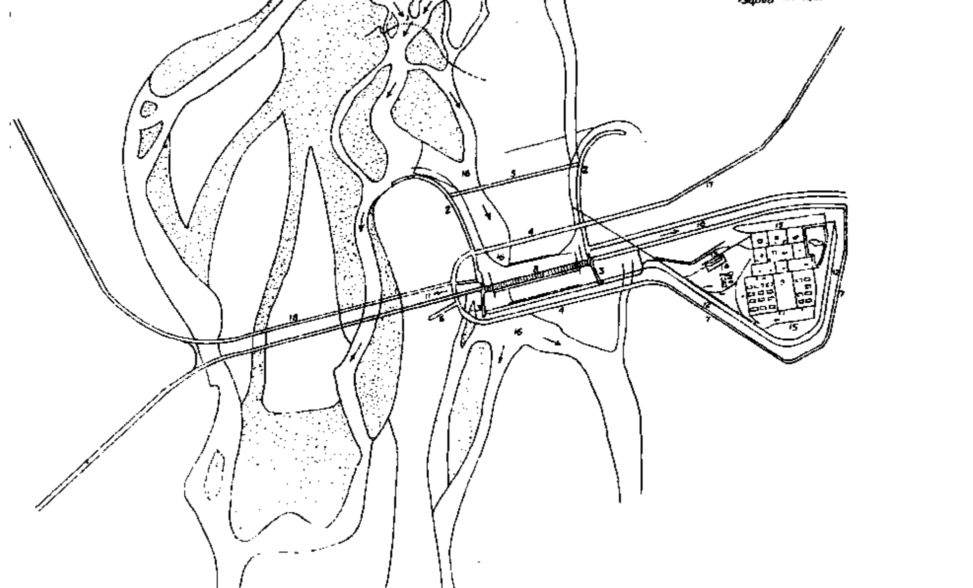
Site	Widths		
	Cunette width	On 5-1-39	On 15-1-39.
1	146	210	255
2	150	181	235
3	146	142	210
4	125	172	185
5	109	155	165
6	107	177	180
7	117	136	144
			Pocket line
8	125	190	191
9	126	170	184
10	128	183	189
11	127	226	233
12	105	163	168
13	130	153	153
14	116	174	174
15	133	142	144
16	126	144	149
17	110	136	140
18	126	141	146

PLATE NO. 1
PAPER NO. 225

GENERAL PLAN
SHOWING
LAYOUT OF VARIOUS SCHEMES
SCALE = 1/30,000 APPROX:

References :

1. Trimmu Ferry of Junction of Rivers Chenab (Right) and Jhelum (Left).
2. Guide Banks—upstream.
3. Guide Banks—downstream.
4. Ring Bunds protecting working area during construction from river attack.
5. Upstream secondary protection bund.
6. Right Spur protecting ring bunds from river attack.
7. Protection Bund round Station Area.
8. Emerson Barrage with weir and left and right undersluices, including silt extractors and head regulators of canals. The long Divide Wall on the right separates the weir from the Right Undersluices (or Right Pocket) and the Left Divide Wall does it from the Left Poket. A Central Divide Wall in the Left Pocket separates the extractor bays of the Undersluices from the non-extractor bays.
9. Playgrounds with Recreation Hall encircled by officers' bungalows and Rest House on top and staff quarters on the other three sides.
10. Main Line Left—which will be lined for 45 miles of its length.
11. Rangpur Canal which will be completed across the river after the latter is diverted over the Barrage.
12. Railway Sidings.
13. Power House.
14. Workshops.
15. Roads.
16. The Right Creek which will be used for diversion of river.
17. Left marginal bund.
18. Right marginal bund.



PUNJAB ENGINEERING CONGRESS.
1939

PLATE NO. II
PAPER NO. 229.

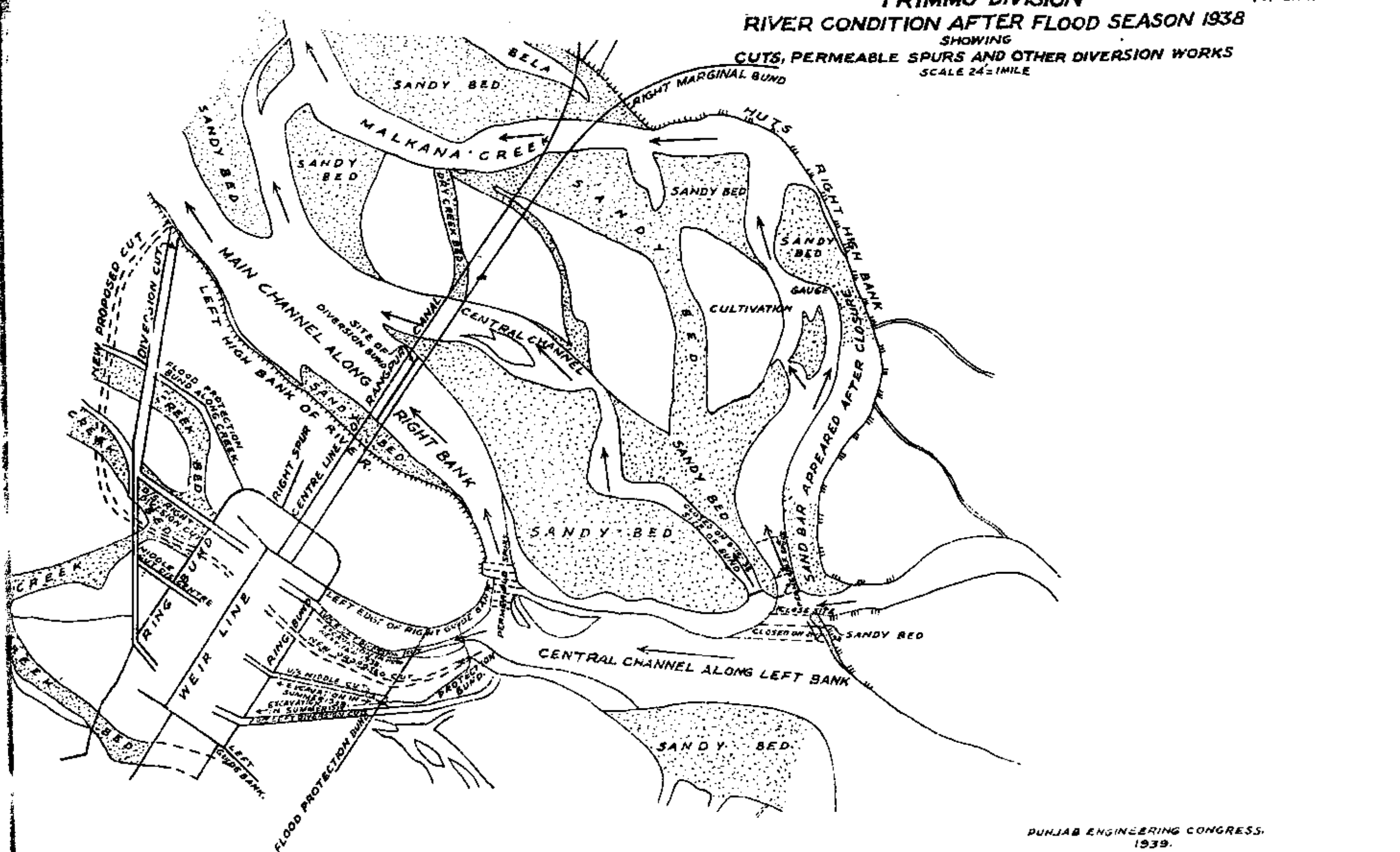
TRIMMU DIVISION

RIVER CONDITION AFTER FLOOD SEASON 1938

SHOWING

CUTS, PERMEABLE SPURS AND OTHER DIVERSION WORKS

SCALE 24" = 1 MILE



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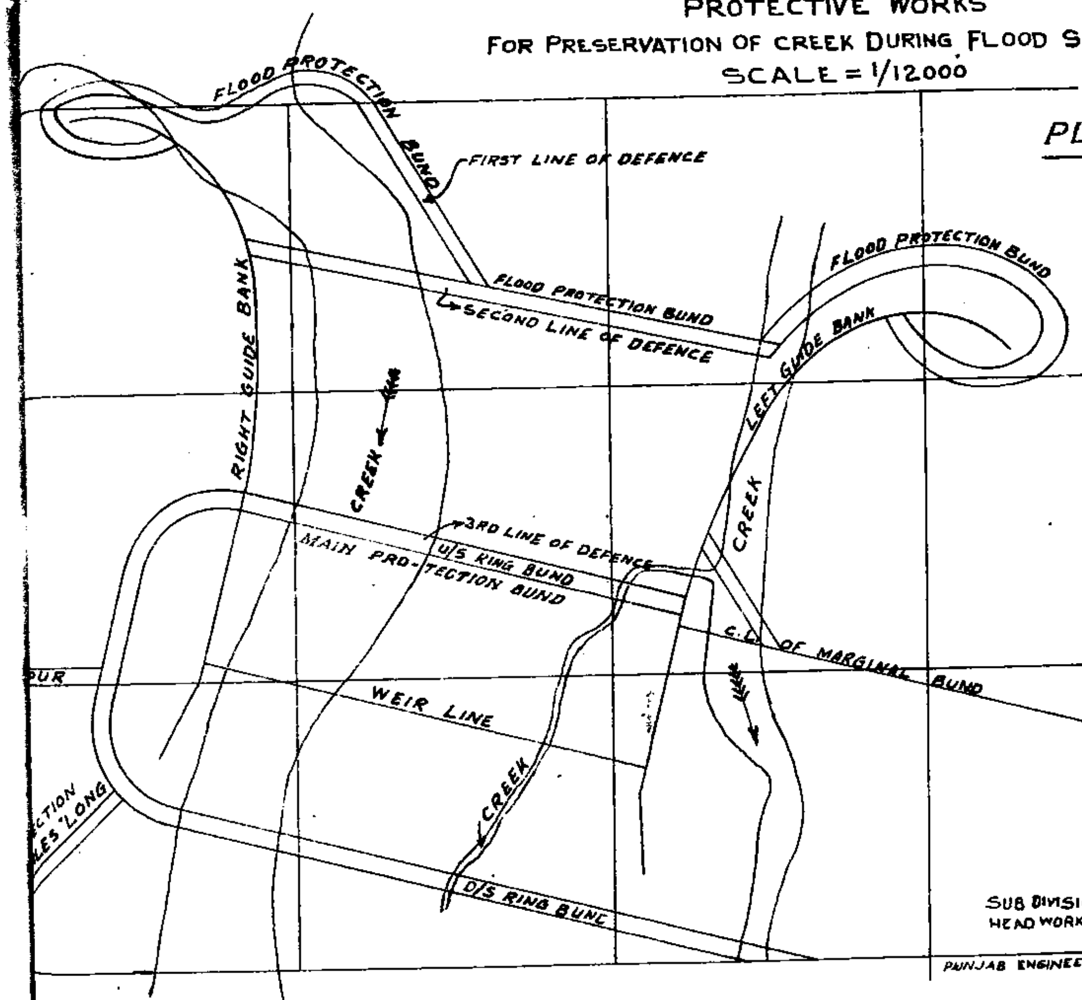
1939.

PLATE No. III

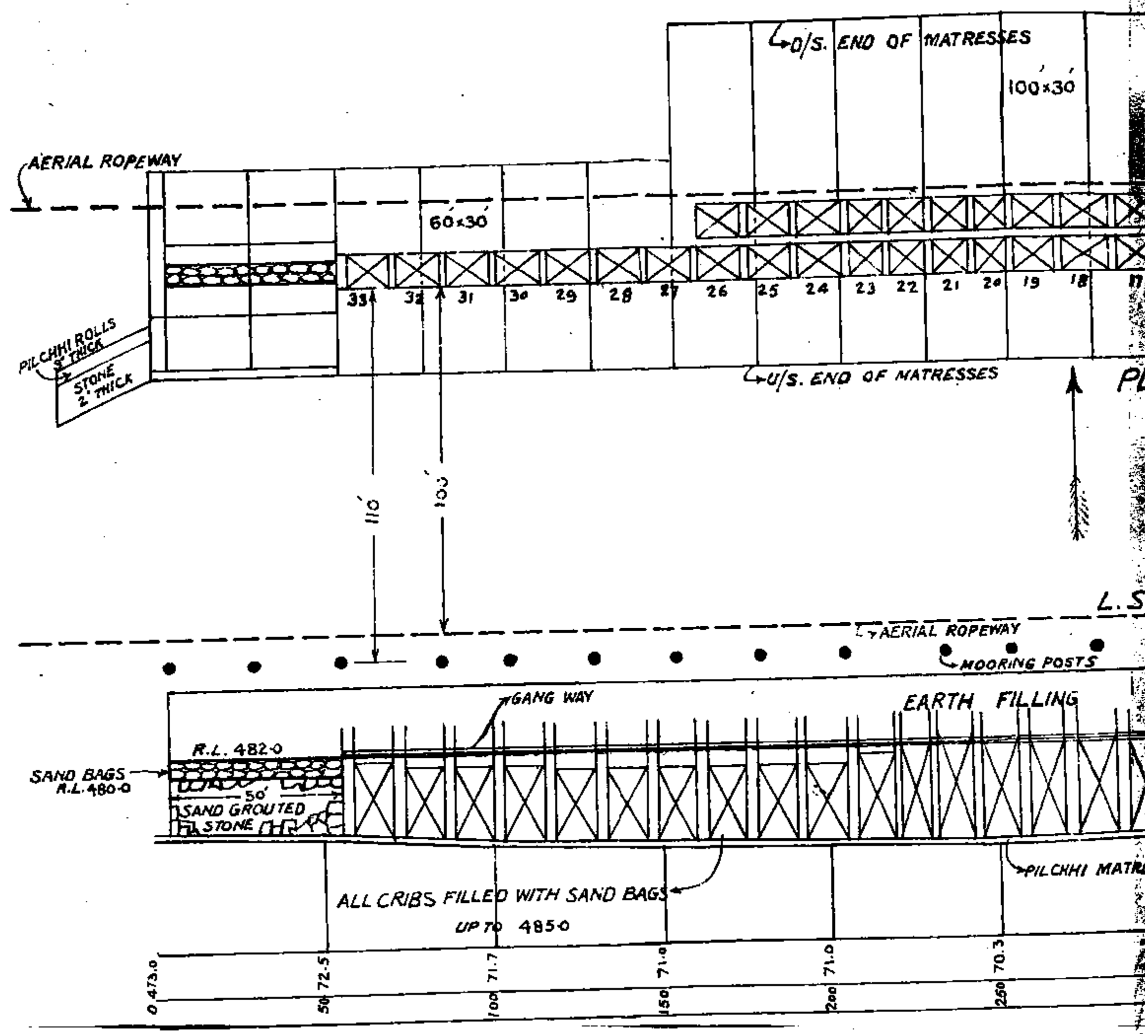
PAPER NO. 229

PROTECTIVE WORKS
FOR PRESERVATION OF CREEK DURING FLOOD SEASON 1938
SCALE = 1/12000



SUB DIVISIONAL OFFICER
HEAD WORKS RIGHT

PUNJAB ENGINEERING CONGRESS.



D/S. END OF MATRESSES
100'x30'
AERIAL ROPEWAY
60'x30'
33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17
PILCHHI ROLLS 3' THICK
STONE 2' THICK
U/S. END OF MATRESSES
PL
110'
100'
L. SE
AERIAL ROPEWAY
MOORING POSTS
GANG WAY
EARTH FILLING
R.L. 482.0
SAND BAGS R.L. 480.0
50'
SAND GROUTED STONE
PILCHHI MATRES
ALL CRIBS FILLED WITH SAND BAGS UP TO 485.0
0 473.0
50 72.5
100 71.7
150 71.0
200 71.0
250 70.3

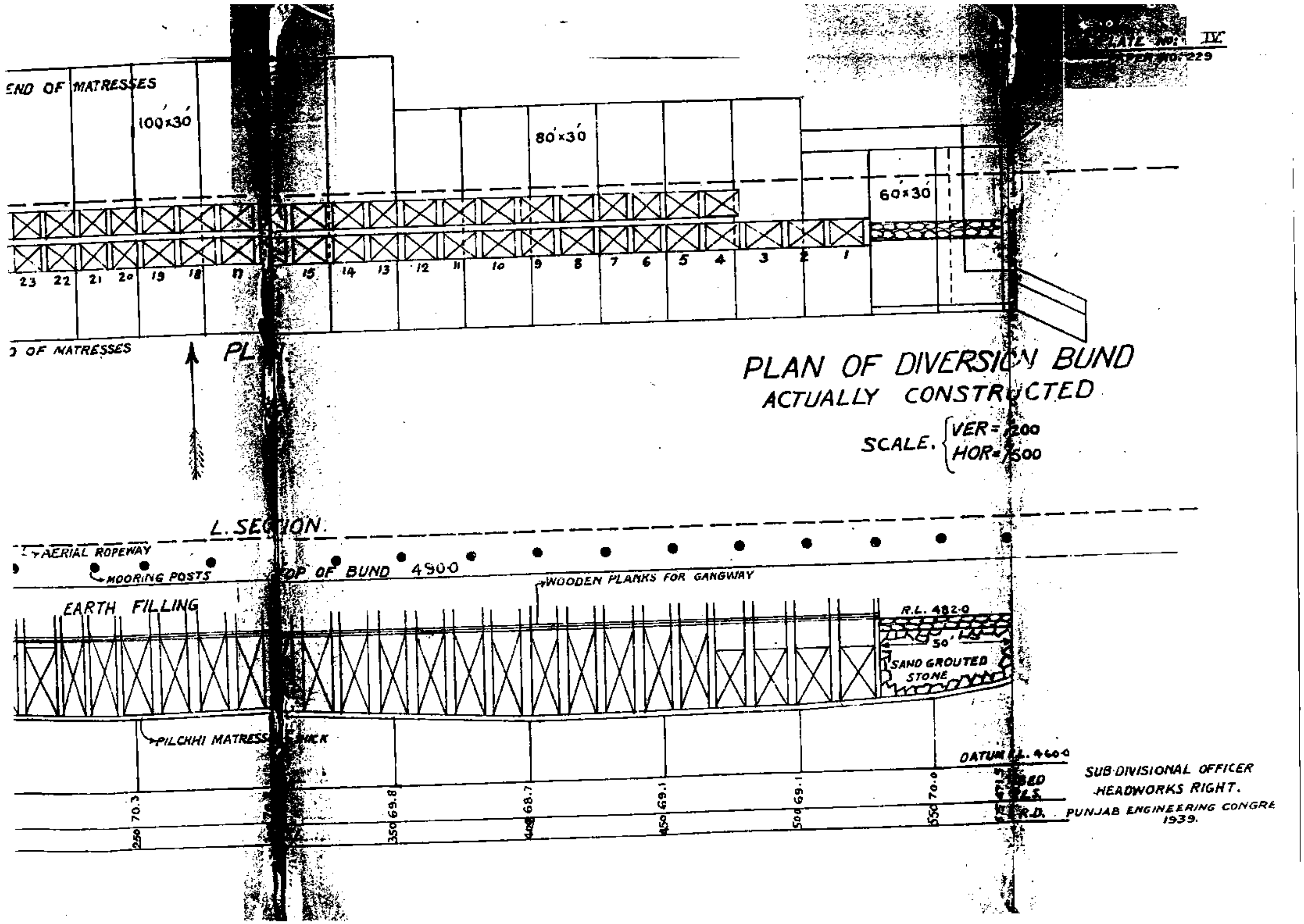
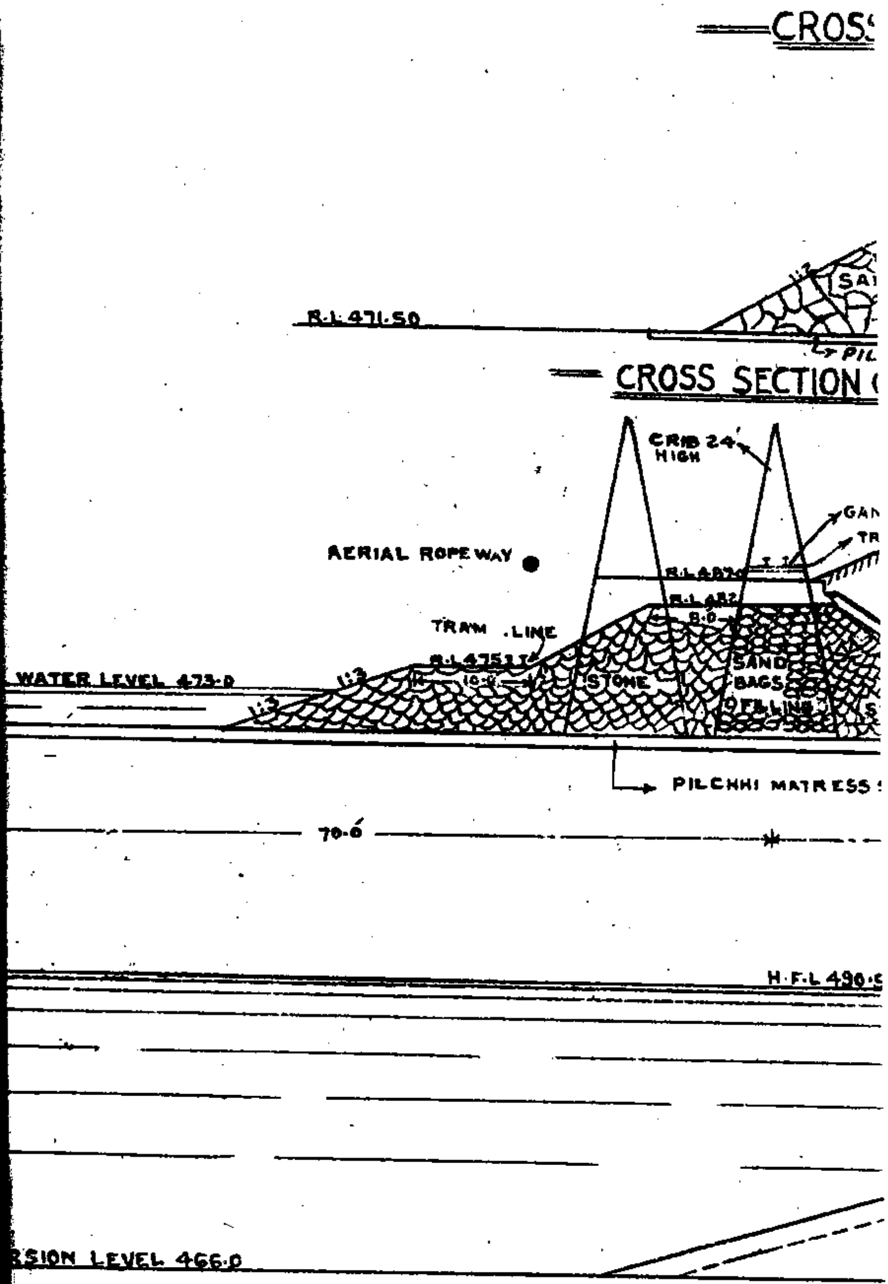


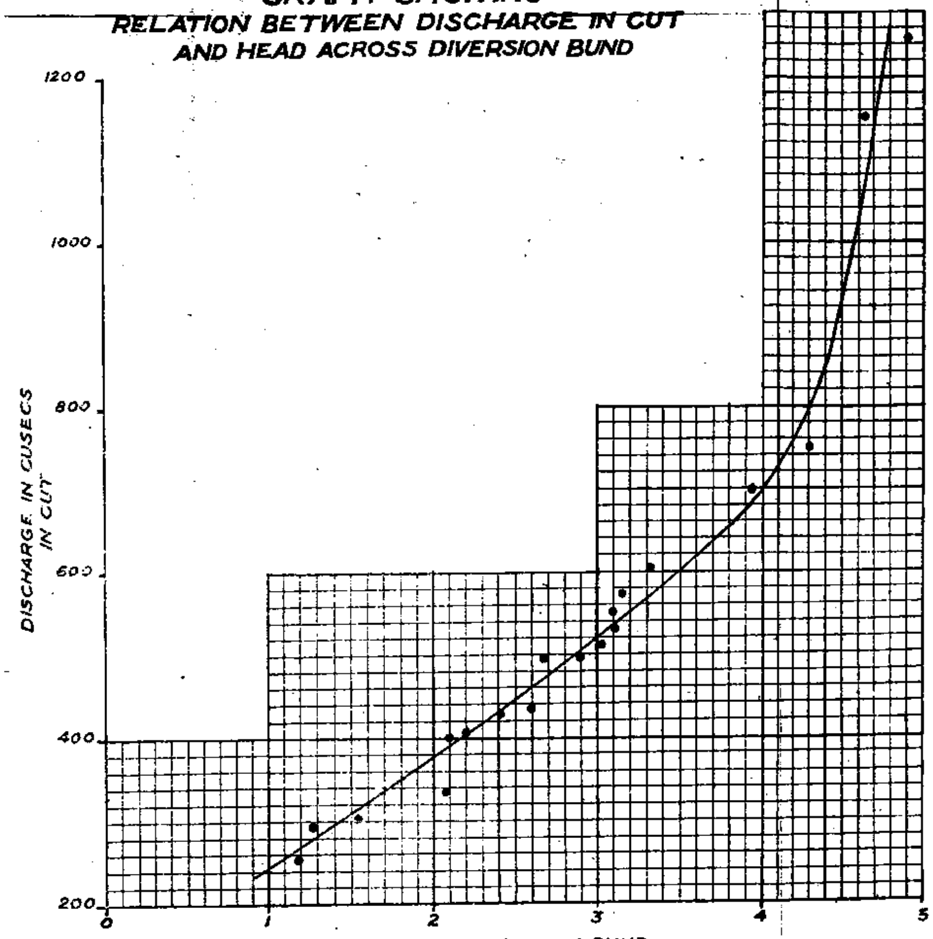
PLATE No. IV
PAPER No. 229
END OF MATRESSES
100'x30'
80'x30'
60'x30'
PLAN OF DIVERSION BUND
ACTUALLY CONSTRUCTED
SCALE. VER=200 HOR=500
L. SECTION.
AERIAL ROPEWAY
MOORING POSTS
TOP OF BUND 490.0
WOODEN PLANKS FOR GANGWAY
EARTH FILLING
R.L. 482.0
50'
SAND GROUTED STONE
PILCHHI MATRESS
DATUM
250 70.3
350 69.8
400 68.7
450 69.1
500 69.1
550 70.0
SUB-DIVISIONAL OFFICER
HEADWORKS RIGHT.
PUNJAB ENGINEERING CONGRE
1939.



CROSS
R.L 471.50
CROSS SECTION
CRIB 24' HIGH
AERIAL ROPE WAY
TRAM LINE
WATER LEVEL 473.0
STONE
SAND BAGS FILLING
PILCHHI MATRESS
70.0
H.F.L 490
RSION LEVEL 466.0

PLATE NO. V
PAPER No. 229

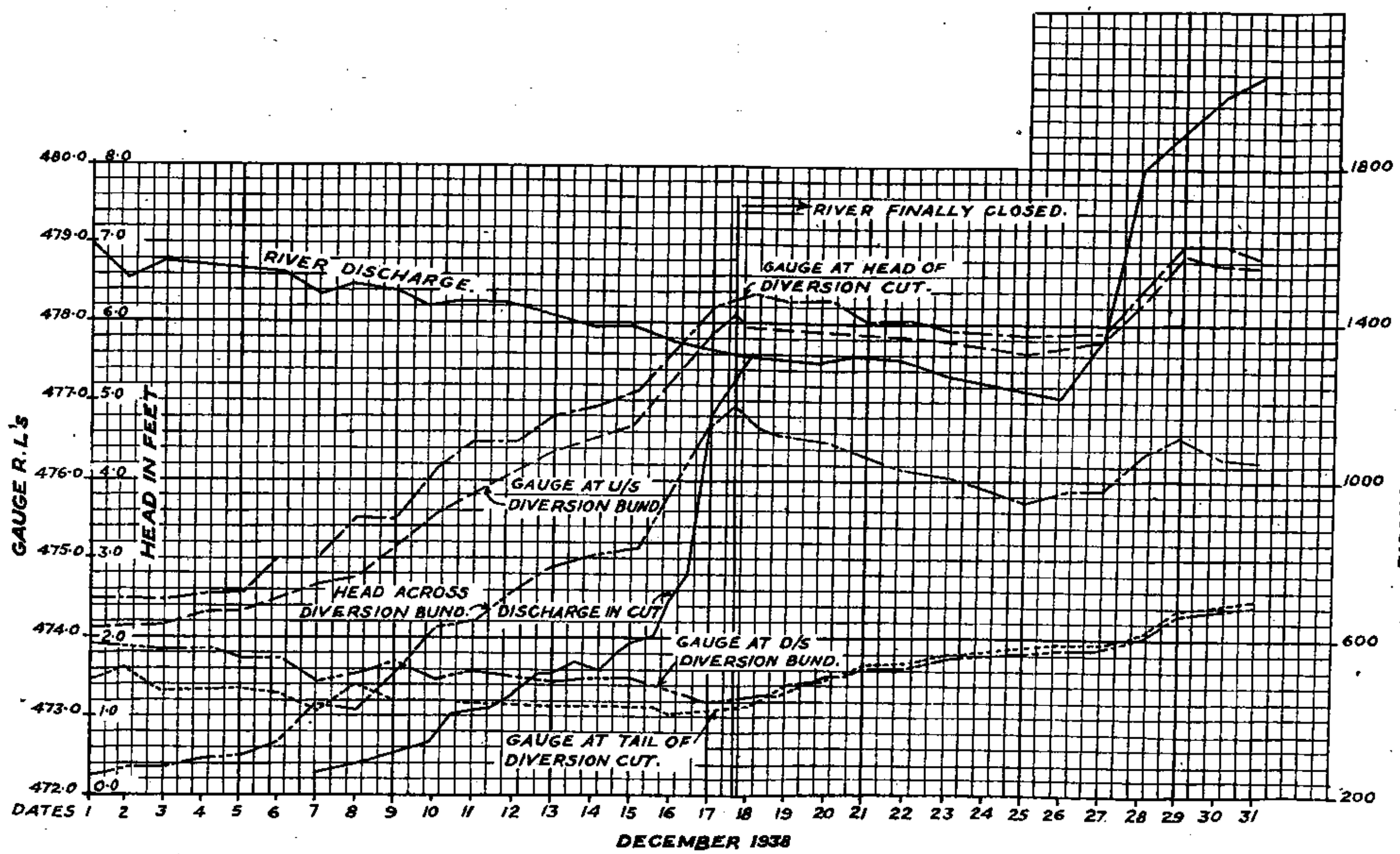
GRAPH SHOWING
RELATION BETWEEN DISCHARGE IN CUT AND HEAD ACROSS DIVERSION BUND



PUNJAB ENGINEERING CONGRESS
1939.

PLATE NO. VII
PAPER NO. 229

GRAPH SHOWING
DAILY WATER LEVELS AT DIFFERENT SITES AND DISCHARGES



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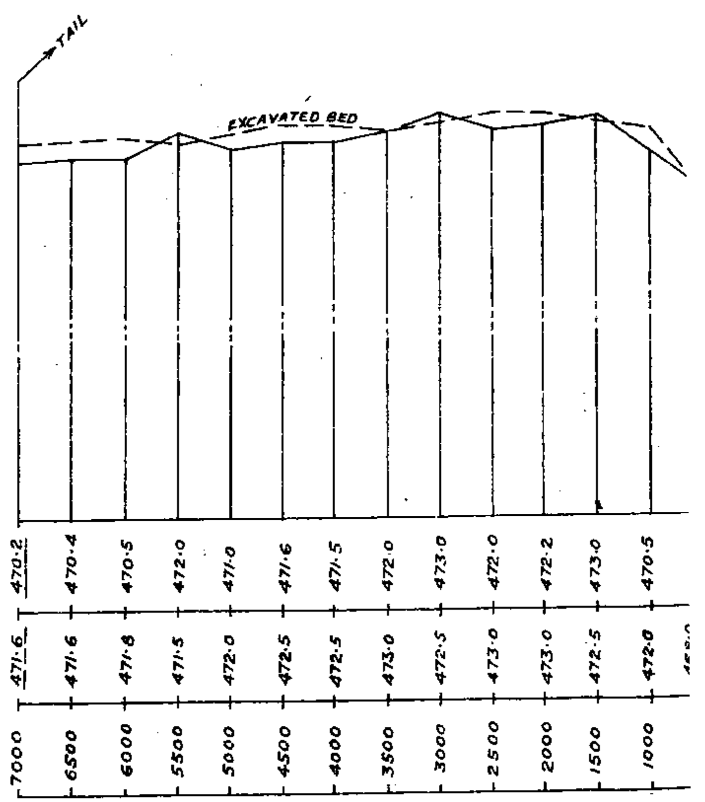
1939.

LONG: SECTION OF HEAD

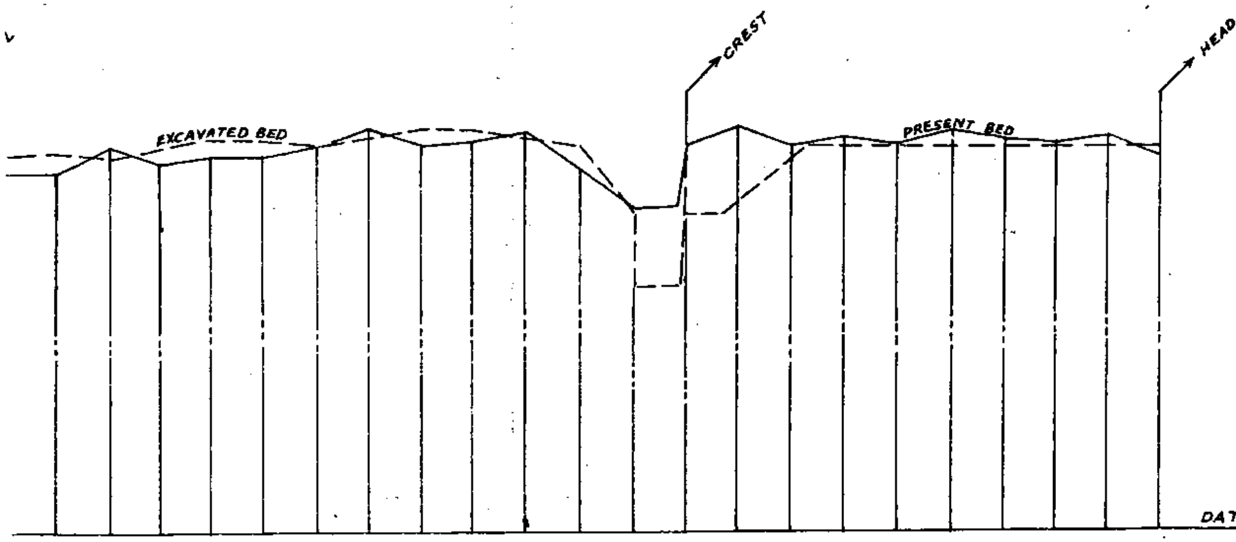
SCALE {H / V



LONG: SECTION OF RIGHT DIVERSION CUT HEAD TO TAIL

PLATE NO. VIII
PAPER NO. 229

SCALE { HOR: 4" = 1 MILE; VER: 1/100 }



DATUM R.L. 450·00

PRESENT BED	470·5	472·0	471·0	471·6	471·5	472·0	473·0	472·0	472·2	473·0	470·5	468·3	472·0	473·1	472·0	472·5	472·1	473·0	472·5	472·3	472·8	471·5
EXCAVATED BED	471·8	471·5	472·0	472·5	472·5	473·0	472·5	473·0	473·0	472·5	472·0	468·0 464·0	472·0	468·0	472·0	472·0	472·0	472·0	472·0	472·0	472·0	472·0
REDUCED DISTANCE	6000	5500	5000	4500	4000	3500	3000	2500	2000	1500	1000	500	0	500	1000	1500	2000	2500	3000	3500	4000	4500

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1939.

FIG. 8

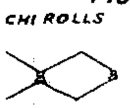


FIG. 9

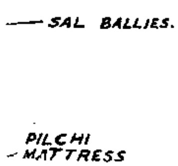


FIG. 10

FIG. 12

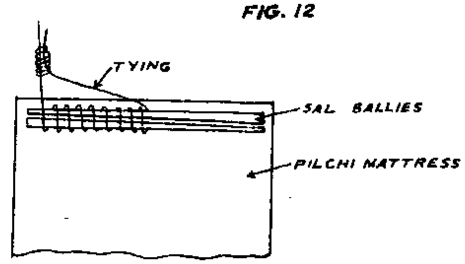


FIG. 13

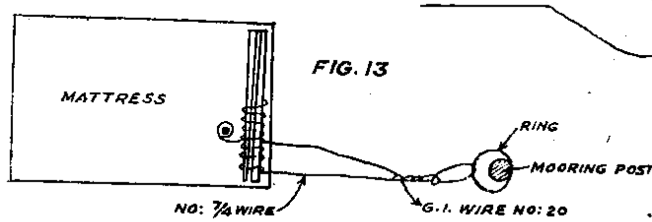


FIG. 14

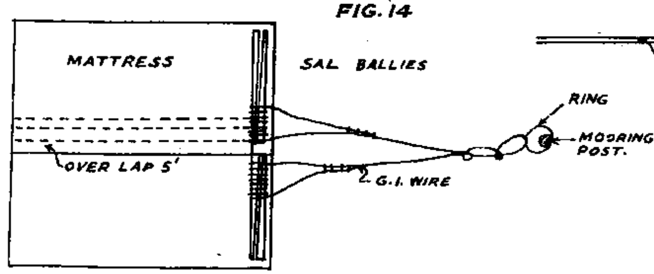


FIG. 15

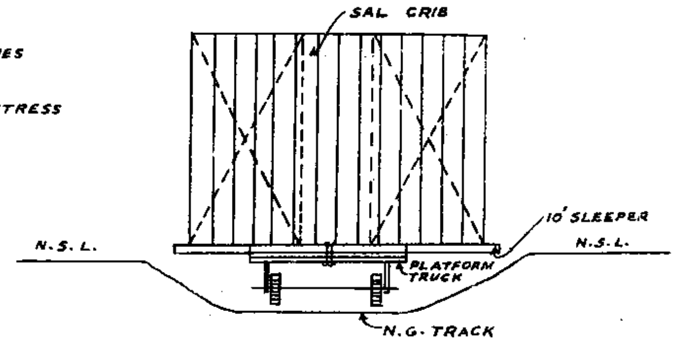


FIG. 16.

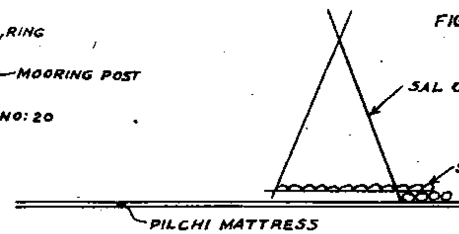


FIG. 17

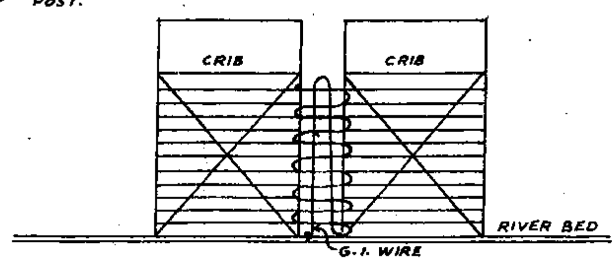


FIG. 5

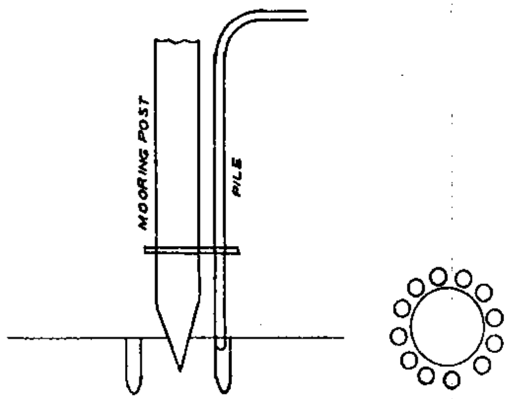


FIG. 6

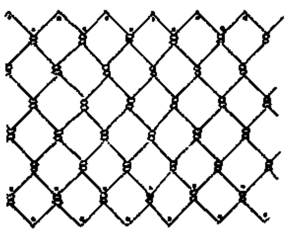


FIG. 7

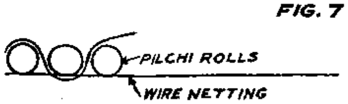


FIG. 8

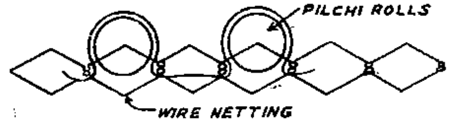


FIG. 9

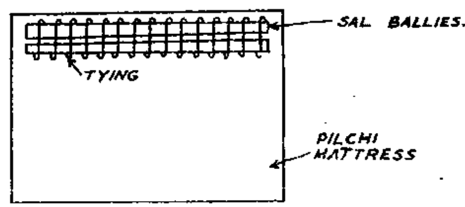


FIG. 10

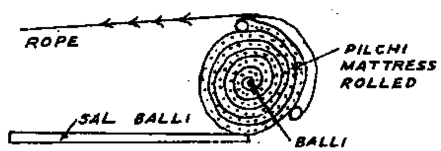


FIG. 11

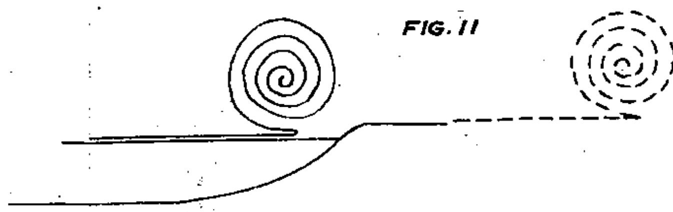


FIG. 12

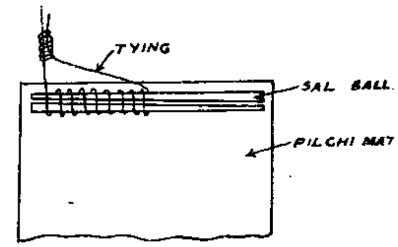


FIG. 13

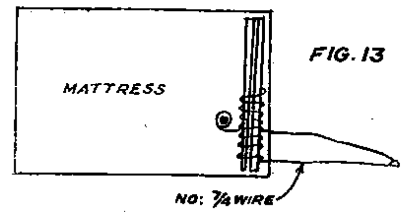


FIG. 14

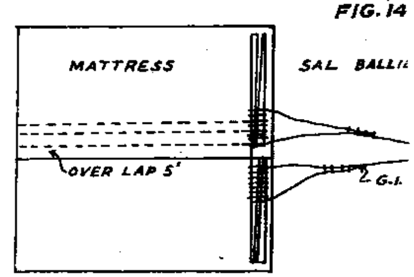


FIG. 3

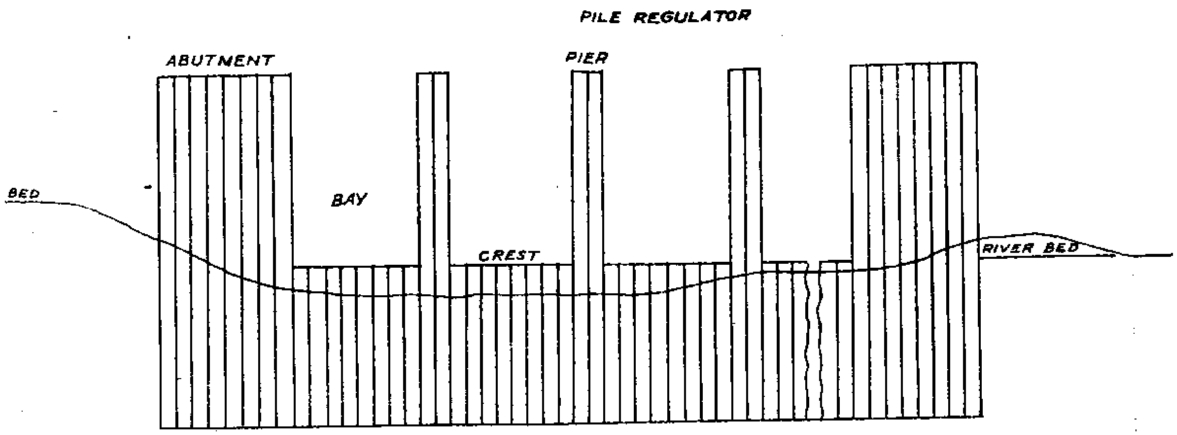


FIG. 5

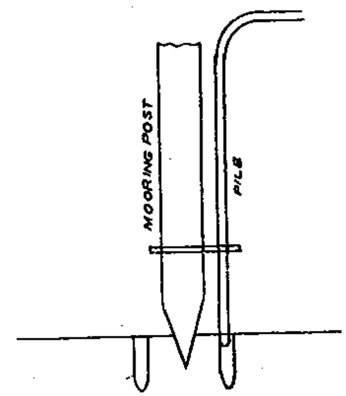


FIG. 4

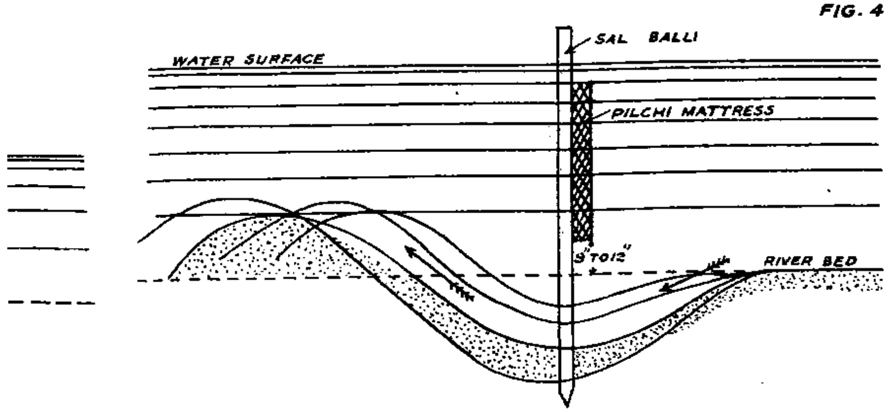


FIG. 6

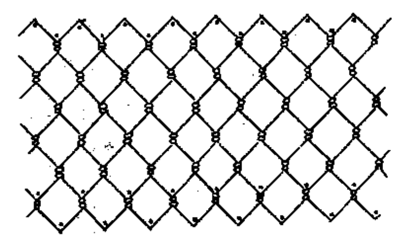


FIG. 7

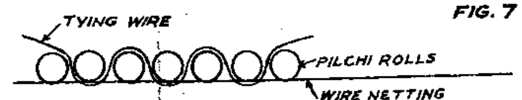


PLATE IX
PAPER NO. 229

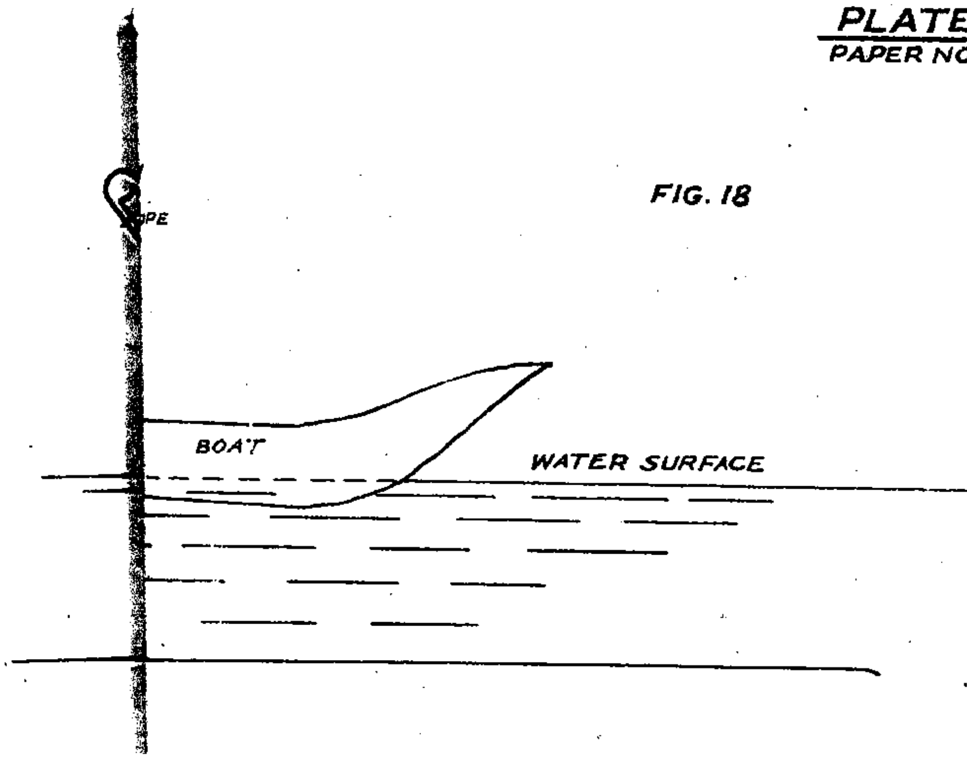


FIG. 18

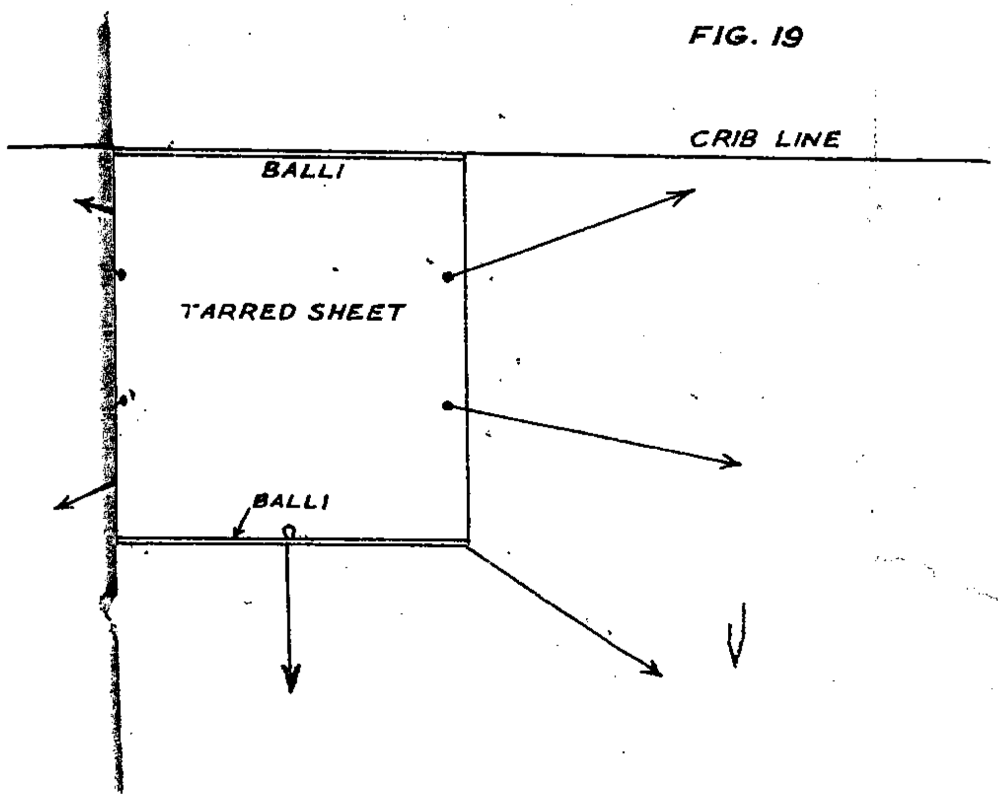


FIG. 19

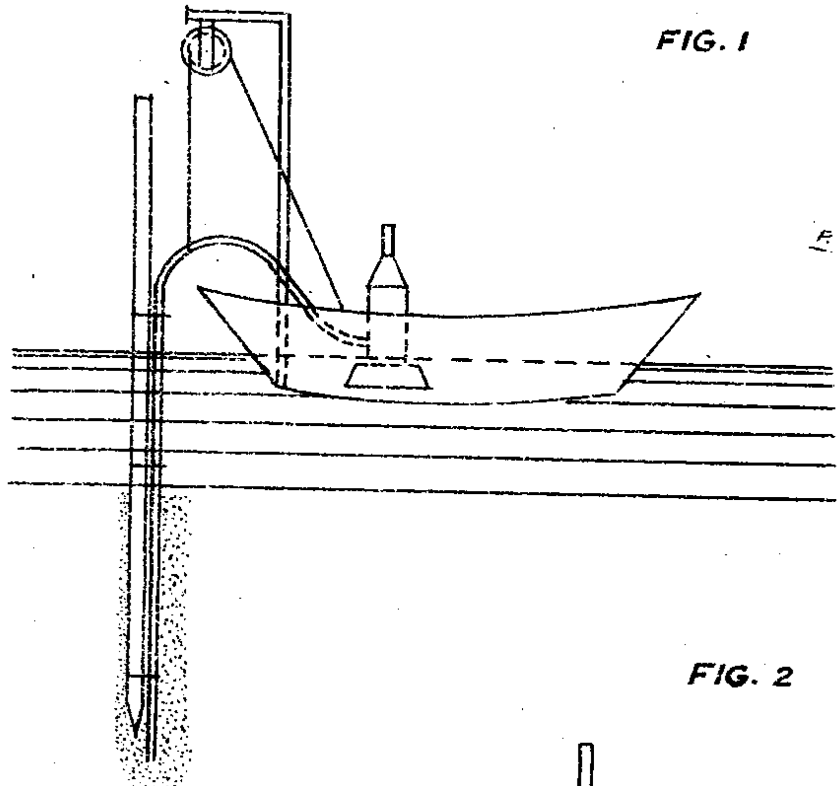
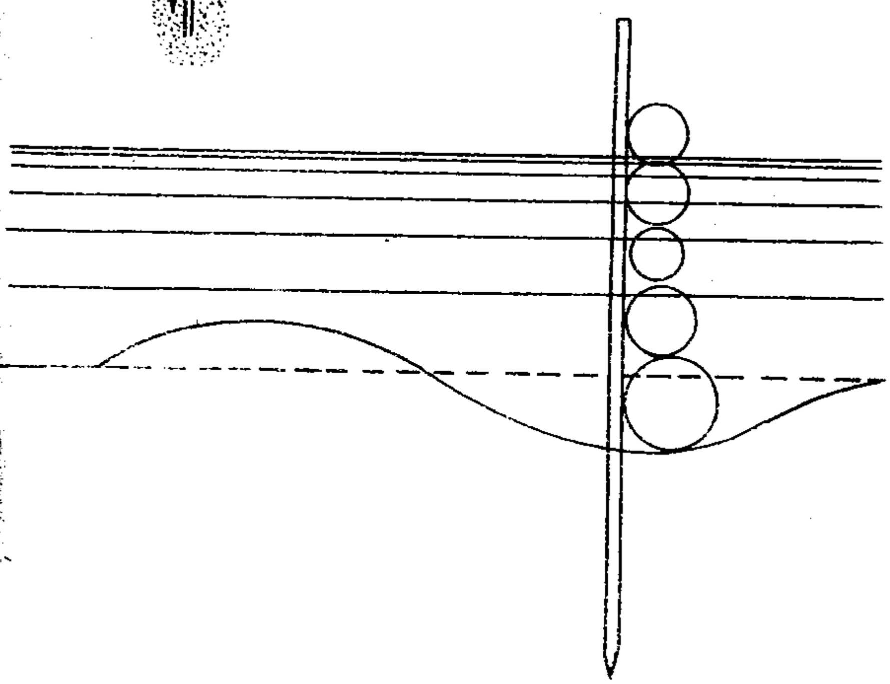


FIG. 1

FIG. 2



DISCUSSION.

The **Author** in introducing the paper said that it had not been possible for him to go through the proof of the paper on account of its late submission and as such there were some mistakes in printing. They would be corrected in due course.

Mention had been made in the Paper ot Appendix A giving costs, rates, analysis, quantities of materials collected and used and other useful information on the subject. This had not been published on account of late receipt. He would therefore give a few details of what it contained. The magnitude of the work would be apparent from the fact that 1,84,000 cft. of stone, 86,500 cft. sand bags, 16 tons G.I. Wire, 1900 ballies, 6 cwt. wire nails and staples, 26000 sft. tarpaulines, 500 gallons of coaltar, 90 lighting points, 4 miles N.G. track, 2,20,000 cft. pilchi were some of the major items. 8 crores of earthwork were needed in connection with the work relating to diversion and the bunds in the river area. Rates of cribs, mattresses, balli sinking were also analysed in this appendix.

He added that River conditions this year had been rather abnormal. After the diversion, the river kept on falling in January and went as low as 900 cusecs. A flood came in the 3rd week of February when the 4th cut which was excavated later was also opened. The entire right half of the barrage functioned in this flood and these cuts developed with the rise of water resulting in considerable scour of *belas*. Before this flood subsided another big rise had occurred which reached Trimmu on 1st March. The entire right half was passing the floods and had completely developed into a river.

On 3rd March the discharge rose to 1,80,000 cs. As the waterway was restricted on account of heavy bela downstream which had still to be scoured the water level rose considerably and was 1·8′ above the maximum flood level ever recorded. The river seemed to be rising still further. The abnormal rise was causing panic to the villages upstream and in order to relieve unnecessary ponding up the left half ot weir was also opened to the river. The bunds and protective embankments withstood the floods very well and have been completely tested as well as the works.

With the right half of the barrage completely developed into a river further floods were not expected to cause any worry. Apart from that sufficient time had been gained for the left half also to be developed before the monsoon and it was hoped that with the protective bunds fully tested the officers responsible for its running in the first year might not have that amount ot anxiety which was usually their lot.

On page—— a statement had been made that wider cut upstream and deeper cuts downstream were more efficient. This had been proved mathematically and was a matter ot simple calculations and the conclusions were based on mathematical analysis, In the end he said that a movie film of the work would be displayed showing the work in various stages. In passing judgment over the photographic achievement, he requested the members to keep in view the ract that both the movie and the paper had been prepared under great strain of rush of work and very little time and attention could be spared for these. The arranging and splicing had been started only three days back and though he felt he had not been able to do full justice yet it would provide enough picture description to give a general idea of how things had worked.

Mr. **F. F. Haigh** congratulated Mr. Kapur on the production of an excellent paper and said that the arrangements at the diversion site had worked well and the diversion had cost considerably less than previous comparable diversions. He doubted, however, if the floating spurs at the guide bank nose had been justified.

He also thought that the diversion cuts might have been better planned. Of course they had been working against time and had had to modify their design under changing circumstances. It should, however, be possible to assist the river development considerably by the use of multiple diversion cuts. A given discharge can only develop a single channel to a limited extent, but by diverting the discharge from one cut to another it was possible to multiply this development by the number of cuts. To this end the cuts should extend independently through the whole area to be developed and should be separated from each other by adequate cut offs through the stone and block protection of the weir. A cut off could be provided across the stone by sand grouting but this could be done in the case of the inverted filter where a pakka curtain wall was required and should be provided in the weir design at suitable ntervals.

R. B. A. N. **Khosla** said that Mr. Kapur had written a very complete and thoughtful paper on a subject which suffered from dearth of literature. The closing of a big river was an undertaking which would tax to the utmost the capabilities and resourcefulness of most engineers. The time tor such diversions was generally very limited. A delay of even a week might at times mean all the difference between success and failure. The programme of works on the weir, the diversion cuts and the actual river diversion had got to be worked out in minute detail, so that, it should advance strictly according to time-table along all fronts. It called for a high class of organization, and forethought, unusual drive and sustained hard work. The actual work of diversion meant long hours during day sleepless nights and a state of almost continuous brain fever. The exact significance of these remarks could only be correctly appreciated by those who had handled similar works. Mr. Kapur had discharged the responsibility placed on his shoulders with great credit. He had completed the work in time and at low cost.

Mr. Kapur had dealt with the work of river diversion at Trimmu in such a complete manner that it needed little elaboration. The speaker as Executive Engineer, had the responsibility of planning the sequence of events and seeing to the execution in due time. His experience of river diversion at Sulemanke had proved of the utmost value in directing operations at Trimmu.

He would like to add a note of warning to those who might be entrusted with works of a similar nature. The head across the diversion bund was the main controlling factor and was of particular importance when the diversion was done over a sandy river bed. Every effort should be made to keep this head as low as possible. This could be done by making the diversion and leading cuts of liberal dimensions. This course might be somewhat more expensive but it would be a good insurance against failure. The cut could be very expensive. It might cost 20,000 or 2 lacs or more. In an extreme case it might set back the programme by one whole year involving considerable expense and the risks of one additional flood season. The limitations of this recommendation should, however, be kept in mind. The volume of earth-work required in diversion cuts is generally stupendous and if too liberal dimensions were adopted it might not be possible to complete the work within the short working period available after the flood season till the date of actual diversion. In such a case, a middle course would be more appropriate. The size of the diversion cuts should be suitably reduced and the diversion designed for the corresponding increase in head.

In conclusion the speaker congratulated Mr. Kapur on his outstanding success in river diversion at Trimmu and thanked him for his most willing and efficient assistance.

Dr. **N.K. Bose** said that the Author had on page 265 referred to those xperiments that had been carried out by the writer at Malikpur Experinental Station. He thought this was the first weir in the Punjab whose very part had been tested in models before construction and the River nodel experiment had been one of the series of experiments that were nstituted by the Research Institute in this connection. Results of these xperiments had been sent up to the Chief Engineer for publication. In this onnection he would only refer to that part of the experiment that had got irect bearing to this paper. In the model, efforts were made to see what nditions would be obtained in the river during the period of construcon of the weir and also how different cuts would develop. Gauges in the odel were observed at various places in the river. During the summer of 938 while the weir was under construction and ring bunds were put und the weir, gauges had been regularly observed in the river at Trimmu. the following table gauges observed at Trimmu and those observed in e model at the same point were given. It would be seen how close was e agreement. He was glad that Mr. Kapur had found that the information supplied by these experiments was useful to him during conuction period.

Comparison of Trimmu Gauges for the floods of 1938 and the corresponding discharge in the Model for the prediversion runs.

Date	Discharge		Trimmu Gauges. Prototype	Model
18-5-38	150,665	Cu/sc	488.7 R.L.	488.0 R.L.
13-6-38	187,809	,,	488.4 R.L.	488.3 R.L.
17-6-38	105,917	,,	487.4 R.L.	487.5 R.L.
28-6-38	133,433	,,	487.19 R.L.	487.0 R.L.
8-7-38	85,588	,,	486.2 R.L.	485.6 R.L.
26-7-38	300,000	,,	489.5 R.L.	489. 7 R.L.

Mr. **R. K. Khanna** said that from the common place name of the subject matter of the paper, he had hardly any inclination to read it, but a study of the paper had been specially recommended to him the previous day. He must say that he would have missed a very pleasant and instructive reading if the paper had not been specially recommended to him. It did not boast of any new theories nor did it contain high sounding, unintelligible scientific discussions and misleading inferences; but in an unpretentious manner, the author had given a lucid account of one of the most difficult operations of headworks construction, which he had rightly called the crowning act of all their labours.

On large inundation canals they were sometimes called upon to close large creeks of rivers or breeches in the canal banks, and they witnessed such display of skill, ingenuity, and resourcefulness as had been brought to bear on the task of diverting the river at Trimmu. But here the stakes were very great, and any serious miscarriage of operations would have cast a shadow over the dazzling achievements of Trimmu Engineers. For this reason the bold resolve to close the creeks and divert the river by means of unconventional methods was all the more praiseworthy.

It was said that necessity was the mother of invention. In this case the non-availability of sheet piles in India was responsible for their adopting the course actually followed otherwise they would have had the ordinary tame affair of sheet piles driven by means of pile drivers and other necessary operations performed in their regular sequence.

They would have missed the striking comparison between the two sets of photographic representations of the methods adopted at Sulemanki and Trimmu, and Mr. Kapur would have been deprived of the great satisfaction which he must be feeling at the successful performance of a most difficult job.

While having nothing but praise for the ingenuity, forethought and clock work regularity with which they had performed their difficult task, he had not been able to understand the difficulties of Mr. Kapur in determining the size of leading cuts. After indulging in so many mathematical calculations and calling to his aid Kennedy and others, he had in the end decided on arbitrary sizes of cuts which proved quite satisfactory. Furthermore his scientific arguments about the necessity of leading cuts being wide at the upper end and deep and narrow at the lower ends, so that these may develop without undue strain being put on the diversion bund and other bunds are not quite intelligible. Of course the cuts should have been sufficiently wide and as deep as could be conveniently made at the upper ends, but neither the slopes of cuts nor the levels at lower ends were of any real significance. As water was being gradually diverted into the leading cuts, retrogression of levels from the lower ends would have steepened their slopes, and the arrival of the first freshet would have developed them. If a really heavy freshet had unfortunately come before the cuts had been well developed, then in spite of the scientific design of the leading cuts, the bunds would have been put to excessive strain.

Mr. **K. R. Erry** said that river diversion was a subject out of the ordinary experience of Irrigation Engineers in general and there was very little published literature on the subject. Mr. Kapur deserved congratulations for writing a valuable paper, on this interesting but difficult subject in a most exhaustive and masterful way.

But on going through the paper, it appeared to the Speaker that some variations in the details of actual construction would have reduced the cost and added to further safety of the work.

He hoped the learned author would be able to elucidate the following points :—

1. *Use of Trangers in place of Cribs.*	1. *Why* trangers were not used instead of cribs. Besides being more economical trangers would have withstood heavy actions better without permitting stone to be carried away by concentrated flow.
2. *Precautions against freshets*	2. The diversion bund design was considered safe for 2000-3000 cusecs. Would it have withstood the action of a large freshet? If not what precautions were taken to safeguard against it?

3. *Small stone bunds preferred to permeable spurs.*	3. After the river was opened into the right pocket, could not be choking be done by small stone bunds instead of permeable spurs. It had been admitted by the author that the spurs were found not very efficient.
4. *Donkey labour could be used instead of trucks.*	4. N.G. Track and trucks were used for stone and earthwork. In his opinion it would have been more economical and equally efficient to employ donkey labour.
5. *Earthwork bunds could be used instead of stone flanks.*	5. Stone flanks were used on pervious mattresses. They were not so efficient, as they permitted leakages. Earthen bunds would have been perhaps more useful, and less expensive.

6. He asked the author to state the actual time taken for each diversion operation. This information would be very useful in calculating time factor in similar operations in future.

7. As stated by the author this work was mostly carried out with departmental labour and not through contractors. The author should explain why it was not possible to do the work on contract, as admittedly this would have been more economical.

The **Author** in replying to the discussions said that the trend of the discussion had been very satisfactory in so far as it had been established that the general scheme of river diversion could not have been materially altered. Mr. Khanna had however found it difficult to grasp the necessity of wider cuts on the upstream and deeper cuts on the downstream. It had been already stated that this was based on mathematical calculation and the proof was simple. A reference was invited to statement on page 265. If bed of the downstream cut could be dug to a further depth of two feet, with a tail water level of 473·0, then working from Kennedy's diagrams to pass 2000 cs., waterlevels required would be 474·75 and 475·32 against 477·0 and 477·65 on the figure of page 265, pointing out to a reduction of 2·3 ft. of head against the diversion bund. On the other hand if extra amount spent on deepening D S cut by 2 ft. had been utilized in widening, the cut would have been 175 ft. wide and this would have given with tail water level of 473·0, levels of 476·0 and 477·0 at th corresponding two points. This conclusively proved that for the sam amount a deeper cut reduced the head more than a wider cut. Similarly calculations could be made for the upstream side and the test of two alternative sections a wider but shallower and deeper but narrower one would prove that on the upstream side a wider cut gives lesser loss of head.

The speaker admitted that the above question had been investigated at a later stage and so could not be made use of effectively, hence the arbitrary size of cuts as pointed out by Mr. Khanna had been adopted but he advised that this principle should not be lost sight of in future.

Mr. Khanna's view about the retrogression of levels would not hold because the possibility of retrogression later denoted undue head on diversion bund which was necessarily to be kept as low as possible. Further the time factor between freshet possibilities and completion of retrogression completely ruled out any reliance on retrogression. He drew Mr. Khanna's attention to the failure of the Diversion Bund at Islam where diversion cuts were required to develop by retrogression.

Mr. Khanna's reference to methods of closing inundation canals in spite of his admission that they could not be made use of at Trimmu in view of stakes involved needed clarification. The difference was that the closing of inundation canals was diversion from a shallower to a deeper channel whereas in river diversion conditions were the reverse. For these reasons the method in use on innundation canals was considered inadequate to meet with the situation on the head work.

For purposes of development Mr. Haigh had suggested working of independent cuts. These cuts for efficient functioning would have to be maintained separately from their off take to exit and would thus involve embankments on belas and where they crossed creeks to prevent their waters meeting and heavy cross bunds in the weir section. Further it would not permit bends because embankments would be ineffective and it was doubtful whether the additional expense would be justified in view of the advantages. The development would certainly be quicker and as such the necessity would be greater higher up in the hills rather than lower down.

Situated in a place like Trimmu in the beginning, only one cut would be needed for initial diversion supplemented by about two more to give relief in case of freshets or rising of floods. Worked in low floods these would give a smaller river. In addition there would be needed a few wider and shallower cuts with good fall in the bed at Weir line so as to develop by degradation. Experience of 1st flood season at Trimmu had shown that cuts should be spaced not more than 600 ft. centres and but for the fact that an additional cut between left and central one would have developed the river much better the remaining cuts at Trimmu were all well planned.

Mr. Erry had suggested the use of trangers in place of cribs: stone in trangers were ruled out because firstly they would be too heavy to manipulate and secondly it would have necessitated proceeding from one end against the requirements of raising over the whole front uniformly. Besides cribs permitted better control over blockage on account of their regular shape.

Regarding Mr. Erry's remarks about protection against freshets, the author stated that the statement of maximum discharges showed that 8000cs. had not been exceeded in December. With 2 ft. depth of water over the bund a discharge of $600 \times 3 \times 2^{\frac{3}{2}} = 5000$ could be passed and the rising flood would certainly have developed the cut to take the rest. In the case of freshet however at least 4 days warning would be available and the bund would have been strengthened by dumping extra stone lower down so as to cover the whole of mattress and even beyond which would ensure scour removed pretty far down to endanger the main bund. Further cribs would be cleared out of obstruction which would have given leeser afflux.

Mr. Erry had suggested use of small stone bunds in place of permeable spurs at the nose of Right guide bank. Stone bunds would not only have been very expensive but also would have been useless without mattresses. Again permeable spurs permitted work in advance whereas stone bunds would have divided up labour most needed for the Diversion Bund.

Mr. Erry's suggestion to omit mattresses under flanks was very useful The object anticipated was that in case of a freshet and water overflowing these would prevent scour but unless they were fully covered with earth they permitted leakage and the one under right flank had actually given lot of trouble on this score.

Mr. Erry had further questioned the ability of N. G. trucks. These were used only for stone work and not earth work and that because donkeys would not tread on stone. Being a heavy traffic on light track N.G. trucks from point of view of progress and efficiency could compete in low leads. It had however the advantage of maintaining manual labour and supplementing work and the best organization was such that would keep all types of labour employed and thus handy.

As to why the work was done departmentally it was interesting and instructive to record the reasons. The Author's experience of the construction at Trimmu in various phases had conclusively proved that all rush jobs should be done departmentally. A contractor interested to save money would distribute labour to bare needs and could afford no reserves or insufficiently occupied labour; whereas in rush jobs what mattered most was the completion of each item at its proper time and hence maintaining of a reserve who might at times be not fully occupied. Further in works of unusual nature rates had to be evolved for various jobs necessitating maintaning accounts for contractor's labour and to avoid arguments and disputes later, it was best to do it departmentally. In execution of big jobs labour psychology was an important factor. It was like mass movement which would take time to gain momentum but once this was gained any change in tactics would result in disorganization and delay, although the method be changed for the better because labour would have to be re-organized and got in going again. Hence it paid not to change methods of execution or start reorganization even if it be a lengthy process which a contractor's ever present desire to save money must lead him to, resulting in delays and annoyances. Departmental execution of work saved from all these worries for which there was seldom time.

In the end the author wished to thank the members for the appreciation given to the movie film of the work.

He thanked Mr. Khosla for his remarks and appreciation. Regarding his remarks on the size of cuts, in the opinion of the author the final course had to be decided on the lines of wider upstream cuts and deeper downstream cuts consistently of course with the quantity of earthwork that could be executed in the scheduled time.

RIVER DIVERSION AT TRIMMU.

APPENDIX A.

	Materials.	Collected.		Brought in use.	
1.	Stone.	2,14525	cft.	1,84,525	cft.
2.	Sand bags (empty cement bags)	89,000	No.	86,500	cft.
3.	G. I. Wire No. 10 and 12	240	cwt.	208	cwt.
4.	G.I. Wire No. 20.	30	,,	23-223	,,
5.	G. I. Wire No. 8 and 10 for crates	90	,,	86	,,
6.	Sal Ballies.	2550	No.	1410	No.
7.	Sal tors.	520	No.	520	No.
8.	Mooring Posts	29	No.	23	No.
9.	Empty barrels.	150	No.	21	No.
10.	Wire nails.	650	lb.	617	lb.
11.	Staples	120	lb.	117	lb.
12.	M.S. bars 3/8″	3½	cwt.	3-0-7	cwt.
13.	Iron rings 15″ diameter.	58	No.	26	No.
14.	Manilla ropes.	1	Maund	1	Maund
15.	Stay Wire 7/14″	17	cwt.	13	cwt.
16.	Brick Ballast.	13755	cft.	5832	cft.
17.	B.G. Sleepers old.	10	No.	10	No.
18.	Crab winch.	1	No.	for aerial ropeway	
19.	Pulley to anchor boats from aerial ropeway	16	No.	16	No.
20.	Flexible wire rope.	1400	lft.	1400	lft.
21.	No. of tarpaulines and (area 3 small and 8 big).	25726	sft.	25726	sft.
22.	Coal tar.	468	gal.	488	gal.
23.	Mexphalt in place of coaltar.	2-1	cwt.	2-1	cwt.
24.	No. of electric points 100 watts.	70	Points.	70	Points.
25.	Flood lights.	4	No.	4	No.
26.	No. of petromax lamps.	Street handing	9	9	
		Hand patromax	6	6	
			15	15	
27.	N. G. Track.	4	miles.	4	Miles.
28.	N. G. Trucks.	220	No.	180	No.
29.	Boat Bridge :— Comprised of	16 No. boats with all equipment			
30.	Pilchhi mattresses. 60 × 30	13		10	
	80 × 30	5		5	
	100 × 30	8		8	
31.	Cribs.	60		54	
32.	Gunny bags for tarpaulines.	1800	No.	1800	No.
33.	*Pumping* :—Bernard pumps 4″ and 6″	2		2	
	Steam portable driven centrifugal 12/14″	3		3	
	Electric Pump. 8″	1		1	
34.	Wire crates, 6 × 6 × 2	201		11	
35.	Quantity of pilchhi . .	220951		220000	

II. *Labour.*

No. of carpenters working daily.	21 No.
No. of blacksmiths working daily.	9 No.
No. of divers working daily.	46 No.
No. of railway gangmen working daily.	40 No.

Coolies :—

Departmental working daily.	900 No
Of Contractors.	800 No

Country Boats working Daily :—

Diversion Bund.	33 No.
Permeable spurs.	6 No.
Miscellaneous.	4 No.
Boatmen.	85 No.
Donkeys Diversion Bund.	800 No.
Marginal Bund.	250 No.
Cuts and others.	1000 No.

III. *Earthwork* :—

Earthwork for closing river in.	9,18,000
Diversion cuts.	5,30,00,000
Earthwork in river portion of canal and margial bund	2,63,36,000
Miscellaneous earth work for diversion operations.	1,99,000
	8,04,53,000 cft.

IV. *Rates and Costs* :—

1. Rate of permeable spurs including pilchi, sal ballies, G. I. Wire etc. — 1-12 Rft.
2. Rate of driving ballies. — 0-7-0 each as per detailed analysis attached.
3. *Extracting sal ballies.*

By Pulley blocks.	0-4-0 each.
By gantry boats.	0-3-0 each.
Estimate cost of permeable spurs	Rs. 15801
Estimated cost of diversion bund	Rs. 59906

Note.—Cost of stone was not provided as it had already been charged to another diversion work and only removal and carriage was provided. If cost had been provided it would have meant an additional cost on stone at 11/-% ft. No provision was made for outturn as it was uncertain but about 90,000 cft. of stone and 13000 bags were recovered.

Rate of empty cement bags was nil as they had already been issued to "Stock cement".

Cost of mechanical driving per sal balli.

	Rs.	A.	P.
Labour.			
10 No. gangmen machinery at 0-10-0 per day.	6	4	0
1 No. Erector Jamadar at 1- 8-0 per day.	1	8	0
1 No. Driver. at 1- 8-0 per day.	1	8	0
1 No. Fireman. at 1- 0-0 per day.	1	0	0
	10	4	0
Stock.			
4 cwt. steam coal @ 21 ton at site.	4	3	0
2 lb. cotton waste @ 3 annas per lb.	0	6	0
Lubricating oil, L.S.	0	8	0
3 No. boats with one boatman @ 2/-	6	0	0
Issue of ropes etc. L.S.	0	8	0
	21	13	0
At an average 50 ballies are driven per day, therefore cost per balli.	0	7	0

STATEMENT SHOWING COST OF EACH MATTRESS AND EACH CRIB.

No.	Materials.	Rate	Unit	60′ × 30′ Quantity	60′ × 30′ Amount	80′ × 30′ Quantity	80′ × 30′ Amount	100′ × 30′ Quantity.	100′ × 30′ Amount.
	Mattress.								
1	G.I. Wire No. 10 and 12	20/-	cwt.	4·5 cwt.	90-0	6 cwt.	120-0	7·5 cwt.	150.0
2	G.I. Wire No. 20 for binding pilchi rolls	20/-	cwt.	90 lbs.	14-0	120 lb.	18-0	150lbs.	23-0
3	Pilchi	15/8/-	%cft.	1350 cft.	205-9	1800 cft.	276-12	2250 cft.	345-15
4	Making pilchi rolls	,,	each	84 No.	28-13	116 No.	39-14	140 No.	48-2
5	Stay wire.	15/-	cwt.	65 lbs.	9-12	65 lb	9-12	65 lbs.	9-12
6	Mooring posts.	11/8/-	each	1 No.	11-8	1 No.	11-8	1 No.	11-8
7	Sinking mooring posts.	-/4/-	1 ft.	12 lft.	3-0	12 lft.	3-0	12 lft.	3-0
8	Iron rings 15″ dia	1/-	each	1 No.	1-0	1 No.	1-0	1 No.	1-0
9	Sal Ballies, tied with mattress for anchoring to mooring posts.	1/8/-	each	2 No.	3-0	2 No.	3-0	2 No.	3-0
10	Sal ballies to fix in river bed for sinking mattress	1/8/-	,,	4 No.	6-0	4 No.	6-0	4 No.	6-0
11	Rolling mattress and carriage to river edge and floating.	-/12/-	%cft.	1800 sft.	13-8	2400 sft. @ 0-15-0	22-8	3000 sft. @ 1-2-0	33-12-0
12	Sand bags for sinking mattress including labour, etc.	-/5/-	each	100 No.	31-4	125 No.	37-8	150 No.	43-12-0
13	Labour for weaving wire netting.	2/4/-	%sft.	1800 sft.	40-8	2400 sft.	54-0	3000 sft.	67-8-0
14	Labour for making mattress.	2/8/-	%sft.	1800 sft.	45-0	2400 sft.	60-0	3000 sft.	75-0-0
15	Manilla Ropes	-/5/-	lb.	2·25 lb.	0 12	2·25 lb	0-12	2·25 lb.	0-12-0
	Total				503-10-0		663-10-0		822-1-0
	For making cribs:—								
1	Sal ballies	1/8/-	each	15 No.	22-8				
2	Sal tors	-/10/-	,,	22 No.	13-12				
3	Manilla ropes.	-/5/-	lb.	1 lb.	0-5				
4	G.I. Wire for fixing all round 6″ apart.	20/-	cwt.	½ cwt.	10-0				
5	Staples.	-/6/-	lb.	2 lb.	0-12				
6	Wire nails.	-/3/-	lb.	10 lb.	1-14				
7	M.S. Bards ⅜″	-/1/6	lb.	7 lb.	0-11				
8	Carpenters, blacksmiths including making gunny way.				16-0				
9	Carriage and placing in position in river bed.				6-0				
	Total ..				71-0-0				