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Diversion of Jammu Tawi and Protection of Upper Marginal Bund at Marala Headworks

By

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Introduction.

Jammu Tawi, a tributary of River Chenab, joins it just upstream of Marala Headworks. The Headworks was constructed in 1905-12 for Upper Chenab Canal which is a perennial irrigation-cum-feeder channel transferring supplies from River Chenab to River Ravi for utilization on the lower Bari Doab Canal. This Canal was opened in 1912 and its present authorised full supply discharge at head is 16,500 Cs. Marala Headworks is situated 15 miles North East of Sialkot about 6 miles from Border line between West Pakistan and Indian-occupied Kashmir.

Another canal, namely, Marala Ravi Link was completed in 1956 and opened on 17.7.56. This second channel has a head capacity of 22,000 Cs. and is non-perennial in character. It is meant for transfer of supplies to the Sutlej Valley canals through River Ravi and the Balloki-Suleimanki Link.

River Character

The main Chenab River emerges from the hills at Akhnoor and in the vicinity of Marala Headwork ; it keeps to the right flank ; maintaining an oblique approach. Below Akhnoor, the main river fans out into many streams which converge again immediately upstream of the Headworks. A small tributary, namely, Manawar Tawi which is a torrential stream also joins the main river from the right (Plate 1.)

Jammu Tawi the main tributary emerges from the hills near Jammu Town in Indian-occupied Kashmir and enters West Pakistan about 10 miles Upstream of Marala Headworks opposite village Pull Bajwan. Before the Headworks was constructed this was also the junction of this tributary with the main river. However ; with the passage of time the main river Chenab, leaving its old course, now known as Chander Bhagha, swung far away to the right and consequently the confluence shifted dowstream. This old course of the river is still semi-active bringing indeterminate quantities of water. Being in Indian-occupied territory there is no way to undertake any training operations on this stream which contributes to the adverse river conditions.

River Chenab has a long snow-fed catchment. The magnitude of its discharge in various periods is as below :

Seasons	Period	Discharges	
		From	To
Winter	October to March.	8,000 Cs.	15,000 Cs.
Early Summer	April to Mid-July.	15,000 Cs.	80,000 Cs.
Monsoons	Mid July to September.	80,000 Cs.	1,20,000 Cs.

In the winter rains the flood discharge is as high as 2,00,000 Cs. while during the monsoons the discharge has been known to go upto 12,00,000 Cs. These figures include the Jammu Tawi contribution, supplemented by the Khana Chak Nallah. The maximum flood discharge of Tawi is estimated at about 3·5 lakh Cs. The stable discharge at present is about 30% of total river supply at Marala, a good part of which is attributed to main river contribution through Khana Chak Nallah.

The order of discharges in Jammu Tawi is as below ;—

Period.	Discharge	
	From	To
October to March	2,000	4,500
April to June	4,500	24,000
July to September	24,000	40,000

Maximum flood discharges in winter rains and monsoon are respectively estimated at 65,000 Cs. & 3,50,000 Cs.

The river slopes above Marala Headworks outside the pond area are very high being 3 feet per mile resulting in high river velocities. The bed material is medium to coarse sand without cohesion and with high permeability. The sediment intensity in river is very high and total sediment in monsoon floods is of the order of 15 Gms : per litre.

The floods, especially in Jammu Tawi, are sudden. Huge quantities of sediment are carried by Jammu Tawi in flood. Canals have to be closed when Tawi discharge is above 30,000 Cs.

River Behaviour in the Past.

Since after opening of the canal the Chenab river has remained on the right. There are no protection works on the right where the ground rises suddenly. At the-Head works the right bank is connected to 100′ high bluff by means of the right retired embankment. There is no training problem on the right. On the left, the country-side is low and the area is protected from river spill by the Upper Marginal Bund which is about 13 mils long.

Jammu Tawi has always been a source of trouble. Its floods are frequent and sudden with steep rise and fall. It brings large quantities of sediment and is the main worry for regulation at Marala. The sudden rise and fall with very steep slopes and high sediment intensities result in an uncertain behaviour of the stream. The stream has a great tendency to meander after it enters West Pakistan. It has been known to flow at right angles and in narrow neck loops. In both bed scour and side erosion it possesses enormous capacities. The maximum observed scour depth is 50 feet below high flood level. The stream can easily eat into 300 feet of clay forshore in a matter of a few hours over a length of a thousand feet. This immense transporting potential of the stream works to 1·5% of flow volume.

Since after 1930 Jammu Tawi started moving to left in reach R. D. 15-40 of Upper Marginal Bund and came close to it. In mid fifties short spurs at R. D. 37, 35, 32, 22 & 20 were constructed at various stages to give local protection. These spurs were constructed when attack developed at a particular place as independent and isolated works. The immediate threat to Upper Marginal Bund by erosion was averted through these measures.

The position was further aggravated by the running of M.R. Link after July 1957. The heavy withdrawals resulted in Tawi approach to the pocket along the left guide bank which was a very undesirable development. The Tawi regime having been upset at the outfall its shift to Upper Marginal Bund in the reach R.D. 5 to 40 speeded up.

In July 1958 Jammu Tawi attacked Upper Marginal Bund just upstream R.D. 32,000 and under a state of grave emergency the Pakistan Army had to be called out. The bund was saved after working round the clock for a week. In August 1959 river attack developed in reach R.D. 6-13. The bund in this reach was again saved with the help of the Pakistan Army by whose efforts 12 stone and 8 tree spurs were constructed at the toe of the bund.

The failure of the Upper Marginal Bund would be a very serious matter as Tawi would cut into the low countryside and M.R. Link Canal. If this occurs in a flood season, when Tawi can rise to 3,50,000 Cs. discharge it would mean the end of M.R. Link Canal, U.C. Canal and vital communications in addition to the flooding of vast areas. Marala is a rim station with key position in the irrigation system of the country. The resulting outflanking would put the Headworks out of operation and canal withdrawals would no longer be possible resulting in total dislocation of a major irrigation system in the province. Not only the local irrigation but the irrigation on Lower Bari Doab Canal and the SVP Canals depend on the running of Upper Chenab and M.R. Link Canal.

The experience of 1958 and 1959 showed that a time had come when the threat to the Upper Marginal Bund must be taken seriously and complete safety ensured for future. The training works and the river conditions at the end of the flood season of 1959 are shown in Plate II.

Proposals for Protection of Upper Marginal Bund.

Detailed surveys were carried out upto the Pak-Kashmir Border and several proposals for securing a respectable foreshore and for training Tawi away from the Marginal Bund were considered and discussed. The main object was to protect the Upper Marginal Bund from direct river attack. A secondary aim was to improve the Tawi approach to the weir which had in the past year developed a straight entry into the pocket along the left Guide Bank.

The plan tentatively decided upon envisaged ;

1. Construction of four new stone armoured spurs in reach R.D. 19,000 to 37,000 utilizing the existing spurs where possible in an inter-dependent system of river training works.

2. Diverting Jammu Tawi opposite R D. 18-19 into Gagh Nallah which had its outfall in Sikka arm of River Chenab.

3. Construction of three spurs below R.D. 19, after diversion, suitably located to protect Upper Marginal Bund and evolve a more favourable approach to the weir.

4. The proposals were to be tested on models at Field Research Station Nandipur and location and alignment of spurs, diversion cuts, diversion bunds suitably adjusted.

In accordance with these main decisions a detailed scheme of diversion and protection was prepared. The plan is shown in Plate III and briefly discussed below :—

The existing spur at R.D. 35,000 which had stabilised in past years and had a reasonable shank length was proposed to be retained in the new scheme with adequate protection of upstream shank which was vulnerable due to short length of T-Head on upstream side. The existing spur R.D. 37,000 was proposed to be extended 200 feet. A new spur at R.D. 31 with T-Head at the present river edge was proposed giving effective shank length of 1,580 feet. This spur working in conjuction with the existing spurs at R.D. 35 & 37 would obviate the danger of attack on the Upper Marginal Bund under all possible approach conditions. The existing spur at R.D. 32 would give protection to the long shank of new spur at R.D. 31.

A new T-Head spur at R.D. 25 located at the river edge was proposed to prevent further erosion of the foreshore which was getting serious.

A T-Head spur R.D. 19,145 with 3,000 feet shank length was proposed to secure the foreshore and hold the river which was repidly cutting to left and eating the foreshore above R.D. 13,000. Another mole Head spur at R.D. 22 was proposed to break the long distance between spur at R.D. 25 & 19 and so give protection to U.M.B. as well as long shank of spur R.D. 19,145.

A diversion cut of 2,800 cusecs capacity was proposed for diversion of Jammu Tawi into Gagh Nallah.

As Jammu Tawi discharge would be about 4,000 cusecs the diversion of balance discharge of 1,200 cusecs could be achieved with a diversion bund from T-Head spur 19,145.

After completion of diversion, three spurs were proposed to be constructed in reach R.D. 5-19 of Upper Marginal Bund (see Plate III).

The general principles kept in view in giving these proposals were :—

(a) Spacing of T-Heads should be sufficiently close to make them effective against attack on the Upper Marginal Bund.

(b) The T-Heads should be long enough with suitable setback in shank to keep them safe against possible embayments. A minimum length of 200 feet on upstream and 50 feet on downstream was adopted generally.

(c) The spur heads be so located as to secure existing foreshore as far as possible and to avoid local or general diversions.

(d) The spur shank on upstream is provided with a small apron of 25′×4′ as far behind T-Head as maximum possible embayment was expected to touch the shank.

(e) Maximum use is made of existing spurs so that they fit in the general scheme. Existing spurs at R.D. 20 & 22 had to be abandoned as their shanks were too small to fit in the scheme but spurs at R.D. 37, 35 & 32 form an integral part of sheme.

(f) The aprons of spurs were to be designed against a scour depth of 50′ below the H.F. Level under the worst conditions of approach and flow. The apron was to be suitably reduced at other positions where flow condition would be less severe.

The scour depth of 50′ below high flood level was based on observation made on spur R.D. 35,000 which came under severe action in 1959 flood and where flow was on a hair pin bend.

Theoretically for a discharge of 3,50,000 Cs., with usual notation :—

$$P_w = 2{\cdot}67\sqrt{Q}$$

$$= 2{\cdot}67\sqrt{350000} = 1{,}576 \text{ Ft.}$$

$$Q = \frac{Q}{P_w} = \frac{3{,}50{,}000}{1576} = 222 \text{ C.S/Ft.}$$

According to laceys eqn. for Regime Flow ;

$$V = 1{\cdot}17\sqrt{FR}$$

$$V^2 = (1{\cdot}17)^2 FR.$$

$$\frac{Q^2}{R^2} = (1{\cdot}17)^2 FR$$

$$R^3 = \frac{Q^2}{F} \times \frac{1}{(1{\cdot}17)^2}$$

$$R = {\cdot}9 \times 3\sqrt{\frac{Q^2}{F}} = {\cdot}9\ Q^{2/3} \qquad (F=1)$$

Substituting 222 for Q ;

$$R = {\cdot}9 \times (222)^{2/3} = 33 \text{ feet.}$$

The maximum scour depth for 180 degree bend on upstream nose would be taken 1·5 R or 49 feet. As heavy boulder is encountered at about 45′ below high flood levels it is safe to design on a scour depth of 50 feet.

(g) The slope protection on T-Head was fixed as 1·5 feet single layer of heavy stone-pitching over ·75 feet of spawl. The protection was to be laid on 6″ pucca earth cover. These dimensions were adopted from Spring's paper for the particular river slope and velocities.

The apron was designed on the basis of Spring's recommendations and practice in vogue in the department. The apron was supposed to launch finally at 2:1 slope and protection was proposed to be 25% in excess of the pitched protection.

Referring to Plate IV.

$V = \sqrt{5} \times (S\text{-}h) \times 1{\cdot}25 \times 2{\cdot}25 = 7\ (S\text{-}h)$ nearly.

(where V is apron content per foot in cubic feet)

$= 7 \times 38$

$= 266$ Cft. /Ft.

Provide maximum apron $60 \times 4{\cdot}5$ or 270 Cft. per ft.

The apron width at nose of spurs at R.D. 7, 10 & 13 has been kept 40′ as these have been laid at very low levels.

Construction of Spurs R. D. 19, 22, 25 & 31

The proposals were ready in October and model experiments started soon after in the Research Institute. In the meantime the erosion of foreshore at R. D. 25 and between R. D. 13 & 19 was going on unchecked and it was necessary to proceed with construction before the final results of the experiments were available. Much waiting for results would have resulted in loss of foreshore at key points and would mean end of the entire scheme.

Accordingly work on spur R.D. 19,145 was started in early November at top speed to gain and maintain a good foothold and check the river from moving to the left. Work was also started on proposed spurs at R.D. 25 & 31. These early decisions and their prompt implementation secured the foreshore, and very valuable time which would have been lost otherwise, was utilized on construction. Had this not been done it would not have been possible to execute the scheme in full before flood season of 1960. Work was also started on spur R. D. 22 as the spurs at R. D. 19 & 25 made its present siting obviously decisive.

By the end of December the spur shanks were built to winter section and spur heads sufficiently constructed to stand the winter freshets. The position of these spur heads was taken into account by the Research Institute in their experiments.

Revised Proposals for Diversion

In the original proposals diversion was scheduled to be effected before end of December so as to get enough time for completion of training works below R. D. 19,145. The work on diversion cut across the river involved 1·2 crore cft of earthwork, mostly under water. The proposed cut was 100 feet wide with 6·0 feet depth below S. S. water level. The work needed crossing of two 110×2½ excavators each weighing over 100 tons which were available. No means of tranporting this weight across the river were available in the country. It was not practicable to dissemble the machines and transport them in parts and assemble them on the right bank as time limit did not permit this procedure.

The alternative was to have a dozen small excavators 40×5/8 weighing up to 20 tons and ferry them accress the river on rafts. These machines with donkey labour and scrapers would be able to complete the digging of cut by the end of December 1959.

Unfortunately, the machinery was not spare within or outside the department and the idea of a diversion before December was dropped for want of the needed resources. The only alternative was to build up the resources and attempt a diversion after the winter rains of 1959-60.

Towards the end of December it was decided that the cut be reduced in size and depth so as to make complete digging possible only by donkey labour. This decision initiated digging of a cut 80 feet wide with a flow depth of 3.5 feet and a capacity of 800 causecs. The balance discharge was proposed to be diverted with suitable brushwork, chaps, booms and diversion bunds. These proposals would reduce underwater digging on the diversion cut and make it possible to dig it without machinery. The underwater digging would be about 3·5 feet but heavy earthwork would be required for diversion of balance discharge which would have to be forced in a small shallow cut.

The diversion operation would need two scraper fleets one on each side with adequate dozing equipment in addition to large quantities of brush work, stone, gunney bags, ballies, rails, trangars and other such equip-

ment The diversion was proposed for late March when Tawi discharge would be about 4,000 Cs. There were good chances of success as earthmoving equipment for diversion bund and spurs below R. D. 19 was promised to be made available.

The diversion proposals as finally decided are shown in Plate III. The work on the cut was started in early January and completed by 10th March, 1960.

Digging of Diversion cut.

Plate V shows L-Section of proposed cut. The survey of Gagh Nallah showed that it would be able to take 4,000 Cs. with one foot rise in levels. The available slope along cut was ·5 per %. The dimensions arrived at were :-

Width = 80 feet.
Flow Depth = 3·5 feet.
Discharge = 800 Cs.
Velocity Generated (v) : 3·0 F.P.S.
Regime Velocity (vo) : 1·88
V/VO : 1·6 (roughly).

The estimated quantities of work on diversion cut were :

1. Earth work dry lead upto 6 chains. : 29·05 Lcs Cft.
2. Earth work under water lead 6 chains : 19·27 Lcs Cft.

Total : 48·32 Lcs Cft.

The execution of work under water necessitated pumping. It was considered necessary to have 6″ coir rope tubewells 250 feet apart on the central line. These were used for excavation in reach R.D.O—4,000 and were worked by 6×5 pumping sets energized from a local Diesel Generating set.

By mid-February two excavators 40×5/8 were received. These were crossed on a locally made raft and used on the tail portion of cut where pumping and excavation by donkey would be cumbersome. In the reach R.D. 4-7 open pumping was resorted to by using diesel pumping sets in a deep pit dug by excavator. The leading drain to this pit was also dug by excavator.

The work on the cut was completed by 10 th March, 1960. As, however, deversion could not be effected till one month later, the labour continued to excavate dry earthwork on sides upto S.S water levels giving a small increase in cut capacity in head reach. The earthwork from excavation was lead 5 chains to form a continuous left bank with a top R.L. of 820·00.

The alignment was proposed along a depression which was a small bye-channel of the main stream during summer and which had silted at its mouth (see long section). The right high bank was a firm bela. The overall width from pucca bela to left bank was not less than 600 feet at any place and this waterway was enough for a discharge of 50,000 cusecs if the left bank could be held against side erosion and failure by overtopping. There was however no necessity to prepare for such a discharge as maximum discharge in Jammu Tawi expected before monsoons was 25,000 Cs. and the spurs lower down had to be completed before monsoons broke obviating necessity for containing the river stream to the right of the left bank.

The following table summarises the main features of the work :

Work

Earthwork by donkey labour	:	44 lac Cft.
Earthwork under water by Excavators (rehandled by donkey labour)	:	6·72 lac Cft.
Period of excavation.		12.1.60 to 25.3.60.

Labour

Donkey labour.	:	50 belchas Peshawari, (consisting of 400 donkeys

Equipment

Generating Set Twin 75 KWT	: 1 No.
Electric Pumping Set 6″×5″	: 4 No.
Diesel Pumping Set 6″×5″	: 3 No.
Excavators 40×5/8	: 2 No.

Proposals for Diversion.

The actual diversion of over 4.000 Cusecs stream which was both steep and deep, into a shallower and flatter cut of 800 cusecs capacity was recognised to be a heavy and tricky job. A diversion would have been easier if the capacity of the cut was well over 50 per cent of the total discharge to be diverted so that right at the start the diversion channel would have been bigger and deeper than the existing channel.

Keeping this handicap in view the diversion operations were carefully planned. These operations as planned and executed are shown in Plate VI. Towards early February the river approach to diversion cut started worsening as the main stream opposite R.D. 19—20, which was on right, developed a side channel on left. This development resulted in shoal formation at mouth of cut for a distance of one thousand feet. The left side channel started drawing more discharge and developed into a cut off.

This development, if allowed to continue, would have spelled the doom of the diversion as it would not have been possible to extend the diversion channel upstream under water. Any attempt at diversion under these conditions had no chance of success as shoals at the mouth of cut would be drawn into the cut choking it immediately on opening. The dangers in this development were recognised and it was decided to choke the left channel and keep the main stream on the right. The objective was achieved by driving two rows of stakes 3 feet apart at mouth of the left channel as shown A—B in Plate VI. The space between the stakes was filled with brushwood rolls weighed down with munj crates filled with stone. As the brushwood stone settled more material was put in and heading up of ·3 feet maintained in the stake line. This heading up pushed in more supply into the right arm and the effect of brushwood chap was to choke the left channel below the chap line. The work was patiently continued day and night till discharge in left channel was reduced to 200 cusecs when with the help of motorised scrapers and dozers the left channel was totally closed by throwing in bund C—D. These operations were completed by early March.

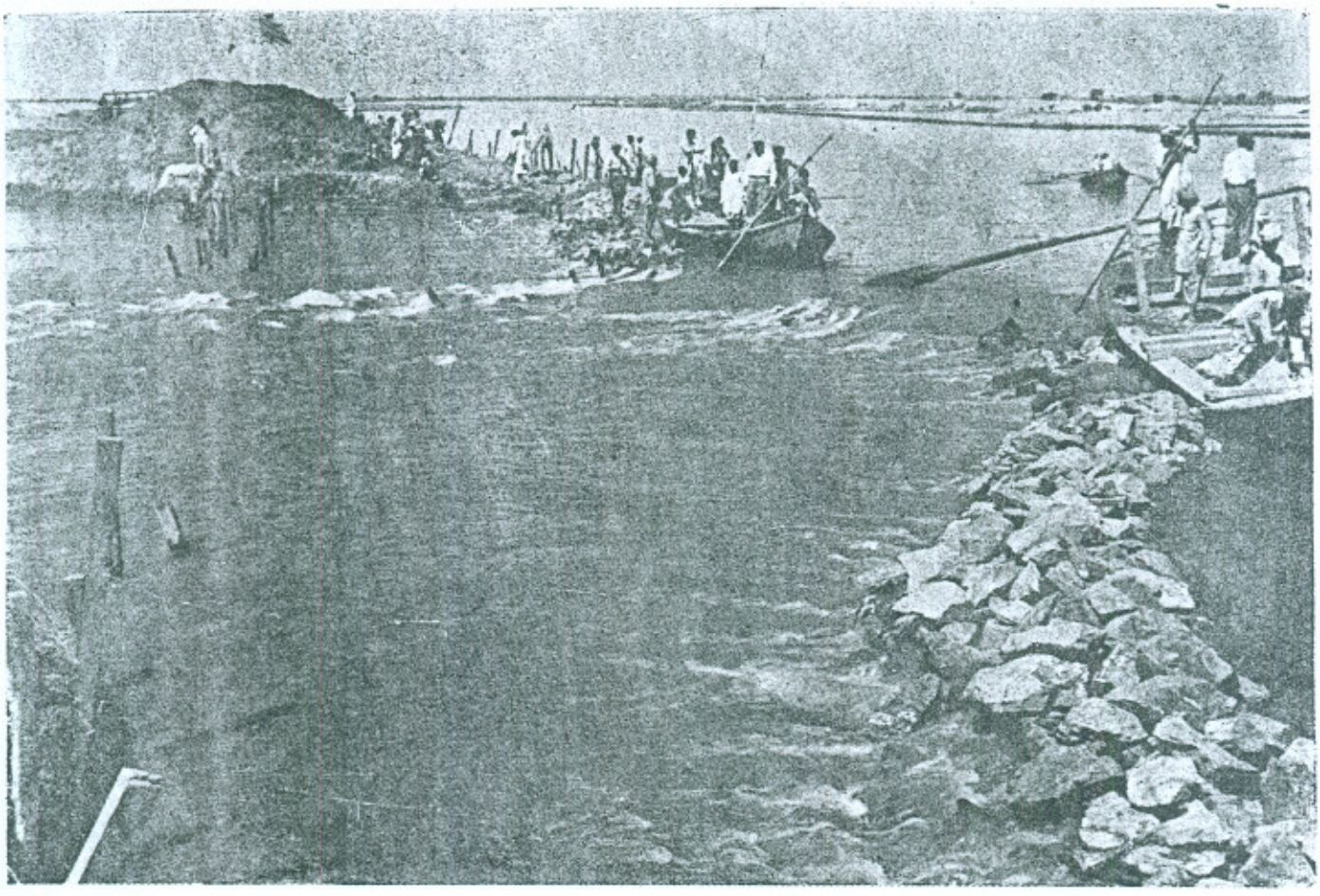
As the river slopes at site were as high as 3 feet per mile it was necessary to put in the diversion bund just at the mouth of cut so that full effect of heading up was utilized in developing the small shallow cut. The alignment D—E (Plate III) was decided and work organised accordingly. There was considerable difference of opinion about the alignment of main diversion bund. It was apprehended that a bund high up at the mouth of cut would suffer erosion and would be difficult to protect after closure. It was however apparent that with a diversion bund far downstream of mouth of cut the diversion had little chances of success as effect of heading up would be mostly lost. A successful closure 500' downstream would necessitate nearly 500 feet long stone boom. Considering cost and availability of stone this was not within the available resources. On the other hand, a main diversion bund advanced under protection would not be so vulnerable to erosion as was thought. The bund with a stake balli line on the upstream toe filled with brushwood and stone could easily hold for discharge upto 20,000 Cs. as sufficient waterway was available between the bund and the right bank.

Once diversion was completed it would be very easy to put in a second line of defence shown F—G about 500 feet downstream in the choked and silted bed. After full considerations the plan shown in Plate VI and described below was approved and put into effect.

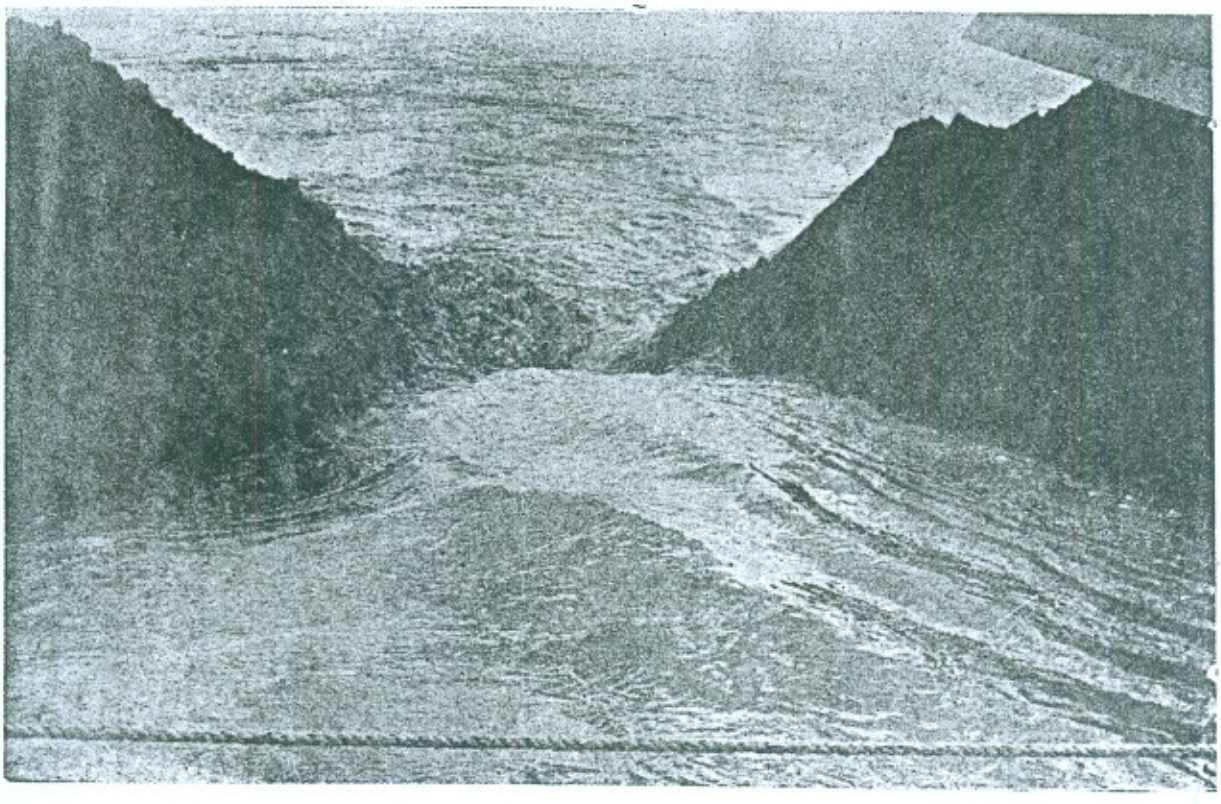
Boom.

1. A continuous double line of stakes 4 feet apart was to be driven across the river bed in the shallow portion along the toe of the proposed diversion bund.

2. A double line of 14″×6″ Ballies 4 feet apart was to be driven along toe of proposed bund in deep portions so as to project only one foot above water levels.



Work on Stone Boom



Final Closure

3. On the ballie boom line 30 feet B.G. rails were to be driven in portions where final closure was to be attempted at 8′ feet intervals.

4. The river bed along the boom was well covered with brushwork sunk with stone filled Munj Crates so as to secure the bed. A three feet depth of flow was to be allowed over the bed cover to avoid local concentration.

5. The main diversion bund D—E was to be advanced in continuation of bund C—D under cover of boom. No advance was to be made from the right side (E) where a good heap of earth was to be collected for final closure.

6. The left edge of diversion cut at its downstream mouth (E) was to be secured by dumping stone giving an impregnable head.

7. When the gap between the impregnable head and advancing diversion bund was 300′ a stone boom was to be thrown in position marked **XXX**.

8. As soon as diversion was completed a second line of defence would be built up in position F—G to top R. L. of 819.00 connecting left spoil bank of cut to shank of spur R. D. 19, 145.

This plan was evolved after careful considerations. The idea was to secure the bed and not to allow flow concentration till final closure with the help of boom which consisted of stakes, ballies and brushwood. The advance from right (cut) side was not to be made as it would induce shoaling at mouth of cut which was to be avoided at all costs. The right end had also to be secured as it would otherwise be eroded as the channel was constricted by diversion bund. The stone boom was limited to 300 feet as it would be possible to devebp the cut to 2000 cusecs without a full stone boom across the whole channel. The cut was to be opened, when river had been sufficiently pushed to right to avoid its getting choked.

The work was planned in accordance with above decisions. Two scraper fleets each containing three dozers and eight scrapers were required. A fleet of Lentourneu motorised scrapers with four motor dozers was received towards end of February and immediately put on job. The earth had to be hauled a distance of about a mile and motorised scrapers by virtue of their speed proved excellent.

A smaller fleet of two crawler scrapers and one crawler dozer was available locally and this was crossed over for the work on the right side. Another crawler dozer available was put in order to push load the motorised scrapers on left in slushy ground. The motor dozers were put on forward end for pushing the bund. Large quantities of stakes 8′×6″ were manufactured and 400 number 14′×6″ ballies purchased and brought to site. Other required materials such as E.C. Bags, Gunny Bags, rails, brushwood and stone were collected and roads for transport built. The various operations of transport on land and river, loading, unloading, handling etc. had to be carefully laid out to avoid congestion, blocking and dislocation. The arrangements made are indicated on Plate VI.

Crossing of Machines

Crossing of following machinery to the rightbank of Tawi was necessary for diversion :

(1) Two excavators 40×5/8 weighing 22 tons each.

(2) Two Allis-Chamber H.D. 20 tractor dozer fitted with blades weighing 23 tons each.

(3) One Allis Chamber H.D. 20 tractor weighing 18 Tons.

(4) Two scraper bowls weighing under 10 Tons each.

The crossing was successfully made by stripping two Derrick Boats and assembling them into a raft. Two derrick Boats can take a load of nearly 37 tons with 2·25 feet draft leaving a free board of about 9 inches. The problems to be tackled were :

(1) To join the boats securely so that they worked together as one under load.

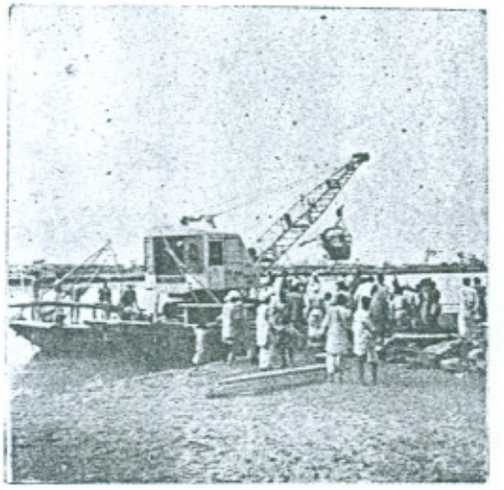
(2) To ensure equal distribution of heavy load to the raft components.

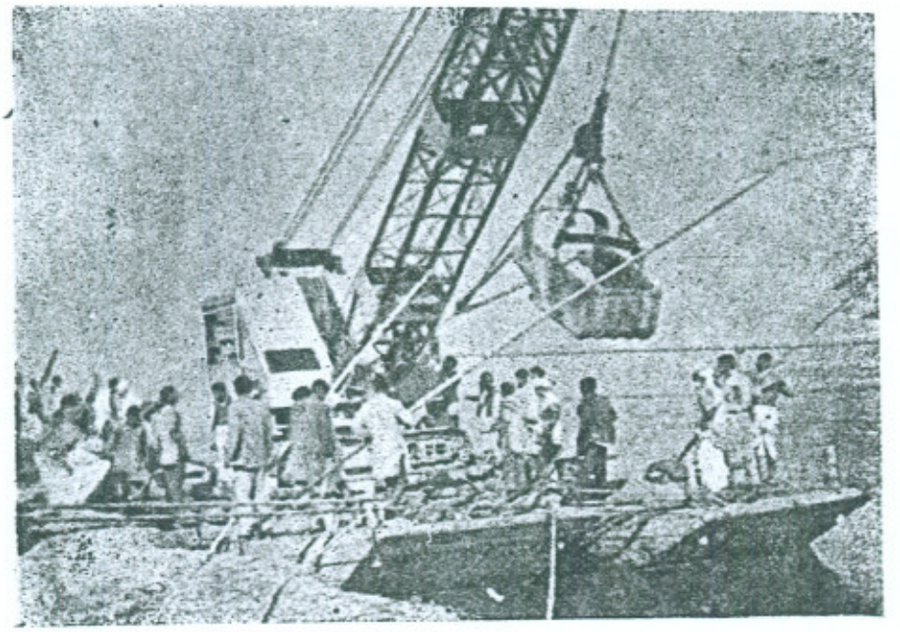
(3) To ensure safe transmission of heavy load to the boat ribs and framework and avoid a structural failure.

(4) To ensure even distribution of weight on raft at time of loading and unloading.

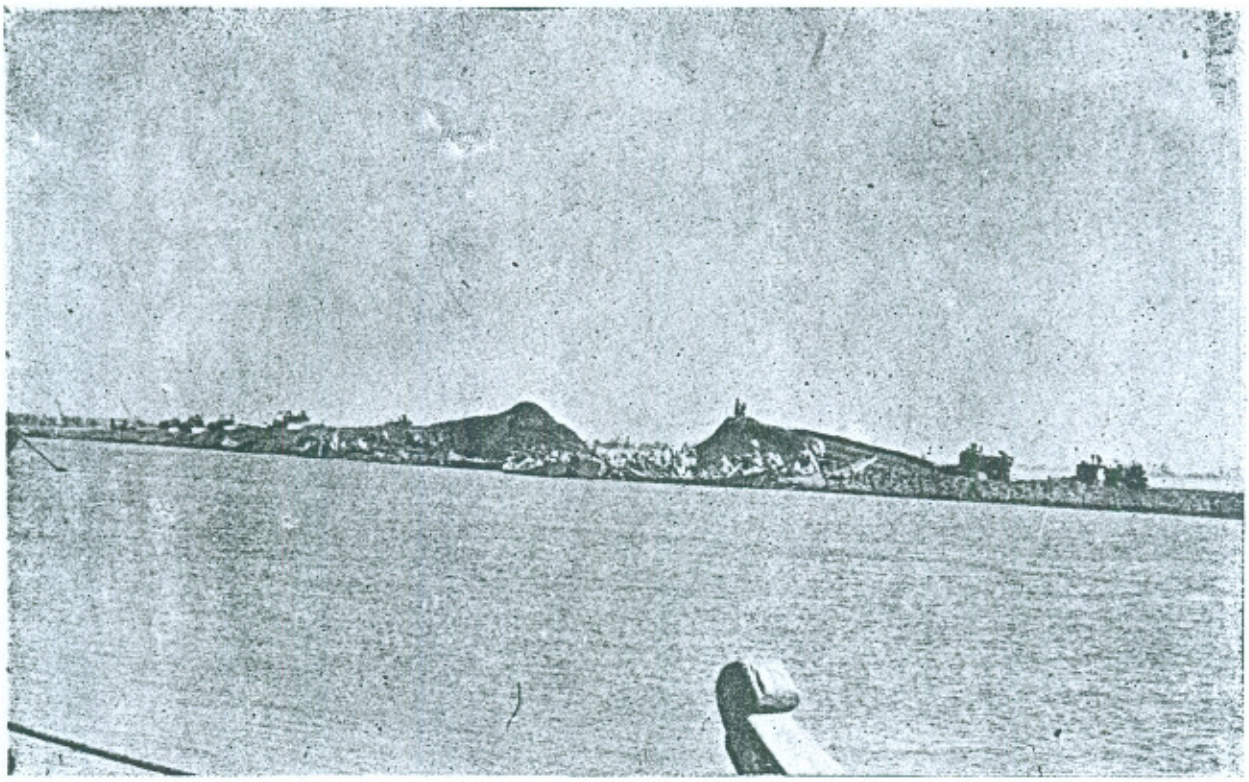
Fool-proof arrangements had to be made as once 23 tons of steel were on the raft in 8 feet deep running stream any mishap would be a disaster. The raft assembly is shown in plate VII. The arrangement ensures load distribution when machine is loaded centrally on the raft. To enable safe loading and unloading the rails were projected 12′ beyond the raft. The site of crossing was fixed at R.D. 12,000 where the stream was flowing in a single channel. The left bank was vertical and about two feet above water level. A loading ramp was cut on the bank about 9 inches below the rail bottom so that when machines were loaded the rails would be free of ground. A sleeper mattress was put on the rail and machines directly crawled over it on to the raft. After loading, the raft was released gently the movement being controlled by adjusting ropes (as shown in Plate VII). The raft was gently turned in deep water by 180° so that loading side was on right for unloading on right bank. The route was marked by ranging rods and had been located in advance by soundings. Only a narrow cross route was available to give the required depth of 3 feet and raft had to be moved carefully and cautiously to avoid grounding (see plate VIII). During some of the crossings the right side bank was low and water shallow. The raft could be hardly brought nearer than 8 feet. The projecting rails were supported on sleeper cribs and machines crawled to bank. The machinery was crossed in two days without any mishap or accident.

A View of Closure operations

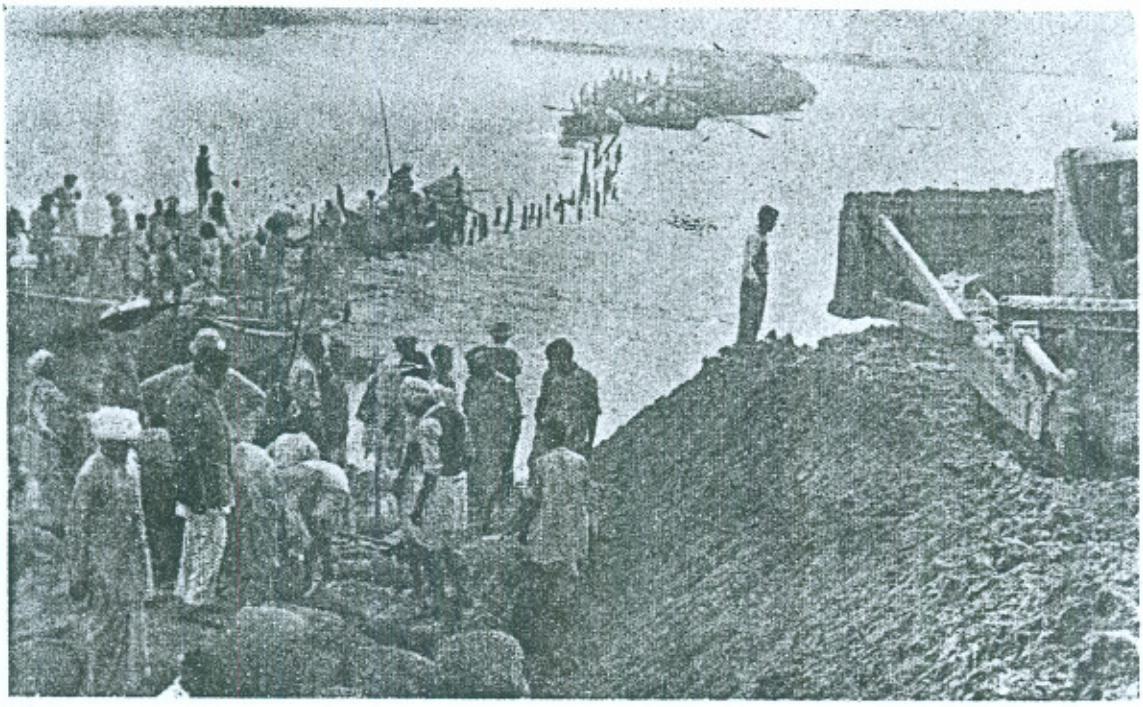




Crossing of Machines



General View of Work



Advancing Diversion Bund

Advancing of Diversion Bund

The diversion bund was started in early March from point **D** under cover of stake boom which was fed continuously to secure the bed. The work was continued round the clock and bund advanced 500 feet without much difficulty when a gap opened in the boom. This gap was 30 feet wide and about 12 feet average depth. The nose of the bund which came under heavy erosion was protected with sand filled gunny bags and gap closed with stone. At this stage a freshet of 12,000 Cs. was passed and this freshet opened many deep gaps in the boom. After the freshet subsided the river remained high above 4,000 cusecs and the gaps in the boom made advance very difficult. The weather remained very bad and yet with great patience each gap was closed with munj crates filled with stone and brushwood. The nose of the bund had to be protected against erosion by gunny bags after every advance which was 50 feet on the average. The order of work was :—

1. Motorised scrapers hauled earth and heaped it high for about 16 hours.
2. The boom was kept fed to hold the bed and avoid flow concentration.
3. After earth heap was ready, bulldozers dozed it into the river under protection of boom in a continuous process.
4. When the heaped earth had been consumed the advanced nose of bund was protected with gunny bags and secured.

Through this process the bund was advanced to position M in Plate VI on 26.3.60. The fanned flow had not been concretrated in a single channel close to mouth of cut. The bushwork and stone on the boom had been settling and the boom was continuously fed. A depth of 5 feet was maintained over the boom. The time was ripe for opening the cut. The discharge in Tawi was 4,500 Cs. on 26.3.60 at 11 a.m. when cut was opened. The heading up on the boom and diversion bund was ·5 feet. The cut was designed only for 800 cusecs but in the initial stages it would take more than this discharge till the cut filled up and flow stabilised. It was essential to exploit the initial heavy flow by quick advance on bund. The effort had to continue at a high speed to prevent silting up of cut when flow stabilised. To ensure this, earth was massed on both sides of the diversion so that on opening the cut a quick advance from both sides could be made. Good advance was made from both sides and it was hoped that closure might be effected without a complete stone boom. Hourly observation of gauges and discharge in the cut and original course were made and it was satisfying to find that cut was taking 1,700 cusecs by midnight. The balance was still in favour of the original channel but satisfactory development of the diversion cut had been gained. The work continued with great vigour from both sides but the push was thwarted by a severe dust storm on 27.3.60 which made working impossible. This interruption in effort resulted in bad erosion of gap and the idea of straight closure without stone boom had to be abandoned. The ends of diversion bund on both sides were protected immediately after the storm which caused this setback.

The stone boom having become essential, transport of stone from Upper Marginal Bund was started by mule-carts as no other transport would work. The stone was carted to river edge and therefrom carried by boats to boom and dumped in position in munj crates. It was quite a difficult operation to keep the boats in position in high velocity and special arrangements for anchoring had to be made. The stone boom was completed on 6.4.60 but the flow through the boom was still 600 Cs. Direct closure was found impossible and the leakage was reduced by covering the upstream slope of stone boom with Tarpualines. The discharge was reduced to about 350 Cs. on 8.4.60 and advancing the bund from both sides a closure was effected. The success was very short-lived because the closure bund was soon blown open by flow underneath. The reason was that closure had been sudden and depth upstream and downstream of bund considerable. Loose stone dumped on boom had drifted to the closure site and after the closure, bund was subject to a cross head of 4 feet which resulted in flow underneath through the stone. This setback was indeed serious and it was obvious that a slow closure was necessary to silt up the bed. To reduce the flow a gunny bags boom in form of a regulator was built downstream of the boom. The ends of this boom were built into abutments by sinking sand filled gunny bags in munj crates. The abutments at right angles to stone boom helped cut the side flow. The abutments were linked in same manner from both sides and gap closed gradually to allow the old channel to silt up. On 10.4.60 at 10 a.m. the gap was closed. The machines had no difficulty in linking the bund which was immediately widened on downstream and strengthened.

The closure was effected for a discharge of 4,109 Cs. against a cross head of 3·8 feet. The gauges and discharges prevailing during the period the diversion operations were in hand and afterwards are depicted graphically in Plates IX & X respectively.

The river bed downstream had silted up and second line of defence was completed by 15.4.60 without difficulty.

The main diversion bund was 50 feet wide to allow movement of scrapers and top R.L was 817.00. It was protected on its upstream by the boom and it was to prove a great help in completing the remaining spurs at R.D. 12,811, 10,000 and 7,000 of Upper Marginal Bund.

The main quantities of work on diversion and working of plant and machinery are given in Appendix I & II.

The average cost of earthwork including re-handling at forward end was Rs. 70/- per % 0 Cft at one mile lead. The scheduled rate at 250 % dearness allowance works to Rs. 107/- % 0 Cft.

Protection of Diversion

The diversion was in danger of failure by overflow and erosion of diversion bund, left bank of cut and second line of defence.

It was appreciated that only the main diversion bund had chances of standing erosion as it had a firm toe and boom protection. The second

line of defence had no firm toe and its portection would not be possible. It was therefore decided that diversion bund be held both against erosion and overflow.

With this policy, the diversion bund was strongly protected with stone in position D (Plate III) where it was liable to severe action. All along the diversion bund and left bank of cut, spurs made of stakes brushwood, stone and filled gunny bags were constructed at 100 feet intervals, Large stocks of materials were kept at 500 feet intervals and labour gangs stationed at 2000 feet intervals. A police gaurd was also posted to thwart any attempts at sabotage. The bund was made secure against overflow by constructing a dowel with top R. L. 819.00. With these arrangements and round the clock watching the left bank was held till 25.6.60 when it eroded in position C—D. The second line of defence as was expected suffered the same fate soon after.

The 3rd line of defence which had been built a few days earlier joining shank of spur R.D. 13 with left bank of cut R.D. 3,500 prevented spill channel developing access to the old river course. This bund had been aligned on an available ridge and, except for heavy filling in small low portions near junctions to shank spur R.D. 13 and lef t bank of cut needed a very small quantity of earthwork. This bund had been heavily protected with brushwood and gunny bags against wave action.

It was not till 10.7.60 when Tawi discharge rose to 40,000 cusecs that the river finally broke into old course below spur R.D. 13. By then, the spur heads and shanks had been built sufficiently high to avoid a break through by river. The X-Section of the diversion cut showing its development at various stages is added at Plate XI.

Behaviour of Diversion Works

As stated, the diversion was effected very late. The best time for diversion would be mid - December before winter rains as that would give sufficient time for construction of suprs at R.D. 13, 10 & 7. The results of model tests had not been encouraging. The development of cut on model was found very slow and specific levels at mouth of cut were very high. In view of these anticipations efficient arrangements already described to hold the left bank of diversion had been made. The diversion bund and bank were maintained under river action and the diversion took upto 40,000 Cs. before complete failure. The first failure took place on 9.6.60 when left bank was eroded in R.D. 2,500—3,000 of cut but 3rd line of defence (Plate III), put in a few days before in anticipation of such happening, prevented the spill from finding access to old course depression.

The main diversion bund gave way on 25.6.60 through erosion of portion C—D. when discharge was 17,400 Cs. (Plate III). By 5th July, 2nd line of defence was also eroded and river gained access to depression between spurs R.D. 13 and 19. Formation of a regular channel to old course was stopped by 3rd line of defence which held till it was topped in high flood of 11.7.60. Fortunately, by that time the spurs at R.D. 13, 10 and 7 were in a position to hold the river in flood.

During high flood of 11.7.60 to 12.7.60 the peak discharges in Jamu Tawi and the river Chenab were respectively 2,49,699 and 5,99,303 Cs. The spurs behaved in an excellent manner. The spill channels were prevented from developing into cut-offs by the spurs and flow entering the pockets was thrown back into the diversion channel. With this action of spur system the river remained on the right, and the left bank level registered a rise. Plate XII shows the current directions during the flood of 11-12.7.60.

The action of spurs is obvious. The only damage suffered by the spurs was erosion of shank slopes by wave action, Gharas by heavy rains and some settlement of stone aprons. There was some damage due to the secondary spill channels along the D/S shanks of spurs.

The Plate XIII shows water levels along Upper Marginal Bund at the time of peak discharge and it will be seen that except for spur R.D. 7,000 the head across spur shanks was not very high. Plate XIV shows current directions on 31.8.60 towards end of flood season. The salutary effect of the training works far exceeds the best expectations. The development of cut during and after diversion is shown in plottings on Plates IX, X, XI.

Construction of Spurs R.D. 13, 10, and 7

The alignment and location of these spurs was fixed on basis of model experiments. The main quantities of work were :

1.	Earthwork	=	1,10,00,000 Cft.
2.	Stone works	=	6,76,000 Cft.

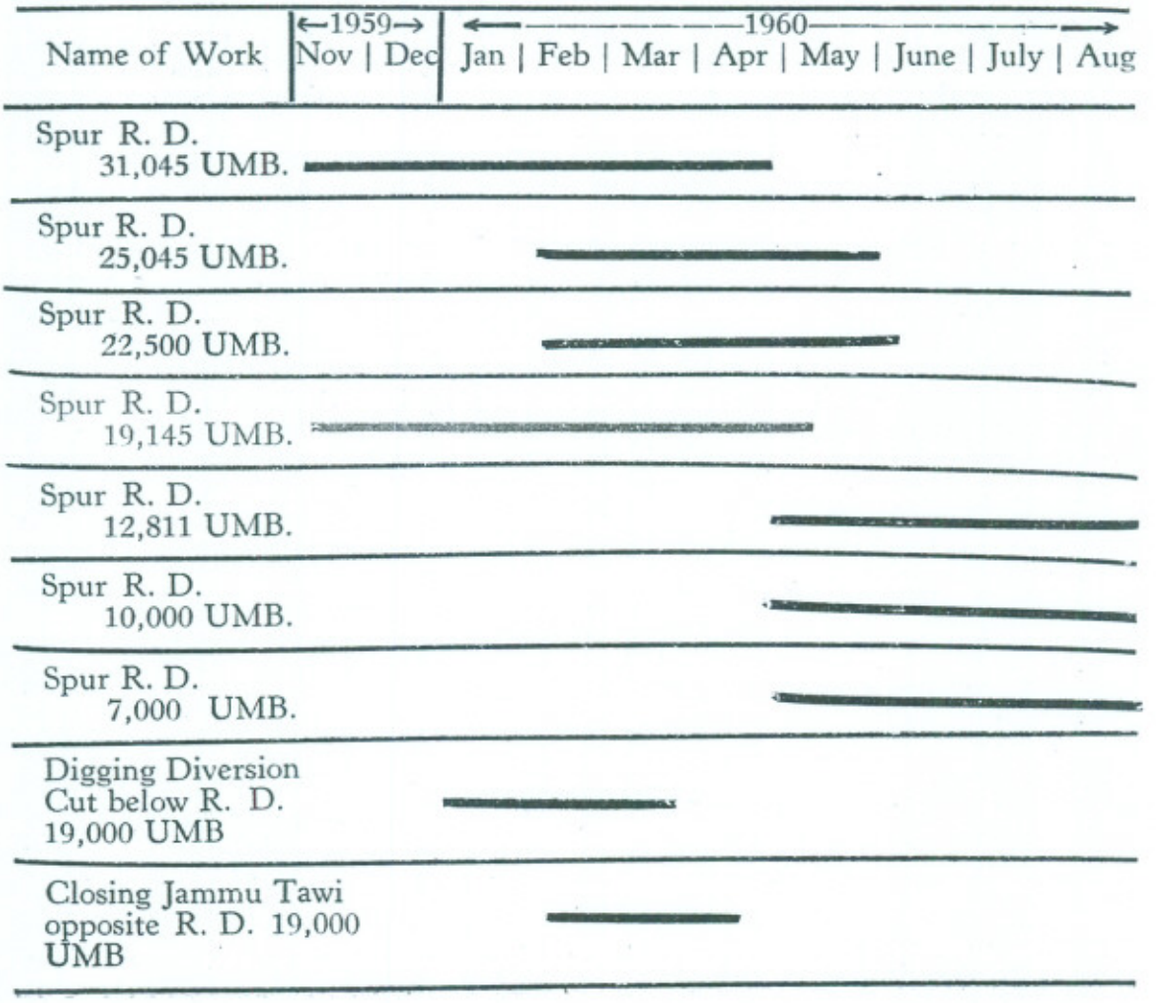
The works were started on 15.4.60 and had to be brought to a safe state before monsoons. The spur shanks crossed the old river bed where water was standing to a depth of 6 feet. In the high and dry portions, donkey labour was used while the river bed portions were done through machines. Good part of earthwork was completed by middle of June when due to rise in river and spill opposite spur R.D. 7,000 the pockets between spurs were filled up and no more earth could be taken from inside the marginal bund. On the outside, ground levels were generally low and S. S. water level was above ground levels. A narrow berm of 20 feet along Upper Marginal Bund and an old bund which was of no use were scraped by machines and by 10.7.60 the earthwork was sufficiently completed to stand floods.

The transport of stone to the spur heads across the old bed was an intricate problem. About 10,000 Cft stone had to be transported a day to spur heads. Motor trucks were used for transport from sidings at Marala to Upper Marginal Bund. Further carriage to spur heads was done by mule-carts which proved to be very efficient means of transport. To avoid dislocation of earthwork separate cart tracks were built for each spur. The soil was coarse sand and had to be covered with 6 inches sarkanda to allow movement of carts. The spill reaching the pockets from opposite spur R D. 7,000 dislocated the transport arrangement in June. The carriage

by boats was resorted to in case of spur R.D. 7000 as spill water created sufficient depth to allow movement of boats. In case of spur R. D. 10, earthwork was stopped and half constructsd shank levelled and covered with sarkanda at top. All cart transport was concentrated on this spur for two weeks and after completing transport of stone, machines were concentrated to raise the earthwork. Similar arrangements were made for spur R.D. 13.

Substantial part of work was completed by 10.7.60 and spurs could stand the high flood of 11.7.60. The aprons were laid with the help of excavators 3 feet below S. S. water level.

The progress of work as followed during the preceding months is graphically depicted below.



General

The statement of quantities and cost are given in Appendix I.

The location of T-Heads and alignment of shanks for spurs R D. 13, 10&7 were given by Irrigation Research Institute and were adopted with minor changes. Very useful information about the behaviour of river after diversion and action on spurs was supplied by the Institute which made it possible to prepare for eventualities well in advance.

Dr. Mushtaq Ahmad, Director Research Institnte and Mr. Muhammad Ali, Research Officer, Field Research Station, Nandipur, often visited the site and gave useful suggestions.

The main scraper fleet was supplied and run by Excavater Division. This fleet did the main work on diversion bund. Mr. Aslam Fazli Sub Divisional Officer Excavator, Sub Division and Mr. M. Siddique his Overseer worked untiringly to keep the machines running at full capacity round the clock.

The Allis Chamber scrapers, dozers and Excavators which did bulk of earthwork on spur shanks and worked on the right side of diversion bund were very efficiently run by Mr. Fazal Qadir, S.D.O., 4th Link Mechanical and Mr. G. H. Butt, Overseer. The co-operation from mechanical side was excellent and the staff incharge did their best under adverse living conditions.

On the civil side, Mr. M. H. Siddiqui, S.D.O. Headworks, Mr. Muhammad Shabbir, Overseer, and Mr. Saeed Amhad, Overseer, were incharge of works. The burden on these gentlemen was heavy and they had to work 24 hours at a stretch quite often during diversion operations. Excellent arrangement of materials, equipment and labour were made well in advance of requirements. The work was well organised and every thing went according to plan in a clock work manner.

The works built have already shown their efficacy in high flood of 11.7.60 and subsequent smaller floods and have by now stood test on all ranges of discharges. It would not be long before the old bed rises high above normal water level and is brought under cultivation. The recurring emergencies, calling of Army, civil and police help and dislocation of administration are over. The local population are relieved of worry and tension due to fear of Tawi which haunted them all the time. The river approach to weir has improved as a prelude to further works for re-modelling of the Headworks.

The diversion works of this magnitude are difficult as river behaviour is unpredictable and weather conditions can upset the whole scheme of work. Unlike set pieces of work, the operations have to be sufficiently flexible to meet the changing conditions and situations which arise all of a sudden. Coolness and patience are needed and situation has to be kept

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under continuous appreciation. Above all, there has to be unity of command, self confidence, cool thinking, capacity for organisation, patience and courage to face the upsets and reverses which are certain to come up on diversion jobs.

Recommendation for Design of Training Works

On basis of experience at Marala the following recommendations are made for design of training work.

When need for training a stream in a particular reach has occured, a complete system of spurs should be planned instead of a few isolated spurs. The exact location of armoured heads will depend upon the specific objective and site conditions. A spacing of two times the effective shank length is suitable for approaches with obliquity upto 45 degrees. This ensures safety of marginal bank from direct river attack. Where flow is expected to be more or less straight the spacing may be increased to three times effective shank length. In case approach obliquity is expected to be over 45 degrees it may become necessary to reduce the obliquity by training the river on the opposite bank.

The marginal bank should have suitable free board depending upon height of wave worked from fetch under highest flood conditions with a minimum of 4 feet. Where no railway line is provided the bank should be at least 25 feet wide to admit of two-way truck trafic. The slopes and section should be designed carefully to ensure safety against cross heads in highest flood. The river side slope should be liberal with good cover to ensure safety against wave action. The details of design will depend on soil and weather conditons.

While considering layout natural impregnable sites and existing spurs should be utilized to fit in the general scheme.

When layout has been decided maximum embayment on upstream should be anticipated and shanks given suitable set-back and protected with an apron of 25′×4′ and slope pitching. No hard and fast rule for exact estimation of embayment is available and experience is the best guide. The dimensions given in fig 1 are recommended for approaches upto 45 degrees and can be safely adopted for general river work.

Secondary spill channels along downstream shank are likely to damage shank during early years in high supplies. To protect against this 8′×5′×4′ stone teeth should be provided at 30 feet distance along downstream shank upto 60% of shank length from T-Head.

The top width of T-Head should be enough to accommodate a reserve of 20% of total stone consumed by the head. The shank should be sufficiently wide to allow of one way or two way traffic. The spur shanks are not subject to heavy cross heads. Generally, a 20 feet bank with3 : 1 side slopes will have adequate section against cross head. Where high crops heads are anticipated the section should be properly designed.