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Remodelling marala barrage & link for silt control

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REMODELLING MARALA BARRAGE & LINK FOR SILT CONTROL

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1. MARALA HEADWORKS

1.1 Marala Headworks (Weir) was constructed in the district of Sialkot (Plate No. 1) during the year 1905-12 on river Chenab, immediately below the confluence of Munawar Tawi and Jammu Tawi Nullahs. Upper Chenab Canal off-taking from this weir then served an areas of 7,25,000 acres in the districts of Sialkot, Gujranwala & Sheikhupura and then joined the river Ravi at the right flank of Balloki Headworks (then called Balloki Level Crossing) to augment the flow of Lower Bari Doab Canal off-taking there. The linkage of the two rivers (Chenab with Ravi) in this manner was thus the first attempt made by the department to transfer surplus water from one river to the other for meeting the shortages on the canal system. The provision of Marala Weir constructed almost con-currently with Mangla, Khanki and Balloki Headworks as well as the canals off-taking from there (year 1904-17) was thus an important intermediatory structure of the Tripple Canal Project Works (Plate No. II) whereby (i) the surplus water of Jhelum river was transferred from Mangla to river Chenab at Khanki via Upper Jhelum Canal, (ii) the surplus water of Chenab river was transferred from Marala to river Ravi at Balloki via Upper Chenab Canal so as to meet the shortage on Lower Chenab and Lower Bari Doab Canals.

1.2 Marala Headworks remodelled from time to time had a length of 4318 feet at the time of independence in the year 1947. It consisted of (Lay-out Plan at Plate III) eight shutter bays each 500 feet wide, 318 feet wide left pocket having 8 undersluice bays of 31 feet span each and Divide Wall 328 feet long. The Head Regulator of Upper Chenab Canal on the left was 338 feet in length and comprised of 12 bays each of 24.5 feet span to cater for a discharge of 11694 Cusecs. The structure was designed for a flood discharge of 7,30,000 Cusecs in the river and had other pertinent features as under:—

Pond Level (Summer).			808.0
Max Flood Level.			818.0
Crest Level	(i)	Shutter bays.	802.0
	(ii)	Under-sluice bays.	792.10
	(iii)	Regulator bays.	792.23 (Solid)
	(iv)	” ”	795.23 (top of rising cill gates raised fully)

Typical cross-section of the weir, undersluice & regulator are at Plate No. III.

1.3 Soon after independence, the supply of the water was cut off by India for the canals having source of supply there. This created a crises situation and after a great deal of diplomatic effort, an agreement was evolved with India in May 1948 to restore the supply in these canals (on maintenance cost sharing basis) tappering off gradually as arrangement for alternative sources of supply are provided for by Pakistan. As a sequel of this phenomina,

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remodelling of Upper Chenab Canal to increase the capacity from 11694 Cusecs to 16500 Cusecss was taken up in the year 1949 and completed in 1953 so as to transfer water to the severed areas of Central Bari Doab and partly Depalpur Canal Systems (Lahore & Kasur Districts) via Bambanwala – Ravi – Bedian – Depalpur Link (Plate No. I). The construction of this link was started during the year 1949 and completed in 1956. Luckily the Head Regulator of Upper Chenab Canal had the flexibility to take the additional discharge and as such practically no remodelling of the weir structure was involved.

1.4 In a bid to provide alternative source for supply of water to the canals on river Sutlej affected by the partitioning of irrigation basin, construction of Balloki-Sulemanki Link (Discharge 15000 Cusecs) was taken up in the year 1951. The requirement of water for the link at Balloki was firmed up (to the extent practicable) by constructing Marala Ravi Link (discharge 22000 Cusecs), outfalling into river some distance upstream of the Ravi Syphon. This necessitated provision of an independent regulator at Marala Headworks which was put on ground alongwith the construction of the Link from the year 1953-56 (Lay-out Plan in Red Colour – Plate III). The compulsion of maintaining a perennial flow into the Upper Chenab Canal from the headworks posed some limitations on the construction area for the Link Head Regulator. The new regulator was therefore located 300 feet on the upstream of the existing structure and in a set back position of 170 feet. This regulator had a length of 496.5 feet and consisted of 17 spans of 24.5 feet width each. The cill crest was kept at R.L. 795.23 i.e. the level corresponding to raised cill gate of the Upper Chenab Canal Head Regulator. Typical Cross Section of the Link Regulator is shown in red on Plate No. III.

1.5 The existing divide wall of 328 feet length placed the Head Regulator of Link completely outside the pocket area. This made the Link to get the water directly from the river without creating any still pond effect. On noticing the effect of excessive silt deposition in the Link soon on its commissioning (in the year 1957), the divide wall was extended in a further length of 312 feet (i.e. with overall length of 640 feet) during the year 1962-63. This extension covered about one third length of the link regulator and thus gave only a partial pocket effect. The extended portion of the divide wall is shown in red on Plate No. III.

II. MARALA BARRAGE

2.1 The provision of alternative sources of water supply to the areas effected by partitioning of the sub-continent soon demonstrated their inadequacy and this situation could not be allowed to perpetuate indefinitely. The international community gauged the sensitive posture of the situation which could culminate into war also between the two countries. Diplomatic dialogue therefore resulted into evolution of an Indus Waters Treaty in the year 1958 and this gave India the exclusive use of Eastern rivers namely Ravi, Beas and Sutlej. To meet the shortage of water on the canals of these rivers, a net-work of Links, some Barrages and two Dams were constructed by Pakistan (termed as replacement works) by securing financial help from the friendly countries including the World Bank. Works constructed under the Indus Basin Replacement Plan from the year 1959-71 are shown in red on Plate No. I.

2.2 The construction of Marala was of a primitive type and not based on any sound hydraulic theory of scientific innovation of sub-soil flow requirement. The unreliable/unsatisfactory condition of the old weir in relation to its extremely important linkage with the Replacement Plan Works warranted either complete remodelling/overhauling of the existing weir or to construct an entirely new structure on which reliance could be placed for an efficient performance in future. Alternative proposals of remodelling and construction of a new structure at a variety of locations were examined and finally decision had been made to construct the new Barrage 1100 feet on the downstream side and also new regulators for the two off-taking channels (existing/old regulators of the canals were abandoned). The construction of new barrage with layout plan as per Plate No. IV was taken up in the year 1965 and completed in 1968. This complex 4472 feet long designed for a flood discharge of 11,00,000 Cusecs has 66 bays of 60 feet span each. The first 13 bays on left (bays 1 to 13) are the undersluices and form 867 feet wide pocket, separated from the other portion by a 1080 feet long divide wall. On the right side 7 bays (bays 60 to 66) again are the undersluices segregated by the divide wall of the same length. The new head regulators for Upper Chenab Canal and Marala Ravi Link are 265 feet and 355 feet long and have 6 and 8 spans of 40 feet width each respectively. The salient features of the new structure depicted on Cross-Sections at Plate No. IV are given here under:–

Crest level.	(i) Normal bays 14 to 59.	800.0
	(ii) Right & Left undersluices (Bays 1 to 13 & 60 to 66).	795.0
	(iii) Regulators (both).	802.0
Pond level.		812.0
Full supply of level in the Link.		804.2
Top level of closed gates.		814.0
Maximum Flood Level.		818.0

Designed Head across.

(i) Normal bays.	24.5 feet.
(ii) Undersluices.	26.0 feet.
(iii) Divide Wall.	5.0 feet.

Designed Capacity.

(i) Canal Regulator.	16,850 Cusecs.
(ii) Link Regulator.	22,000 "

III. MARALA RAVI LINK

3.1 This link taking off initially from old weir and now from new barrage is about 63 miles long and has a design capacity of 22,000 Cusecs at head, worked out as under:–

		Cusecs.
(i) Planned delivery for Balloki through river Ravi.	=	17,000
(ii) Grow More Food Irrigation Channels along Link	=	2,000
(iii) Transfer to Bambanwala Ravi Bedian Depalpur Link via Sub Link.	=	2,000
(iv) Losses.	=	1,000
Total Capacity at Head.	=	22,000

The channel was designed as per Lacey's theory with parameters as under:–

(i) Slope	1 foot per 10,000 feet upto R.D. 249, 850. 1 foot per 8000 feet from R.D.249,850 to R.D. 301,500. 1 foot per 6600 feet from R.D. 301,500 to R.D. 317,315 (Tail).
(ii) Lacey's silt factor 'f'.	= 0.98
(iii) Bed width.	= 345.0 feet.
(iv) Depth.	14.6 feet.
(v) Full supply level at head.	= 803.80
(vi) Silt carrying capacity.	= 0.70 grams/litre.

It is a non-perennial unlined canal and flows normally from April to September depending upon availability of surplus water in river Chenab.

3.2 The link was opened for operation in July 1957. The location of the old regulator in a retarded position and absence of pocket/still pond effect in front of it caused the river water to flow almost directly into the link thereby causing heavy deposition of silt (about 4.5 feet depth) in the head reach by end of summer season 1958. By end summer season 1959, the depth of silt had risen to about 8.2 feet. The situation kept on aggrevating with the passage of time as would be seen from the silt depth data of the head reach at Annexure 'A' and plotted at interval (years 1959, 1962, 1968, 1975, 1985 at Plate No. V. The silt carrying capacity presumed at 0.7 grams per litre at full supply was made at times to exceed far more than the designed limit even at low discharges to avoid repeated closure of the link so as to meet the pressing demand of Sutlej Valley Canals, The relaxation of silt entry criteria continued till the situation eased out after construction of the other links envisaged in the Indus Basin Plan to connect river Sutlej.

3.3 The excessive silt entry/deposition rendered the old regulator non-modular and thus encroached upon its discharging capacity. Steeper slope acquired in the head reach by siltation (to about 0.15 as against 0.1 per 1000), eroded the berms and banks to widen the section. The higher elevation of flowing water in the link submerged a few of its bridges in the head reach. Lesser quantity of water in the link began to flow by meandering from one side to the other thereby causing scour on the outer curves and damage to the banks. The channel widened as much as 570 to 770 feet in the head reach as against designed width of 345 feet. Full supply level at head of link in the year 1959-60 had risen to about 807.50 with only 15,000 Cusecs discharge as against the designed level of 803.8 for 22,000 Cusecs. Maximum attainable pond level of 808 above the weir (the top of the shutters), often became difficult to maintain during April, May, September and October when nil escapages below the weir tended to exceed the allowable head across limits. During this period, feeding of the Link was badly impeded causing serious shortages on the dependent systems at the time of keen demand. The situation being quite precarious, therefore, demanded provision of some remedial measures on priority basis.

3.4 To improve upon the working of the head regulator and excessive silt entry phenomina, the following steps were taken at the head works during the year 1960-64:–

(i) The shutters of the weir in the first two bays were replaced or modified to maintain a pond level of 809.5 provided the head across limits did not exceed. In the remaining bays overflow from the top of shutters (above R.L. 808.0) was permitted upto a depth of about 0.8 feet.

(ii) The divide wall/groyne was extended from existing length of 328 feet to 640 feet to cover about one third postion of the Link Regulator.

(iii) Earthen spurs with stone pitched noses and sides protected by pilchi/kahi pitching were constructed on both sides of the link in head reach to tighten the bed width upto design during the year 1961-62.

(iv) Training works were constructed along the left Upper Marginal Bund to shift the confluence point of Jammu Tawi towards right so as to check its direct entry into the pocket.

The efforts made above proved almost futile in remedying the problems. Further steps to invest on the old weir were then stopped on final decision having been taken in the year 1964 to construct a new barrage as well as the regulators for the two canals.

3.5 By the year 1960, the excessive silt entering the link at the head had travelled upto R.D. 2,00,000 as under:—

R.D. 0–10,000	average depth	9 feet
R.D. 10,000–20,000	,,	7 ,,
R.D. 20,000–30,000	,,	6 ,,
R.D. 30,000–40,000	,,	5 ,,
R.D. 40,000–50,000	,,	5 ,,
R.D. 50,000–1,00,000	,,	4 ,,
R.D. 1,00,000–1,50,000	,,	2 ,,
R.D. 1,50,000–2,00,000	,,	2 ,,

The extent of silt deposition in the first 40 miles was about 250 million cubic feet of which the removal would have been time consuming and expensive too. Removal was in any case no remedy, as the same would have been again deposited due to unfavourable conditions at head. The only way for increasing the silt transporting capacity of the channel was to steepen the slpe of the link. This too could not be introduced due to open foundations of many bridges and pucca/rigid floors of syphons/superpassages on way. The regulating bridge-cumfall at R.D. 237,500 was the only structure which could afford lowering of its crest by 4.34 feet by remodelling it suitably. With retrogression smoothly travelling upwards, this was expected to generate a steeper slope of 1 in 8,333 (i.e. 0.12 per 1000) in the channel on the upstream to correspond with Lacey's silt factor of 1.08 (against 0.98 designed) and thus improve upon the silt carrying capacity from 0.70 to 0.98 grames per litre. The projected lowering of the fall was done in two stages during the year 1960 and 1961 by providing simultaneously the required additional protection on the allied works. The retrogression however travelled in a length of about 5 miles only with prominent effect limited upto Deg Nullah Syphon at R.D. 220,122. Very hard clayey strata at bed frustrated erosive action of the steeper slope thereby causing almost a complete failure of this scheme.

3.6 Perusal of channel data in the head reach has revealed that Upper Chenab Canal was in scour of 1½ to 2 feet upto the year 1953-54 i.e. before its remodelling from a discharge of 11694 Cusecs to 16500 Cusecs. The increased withdrawal of discharge in this canal reduced with-
Cusecs to 16500 Cusecs. The increased withdrawal of discharge in this canal reduced the extent of scour to about 3/4 feet till the link also became operative. Combined withdrawal of discharge by the two canals around 30,000 Cusecs marred the stilling effect in the

pocket causing further siltation of this channel (Like the Link Canal) upto about 1.5 feet till the new Barrage became operational in the year 1968. With the change in the source of supply at new barrage and better performance of the pocket effect, slight scouring tendency was again noticed in the Upper Chenab Canal which presently is of the order of about 2.0 feet. Experience has shown that this channel faces no serious sedimentation problem with a silt load of about 0.7 grammes per litre which corresponds to a silt factor of 1.2 corresponding to the full supply discharge of 16500 Cusecss and a slope of 1 in 6667 of the channel.

IV. PROBLEMS AT BARRAGE

A. RIVER APPROACH.

4.1 Marala old weir and now the barrage is situated near the foot hills and immediately below the confluence of Munawar Tawi and Jammu Tawi with the main river Chenab. The slopes of these streams near the headwork are quite steep; Chenab and Munawar Tawi about 0.3 per 1000 while that of Jammu Tawi varies in the range of 0.2 to 0.25 per 1000. Further up (beyond 4 miles) slopes are more steep. The bed of these streams upto a distance of about 4 miles above the barrage is of fine to coarse sand (all formed by the river Chenab while adopting various courses of flow) while further up it has pebbles on Munawar Tawi and Chenab sides and clay along Jammu Tawi. The water flowing on steep slope with high velocity picks up the bed load of which the quantum increases as the discharges go up. Floods specially in Jammu Tawi are sudden and bring down huge quantity of sediment, mostly clay or silt from above and picks up fine course sand material also on entering the bed formed by river Chenab near the barrage.

4.2 The position narrated above demands that the various streams of flow should join each other at a respectable distance from the barrage so that the turbulance effect does not travel close to the pocket and thus induce excessive sediment load to pass into the off-taking channels. The conditions at Marala are of peculiar nature which do not obtain at other headworks. Unfavourable approach conditions can cause a disaster as experienced in the year 1929-30, when open flow stream towards Upper Chenab Canal made the same to silt up in the head reach by about 5 feet in a single day. The same situation more or less repeated at the time of commissioning the link in the year 1957 and continued upto the year 1959 when Jammu Tawi joined the river almost directly above the left undersluices channel of the old weir. The river course of this period marked on Plate No. VI would amply clarify this position. To shift the confluence point of Jammu Tawi away from the undersluices channel, a battery of Spurs (7 No.) were constructed along the left upper marginal bound with added advantage of its protection also (Plate No. VI) A careful watch on the courses of the stream is therefore warranted to avoid repetition of the conditions prevailing during the year 1957-59.

4.3 The pattern of flow and approach of river to the barrage should be in such a manner that the pocket draws water for the off-taking channels from the outer (concave) side which has comparatively less sediments. Manipulation of the barrage gates should be made in such a fashion that the main river stream remains on the right to fulfil the above condition as far as practicable.

B. LEFT ROCKET.

4.4 Model studies carried out by Irrigation Research Institute have established that if slope in the approach channel to the pocket is steeper than 1 in 4500, then the quantity of silt entering the channels increases considerably (Engineering Congress Paper No. 227). To eliminate harmful silt entry into the canals, a careful watch on the approach velocity to the pocket should be kept in addition to avoidance of any turbulance at or near the pocket zone. With the manipulation of barrage gates and pond level this should not be difficult to accomplish particularly during the summer season.

4.5 The size of left pocket i.e. 867 feet width and divide wall 1080 feet long, is more or less in conformity with the recommendations made by the Research Institute in the year 1963, but these experiments had been conducted with barrage location 500 feet below the crest line of the weir. For ease of construction, the barrage has however been located at a distance of 1100 feet below. This departure demanded fresh experimentation and evolution of the related parameter of the pocket.

4.6 It has been felt that the pocket is comparatively wider than that required for the length of divide wall provided for at site. This makes the turbulance effect to approach the pocket thereby relaxing control on the sediments movement. The present divide wall ends at a small distance from the upstream abutment end of the link regulator. The result is that the supply encircling the upstream end of the divide wall has a tendency of direct entrance into the Link Canal. Some research tests showing improvements had been made in the year 1961 by keeping pocket size of 750 feet width and 1470 & 1650 feet length. To begin with perhaps shorter length of 1470 feet (i.e. extension by about 400 feet) may be worth-while to try. In any case extension of divide wall to its optimum length corresponding to a pocket width of 867 feet needs to be re-established by carrying out fresh experiments in the Irrigation Research Institute. A comparison of divide wall lengths, pocketwidths and designed withdrawals at other barrages as per data given below will show that the length of divide wall provided at Marala in relation to the width of pocket is rather short:—

Name of Barrage		Width of Pocket (feet).	Length of Divide Wall (feet).	Length of Canal Regulators (feet).	Designed withdrawal (Cusecs)
Kalabagh		462	300	200	7500
Chashma	(i) Left	730	709	350	21700
	(ii) Right	250	408	86	5000
Taunsa	(i) Left	462	452	140+198	8850+12000
	(ii) Right	261	323	198	8301
Rasul		395	707	350	25600
Trimmu	(i) Left	289	560	140+	5249+11000
	(ii) Right	215	600	82	2710
Qadirabad		335	502	260	18600
Khanki		295	540	332+165	11727
Panjnad		420	800	340+44	9267+1064
Islam	(i) Left	250	600	164+22	5400+558
	(ii) Right	290	680	164	4883
Sulemanki	(i) Left	240	700	164+116	4917+3366
	(ii) Right	230	700	188	6595
Balloki		No divide wall		350+320	7650+18500
Sidhnai		250		117+303	4005+10100
MARALA		867	1080	265+335	16850+22000

4.7 Under the present condition by operating undersluices, it is not possible to flush the pocket fully, particularly below the level of broken old weir crest (R.L. 792). Mounds of deposited silt continue to stay at higher elevation as would be visible from the pocket plan before and after flushing operation at Plate No. VII. A partial flushing of the pocket retains a higher level of silt in the pocket as a consequence of which the velocity of flow in it does not fall appreciably to shed the majority of incoming sediments. The effect of drag by opening the undersluicies is again not sufficiently forceful to completely dislodge the slushy clay deposits from a distance.

4.8 Perusal of the pocket plan (Plate No. VII) would show that the outer paraphery in front of the regulators and along the sheet pile caissons of the divide wall are paved while the central portion has been left as Kacha. Experience has shown that when the undersluices are operated for flushing, the silt deposited on the paved portion gets washed easily while the portion on kacha bed takes a much longer time & effort. Mounds of unwashed silt stay in position in the Kacha Zone perhaps due to more firm bondage with the ground soil strata. Model experiments may indicate need/extent of further paving the pocket zone to improve upon the volume for silt deposition and then washing off the same with ease.

C. SILT EXCLUSION.

4.9 The deposition of silt in the pocket is a continuous function, less in winter and more in the summar season. Regulation rules prescribe flushing of the pocket when average silt level tends to go beyond 799, as higher deposits get sucked into the canals (more by the link, being on the upstream side) due to crest level being 802. During winter only Upper Chenab Canal (being a perennial channel) draws water as per available river flows which reduce to as much as 5000 Cusecs in the months of December to February and hence deposition of silt in the large pocket does not pose any problem in this period. Only a spordic freshet of rains affords an opportunity for pocket flushing in winer and even this chance gets denied in some years. Majority of siltation takes place in the months April to July (Table at Annexure 'B') when the component of Chenab river by snow melt is fairly large and brings sandy sediments into the pocket. A sample of silt charge brought by the river Chenab and Jammu Tawi in this period as observed in the year 1984 may be glanced at Annexure 'C'. In this period surplus river flows are generally not available to open the undersluices for flushing the pocket.

4.10 For an effective flushing of the pocket, a minimum of 60,000 Cusecs is required to flow through the undersluices by not allowing to exceed the head across limit of 5 feet along the divide wall. To attain this situation, about 180,000 Cusecs discharge is required for passing in the normal bays. This means that flushing operation can only be resorted to when the total discharge on the upstream of the barrage is about 240,000 Cusecs or more. The frequently of this discharge is very low during the year and frequent flushing is therefore not possible to practice at Marala.

4.11 In view of the peculiar situation narrated in the two paras above, some control on the silt entry into the off-taking channels can be exercised by the provision of a skimming platform or silt vanes in front of the regulators. With this mechanism even a small quantity of surplus water can maintain the immediate vicinity of the regulators free from silt deposits and thus minimise picking up of the sediments by dragging action of the canals in this zone. Unfortunately this facility of silt exclusion has not been incorporated at Marala.

D. MASONRY DIVIDE WALL.

4.12 The divide walls at Marala have been constructed with massive caissons of steel sheet piles upto their junction with the masonry walls of old weir bays 1 and 7 (Details at Plate No. VIII). The masonry portion is only 5 feet wide at top and has shallow as well as narrow foundation. Whereas no head across limit is of significance to the wider/massive portion of sheet piles framework, the masonry wall cannot withstand the same beyond 5 feet. In a bid to flush the pocket with a lower discharge in the river (as against about 240,000 Cusecs described in para 4.10) in the past (year 1968-69) as soon as the head across limit of 5 feet increased, cracks developed in the masonry portion where the old weir floor did not exist. Strengthening of this wall in a length of 61 feet was done in the year 1969-70 (Details at Plate No. VIII) to safeguard it from future damage. The limitation of 5 feet head across the divide wall therefore places an embargo that flushing of the left pocket at lower discharges cannot be practiced in the present shape.

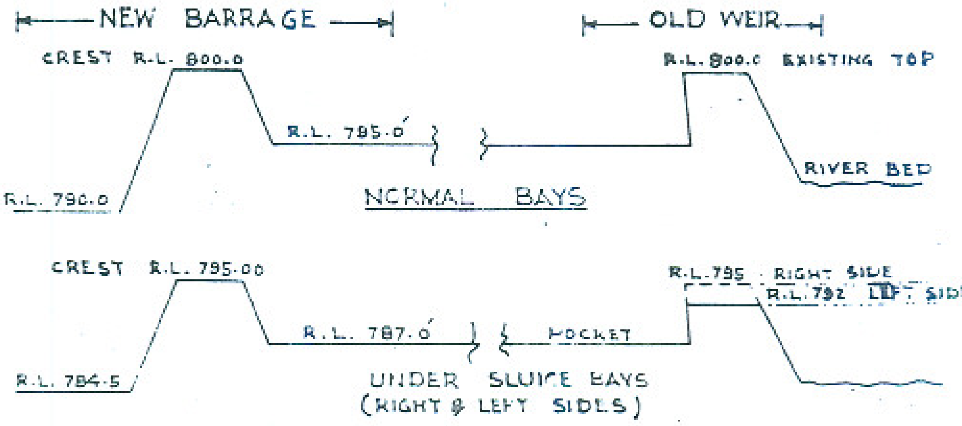
E. REGULATORS

4.13 The crest level of regulators has been kept at 802 while the limit of silt level in the pocket is defined as 799. With the flow of water into the canals at pond R.L. 812, as already stated, silt gets drifted through the regulators. The situation gets more aggravated on siltation of the pocket further; as much as at the level of regulators crest (Refer Table at Annexure 'B' and Plate No. VII) due to non availability of adequate discharge in the river for flushing. Even the prescribed difference of 3 feet from projected pocket silt R.L. 799 upto regulator crest R.L. 802 is too less to hamper the phenonima of picking up of the load from the silted bed for the withdrawals envisaged.

4.14 At old weirs including Marala, rising cill gates used to be provided in conjunction with the lowering gates at the canal head regulators. This flexibility afforded facility of a raised crest when reqiuired to cut off entry of heavy silt laden water at bottom of the stream flow. The rigid crest and radial gates lowering technique of new barrages has left no room to operate in that fashion. Raising crest of the regulator suitably, incorporation of rising cill gates, possible raising of the normal pond limit and a combination of them may considerably help in exercising a better control on silt entry into the link canal.

F. OLD WEIR CREST

4.15 The old weir 1100 feet upstream of the new barrage had become redundent due to its submergence by the pond effect. The crest of the old weir at R.L. 802 was knocked down to R.L. 800 in front of the normal bays of the barrage, to R.L. 795 opposite right undersluices and R.L. 792 in front of the left undersluices. A schemetic view of the position opposite normal bays and the undersluices is given here under:—



The raised crest of 5 feet at the old weir above the upstream floor of the normal bays and the left undersluices function as bhobby traps for silt to deposit in the inter-mediatory lengths.

4.16 The hidden barrier of old weir masonry creates shoaling effect on the upstream side and these shoals gradually shift with flow of water for canals to the pocket side. The barrier in front of normal bays at R.L. 800 induces silt laden lower layers of flood water to enter the pocket area where corresponding level of such barrier at R.L. 792 is lower by 8 feet. The difference in the broken crest levels of the old weir on either side of divide wall also tends to increase the differential head of water across the left wall while flushing for pocket clearance. While resorting to pocket flushing, the clearance of silt from below old weir crest R.L. 792 upto undersluice floor level 787 becomes very difficult to accomplish with the above features in position. Knocking down the crest of old weir from R.L. 800 to R.L. 795 i.e. flush with the upstream floor level of normal bays, will have a very healthy effect on silt entry into the pockets. The extent of relief can however be got ascertained by carrying out the model studies.

V. PROBLEMS ON LINK

A. REDUCTION OF CAPACITY

5.1 Eversince construction of the link in the year 1957, it has seldom run for a discharge of more than 20,000 Cusecs from the old weir except for a few odd days in the years 1959, 1960 and 1961 as would be evident from the following table:—

Maximum Daily Discharge Run (Cusecs).

Year	April	May	June	July	August	September
1957	3500	7200	13000	14000	14500	600
1958	10500	12000	17000	18000	18000	18000
1959	—	19000	20500	21000(2 day)	10000	15000
1960	—	16500	21957(1 day)	22000(3 day)	22000 (2 days)	19310
1961	—	19610	21000(5 day)	18000	15928	16192
1962	14250	14250	18920	19190	14857	14742
1963	16000	15709	15654	16904	—	—
1964	12000	12968	15644	15000	15000	14344
1965	4680	13920	14195	14514	14148	9504
1966	3489	13468	15203	14562	14535	13527
1967	14298	14873	15944	13680	12760	12024

This low running accentuated the silting problem on account of attaining lesser velocities of flow in a bigger channel section.

5.2 The situation as above continues after commissioning of the new barrage from 1968 till today as is clear from the data upto the year 1986 below:—

Maximum Daily Discharge Run (Cusecs).

Year	April	May	June	July	August	September
1968	6597	11000	14000	14000	14000	14000
1969	10000	13000	14000	14000	14000	14000
1970	–	10000	14000	15000	15000	15000
1971	8000	–	14200	14000	14400	11080
1972	2000	10000	13800	14500	14700	14700
1973	14500	14900	15000	14600	13000	11800
1974	2500	9000	16300	16896	16578	16578
1975	8000	14000	15000	15000	13000	15000
1977	6000	9000	14200	14200	15250	15500
1978	5000	9000	15000	15000	15000	15000
1979	5000	10000	14500	14500	14500	15700
1980	15000	16500	17000	17500	18000	18000) See
1981	5000	16000	17667	18000	18000	18250) Note
1982	–	1000	17100	17800	17800	17800) Below
1983	–	12500	13335	13575	15371	15366
1984	–	13713	14432	14432	14432	14432
1985	–	14000	15130	15000	15000	15000
1986	5000	7000	12960	12960	12960	–

Note: The data recorded/reported in the year 1980 to 1982 is erroneous as the same had been computed from a gauge on upstream side of the submerged bridge at R.D. 18150 M.R. Link where the phenomina of heading up was amply clear. In addition double check of levels in the closure period of the year 1982-83 revealed this gauge to be out by 1.3 feet (on the upper side) and has been rectified since then. In fact during this period also the discharge has seldom gone above the figure of 15,000 Cusecs as further confirmed by calculations from the link regulator gate openings.

The link in the present form has thus been de-capacitated to about 15,000 Cusecs as against designed discharge of 22,000 Cusecs.

B. SILT DEPOSITION

5.3 With the progressive entry of fine to coarse sand material into the link, the channel has gradually silted upto the first fall structure at R.D. 237, 230 as per latest long section at Plate No. IX. Average depth of silt reachwise as obtaining in the years 1960 and 1985 is compared below:–

Reach (Unit 1000 feet).	Year 1960		Year 1985	
	Average depth (feet).	Quantity of silt MCFT.	Average depth (feet).	Quantity of silt MCFT.
R.D. 0-10	9.0	32.0	11.37	41.2
R.D. 10-20	7.9	25.0	10.15	34.4
R.D. 20-30	6.0	20.0	8.15	31.5
R.D. 30-40	5.0	17.5	7.60	27.8
R.D. 50-100	4.0	70.0	4.69	86.4
R.D. 100-150	2.0	35.0	3.44	57.5
R.D. 150-200	2.0	35.0	4.31	74.2
R.D. 200-237	–	–	3.65	43.3
Total:		252.0		421.5

Increase in quantity of silt in 25 years.	=	169.5 Mcft.
Percentage increase in 25 years.	=	67.3%
Average annual increase in quantity of silt.	=	6.78 Mcft.
Precentage " "	=	2.7%

B. The above shows that by the year 1960 i.e. during initial 3 years of operation, a total of 252 Mcft of silt had deposited in the link. The siltation process has contined since then and now it stands at 421.5 Mcft in the same reach. The deposition is on the increase every year calling for provision of remedial measures on emergency basis failing which the discharging capacity of the link will continue to dwindle with the passage of time.

5.4 The deposition of silt has made the link to acquire a steeper slope of the bed which on an average stands at about 0.17 per 1000 feet (Plates No. IX) upto Aik Nallah super passage at R.D. 90190. This means that heavier sand charge of coarse, medium and fine grains classification is not being carried by the channel. This is gradually aggravating the siltation position in the entire length of the link. The channel would therefore require re-designing to conform not only with the existing condition but also by keeping in view the likely deterioration if not checked or taken care of for sometime more.

C. BANK EROSION

5.5 The process of siltation has resulted in widening of the channel section so much so that the width had increased to an average of 670 feet in the head reach by the year 1959-60 as already explained in para 3.3. Passage of low discharge in the link (Less than 10,000 Cusecs) adopted a meandering course of flow causing erosion of banks and scour at the outer curvature. This pattern of flow remains always problematic necessitating bank protection in the form of kila bushing and its cross spurs. Inspite of this effort, the channel has widened considerably upto Syphon at R.D. 135 as would be clear from the table below (also see Plate No. IX.)

Reaches (Unit 1000 feet).	Bed width (feet)		Reach	Bed width (feet)		Reach	Bed width (feet)	
	Design	Existing		Design	Existing		Design	Existing
0 – 5 (Lined)	345	378	80-85	345	390	160-165	340	361
5 – 10	"	390	85-90	"	375	165-170	"	362
10 – 15	"	390	90-95	"	370	170-175	"	344
15 – 20	"	400	95-100	"	380	175-180	"	345
20-25	"	410	100-105	340	372	180-185	335	340
25 – 30	"	405	105-110	"	380	185-190	"	330
30 – 35	"	402	110-115	"	385	190-195	"	322
35 – 40	"	406	115-120	"	368	195-200	"	348
40 – 45	"	396	120-125	"	374	200-205	"	344
45 – 50	"	401	125-130	"	400	205-210	"	344
50 – 55	"	396	130-135	"	385	210-215	"	344
55 – 60	"	351	135-140	"	344	215-220	"	328
60 – 65	"	379	140-145	"	344	220-225	"	330
65 – 70	"	404	145-155	"	335	225-230	"	351
70 – 75	"	375	150-155	"	334	230-235	"	324
75 – 80	"	365	155-160	"	332	235-240	"	330

The widening tendency and a continuous fight along the banks cannot be averted unless the designed width is made rigid in one form or the other. Operation of link with great variation in the discharges of flow (depending upon availability of water in the river in relation to the demand of channels at Balloki) will always be problematic otherwise.

D. RISE OF FULL SUPPLY LEVEL

5.6 Siltation of the channel has in turn made the full supply level in the link to rise drastically so much so that the head regulator would become non-modular in case an attempt is made to push the discharge of around 15,000 Cusecs in it. The full supply level immediately below the regulator goes upto 811.6 at a discharge of merely 15,000 Cusecs as against the design figure of 804.20 corresponding to a discharge of 22,000 Cusecs i.e. registering a rise of 7.4 feet. Perusal of long section upto R.D. 100,000 giving existing data with 15,000 Cusecs flow as against designed parametes of the link at Plate No. IX would be quite revealing as further abstracted below:–

Reach (1000 feet).	Designed Bed level	Existing bed level	Water level with 15,000 Cusecs	Designed full supply level with 22,000 Cusecs.	Rise of bed level (feet).	Rise of water level (feet).
R.D. 0	789.9	802.1	811.6	804.2	12.2	7.4.
R.D. 25	786.9	795.5	806.7	801.2	8.6	5.5
R.D. 50	783.9	790.9	799.3	798.2	7.0	1.1
R.D. 75	780.9	784.7	796.4	795.2	3.8	1.2
R.D. 100	778.0	780.4	792.7	782.3	2.4	(-) 0.4

Higher water levels in the link thus do not only impair the modularity of the head regulator, but it also encroaches up on the free board of the channel necessiating raising and strengthening of the bank in the filling reaches.

E. SEDIMENT LOAD

5.7 Testing of the bed material at site during the year 1969 indicated average silt diameter of 0.54 m.m. with 96.6% coarse plus medium grade as under:–

Dia of silt m.m.	Mean dia m.m.	Part % age	Contents	Classification
0.08 – 0.20	0.14	3.4	0.476	Fine
0.20 – 0.5	0.35	54.5) Total 96.6%	19.075	Medium
0.5 – 1.0	0.75	40.5)	30.375	"
1.0 – 1.5	1.25	0.9)	1.125	Coarse
1.5 – 2.0	1.75	0.7)	1.225	"

Total of corase & Medium = 51.80

$$\text{Mean silt dia} = \frac{51.80}{96.6} = 0.54 \text{ m.m.}$$

. with the grain size as above, Lacey's silt factor works out to 1.29 as against long section of the link designed for 0.98. Silt load actually experienced at site and its grain size demanded provision of a steeper slope in the channel which has no longer remained practicable in the total length due to limitations of feeding for full discharge at head in silted condition, presence of innumerable structures and cross drainage works already constructed and levels required to feed the grow more food channels enroute.

5.8 The link has been designed with hydralic parameters as under:–

Reach	Discharge	Bed width	Depth	Lacey's factor	Slope per 1000 feet
0-1000	22,000	345	14.6	0.98	0.1
100-180	21,000	340	14.3	0.97	0.1
180-250	20,500	335	14.3	0.96	0.1
250-302	20,000	330	13.6	1.00	0.25
302-313	20,000	330	13.2	1.26	0.15

The data obtaining at site for a discharge of 15,000 Cusecs upto R.D. 100 is abstracted on the average as under:–

Q = 15,000 Cusecs.
B = 380 Feet
D = 9.4 to 11.0 feet
S = 0.17

Lacey's factor with these parameters works out to:–

$$S = \frac{1}{1.844} \times \frac{f^{5/3}}{Q^{1/6}}$$

$$\text{or} \quad 0.17 \doteq \frac{1}{1.844} \times \frac{f^{5/3}}{(15000)^{1/6}}$$

or f = 1.30 as against the value of 1.29 arrived at in the year 1969 by testing the material at site.

5.9 Representative samples of deposited sediments taken at R.D. 1000,5000,10000 & 15000 during August 1986 have been got tested in the Research Institute and gradation curve plotted on Plate No. X. On the basis of this data average diameter of the material deposited at bed works out to 0.50 m.m. with 95% coarse and medium grade as abstracted here under:

Dia of material m.m.	Mean dia m.m	Part % age	Contents	Classification
0.08-0.20	0.14	5	0.7	Fine
0.20-0.5	0.35	60	21.0	Medium
0.5-1.0	0.75	35	26.3	"
1.0-1.5	1.25	–	–	Course
1.5-2.0	1.75	–	–	"

Total of coarse & Medium = 47.3
Mean Silt Dia. = 0.50

With the quality of bed material as now existing at site, Lacey's silt factor comes to 1.25 as against 1.3 on the basis of 15,000 Cusecs flow presently or 1.29 worked out in the year 1969 or 0.98 adopted for design in 1952.

F. RUNNING LINK IN WINTER

5.10 Bambanwala-Ravi-Bedian-Depalpur Link takes off from Bambanwala regulator at R.D. 133,000 Upper Chenab Canal. This channel has 10 non-perennial distributaries off-taking upto R.D. 187,000 i.e. the junction point of sub-link from Marala Ravi Link. The capacity of the sub-link is 3500 Cusecs which is more than sufficient to meet the perennial requirement on B.R.B.D. Link across Ravi Syphon for Central Bari Doab Canal System around Lahore.

5.11 During the year 1961, Marala Ravi Link was operated in winter to feed C.B.D.C. System via its Sub Link in a bid to wash down the silt from the head portion. The silt free river water of winter no doubt picked up the silt from a small portion in the head reach, but the position became again the same on re-operation of Link in Summer. Similar operation repeated in the winter season of 1985-86 showed the behaviour as experienced previously and hence proved to be practically ineffective.

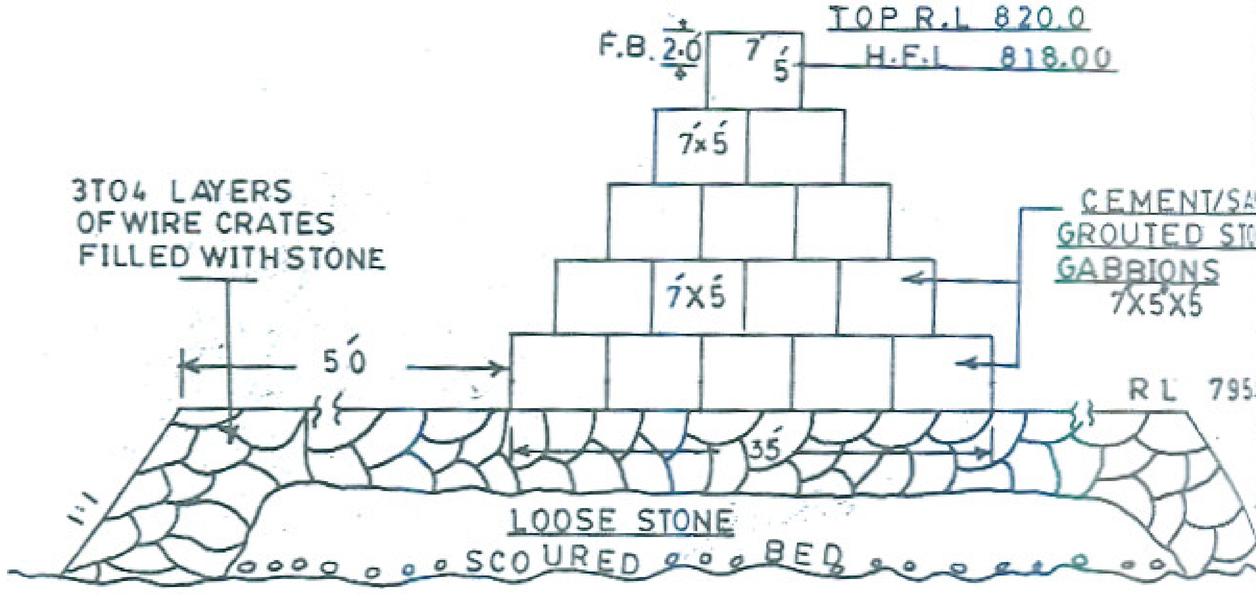
G. SILT EJECTION

5.12 Provision of a silt ejector along the canal at a suitable site would be a useful media to throw out excessive/heavier silt load. Absence of an old river creek/course on the left side (where the canals off-take) did not prompt provision of an ejector on the canals at Marala. The first cross-drainage structure of Tunnelwah at R.D. 18150 of Link could be availed, but the related levels of the river Chenab do not permit this consideration as would be clear from the tentative lay-out plan and long section plotted at Plate No. XI. Proposals to pass the flow of water from Ejector along the route of Tunnel-wah would only mean silting of that channel as the same has a very mild slope of 1 in 18000 and has a long path of over 15 miles upto its junction with the river. The disposal of heavy silt laden water without availability of a steeper slope in the leading channel is liable to even choke up the deep barrels of U.C.C. Syphon R.D. 17,050 enroute as would be clear from Plate No. XI. This state of affairs would prove extremely disastrous because of non-availability of water way across the channels for the designed discharge of Tunnel-wah Flow (3500 Cusecs).

VI. PROPOSALS FOR BARRAGE

A. DIVIDE WALL EXTENSION

6.1 Description in Para 4.6 would indicate that the existing wall of 1080 feet length is rather short in relation to 867 feet width of the pocket. The wall protudes out only a small distance from the upstream end of the link regulator, thus allowing the turbulances to enter the pocket in the zone contributing flow for withdrawal by the Link regulator. The optimum length can only be arrived at by conducting the model studies, but perhaps extension by about 400 feet would be obligatory as discussed earlier at Para 4.6. This extension can only be made with stone dumping upto low winter water level during the annual closure and building up the upper portion by gabbions of stone grouted in cement-sand mortor to maintain a reliable geometry of the work. The extension portion should be capable of withstanding a differential head of over 5 feet and to cater for scours by swirling action at nose. The construction of this wall shall only be possible during annual closure period(s) and its tentative shape can be as per sketch below:–



B. **SILT EXCLUDER**

6.2 The process/extent of silt deposition near the canal regulators can be controlled to a considerable extent by constructing silt vanes to form a silt excluder in the pocket. The heavier silt charge at bottom layer of flow in the pocket would thus be made to pass below the barrage via these vanes by partial operation of under-sluice gates facing the ejector as disscussed in Para 4.11. At the beginning of Summar Season when supply in the river is not adequate to meet the requirement of discharge at Khanki/Qadirabad Headworks, a discharge of about 5000 Cusecs is usually released below Marala. This water can be made to pass via the vanes of the silt excluder, thus ensuring its most effective performance because of availability of excessive head of flow at that time i.e. low water level in the river downstream the barrage. It is suggested that the silt ejector comprising of 12 vanes should be constructed opposite first two bays of the undersluice as per arrangement indicated on Plate No. XII. Refinements as well as efficacy can be better established by conducting model experiments. The construction of the excluder will require advance planning on account of tight time schedue of execution during annual closure period(s).

C. **COMPARTMENTATION OF POCKET**

6.3 As stated in Para 4.10 flushing operations in the pocket are made when supply in the river is of the order of 240,000 Cusecs. Since the frequency of this discharge is very low, flushing operation has to wait unless the off-taking channels can be closed due to low demand on the systems dependent on their flow. In absence of these parameters silt deposition in the pocket continues to build up inducing more and more silt into the off-takes.

6.4 Due to limited period of high flows (above 240,000 Cusecs), complete flushing of the pocket is usually not possible to accomplish and heaps of silt continue to stay in position to aggravate the silting effect subsequently. Excessive width of the pocket is also a factor retarding the silt washing effect.

6.5 Compartmentation of the pocket into three zones will permit partial flushing operations to be undertaken even at low discharges in the river and at more frequent intervals also. The draging effect (deficiency indicated in Para 4.7) will as well be more pronounced in a narrow width of flow by compartmentation of the pocket. Tentative arrangement of compartmentation as well as the relative position of the proposed silt excluder is shown on Plate No. XII i.e. Bays No. 1 & 2 for excluders; Bays No. 3, 4 & 5 first compartment; Bays No. 6, 7, 8 & 9 second compartment and Bays No. 10, 11, 12 & 13 the third compartment.

6.6 Appropriate locations of the additional dividing walls and their lengths would of course need a detailed model study. The walls being fairly high and also liable to encounter some differential head will require proper foundation of a reinforced concrete raft and provision of sheet piles cut off to support the massive structure. The construction of these walls would no doubt be a difficult operation to be managed during annual closure period(s).

D. PAVING POCKET FLOOR.

6.7 As stated in Para 4.8, the flushing of pocket in the unpaved portion is time consuming and sometimes not possible to wash completely. Pavement of the Kacha portion of the pocket is expected to expedite the process of flushing in a more reliable manner. Only a thin filament of concrete about 2 feet thick, placed in compartments separated by expansion joints would be adequate to achieve the desirable objective. This work will also be possible to do during the annual closure period(s) with advance planning.

E. REMOVING OLD WEIR CREST.

6.8 As mentioned in Para 4.15, the present level of the broken crest of old weir is 5 feet higher than the upstream floor levels of normal bays of the barrage. The harmful effects of this feature in relation to silt control has been discussed earlier in Para 4.16. Removal of this barrier upto the upstream floor level of the normal bays of the barrage is of paramount necessity. This work is again required to be done in the closure periods by managing the appropriate type of explosives in advance.

F. MODIFYING LINK REGULATOR CREST

6.9 Existing head regulator of Link has crest at R.L. 802 and 320 feet clear water way. Usual level of silt in the pocket is about 800.5 which gets sucked into the Canal. To reduce the intake of these sediments, the crest if raised by 2 feet, will still be adequate to draw the authorized discharge of 22,000 Cusecs into the link at normal pond R.L. 812 as under:—

$Q = C B H^{3/2}$ Assuming C for modular working as 3

$Q = 3 \times 320 \times (812\text{-}804)^{3/2} = 21722$

Say $= 22{,}000$ Cusecs.

6.10 In case provision for rising cill gate of 2 feet above the projected rise of regulator crest as at para 6.9 above is also incorporated, the withdrwal of discharge into the Link will not be possible to make for 22,000 Cusecs at normal pond R.L. 812 as under:—

$Q = C B H^{3/2}$

$= 3 \times 320 \times (812\text{-}806)^{3/2}$

$= 141109$ Cusecs.

Say $= 14000$ Cusecs.

Raising of the pond by one foot i.e. to R.L.813 would be of some help out not adequate for the purpose as below:–

$$Q = C\,B\,H^{3/2}$$
$$= 3 \times 320 \quad (813\text{-}806)^{3/2}$$
$$= 17779 \text{ Cusecs.}$$
$$\text{Say} = 18000 \text{ Cusecs.}$$

6.11 It would be seen from Para 6.10 above that a combination of raising by 2 feet each, with raised crest and rising cill gates imposes a limitation in the drawal of the discharge upto 18000 Cusecs only. A compromise of 1½ feet raise in each case may be a suitable choice as under:–

(i) With crest rise of 1.5 feet and pond R.L. 812

$$Q = C\,B\,H^{3/2}$$
$$= 3 \times 320 \quad (812\text{-}803.5)^{3/2}$$
$$= 23790 \text{ Cusecs.}$$

(ii) With rise on Crest & Cill gate each 1.5 feet and pond R.L. 813

$$Q = C\,B\,H^{3/2}$$
$$= 3 \times 320 \quad (813\text{-}805)^{3/2}$$
$$= 21722 \text{ Cusecs.}$$
$$\text{Say} = 22000 \text{ Cusecs.}$$

This arrangement would perhaps be a suitable choice on confirmation of the results by model studies and also if the working of the head-regulator remains Modular (discussed later at para 7.9).

6.12 The modification of regulator crest and provision of cill gates/machinery would be possible to do in the annual closure period(s). Tenative details of work are shown on Plan at Plate No. XIII.

G. RAISING POND

6.13 At present normal pond level is maintained at R.L. 812 while the top of completely lowered gates of the barrage is at R.L. 814 i.e. there exists a free board of 2 feet. The operational pond can thus easily be raised to R.L. 813 as required at Para 6.11 by compromising on the free board of barrage gates to one foot. This rise will provide greater depth of flow in pocket, reduce slope of river towards barrage and thus induce less silt charge into the pocket. Regarding head across, the position is quite safe as the barrage would be subjected to a maximum head 23.0' as against designed limit of 24.5 feet because the tail water level has never gone below R.L. 790.0 so far. In actual practice at the time of operating higher pond (for 22,000 Cusecs flow into link) releases below the barrage in Summar would invariably take place thereby subjecting the structure to a much lesser head across position.

VII. PROPOSALS FOR LINK

A. DESILTING

7.1 Visualizing the magnamity of desilting operation, fall at R.D. 237,230 was lowered by 4.34 feet in two states during the year 1960 & 1961 in a bid to steepen the slope and generate retrogression upwards. This experiment failed as discussed in Para 3.5.

7.2 In the year 1964 decision was made to desilt the excessively silted portion of the link by regrading according to the then acquired bed slope of 0.17 per 1000. This entailed about 24 Million cft of silt removal from 9 miles of head reach. The proposal however did not materialize for one reason or the other.

7.3 In the year 1965 the department moved WAPDA to desilt M.R.Link simultaneously with the construction of new barrage to make the channel function as envisaged, but no heed was paid to this request.

7.4 Mechanical dredging was considered at a number of occasions by utilizing the idle dredgers at Trimmu and Qadirabad. The space limitation for disposal of slurry viz-a-viz the quantum of silt load became a bottle neck, in addition to odd working conditions on account of the parallel channel of U.C.C. & large number of bridges on the link barring passage of dredger across them.

7.5 In the years 1985 & 1986, idea was mooted to shift the dredger of Qadirabad for operation in the head reach only (upto R.D. 7) at Marala so as to create a zone of trap for the incoming sediment load. The space limitation for the disposal of effluent nearby and farness of the river channel downstream the barrage (across U.C.C.) did not again allow the idea to materialise. In addition, the inspection of the dredger by expert mechanical hands revealed that the machinery with the passage of time had deteriorated so much that it could not be made to run it without replacement of many parts (requiring import) and thorough overhauling at a substantial cost. The dismantling, shifting and re-assembling is yet another project declared by some to be non-feasible in relation to condition of equipment at present and the costs involved.

7.6 Any scheme of desilting the channel to the original design without considering the existing parameters of flow, silt charge, extent of siltation/condition of link at present, trends of operation/siltation in future, limitations at barrage etc. would in isolation be a fruitless exercise as well as wasteful expenditure wise. Some desilting would however be called for by re-designing/regarding the channel which would be discussed at appropriate place later.

B. RE-GRADING

7.7 Link Canal in a length of 20 miles from head is excessively silted up and partial removal of this deposit seems to be the only/immediate method to restore the lost capacity. Experience and past studies have indicated that silt charge less than equivalent to lacey's factor of 1.3 would not be appropriate to adopt, Even the presence of steep bed slope of 0.17 per 1000 has not been instrumental in washing down the deposited silt or halting further siltation. In the given situation, silt factor of 1.5 with matching slope of 2.20 per 1000 may perhaps accelerate the process of washing the deposited silt lower down as well as over-come the problem of silt deposition in future, but the same may not be possible to incorporate for maintaing modularity at head, unless the grade is made up from upstream floor level of Aik Nullah crossing (R.L. 779.08) at R.D. 90190, of course entailing huge quantity of excavation (about 165 Mcft). A via-media with Lacey's silt factor of 1.4 and matching bed slope of 0.18 per 1000 may yield better results. Hydraulic parameters of the channel with different Lacey's silt facotrs of 1.1 (Designed), 1.3, 1.4 & 1.5 for a discharge of 22,000 Cusecs have however been worked out at Annexure 'D' for the sake of comparison.

7.8 Long-Section for re-grading the channel upto Aik Nullah crossing at R.D. 90190 and silt level obtaining there, conforming to Lacey's silt factor 1.4 and corresponding slope of 0.18 per 1000 for the designed discharge of 22,000 Cusecs has been plotted at Plate No. IX by keeping bed level at Aik Nallah crossing as silted upto R.L. 782 against its upstream floor level of 779.08. On this long-section silt for removal shaded in red works out to about 65 Million Cubic feet and the same may be possible to accomplish in one closure season of winter and is hence recommended for execution. Lower down no re-grading is porposed for the present as situation is yet not out of hand there.

7.9 With the regarding proposed at para 7.8 above, the modified design full supply level at head for 22,000 Cusecs works out to R.L. 810.8. The feasibility of raising the regulator crest upto top of rising cill at R.L. 805 has already been established at Para 6.11. In this way, the modularity of the head regulator does not get impaired as would be clear from the calculations below:–

Proposed Pond R.L. 813   Proposed Crest R.L. 805   Proposed D/S Water R.L. 810.8

Drowning ration $= \frac{810.8 - 805}{813 - 805} = \frac{5.8}{8} = 72.5\%$ Hence Mudular according to khosla's curve.

With lowering of the cill gates upto the proposed rigid crest R.L. 803.5, the drowning ratio would be $\frac{810.8 - 803.5}{813 - 803.5} = \frac{7.3}{9.5} = 77\%$ i.e. border line of modularity.

7.10 In case provision of rising cill seems out of fashion with the present day technology or construction practices, in that case, raising of crest of the regulator by 2.0 feet i.e. upto R.L. 804.0 would be desirable to adopt.

7.11 The design parameters proposed for re-grading as at Para 7.8 will be adequate for silt transportation capacity of 0.88 Gram/Litre as against previous design limit of 0.7 Gram/Litre. Lesser discharge in the canal will reduce the velocity of flow in the wider section (as well as on account of steeper slope required for it) and consequently effect silt transportation capacity. This limit will thus reduce to 0.7 Gram/Litre for a discharge of 18,000 Cusecs, to 0.60 Gram/Litre at 15,000 Cusecs, to 0.5 Gram/Litre at 12,000 Cusecs and to 0.4 Gram/Litre at 10,000 Cusecs and lower down. In the past only a single limit of 0.7 Gram/Litre had been introduced irrespective of the variation in discharge which perhaps became major factor contributing to rapid/excessive siltation.

7.12 By having regards to the condition of the channel, quantity/quality of silt load and the volume of earth-work involved in excavation, as a first step re-grading is being proposed as per para 7.8 i.e. silt factor of 1.4 bed slope 0.18 per 1000 moving upwards from the silted bed of Aik Nallah crossing thus entailing about 65 Mcft earthwork excavation. With the provision of silt entry control devices suggested in Chapter-IV, the channel is expected to follow a better regime of flow by movement of deposited silt to the lower reaches. Second stage re-grading may then be called for by assuming perhaps a silt factor of 1.3, bed slope 0.16 per 1000 and working upwards from the then silted bed at Aik Nallah Crossing. The third stage of re-grading may be appropriate by keeping the bed of link as per upstream floor of Aik Nallah Crossing and provision of slope corresponding to Lacey's silt factor of 1.3. The position of link beds corresponding to second & third stage re-grading has also been marked by way of illustration on the long-section at Plate No. IX. At these stages the operative pond will be at R.L. 812.0 as against suggested R.L. 813.0 for first stage regarding.

C. BANK PROTECTION

7.13 The behaviour of any channel cannot be predicted unless it is made to run within some defined limits, more so, where discharge variations are also expected to be rather large. The operational pattern of Marala Ravi Link requires it to flow even for a low discharge of 5,000 Cusecs and may be at one stage to 3,000 Cusecs (when demand of C.B.D.C. System on Lahore side may have to be met with in winter via its Sub-Link). This situation calls for lining the sides of the link in the entire reach to avoid widening tendency as experienced in the past and also to put an end to the operation of bank protection which has remained trouble-some all along. Since side lining is an expensive proposition, it is proposed to economise the process (without compromising on the objective) by resorting to provision of stone pitched profile walls 100 feet long at every 1000 feet (arrangement shown on Plate No. XIV). It is hoped that this provision will keep the geometry of the channel prism intact and also maintain stream line flow in the canal.

7.14 The strutting of the link in the fashion indicated in para 7.13 will automatically create berms in the intermediatory lengths of 900 feet and this process can further be accelerated by providing in between a row of killa bushing. The stone pitching of profiles is further proposed to be done conforming to long section with Lacey's silt factor of 1.3 i.e. slope of 0.17 per 1000 by keeping bed of the Link as per upstream floor level (R.L. 779.08) of Aik Nallah crossing at R.D. 90190 and moving upwards there-from, all in line with the expected ultimate position of the link canal (proposed for third stage re-grading), when the effect of some or all the measures suggested for silt entry control in Chapter-VI would also be visible. Needless to mention here that tightening of the channel section to design width is of paramount necessary failing which all the effort of re-grading may prove wasteful in due course.

D. STRENGTHENING BANKS

7.15 With the rise of fully supply by 6.6 feet (810 8–804 2) proposed at head, the filling reach of the link from R.D. 18000 to R.D. 70000 will require strengthening of the banks particularly on left (Sialkot side) for a reliable/safe operation. A few odd places lower down may as well deserve similar treatment. Three bridges at R.D. 29300, 34100 & R.D. 39100 will require raising of the decking part to avoid syphoning action at these sites. Similar treatment to bridges at R.D. 7044 and R.D. 18150 was done a few years back, as had urgently been necessitated at site.

VIII. PRIORITIES AND COSTS

8.1 A set of remodelling proposals have been made in Chapters VI & VII. By having regards to the mode/periods of construction, relative priorities are assigned in the list to follow. Rough cost estimates of each proposal have also been made and expenditure involved (based on price level of year 1985-86) indicated against them as under:–

A. BARRAGE		Rupees in Million
(i) Raising crest of Link Regulator by 1.5 feet.	=	2.50
(ii) Removing old weir crest (facing normal bays only)	=	10.00
(iii) Providing rising cill gates 1.5 feet high in the Link regulator.	=	8.00
(iv) Extension of left divide wall.	=	20.00
(v) Constructing silt excluder in the left pocket.	=	40.00
(vi) Providing 2 No. Walls in left pocket	=	35.00

B. LINK CANAL		
(i) Re-grading bed.	=	20.00
(ii) Bank protection.	=	30.00
(iii) Strengthening banks.	=	25.00
(iv) Raising decking of bridges R.D. 29300, R.D. 34100 & R.D. 39100.	=	3.50

IX. ACKNOWLEDGEMENTS

9.1 Gross reduction in the capacity of Link Canal from designed discharge of 22,000 Cusecs to about 15,000 Cusecs has always remained a cause of grave concern to the Department. Examination of the problem at individual level did not bring out a total analysis of the field situation and hence no workable solution came to surface in the past. A Committee of senior officers of the Department was constituted in November 1985 to deliberate on the subject and formulate recommendations. This Committee held one meeting at Lahore on 9-12-1985 and another at Marala on 2-1-1986, but could not finalize the assignment due to other pressing engagements of the members. The author being incharge of the canal system could not afford to wait long and hence decided to bring out an independent analysis of the whole situation by also taking cognizance of the discussions held already by the above Committee.

9.2 The author appreciates the role of M/S Mohammad Ismail Shaheed Superintending Engineer, Drainage Circle Sargodha, Ch: Muhammad Daud, Executive Engineer, Marala Division and Mr. Dilawar Khan Kirmani Sub Engineer, Marala Headworks for their valuable contribution without which the finalization of this paper would have been extremely difficult if not altogether impossible. The author also wishes to place on record the valuable ideas brought out by the learned Members of the Committee during the discussions held in the two meetings. Thanks are particularly due to Ch: Nazar Muhammad, Secretary, Irrigation & Power Department, Government of the Punjab who became instrumental in keeping the subject alive and it is only through his persuation that the completion of this study became possible.

ANNEXURE –A

STATEMENT SHOWING SILT DEPTH IN M. R. LINK R.D. 0 – 10000

Year	March	April	May	June	July	August	September
1957				Not observed			
1958				Not observed			
1959	–	–	3.55	7.24	7.52	8.90	8.24
1960	–	– 6.74	6.74	6.94	9.20	7.58	6.38
1961	–	–	4.57	7.56	N.O.	8.83	8.19
1962	–	7.21	6.55	6.21	7.05	9.29	8.10
1963	7.25	6.28	5.95	6.29	6.92	N.O.	N.O.
1964	–	7.55	7.28	6.88	8.29	8.39	6.79
1965	–	–	–	6.88	8.2	7.88	8.35
1966	–	8.10	7.37	8.58	8.76	9.77	9.88
1967	–	8.46	7.94	7.46	8.99	9.57	9.14
1968	–	5.39(Relates to new portion of the channel to					4.72
1969		– connect the Link with the new barrage. This					
1970		portion also got silted).					
1971	–	6.0	6.80	6.50	6.20	6.90	9.40
1972	–	5.60	5.80	5.40	5.80	5.60	6.00
1973	–	4.90	8.00	6.80	7.50	7.40	6.70
1974	–	5.60	7.00	7.50	7.70	8.00	8.00
1975							
1976	–			6.55	6.55		7.00
1977	–	–	–	6.51	6.52	6.70	6.82
1978	–	–	7.30	8.92	9.00	9.32	7.16
1979	7.34	7.45	7.99	8.53	9.57	8.00	8.70
1980	–	–	6.25	7.04	6.56	7.55	6.30
1981	–	–	9.65	8.12	8.69	9.54	8.54
1982	–	–	8.54	9.63	8.84	8.26	7.50
1983	–	–	8.65	8.00	6.74	9.05	7.72
1984	–	–	7.61	8.45	8.43	8.95	8.79
1985	–	–	8.07	9.27	10.07	9.60	8.05
1986	8.99	10.68	9.80	9.93	11.08		

ANNEXURE 'B'

SILT LEVEL OF LEFT POCKET OF MARALA BARRAGE 1968 – 86

Year	April	May	June	July	August	September
1968	798.4	797.5	799.00	795.2	795.6	793.5
1969	797.5	N.O.	800.05	793.6	793.1	795.1
1970	797.95	796.20	796.00	707.45	798.05	798.9
1971	798.10	798.60	799.00	800.00	794.30	794.40
1972	795.3	795.05	799.45	800.40	798.85	796.40
1973	801.75	795.70	801.00	794.45	793.45	795.60
1974	796.20	796.25	799.20	295.65	801.25	801.50
1975		797.75	801.25	791.80	793.20	794.60
1976				792.00	794.00	793.85
1977	796.55	796.85	798.70	792.70	798.60	798.05
1978	794.05	801.45	801.95	801.45	802.05	801.80
1979	798.20	801.30	802.60	803.65	797.75	802.10
1980	796.55	798.25	800.05	798.55	800.80	802.55
1981	800.15	801.30	801.70	795.10	800.25	802.40
1982	800.70	801.95	802.60	803.25	798.25	800.30
1983	800.15	801.40	802.45	799.70	798.50	794.95
1984	796.30	797.70	798.80	800.00	800.80	801.10
1985	798.70	799.10	799.93	798.90	800.30	798.40
1986	799.20	800.00	801.20	802.61		

ANNEXURE–C

SILT OBSERVATIONS OF RIVER CHENAB & JAMMU TAWI (IN GRAMME/LITRE).

Date	May 1984		June 1984		July 1984	
	Chenab	Jammu Tawi	Chenab	Jammu Tawi	Chenab	Jammu Tawi
1.	–	–	0.266	0.140	–	–
2.	–	–	–	–	–	–
3.	–	–	0.252	0.140	0.716	0.420
4.	–	–	0.308	0.154	0.574	0.504
5.	–	–	0.280	0.182	0.574	0.504
6.	0.105	0.049	–	–	0.518	0.420
7.	0.112	0.070	–	–	–	–
8.	0.159	0.084	0.252	0.126	0.490	0.350
9.	0.077	0.049	–	–	0.420	0.294
10.	0.112	0.063	0.154	0.126	0.532	0.364
11.	0.120	0.070	0.196	0.140	0.476	0.280
12.	–	–	0.196	0.140	0.378	0.308
13.	0.140	0.098	0.140	0.126	–	–
14.	0.140	0.112	0.32	0.238	–	–
15.	0.168	0.084	0.308	0.168	–	–
16.	0.154	0.098	–	–	–	–
17.	0.182	0.112	0.350	0.168	–	–
18.	0.252	0.098	0.420	0.252	–	–
19.	–	–	0.378	0.238	–	–
20.	–	–	0.504	0.226	–	–
21.	–	–	0.226	0.154	–	–
22.	0.196	0.140	0.280	0.196	–	–
23.	0.140	0.112	–	–	–	–
24.	0.210	0.126	0.350	0.224	–	–
25.	0.210	0.140	0.420	0.308	–	–
26.	–	–	0.588	0.392	–	–
27.	0.350	0.210	0.672	0.420	–	–
28.	0.238	0.140	0.700	0.378	–	–
29.	0.196	0.126	–	–	–	–
30.	0.224	0.154	–	–	–	–
31.	0.252	0.154	–	–	–	–

DESIGN PARAMETERS OF MARALA RAVI LINK CANAL WITH DIFFERENT SLIT FACTORS

S.No.	Data with F.S. Discharge as 22,000 Cusecs.	Lacey's silt factor 'f'			
		1.1 (Design)	1.3	1.4	1.5
1.	Slope/Foot = $0.000542 \frac{f^{5/3}}{Q^{1/6}}$	0.00012 (1 in 8333)	0.0001586 (1 in 6305)	0.0001795 (1 in 5571)	0.0002014 (1 in 4965)
2.	Area = A = $1.26 \frac{Q^{1/6}}{f^{1/3}}$	5073 Sft	4798 Sft	4681 Sft	4575 Sft
3.	Wetted parameter = $W_p = 2.67\ Q^{1/2}$	396 Feet.	396 Feet.	396 Feet.	
4.	Full supply depth = D				
	With side slope ½ : 1		12.9'	12.5'	12.2'
	With side slope 1 : 1	14.3'	12.9'	12.6'	12.3'
	With side slope 1½ : 1	—	13.1'	12.7'	12.4'
5.	Bed width = B (Side Slope ½ : 1)		367 Feet	368 Feet	369 Feet
	1 : 1	345'	360'	360'	361'
	1½ : 1	—	349'	350'	351'
6.	By adopting "Kirmani's Section"				
	Bed width.	—	354'	355'	356.5'
	Depth		12.9'	12.5'	12.2'
	Top width	—	419 Sft.	419'	419'
7.	Velocity of flow (ft./sec).	4.34	4.54	4.69	4.81
8.	Silt transporting capacity (grames per litre)	0.73	0.81	0.88	0.94

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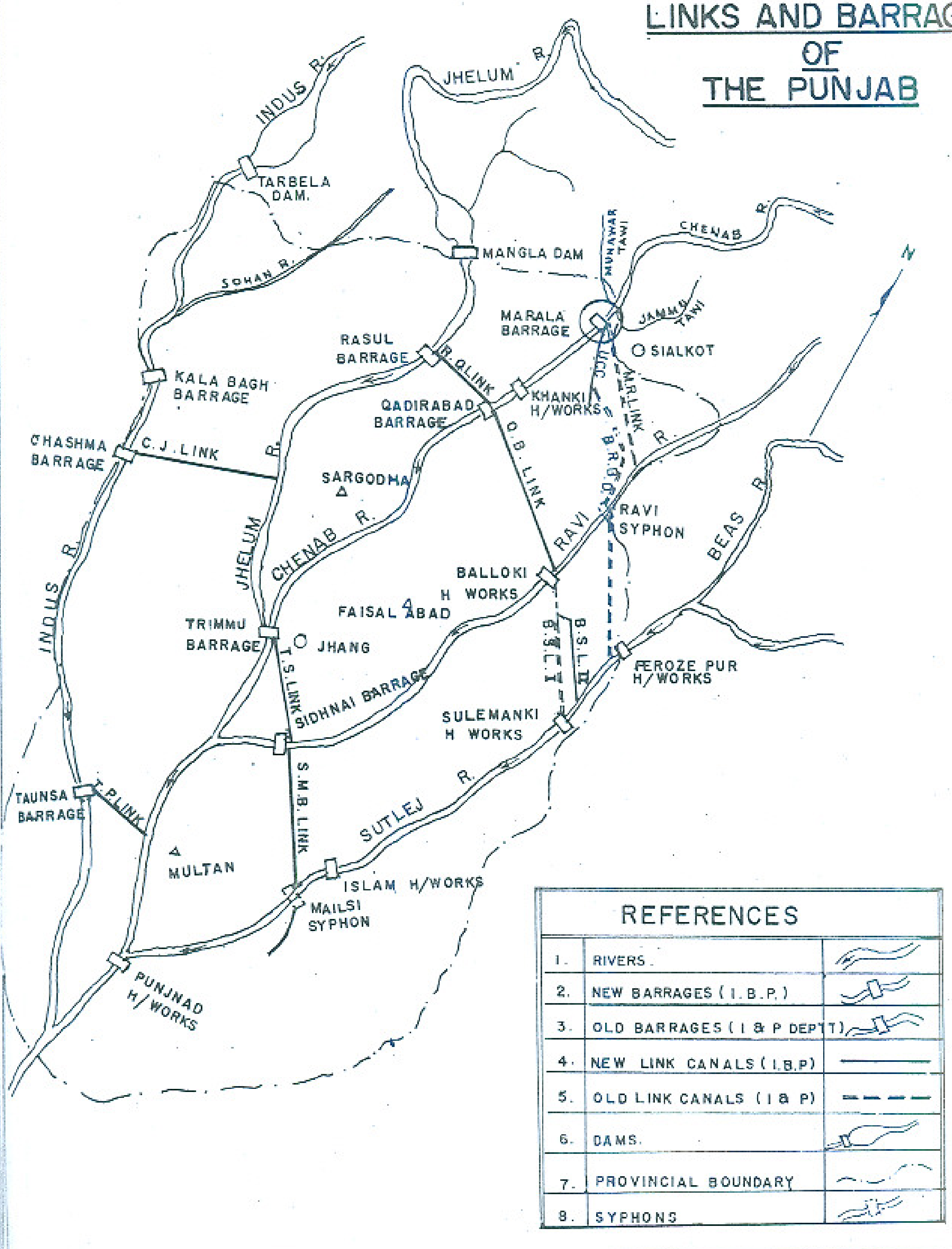
PLATE NO I

LINKS AND BARRAGES OF THE PUNJAB



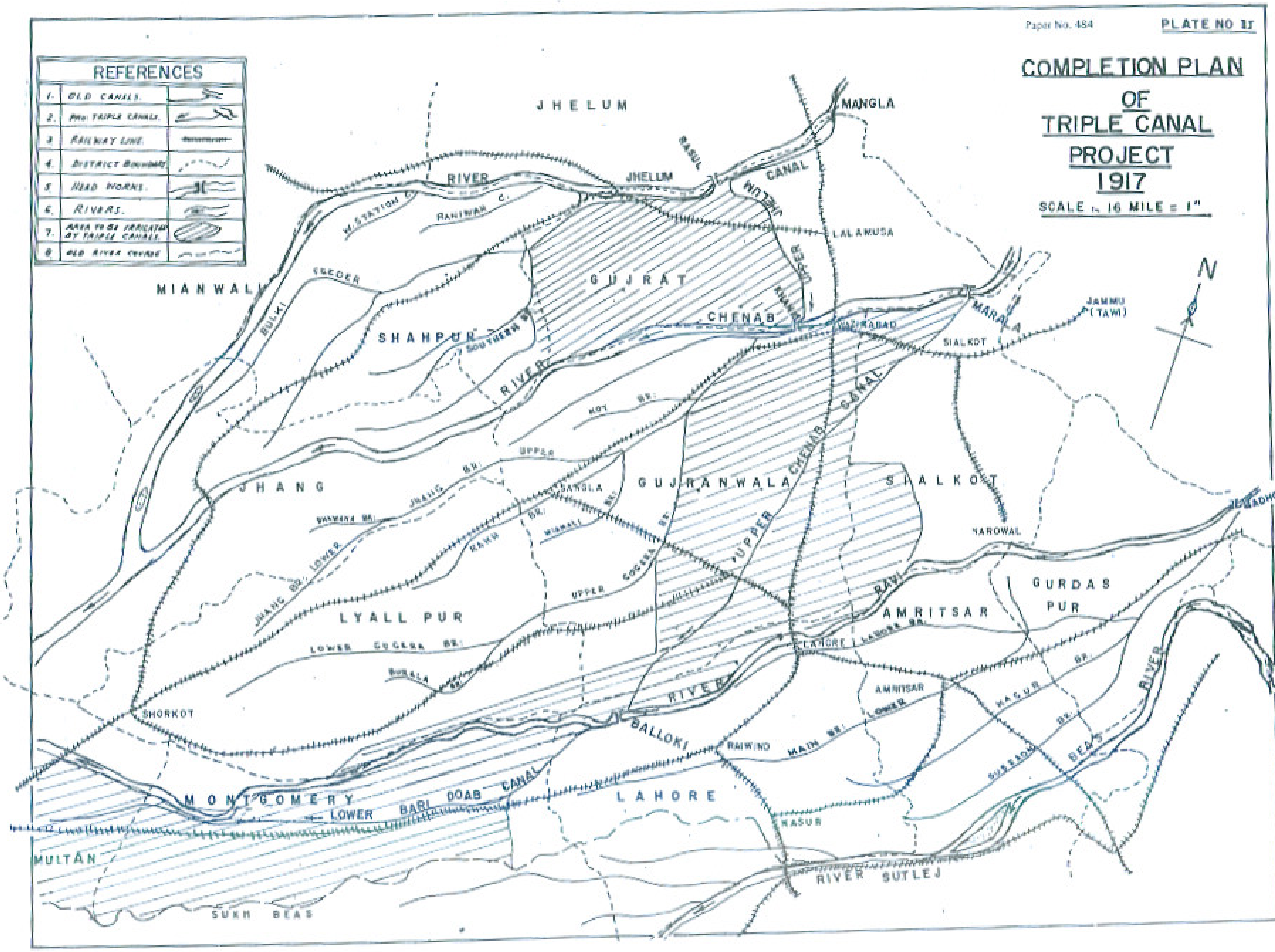
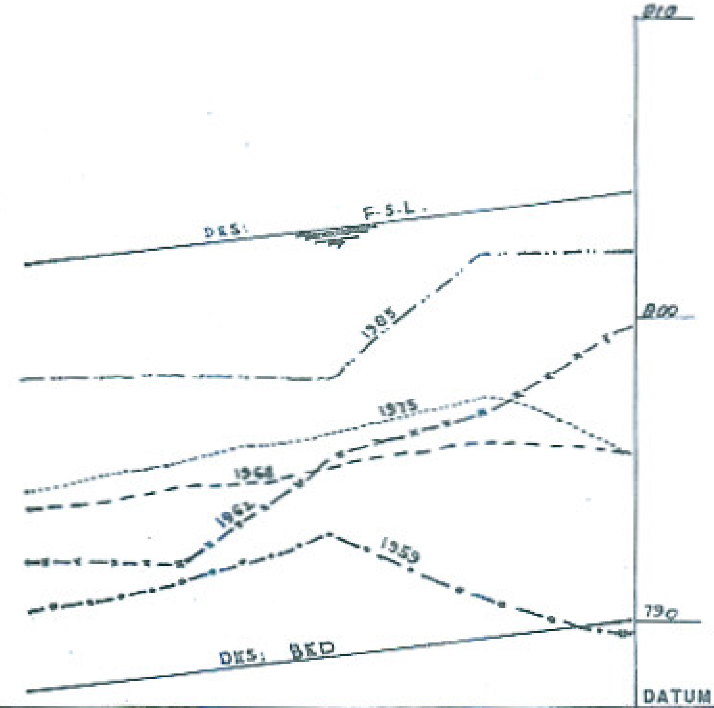

Paper No. 484
PLATE NO II
COMPLETION PLAN OF TRIPLE CANAL PROJECT 1917
SCALE 1 16 MILE = 1"
N
REFERENCES
1. OLD CANALS.
2. PRO: TRIPLE CANALS.
3. RAILWAY LINE.
4. DISTRICT BOUNDARY
5. HEAD WORKS.
6. RIVERS.
7. AREA TO BE IRRIGATED BY TRIPLE CANALS.
8. OLD RIVER COURSE
JHELUM
MANGLA
RASUL
JHELUM CANAL
RIVER
LALAMUSA
UPPER
GUJRAT
CHENAB
MARALA
JAMMU (TAWI)
SIALKOT
MIANWALI
SHAHPUR
RANIWAH C.
FEEDER
SOUTHERN BR.
KOT BR.
UPPER CHENAB CANAL
JHANG
GUJRANWALA
SANGLA
JHANG BR.
LOWER
RAKH BR.
UPPER GOGERA BR.
LYALL PUR
LOWER GOGERA BR.
BURALA BR.
SHORKOT
NAROWAL
GURDAS PUR
RAVI
AMRITSAR
LAHORE
MADHOPUR
BALLOKI
RAIWIND
MAIN BR.
KASUR BR.
SABRAON BR.
BEAS
MONTGOMERY
LOWER BARI DOAB CANAL
KASUR
RIVER SUTLEJ
MULTAN
SUKH BEAS

PLATE NO V

Paper No. 484

L. SECTION OF MARALA RAVI LINK

SHOWING SILT POSITION



		R.D. 20	R.D. 15	R.D. 10	R.D. 5	R.D. 0
SILTED BED	1985	797.90	798.0	797.90	802.10	802.10
	1975	794.20	795.19	796.02	797.48	795.41
	1968	793.63	794.41	795.00	795.79	795.40
	1962	791.72	791.97	795.27	796.97	799.70
	1959	790.06		792.89		789.59
DES: DATA	F.S. DISCHARGE	22000 Cs:				
	F.S. SLOPE	0.12 %oo OR 1 IN 8333				
	F.S. DEPTH	14.3'				
	BED WIDTH	345'				
	F.S. LEVEL	801.80	802.40	803.00	803.60	804.20
	BED LEVEL	787.50	788.10	788.70	789.30	789.90
	N.S.L.	798.65	800.03	801.00	805.12	820.50
	R.D.	20	15	10	5	0

Paper No. 484

PLATE NO VI

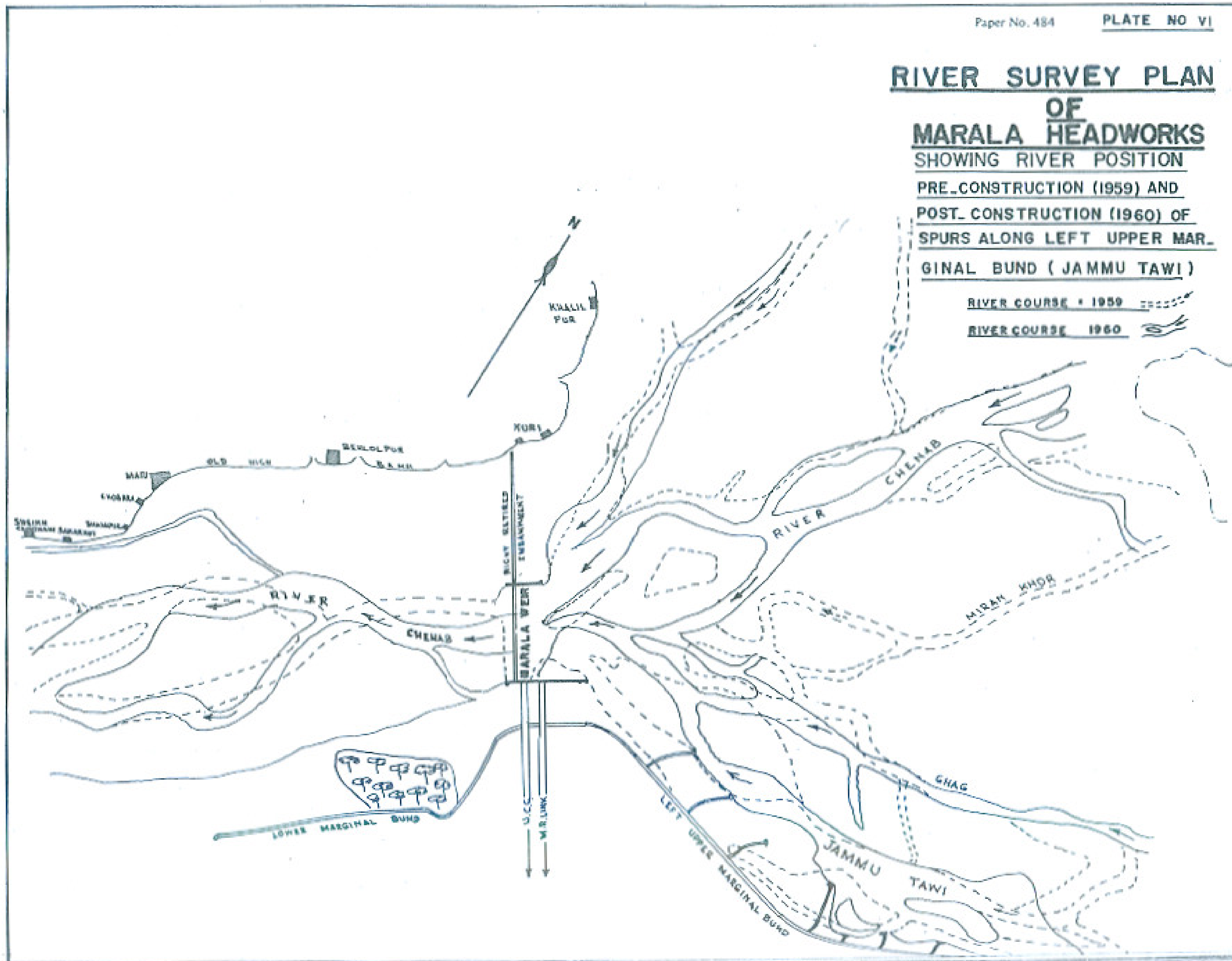
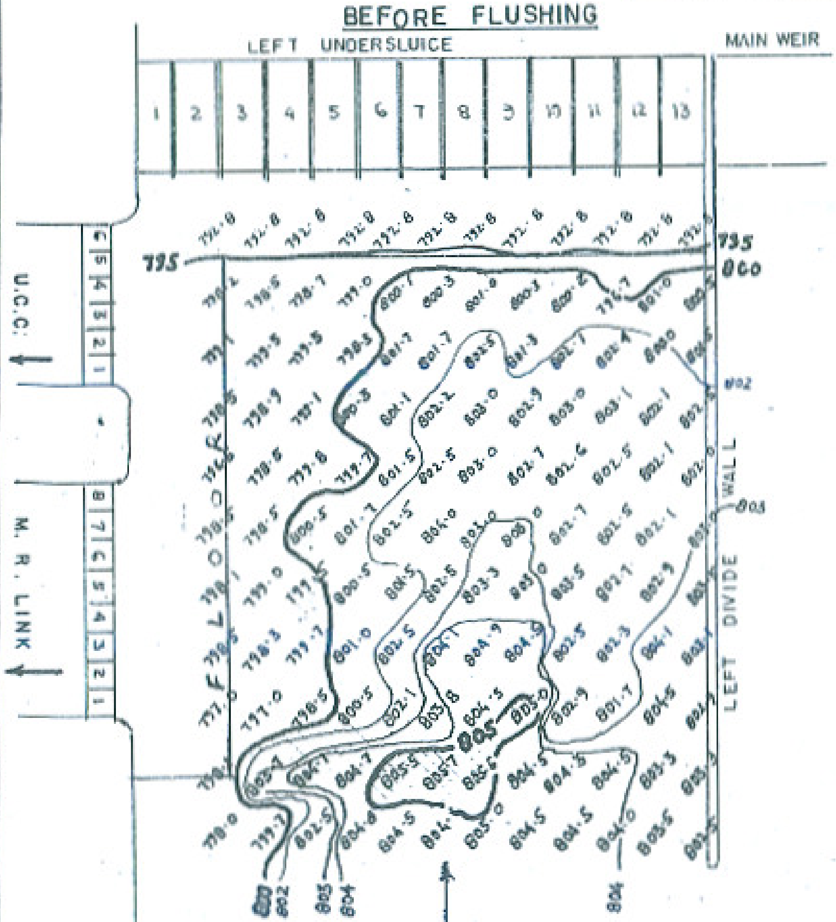


PLATE NO VII

Paper No. 484

SILT SOUNDINGS OF POCKET OF MARALA BARRAGE

BEFORE FLUSHING



DATE OF OBSERVATION 28.7.86

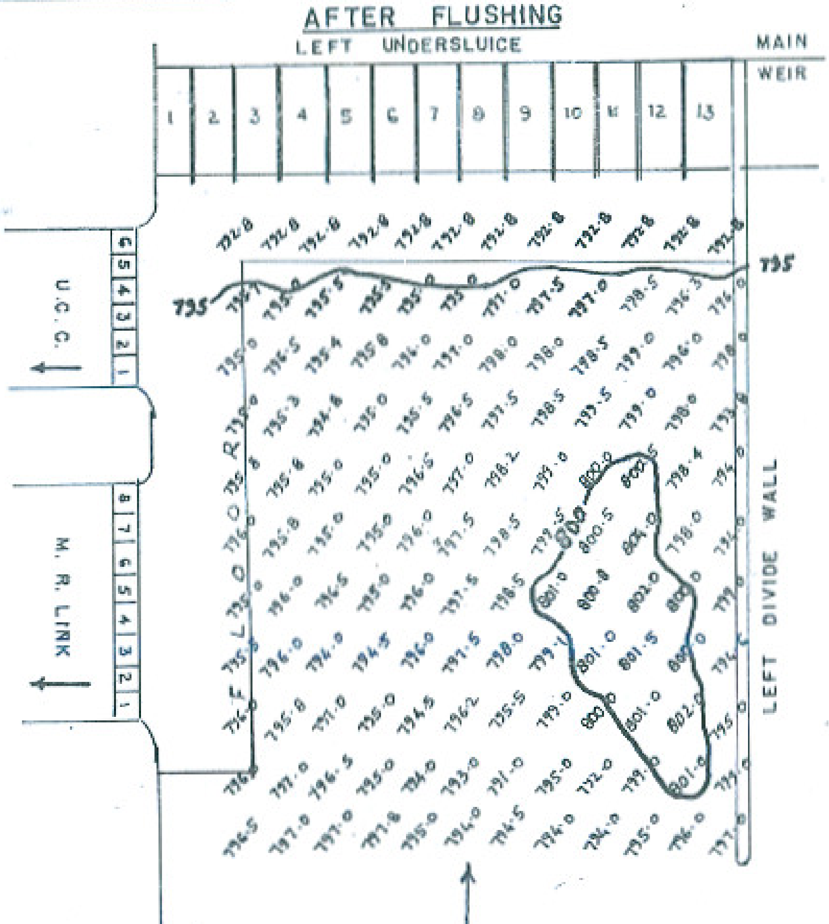
AV: SILT LEVEL 802.61

SILT DEPOSIT R.L. 795.00 – 800.00

SILT DEPOSIT R.L. 800.00 – 805.00

SILT DEPOSIT R.L. 805.00 & ABOVE

AFTER FLUSHING



DATE OF OBSERVATION 3.8.86

AV: SILT LEVEL 796.45

SILT DEPOSIT R.L. 795.00 – 800.00

SILT DEPOSIT R.L. 800.00 – ABOVE

PLATE NO VIII

Paper No. 484

DETAIL OF LEFT DIVIDE WALL
MARALA BARRAGE

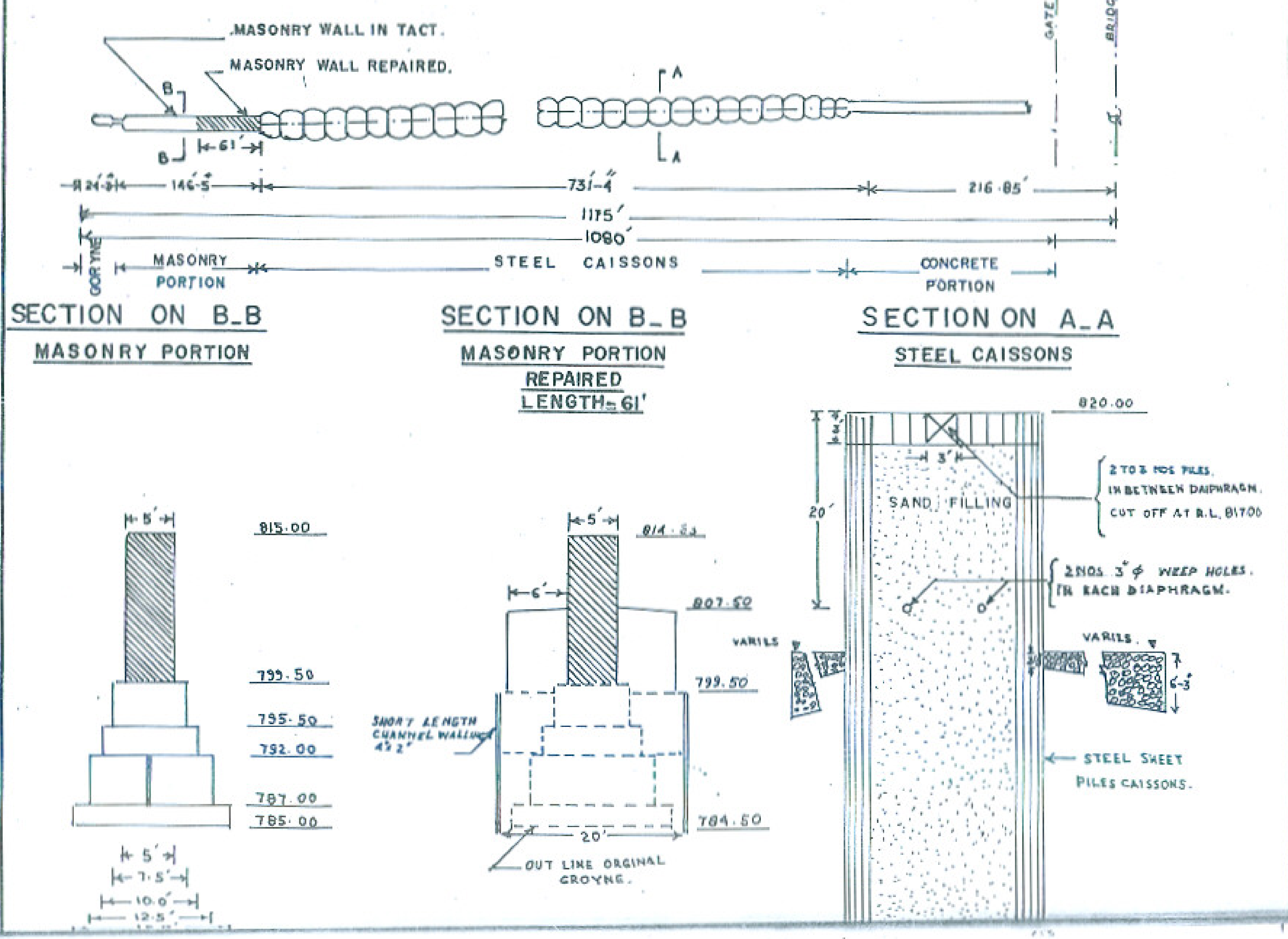
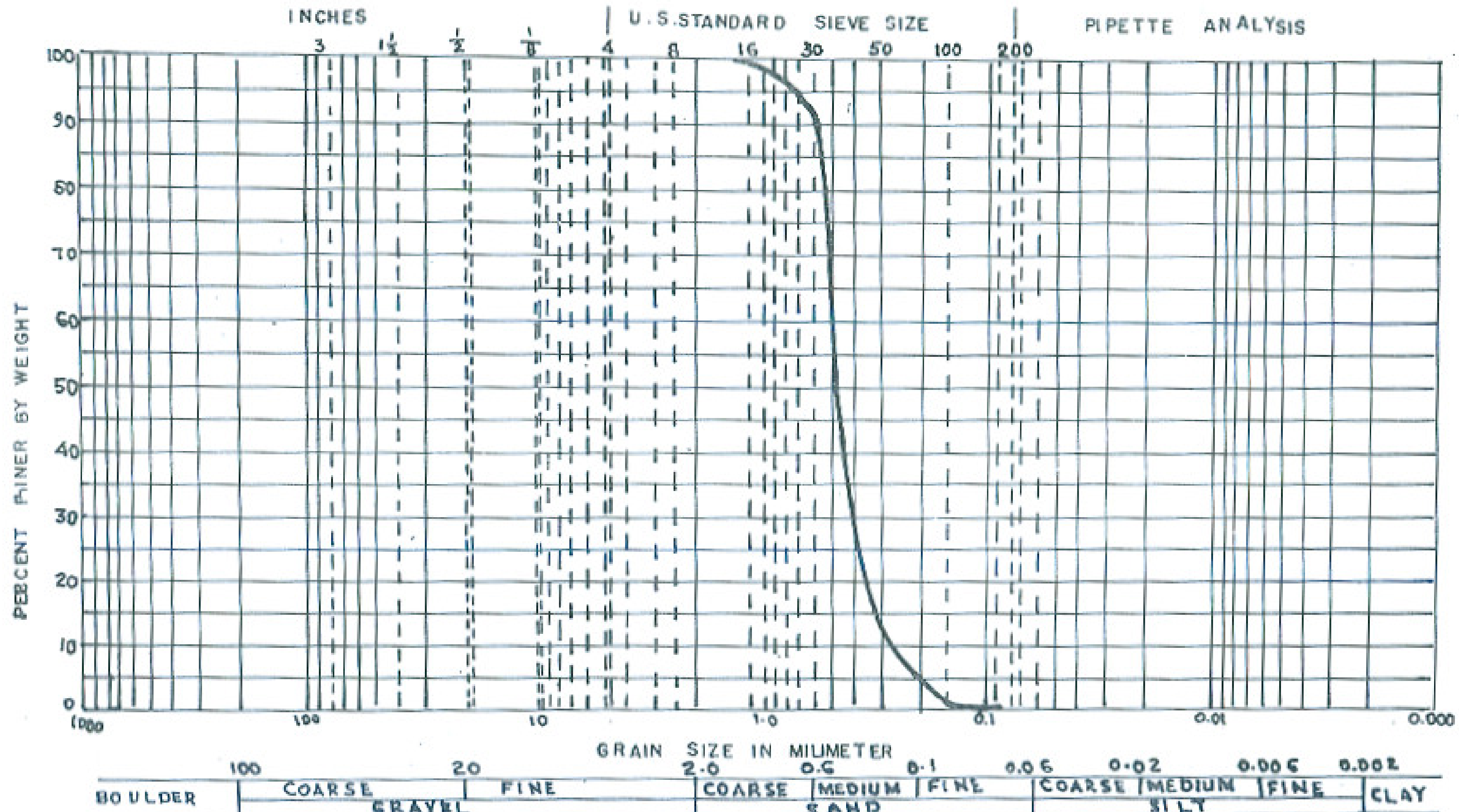


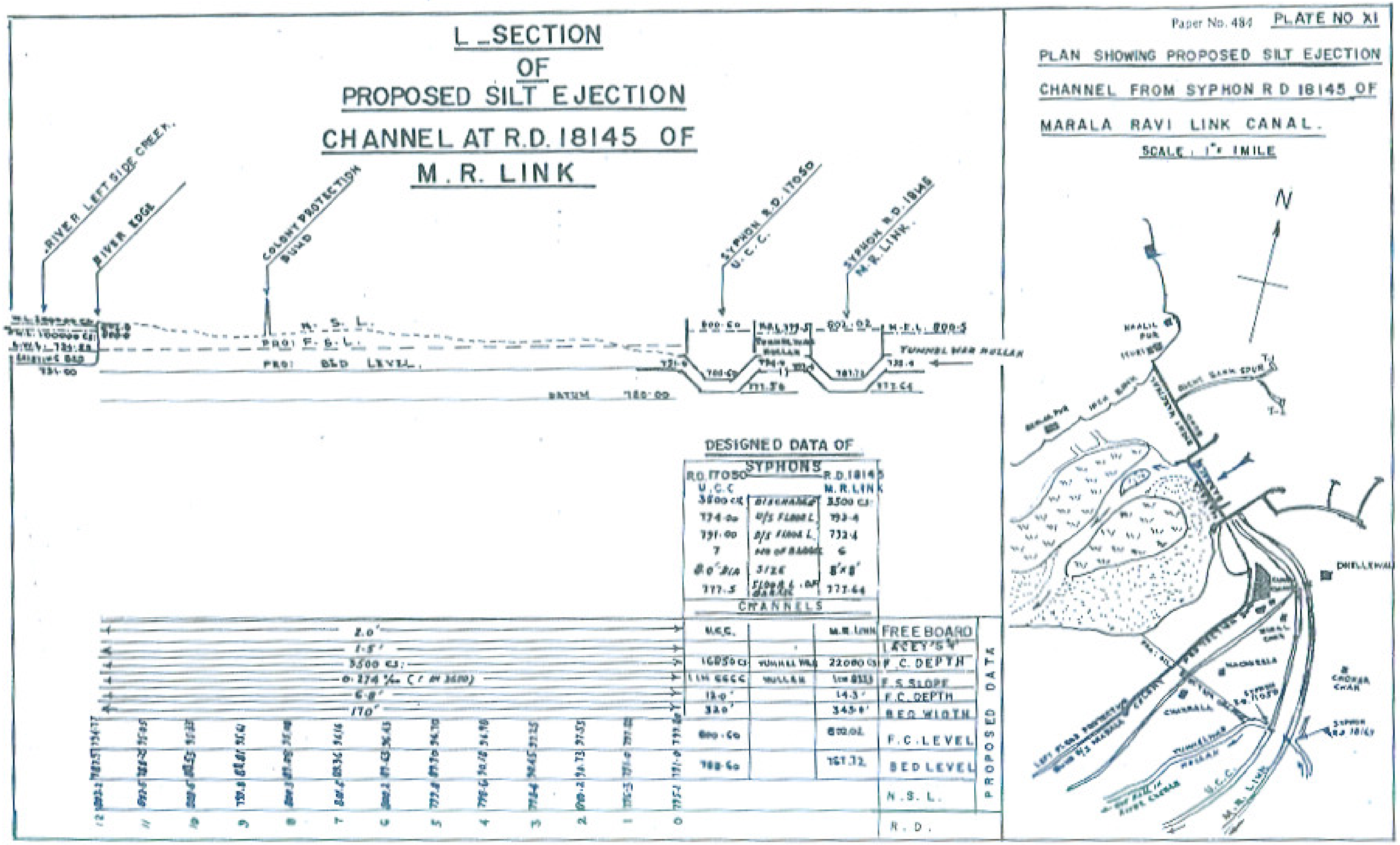
PLATE NO X

GRADATION CURVE OF M.R. LINK

R.D. 1000 _ 15000



Sample No	Elev or Depth	Classification	LEGENDS	D_{80}	D_{50}	D_{60}
AVERAGE	R.D. 1000		———		0.50	
GRADATION	TO 15000					

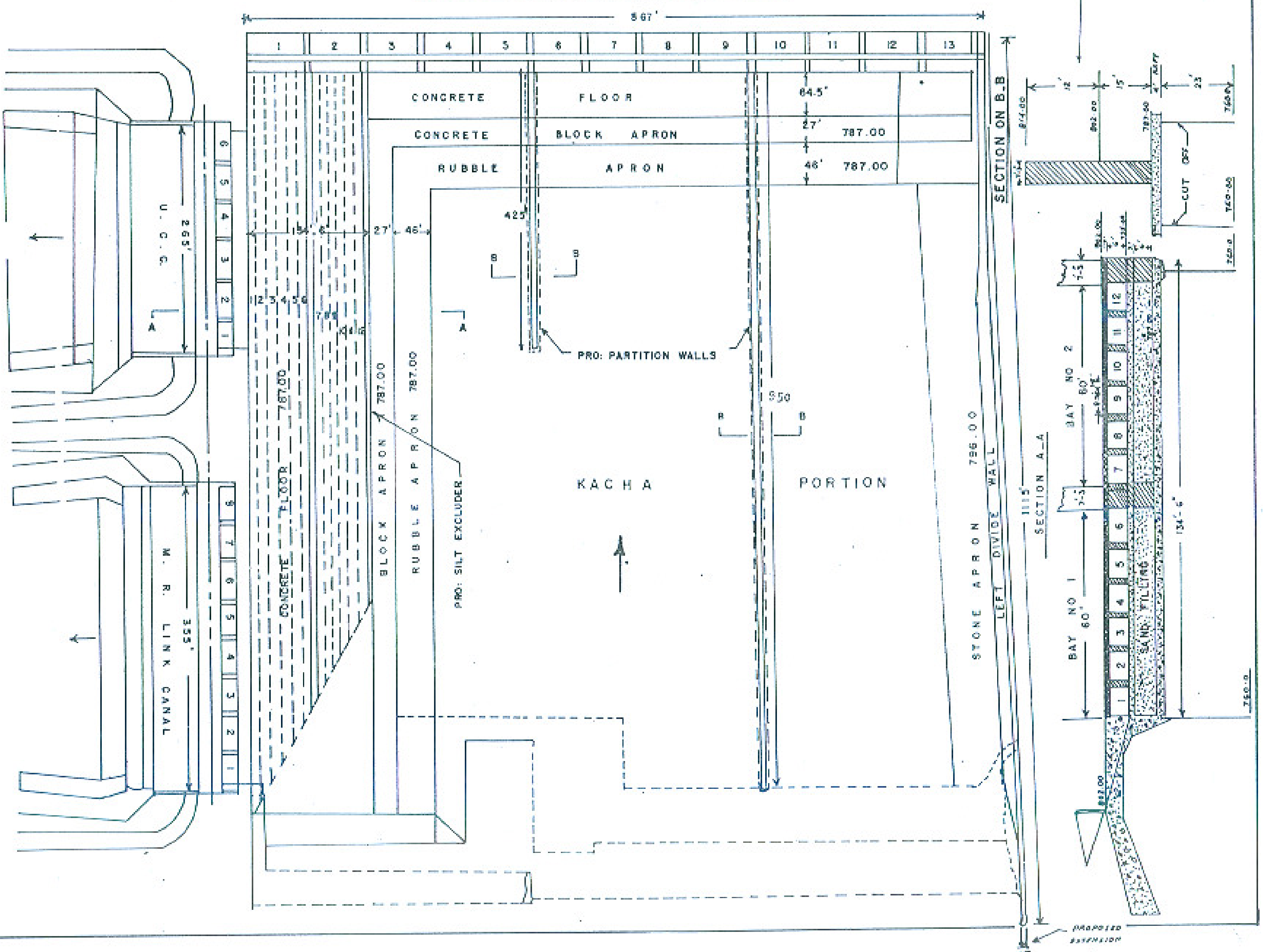

Paper No. 484
PLATE NO XI
PLAN SHOWING PROPOSED SILT EJECTION CHANNEL FROM SYPHON R D 18145 OF MARALA RAVI LINK CANAL.
SCALE : 1" = 1MILE
N
L_SECTION OF PROPOSED SILT EJECTION CHANNEL AT R.D. 18145 OF M.R. LINK
RIVER LEFT SIDE CREEK.
RIVER EDGE
COLONY PROTECTION BUND
SYPHON R.D. 17050 U.C.C.
SYPHON R.D. 18145 M.R. LINK.
N. S. L.
PRO: F. S. L.
PRO: BED LEVEL.
DATUM 780.00
TUNNEL WAR NULLAH
DESIGNED DATA OF SYPHONS
R.D. 17050 U.C.C
R.D. 18145 M.R. LINK
DISCHARGE
D/S FLOOR L.
U/S FLOOR L.
NO OF BARRELS
SIZE
CHANNELS
FREE BOARD
LACEY'S 'f'
F.C. DEPTH
F.S. SLOPE
F.C. DEPTH
BED WIDTH
F.C. LEVEL
BED LEVEL
N. S. L.
R. D.
PROPOSED DATA
2.0'
1.5'
3500 Cs.
6.8'
170'
DHILLEWALI
M.R. LINK
U.C.C.

Paper No. 484

PLAN OF LEFT POCKET OF MARLA BARRAGE

SHOWING

PROPOSED SILT EXCLUDER & PARTITION WALLS



M.R.LINK HEADREGULATOR

SHOWING

PROPOSED RAISING OF CREST & SILL GATES

PLATE NO. X[illegible]

Paper No. [illegible]

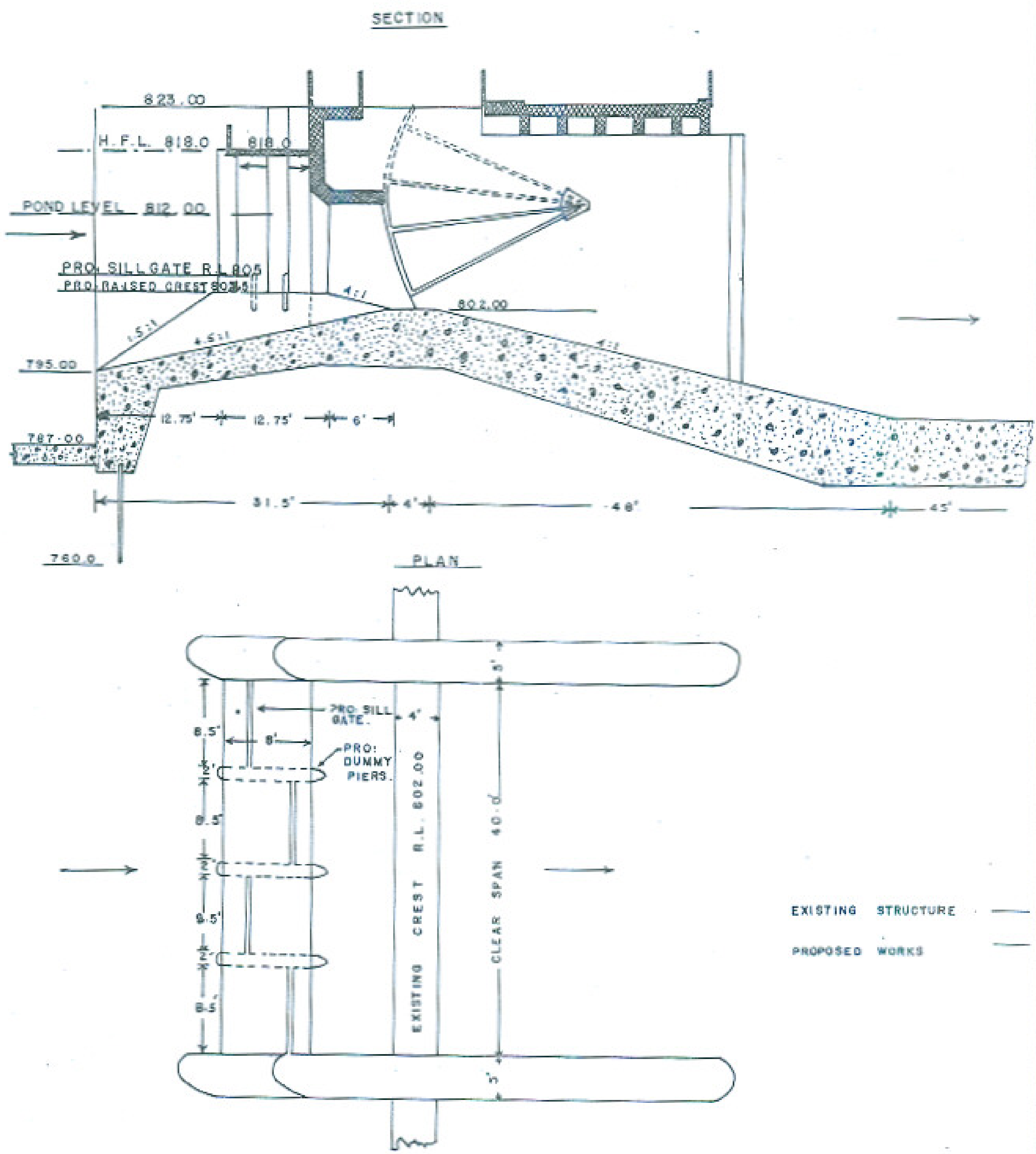


PLATE NO XIV

Paper No. 484

PRO: STONE PITCHING OF M.R.LINK

FOR TIGHTENING OF SECTION