PANJNAD HEADWORKS AFTER 1973 FLOODS

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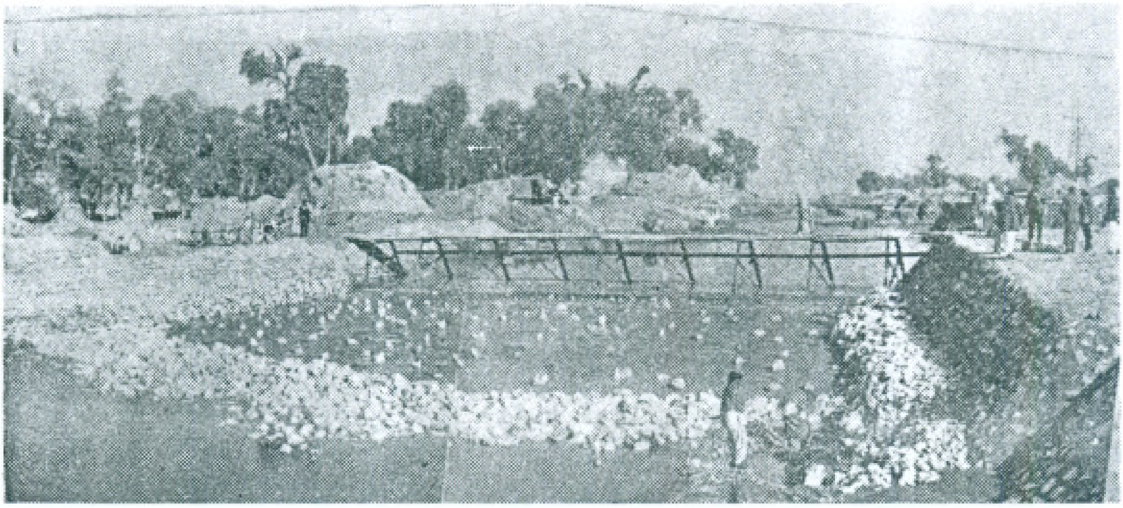
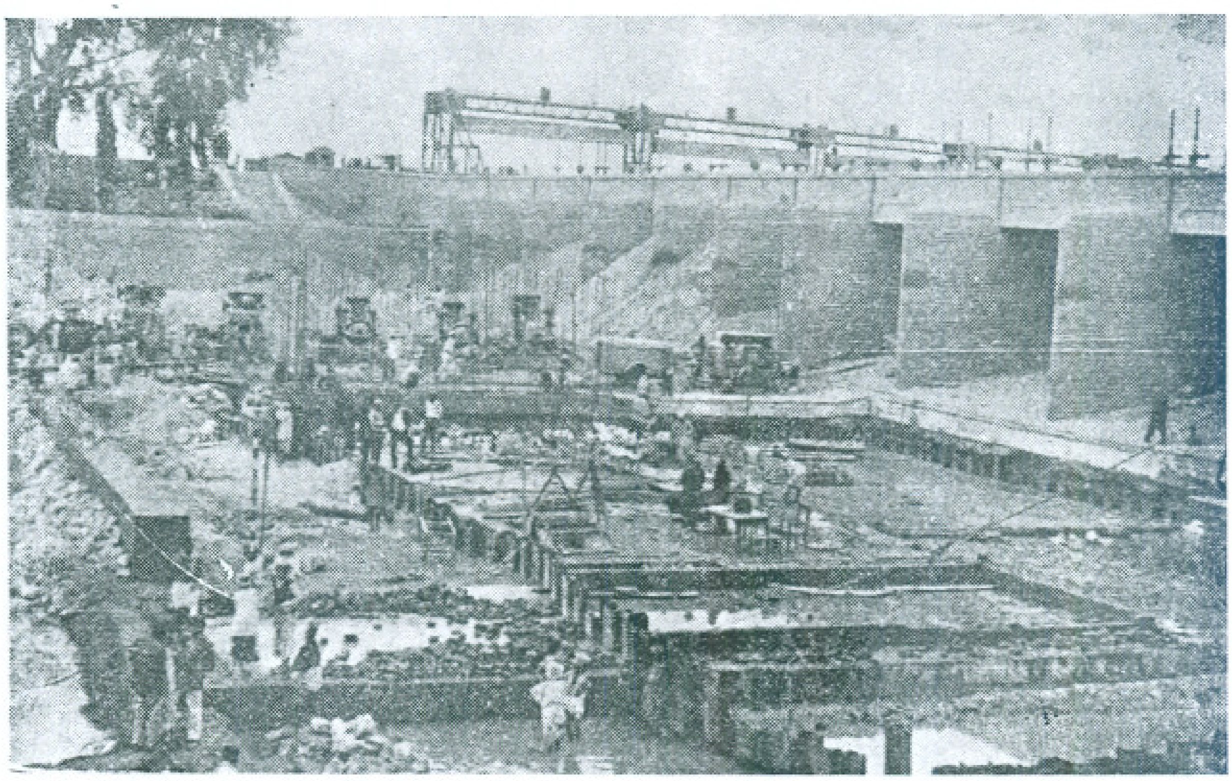


PHOTOGRAPH NO : 1

Temporary Regulator of Panjnad Canal in the Diversion Channel

PHOTOGRAPH NO : 2

Nature of damage to Panjnad and Abbasia Canal Regulators by 1973 floods



PHOTOGRAPH NO : 3

Reconstructing damaged Regulators of Panjnad and Abbasia Canals

PANJNAD HEADWORKS AFTER 1973 FLOODS

By

MR. MOHAMMAD ASLAM CHOHAN*

1.1 Panjnad Headworks below the confluence of Chenab and Sutlej rivers was constructed at a cost of about Rs. 1.93 crores in the year 1928-32. This was initially planned to have 33 bays of 60 ft. span each to cater for a flood discharge of 4,50,000 cusecs, In the year 1929 while the construction was still in progress, a higher discharge of 5,49,106 cusecs was received at the site and accordingly 14 bays of 60 ft. span each were added on the right side of the junction groyne to cater for an overall discharge of 7,00,000 cusecs. Two canals take-off from the left bank and irrigate an area of about 14.7 lacs acres in Bahawalpur and Rahimyarkhan districts. The larger canal *i.e.* Panjnad has a designed capacity of 9,567 cusecs (2832 cusecs perennial and 6735 cusecs non-perennial) while the smaller canal *i.e.* Abbasia is designed for 1,064 cusecs (426 cusecs perennial and 638 cusecs non-perennial). The weir spans are provided with framed iron-decking capable of withstanding a rolling load equivalent to class 18 loading of the army (*i.e.* 18 tons total and 7.6 tons axle load) and has 10 ft. wide road width. Provision has also been made in the foundation and piers to take a broad-guage railway line across the river whenever felt necessary. The Chenab and Sutlej rivers above the weir are contained by two marginal bunds, one on each side, to protect from flooding of the irrigated/habitated areas. The location of the headworks, Marginal Bunds and main course of the rivers as existing at the time of construction in the year 1929 and after 1973 floods is shown in Plate-1. The lay out of the headworks, typical cross-sections of the weir on the left and right sides of the junction groyne and also of the canal regulators are shown in Plate-2. The pertinent designed data of the Headworks is given in Annexure-I.

1.2 At the time of conceiving the scheme for the construction of a barrage at Panjnad, a maximum discharge of 4,06,863 cusecs had in the past passed at this site in the year 1927. A higher discharge of 5,49,106 cusecs in the year 1929, prompted a reappriasal of the whole situation and the

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scheme was accordingly revised to cater for a probable maximum discharge of 7.0 lacs cusecs. Since then discharges above 5 lacs cusecs were received only four times in the years 1950, 1955, 1957 and 1958. The highest discharge prior to 1973 was 6,76,722 cusecs in the year 1950 as would be clear from the statements of peak river discharges at Annexure-II.

2. Floods of 1973

2.1 Flood warnings at Panjnad headworks were received that river Chenab had recorded a maximum discharge of 7.70 lacs cusecs at Marala Barrage on 9th August 1973 10.10 lacs cusecs at Khanki Headworks on 10th August 1973 8.54 lacs cusecs at Qadirabad on 10th August 1973 and 6.98 lacs : cusecs at Trimmu Barrage on 13th August 1973. River Ravi was reported to be in spate recording a peak discharge of 2.5 lacs cusecs at Balloki Headworks on 10th August 1973 and 2.1 lacs cusecs at Sidhnai Barrage on 18th August 1973. Similarly maximum discharge in river Sutlej was reported to be 1.8 lacs cusecs on 15th August 1973, at Sulemanki headworks and 1.62 lacs cusecs on 18th August 1973, at Islam headworks.

2.2 The river at Panjnad headworks entered the low flood limit (above 2.0 lacs cuses) on 10th August 1973. It entered into medium flood stage (above 3.0 lacs cusecs) on 13th August 1973 and then touched the high flood limit (above 4.0 lacs cusecs) on 14th August, 1973. Thereafter the river registered a sharp rise giving a peak discharge of 8,02,516 cusecs on 17th August 1973 and finally became normal *i.e.* below 2.0 lacs cusecs on 30th August 1973. The pattern of rise and fall of the river at Panjnad Headworks and corresponding discharges at Trimmu, Islam and Sidhani headworks is shown in the hydrograph attached as Plate No : 3.

2.3 The rate of rise of water and quantum of inflow at Panjnad Headworks during the August, 1973 flood was much more than the record floolds of past years *i.e.* 1950, 1955, 1957 and 1958 as would be clear from the comparison of hydrographs shown in Plate No. 4. The inflow of water while the river remained in spate (above low flood limit) has been of the order of about 17.64 Million, acre feet as compared to 17.44, 8.25, 9.51 and 13.15 Million acre feet in the years 1950, 1955, 1957 and 1958 respectively.

2.4 The rise of flood against the marginal bunds has also been very fast as would be seen from the data given on the next page.

Paper No. 413

Statement showing High Flood levels along Marginal Bunds at Panjnad Headworks.

LOCATION		Dates	13-8-73	14-8-73	15-8-73	16-8-73	17-8-73
		Discharge	3.6	3.85	5.4	7.42	7.62
		Designed Top R.L.	Lacs cusecs	Lacs cusecs	Lacs cusecs	Lacs cusecs	Lacs cusecs
A—RIGHT MARGINAL BUND							
Overall R.D.	5	349.03	341.80	342.95	343.95	345.38	
	10	349.38	342.05	343.20	344.20	345.48	
	22	350.73	342.29	343.39	344.39	346.74	
	27	351.25	342.07	343.12	344.04	347.63	
	36	352.00	345.85	346.80	348.00	348.40	
	40	352.25	346.35	347.40	349.00	349.43	
	58	354.50	349.05	349.82	351.52	351.95	
	63	354 50	349.57	350.33	351.45	351.95	
	68	354.90	349.91	350.67	352.17	353.57	
B—LEFT MARGINAL BUND							
Overal RD	5	349.50	340.60	342.05	343.50	343.80	344.70
	10	349.80	341.20	342.70	344.00	344.50	345.30
	15	350.20	341.80	343.30	344.50	345.00	345.80
	20	350.50	342.50	343.90	345.00	345.50	346.25
	25	350.70	343.10	344.50	345.40	345.80	346.70
	31	351.10	345.00	345.55	346.30	346.60	347.70

The abrupt rise of water caused numerous leakages in the unsoaked height of the bund and consequently the Right Marginal Bund breached at two points on 15-8-73 evening when the effect of about 7 lacs cusecs was causing pressure against the embankment. Inspite of these breaches, the situation continued to worsen and ultimately the Left Marginal Bund also gave way at ten places between the night of 16 and 17-8-73 when a peak discharge of 7,62,516 cusecs was passing through the barrage. The detail of breaches in the marginal bunds is given in the Plate No : 1. It is estimated that a maximum discharge of abut 33000 cusecs and 1,70,000 cusecs passed through the breaches in the right and left marginal bunds respectively. Out of this an overall discharge of about 40,000 cusecs may be termed as the river component and the balance from the reservoir storage. The total river discharge of 8,02,516 cusecs at Panjnad thus surpassed the previous record flood of 1950 by over 1,26,000 cusecs.

2.5 Almost throughout the long duration of peak flood in the range of 4 to 8 lacs cusecs, strong wind storm continued to blow. This kept on damaging the upstream slope of the bunds by wave wash. The windstorm had a pronounced shaking action on the big trees grown on the slopes which tended to loosen the earth and cause cracks in the earthen embankments. There was also intermittent heavy rain (recording 1.60″+2.65″+2.90″+0.20″=7.35″ rain fall) in the peak flood days from 14.8.73 to 17.8.73. This developed deep rain cuts, made the banks slippery, seriously hampered the mobility of labour, materials, machinery etc. and thus jeoparadized the watching operations at the critical juncture. Under these circumstances when the flood discharge and high flood levels had far exceeded the designed limits and other calamities of nature like heavy rain-fall and strong wind-storm were causing serious damage, the embankments simply could not stand the pressure of all the damaging forces acting jointly. The breaches thus appeared unavoidable, beyond the control of human efforts and can rightly be termed as a natural calamity.

3. Flood Damages

3.1 The water from the breaches in the right marginal bund travelled to the old course of the river and joined the main-stream at a short distance below of the barrage. The damage on this side was not very significant except severing of the National Highway between mile stones 521/2 to 522/0, which too could be averted had there been a road bridge or a cause-way for the passage of the water at the site of natural depression.

3.2 Flood water passing from the breaches in the Left Marginal Bund shattered the canal railway line (connecting Deranawabsahib with the Headworks), caused serious damage to Uch Sharif township, breached/overtopped Abbasia Canal and adopted the route along Turakari depression (old river bed). After damaging all the obstructions on the way, the water started heading up against Minchin Branch. To relieve pressure against this canal and to save Khanpur town, efforts were made to push water towards Cholistan by making numerons cuts in the railway track and Abbasia feeder etc. Inspite of many relief cuts the flood water kept on rising swiftly and ultimately overtopped Minchin Branch, Abehayat and Shirin Distributaries which provided protection to Khanpur town. After inundating Khanpur, the flood water started flowing towards Rahimyarkhan side. To avert danger to this important city, more cuts were made in the railway line, Tarinda Disty, Sadiq Branch and other small channels which successfully diverted the water into comparatively less developed areas. With the spread of water in the vast zone and reduction of flow from the breaches, the flood water lost its furiousness in a few days and eventually stopped flowing near the border of Sind province.

3.3 The abnormal rise of river level on the down-stream of heaworks, breached/overtopped the Minchin Bund running parallel and close to the left bank of the river, This inundated a sizeable area on the right side of Panjnad canal upto Malkani escape.

3.4 The flood water passing through the breaches in the Left Marginal Bund entered into Abbasia Canal after breaching its left bank at RD 5 and 8. A part of the flood water started gushing in the reverse direction i.e. towards the head-regulators. On noticing this phenomena, the gates of Abbasia Canal head-regulator were opened to push away the back flow, but the flood water kept on rising rapidly and ultimately overtopped the divide wall separating the Abbasia and Fanjnad head-regulators. Due to excessive head across, the wall collapsed and enormous quantity of water began to flow into the low level Panjnad Canal by taking a sharp hair pin U-turn. This pattern of flow caused severe swirling action and deep scour as a result of which the entire downstream floor of the Abbasia regulator and bays No : 9 to 12 of the Panjnad regulator broke down, settled and got damaged seriously. There was also an imminent danger of a complete collapse of the regulators but the situation somehow remained under control by opening the gates of the two regulators and by dumping stone round the clock for many days.

3.5 It is estimated that a flood discharge of about 6000 cusecs (against channel capacity of 1064 cusecs) flowed in Abbasia canal towards the regulators. With the opening of regulator gates necessitated for pushing away the back flow, a total discharge of about 15000 cusecs is estimated to have passed into Panjnad Canal against its designed capacity of 9567 cusecs. Such an excessive flow was liable to shatter the masonary works of the entire canal system. The relief cuts in the right bank were rather liable to aggravate the condition due to higher water level in the river. To overcome this ugly situation, relief cuts were made in the left bank of the canal at RD 55 and 75. This gave a substantial relief and averted damage to the massonry works of the canal system lower down. The discharge from these cuts again joined the main flow of breaches in the Turakari depression as per para 3.2 above.

3.6 The area ffooded by the water flowing through the breaches in the Marginal/Flood Bunds at Punjnad and the route edopted by the same is shown in the Plate No. 5. The area flooded is estimated to be about 5.5 lac acres, Apart from human sufferings, creation of manifold socio-economic problems and set back to national economy, the damage to the crops, built up property, irrigation system, roads, railway links, telephone telegraph lines etc. was immense and ran into crores of rupees.

4. Causes of Damage

4.1 There have been extensive and wide spread loss of public and private property due to damages at Panjnad Headworks. It would, therefore, be worthwhile to list out major causes of these damages so that in the light of this experience suitable remedial/protective measures can be devised in the due course to check re-occurance of such a catastrophe in future, as far as possible. Major causes of the damage in the opinion of the author are given in the following paragraphs :—

4.2 An overall discharge of 8,02,516 cusecs as experienced at Panjnad between the night of 16 and 17 August, 1973 is far in excess of the designed capacity of the Barrage which is 7 lacs cusecs. With all gates open and by the passage of 7,62,516 cusecs across the weir, the levels attained upstream and dpwnstream were much in excess of the designed afflux level of 341.5 and 338.5 respectively. Maximum guages attained are given below :—

Weir Bays		Upstream Guage		Downstream Guage
Left Flank	R.L.	341.0	R.L.	340.30
Bay No. 4	,,	341.20	,,	340.30
Bay No. 5	,,	342.05	,,	340.35
Bay No. 33	,,	343.05	,,	340.50
Bay No. 34	,,	340.95	,,	340.50
Right Flank	,,	341.05	,,	340.50

This naturally subjected the structure to the conditions to which it was not expected to cater for. Since the possibility of receiving a similar high flood (or even slightly greater) cannot be ruled out, it is desireable to provide additional water-way at this barrage for safe passage of the floods in future.

4.3 For the last many years due to dry cycle in the country and by the construction of Dams upland (Mangla in Jhelum and Bhakra on Beas river), there have not been very significant flows in the river channels. This has resulted in general accretion of the river beds as a consequence of which higher flood levels are being attained corresponding to same discharges in the preceeding years as would be clear from the following Table :—

Discharge	Flood levels on the Downstream of Panjnad Headworks					
		Year 1950		Year 1957		Year 1973
2 Lac cusecs	R.L.	334.1	R.L.	333.6	R.L.	336.7
3 Lac cusecs	,,	335.8	,,	335,6	,,	337.6
4 Lac cusecs	,,	337.3	,,	336.4	,,	338.4
5 Lac cusecs	,,	338.1	,,	337.1	,,	339.2
5.5 Lac cusecs	,,	338.6	,,	337.9	,,	339.4
6.0 Lac cusecs	,,	339.1		—	,,	339.5
6.77 Lac cusecs	,,	339.8		—	,,	339.75
7.00 Lac cusecs		—		—	,,	339.9
7.62 Lac cusecs		—		—	,,	340.3

The attainment of higher water levels on the downstream adversely affected the modularity of the Annexe weir (Bays 34 to 47) and the same only passed a discharge of about 1,63,000 Cs ;against its designed capacity of 2,50,000 causecs.

4.4 The confluence point of Sutlej and Chenab rivers has in the course of time shifted close to the left guide bank at a short distance of about 2000 ft. upstream of the weir line. The Chenab river which is bigger in size and also more active has formed a deep embayment behind the right guide bank and sweeps the main flow on to the left side of weir axis while approaching the headworks. This approach has a tendency to throw silt on the inside of the river bend in front of the right half of the barrage. This creates difficulty in maintaining an active channel on the right side which in turn curtails the discharging capacity of the annexe weir. As stated earlier, the annexe weir passed a maximum discharge of 1,63,000 cusecs only while the original weir (bays 1-33) caternd for 5,99,512 cusecs *i.e.* 1,49,512 cusecs more than its designed capacity. Had the approach of river been favourable in the entire width of the barrage, the annexe weir would also have taken its proportionate share of discharge and in that event, may be the flood heights against the embankments would have reduced slightly. This situation calls for devising ways and means to fully activate annexe weir *i.e.* Bays 34 to 47 of the Barrage.

4.5 The approach of river Sutlej and Chenab to the headworks has been undergoing a change from year to year. As the river tended to approach near any flood embankment, the practice has been to construct retired bunds and not to attempt checking the river swings beyond certain limits. In the year 1959, river Sutlej took a deep embayment behind Left Guide Bank. The nose came under active attack and a portion of the same got washed away. The same pattern of flow (rather worse) has now been adopted by Chenab river behind the Right Guide Bank. These changes have not tnken place overnight, but came into being through many years. The dangerous and adverse approach of the Chenab River is not only posing threat of out-flanking the barrage or attacking the Right Guide Bank nose, but the same is also progressively masking a portion, of the barrage to the detriment of its discharging capacity. In addition, the sharp bends of river close to the flood embankment, causes the flood water to rise in a particular zone, which during high floods threaten their safety. The breach of Left Marginal Bund in August 1973 in the reach of Uch Diversion (between RD 31-34) seems to be on account of sharp bend of Sutlej river in this zone. Likewise the close proximity of Chenab river loop would have caused a breach in the reach RD 4-9 Right Marginal Bund, but the situation seems to have remained under control due to existance of metalled road embankment forming a wide pushta on its back. The need of constructing river training works is, therefore, of paramount importance for the safety of the barrage as well as the marginal bunds.

4.6 The marginal bunds and the numerous retirements were constructed from time to time in a customary manner by donkeys and manual labour without resorting to compaction. The bunds were last designed on the high flood levels of 1950 and 1955 by maintaining 5 ft. free-board and a uniform slope of 3 : 1 on the upstrem and 2 : 1 on the land side without any consideration of the hydraulic gradient line suited for the type of soil. The top-width of the main bunds was adopted as 20 ft. while in case of retired embankments it ranged from 12 ft. to 15 ft. On severing of the main bunds by the river action, the retired embankments were seldom widened or strengthened.

The embankments designed and constructed in the aforesaid manner are more prone to damages in the floods by settlement, cracking and other weaknesses like clods, holes of burrowing animals, roots of plantation etc. Evidence has shown that leakages in the marginal bunds started appearing as soon as flood discharge of about 5 Lac causecs started exerting pressure on the embankments. The rise of flood water against the marginal bunds in the year 1973 has been far in excess over the years 1950 and 1955 on the basis of which these embankments had been designed (Refer statement of para 2.4). The perusal of this statement shall also reveal that the rate of rise of water against the bunds was very fast and extremely dangerous particularly when these works remained dry and unsoaked for about a decade. The design and quality of the marginal bunds, therefore, needs to be improved considerably to ensure their reliability against future floods.

4.7 Almost throughout the long duration of peak flood in the range of 4 lacs to 8 lacs cusecs, there has been constant blowing of severe wind storm causing voilent wave wash action on the bunds. This action was unique of its type as the wind storm made the broad sheet of ravaging flood water to rise and hit the unprotected slopes of the banks with effective slashing power. Most of the watching establishment had thus to be kept engaged on the continuous operation of providing bushings all along the slopes being erroded by the wave wash.

Another detrimental effect of the wind storm was that it had pronounced shaking action on the big trees grown on the slopes which loosened the earth of bank near their trunk zone and developed radial cracks. This progressively made the bank weaker and easily susceptible to leakages.

4.8 The action of the wind storm/wave wash as explained at para 4.7 above was further agravated due to intermittent heavy rainpours on the banks. The rains not only started developing deep gharas but it also created difficulty (particulary in the darkness at night) to distinguish between a leakage through the bund or rain water flowing along the slopes. The rains made the banks slippery and rendered watching operations much more difficult as the mobility of labour, materials and machinery had been badly thwarted.

5. **Protective Measures**

5.1 The unprecedented high flood of August 1973, made numerous breaches in the marginal bunds and caused large scale devastation in the thickly populated area. To avoid repetition of such catastrophe, it is essential to devise ways and means of improving the existing works and also incorporate additional protective measures for reliability against future floods. An outline of these works as considered appropriate by the author (during his short stay at Panjnad) is given in the paragraphs to follow :

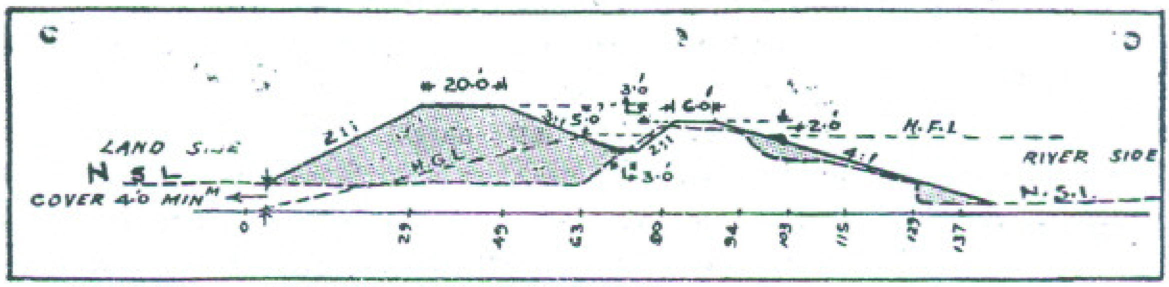
5.2. Marginal Bunds

5.21 As stated earlier the existing bunds are weak and have numerous inherant flaws in them. Full reliance on these bunds cannot, therefore, be placed in whatever manner their sections are modified in the customary manner of raising and strengthening. The design and quality of marginal bunds, therefore, need improvement on a scientific basis. Such embankments in case of Indus Basin works were constructed of graded material fully compacted at optimum moisture contents and these exhibited much more reliability in the recent floods.

5.22 The marginal bunds remain dry for about 10 months of the year as a result of which cracks develope by shrinkage of earth. This phenomena is particularly marked in soils containing clay or Kallar as major ingredients. Such soils, therefore, prove very treacherous when the water touches them and are prone to leakages more easily. To safeguard against this dangerous behaviour, the practice in Sind Province is to have wetting channels along the upstream slopes. These channels are filled with water and the main embankments are soaked properly upto the anticipated levels in advance of the flood season. The embankments are in this way artificially put to test for detection of possible weak spots and to facilitate the timely repairs.

5.23 The practice of providing side slopes arbitrarily at 3 : 1 on the upstream and 2 : 1 on the downstream has no scientific basis. These slopes should vary with the type of soil, height of embankments and the importance of the site in regards to its being vulnerable etc. The section of the bund should have stable slopes and be adequate to fully cover the hydraulic gradient line established for the particular soil.

5.24 All thsese issues were thoroughly examined by a Board of Chief Engineers Irrigation and it was decided that as far as possible the existing bunds having numerous weaknesses and being unreliable be made use of as a part of wetting channel and the main embankments should be constructed afresh on the land side by fully compacting the earth at optimum moisture contents. It was also decided that the new embankments should have 20 ft. top width, 5 ft. free-board above the high flood levels observed in 1973 and that the hydraulic gradient as appropriate for the type of soil be provided as earth cover of atleast 4 ft. The theoretical location of the wetting channel within the existing bund and the proposed section of the new bunds is shown on the typical cross-section below:—



NOTATION:- NEW WORK IS SHOWN SHADED

5.25. The scheme of work outlined in Para 5.24 above has been cleared by the Punjab Flood Commission. The work has also been taken in hand on these lines by deploying earthmoving machinery as much as could be made available. The quantum of work is very large and the whole scheme may be completed by May 1975. Soil samples have been sent to the Irrigation Research Institute for establishing the Hydraulic Gradients and on receipt of the results, if requred, the land side slopes shall be suitably modified.

5.3 **Second Defence Bund**

5.31 The left marginal bund at Panjnad provides protection to a vast area including rail, road, gas, power and telecommunication network connecting Karachi with the capital of the country. The area of Bahawalpur and Rahimyarkhan districts getting protection behind this bund is fully developed by the Abbasia and Panjnad Canal Systems. Before the development of Sutlej Valley and construction of barrages on this system, the river Sutlej at some stage used to flow in the depression namely Turakari. This depression starts from Panjnad and goes upto Sadiqabad via Uchsharif, Chanigoth, Liaqatpur, Khanpur and Rahimyarkhan. The alignment of Left Marginal Bund plugs the mouth of Turakari depression and as such any mishap in this bund is liable to shatter the entire economy of the country apart from repeating a calamity of the type encountered in the year 1973. The safety of this bund is, therefore, of vital importance and needs to be ensured at all costs.

5.32 The existing marginal bund is being raised and strengthened as discussed in para 5.2 above, but its complete reliability cannot be guaranteed in view of the numerous weaknesses discussed earlier.

In addition this bund is full of old plantation, and in case wind storm again coincides with the stage of high floods, development of leakages from the roots can take place and thwart all hopes of its safety. As the stakes involved are very large, the arrangements of protection on the left side should be more secure. It is, therefore, suggested that a second defence bund behind the left marginal bund be constructed at the earliest so that in the event of a mishap in the first bund, the second defence can hold the flood water. The proposed bund is estimated to cost about Rs. 2.0 crores which is very insignificant when compared with the losses encountered in the year 1973.

5.33 The tentative alignment of the second defence bund is shown in the Plate No. 6. The design of this bund should be similar to the original bund *i.e.* it should have adequate free board, slopes, wetting channel and be fully compacted. The area between the two embankments be suitably divided into compartments by providing cross bunds, because the high flood levels towards the tail side are sufficiently higher and in case of breach in the original bund, the flood water is otherwise liable to overtop the defence bund due to pocketing effect.

5.4 **Additional Waterway**

5.41 The high flood of August 1973 was far in excess of the designed capacity of the barrage. Unless adequate water-way is provided, higher discharges shall continue to pose threat on the safety of this vital structure and its allied works.

5.42 An accurate record of flood discharges at Panjnad is known for the last 52 years *i.e.* from 1922 to 1973. Probability curve of the peak discharges in this period is drawn on Log Log scale at Plate No. 7. It shall be seen that the discharge of about 10 Lac cusecs has probability occurance of 0.75 %, 9 lac cusecs 1.00 % and 8.5 lac cusecs 1.50 %. The barrage and irrigation system is to have a perpetual life and, therefore, it would be advisable to design works for a probability of atleast 100 years which gives a discharge of 9 Lac cusecs approximately. The additional water to be catered for, thus works out to about 2 Lac cusecs.

5.43 The extension of the barrage on the left side is not possible due to existance of canal regulators at this end. The extension on the right side shall entail construction of about 11 more bays which for purpose of study may be named as Second Annexe. The arrangements to incorporate this provision shall entail dismantling of existing right guide bank on the upstream side beyond about 1000 ft. from the weir line, stone protection of its side towards the 2nd annexe and new construction of the Right Guide Bank at the modified location. This scheme shall be extremely costly and may at the same time give no relief in case its approach is also masked by an adverse river entry as presently existing at site. The unsatisfactory function of the existing annexe and difficulties being experienced for the last many years to keep the same in modular operatable condition do not justify the consideration for the construction of a second annexe weir.

5.44 The only alternative, therefore, appeares to construct a spillway regulator at a location best suited for consideration of river approach and disposal of the flood water. Perusal of Index Plan at plate No. 1 would show that a depression continues to exist at the old course of river (prior to the construction of the barrage) in the reach RD 5—9 Right Marginal Bund. The flow of water from the breaches in the Right Marginal Bund in August, 1973 also joined this depression before out-falling back into the river on downstream of the barrage. In order to confine water within the old established route and to minimise inundation of the surrounding area, the most appropriate site for the location of spillway regulator appears to be between RD 5—9 Right Marginal Bund at a precise location to be determined by model studies.

5.45 Whereas the precise layout and design of the spillway regulator can only be settled after detailed analysis and model studies, the tentative arrangements and typical cross-section can roughly be as shown in Plate No. 8 with salient features as under :—

(*i*) High Flood Level	= R.L. 345.5 (As observed in August 1973)
(*ii*) Crest Level	= R.L. 330.0
(*iii*) Upstream Floor Level	= R.L. 325.0
(*iv*) Downstream Floor Level	= R.L. 320.0
(*v*) Discharge	=2,00,000 cusecs
(*vi*) Waterway required	$=2.67\ Q^{\frac{1}{2}} = 1190$ ft.
(*vii*) Waterway suggested :	
(*a*) Clear	=1080 ft. (*i.e.* 18 bays each of 60 ft. span)
(*b*) Overall	=1199 ft. (with 17 piers of 7 ft. width each)

Since the passage of flood water will cut across the National Highway, decking will also be required over the spillway regulator to maintain uninterupted flow of road traffic.

5.5. Extension of Junction Groyne

5.51. The approach to the Headworks is determined by the point of confluence of rivers Sutlej and Chenab above the weir and their relative quantum of flow at different stages of floods. Prior to 1955, for many years, the approach to the Headworks was nearly straight as the confluence of the two rivers was fairly upstream and the combined river flowed straight towards the weir. In 1955 just below the confluence (about 2 miles upstream of the weir), two channels emerged. The left channel being major and more active approached in a smooth curve and impunged on the barrage about bays 5-25. The right bank channel was the lesser arm of the river. It had a curved alignment and fed annexe weir as well as bays 26-33. In the last flood of the season in October, 1955, the Sutlej made a large contribution of 3,24,000 cusecs to the total discharge of 5,50,000 cusecs and this made right arm more active and major in size. The island between the two arms also developed in size towards right and sharpened the curvature before approaching the weir.

5.52. In the year 1956, the right arm erroded its right bank and made an oblique approach to the barrage causing siltation along the Right Guide Bank. Progressively the entry of the annexe was masked and a narrow gullet along the junction groyne nose was left for the passage of water on to bays 34-47. The pattern of flow was that the main current approached bays 25-28, developed parallel flow along bays 29-30, made swirling action opposite bays 31-33 and then entered the annexe weir through a narrow gullet. An attempt to keep the annexe weir more active in 1956 caused enormous scours as a result of which :—

(*a*) the upstream pervious and impervious floor settled in bays 24 to 29.

(*b*) Wells under the upstream noses of piers 25 to 27 tilted/settled and got cracked.

(*c*) The sub-strata scooped out into the scour pit and resulted in formation of cavities under the upstream and downstream glacis of bays 25 to 27.

These damages seriously shattered reliance on the structure and had to be set right in a tight schedule at an enormous cost.

5.53. The design of a twin barrage is usually prone to develope shoaling across the entry to the subsidiary weir and also form gullet or deep channel alongside the junction groyne. The short length of the junction groyne (300 ft. from the gate line) fails to keep the swirls sufficiently upstream of the main barrage and in case no remedial measures are devised, a slight error in regulation can again cause enormous damage to the weir.

5.54. While analysing the reasons for the damage to Panjnad Headworks in the year 1956, Sir Thomas Foy (an eminent irrigation engineer of Indo-Pak sub-continent) put forth the idea of extending the junction groyne. He tentatively suggested extension in a length of 200 ft. (*i.e.* overal 500 ft.) and also recommended that model studies be carried out to decide the precise lay-out and design. Model studies were thereupon conducted by the Irrigation Research Institute and in the year 1960, (Technical report No. 255/Hyd/1960) it was held that "divide groyne when extended in a length of 1000 ft. is advantageous in shifting the scour from the vicinity of upstream weir floor to a point sufficiently away, but to obtain better distribution of flow and to avoid undue over-straining of the central bays and to minimise the recurring expenditure on replanishment of aprons by scour, it is imperative that the approach to the weir be also corrected."

5.55. In absence of a clear cut recommendation and the Research Institute having linked up the issue for extension of the junction groyne with the river approach conditions, the implementation of the scheme in piece-meal do not seem to have been considered appropriate. The attention then remain focused on finding a solution to correct the river appoach. In the year 1970 (Tech. Report No. 650/Hyd/1970) the Research Institute came out with a very ambitious plan of constructing two 'Y'-shaped spurs (to be discussed later) which in those days entailed an expenditure of Rs. 80 lacs approximately. The entire scheme, therefore, remained shelved primarily on account of excessive cost and no positive steps seem to have been taken in evolving a workable solution.

5.56. A cursory glance at the course of Chenab river (Plate No. 1) would reveal, that the approach conditions are extremely dangerous to the weir and is also putting a great strain on the discharging capacity. Visualizing the gravity of the situation, the matter has again been referred to Reseasch Institute for conducting model studies for the set of river conditions now existing at site and finally advise in the matter. Their original recommendation in respect of junction groyne is, however, expected to undergo no significant change as the optimum extension to 1000 ft. is even held by them to match the approach conditions obtaining in the year 1968. The proposed geometry of the divide groyne is shown in Plate No. 9 which subject to further modifications as necessitated by the Model studies is recommended for implementation as early as possible.

5.6. Correcting River Approach

5.61. To check the tendency of excessive shoal formation within the guide banks, to avoid development of scour holes in the vicinity of weir structure and to minimise the pressure on the marginal bunds it is essential to maintain approach of the river within certain extreme limits. Unluckily no river training works have ever been constructed at Punjnad. Whenever threat to a particular flood embankment was posed, the past practice has been to construct retired embankments and allow the river to meander as suitable for its curvatures. This is surely not a scientific way of dealing with the problem. The Index Plan at Plate No. 1 would show that a large number of retired bunds have in the past been constructed, thereby gradually exposing more and more area to river spills and flood ravages.

5.62. The river has also been taking extremely dangerous loops very close to the structure. The deep embayment on the left side in the year 1959 washed away a portion of the left guide bank nose and it had to be reconstructed in a comparatively shorter length at a huge cost. Even a more grave situation has now been created by a deep swing of Chenab River behind the Right Guide Bank. There is every possibility of an attack on the Right Marginal Bund in the reach where there is no scope of constructing even a retired embankment (i.e. RD 4-10). Apart from anticipating an attack on the Right Guide Bank nose, the possibility of outflanking the barrage in the coming floods cannot be ruled out. Panjnad Headworks is thus exposed to grave risks on account of unfavourable river approach conditions and the problem needs to be tackled on warfooting basis,

5.63. As stated in para 5.55 above, model studies were carried out by the Irrigation Research Institute and in the year 1970, they proposed two Y shanks of the spurs as per location marked on Plate 6. The shanks of the spurs cut across the main river course. These shanks can thus only be constructed by first diverting the flow of Chenab on to Sutlej after excavating a long and deep leading cut (length about 4700 ft.) coupled with a cross bund (length about 1500 ft.) to block the passage of water. As is well known, Chenab river is more active, bigger in size and its bed is sufficiently lower than the Sutlej arm. The excavation of deep leading cut within the pond effect and close to the Barrage is an uphill task and cannot be accomplished without resorting to huge pumping and deployment of a big fleet of earth-moving machinery. In addition, due to the peculiar location of the leading cut within the two arms of Sutlej and Chenab rivers, the transportation of heavy machinery to the site of work across the river and on a slushy/boggy area shall be full of risks and extremely difficult. The earthwork of leading cut alone is of the order of about 80 lac cft. Even if the hazards of a winter freshet are eliminated, the tight working season from December-March makes the scheme very difficult to accomplish.

Assuming that the diversion channel can some-how be excavated, the earthwork for the corss-bund and the two shanks is of the order of 25 and 300 lac cft. This much work again in a period of 4 to 5 months cannot be done in the normal conditions unless the Government makes a special arrangement to provide a large fleet of earthmoving unit.

5.64 The construction of armoured noses of the two spurs require about 30 lac cft. stone. The peculiar location of the spurs across the main river course shall bring these works under active and severe attack during the floods and an additional quantity of about 5 lac. cft. stone shall have to be kept reserve at site to avert any untoward development. If the quantity of stone for the extension of junction groyne i.e. about 10 lac. cft. is also added, then overall requirement of stone for execution of the entire river training scheme at Panjnad works out to about 45 lacs cft. The established sources for the supply of stone are only Sikhawala Quarry and Rohri. These sites meet the demand of stone for all the irrigation works and their capacity of manufacture is also limited. The haulage of such an enormous quantity of stone over the long distances by rail/road is by no means an easy job and may not be possible to arrange in a single working season.

The proposal of Irrigation Research Institute to construct two massive Y-shapped spurs coupled with major diversion arrangement cannot, therefore, be termed a practical solution and needs to be thrashed out in more detail to make the scheme workable and to be constructed in stages over a period of two to three years.

6-REPAIRS TO THE DAMAGED REGULATORS OF PANJNAD AND ABBASIA CANALS

6.1 Extent of Damage

6.11 After having discussed the salient features of the Headworks and making an attempt to find a solution of the burning issues, it would be of interest to briefly narrate here the manner in which an intricate job of repairing the damaged canal head regulators was planned and executed. As already stated in Para 3.4, the Abbasia and Panjnad Canal Head Regulators got seriously damaged by the back flow of flood water in the Abbasia Canal. The extent of damage shown in Plate No. 10 and 11 is listed hereunder :—

(*a*) The divide wall segregating the Abbasia and Panjnad regulators collapsed in the portion which was not resting on well foundation. This part broke into pieces and got settled in the deep scour holes. The well on the downstream end of the divide wall settled and cracked. This caused the balance portion of the divide wall also to tilt and crack at a number of places (See photograph No. 2).

(*b*) All the floor of Abbasia Regulator downstream of glacis whether pervious or constructed in solid concrete collapsed. Whereas the pervious portion was settled deep into the scour pit, the concrete floor got badly cracked/tilted and also launched.

(*c*) The Glacis of Abbasia Regulator developed wide radial cracks extending from about the middle of the bays (in alignment with the pier nose) upto the flanks in width of about 5 ft.

(*d*) The sub-strata below the glacis of the Abbasia Regulator got scooped out and was washed away in a distance of about 5 ft. to 10 ft. from the pier nose. The effect had gone as far as to make the brick masonry of the foundation well on the downstream side of pier clearly visible.

(*e*) A major portion of the left flank wall of Abbasia Regulator collapsed. The foundation block of the balance portion also got settled/tilted and wide cracks developed into it upto the abutment.

(*f*) The pervious and impervious floor of bays No. 9 to 12 Panjnad Regulator on the downstream of glacis portion collapsed. Whereas the pervious portion got settled deep into the scour pit, the concrete floor broke into pieces and was launched in a steep slope.

(*g*) Apparently bays 1 to 8 Panjnad Regulator remained in tact. In this portion the construction joints of the downstream floor seemed to have slightly opened out and a long new crack also developed as per location shown on Plate No. 10. The sub-strata underneath this portion seemed to have been disturbed.

(*h*) A discharge of about 15000 cusecs is estimated to have passed in Panjnad Canal during the floods. The flood water of Abbasia Canal entered the canal by adopting a sharp bend and this caused bed of Panjnad Canal to scour on the down-stream side of bays No. 1-7 upto 20 ft. below designed bed. The curtain wall at the end of impervious floor being just 5.5 ft. deep do not seem to have provided adequate barrier to the substrata as a result of which the disturbance of sub-grade made the floor to crack. Levelling of the area, however, did not reveal any settlement of the horizontal floor and concrete blocks in this zone.

6.12 From the foregoing it shall be seen that the damage to the structure has been very large. With the arrival of gushing back flow in Abbasia Canal, had the opening of the gates of the regulators and dumping of stone not been done spontaneously, there was every possibility of regulators to collapse completely. In that case uncontrolled flow into the canal from the weir pond (maintained at High Flood Level 341 to 343) in enormous quantity would have caused still more devastation in the developed areas of Bahawalpur and Rahimyarkhan districts. In such an eventuality a large number of masonry works along the canal system might have been washed away and operating of the canals for a long period would have remained suspended. A large area (about 14.7 lac acres) dependent on the canal system would have faced famine conditions and inflicted a crushing blow on the already dwindling economy of the country.

6.2 Feeding the Canals.

6.21 As the flood subsided, the breaches in the Left Marginal Bund were closed and this also stopped the back flow towards Abbasia Canal. In the meantime, the demand of water for irrigation purposes also developed. In absence of any alternative, the only way out seemed to utilize the so-called undamaged bays 1-8 of Panjnad regulator for feeding partial supply into the canals. The operation of the regulator in this fashion even partially was extremely risky, but could not be helped for safeguarding the flood effected area from further ruination. Before actual operation the damaged portion was, however, cordoned by erecting a curved pervious stone bund. This checked direct flow over the damaged zone and also provided a cushion of water over the same to keep the differential head across the structure within safe limits. The scheme worked reasonably well and the pervious bund also permitted seepage of water through it to feed partial supply into Abbasia Canal. In this manner a maximum discharge of 8500 cusecs (against designed capacity of 5370 causecs) was released through bays No. 1-7 (8th bay having been blocked by the stone bund) out of which a maximum of 404 causecs could pass on to Abbasia Canal. The excessive and concentrated flow in bays 1-7 may as well have caused the scour in the bed of canal to agravate. (Refer para 6.12)

6.22 The arrangements outlined in para 6.21 above continued satisfactorily so long as the water level in the Panjnad Canal remained sufficiently high to give some command for Abbasia Canal. As soon as the supply in the river reduced towards the end of October, the water level in the Panjnad Canal also dropped and feeding of Abbasia Canal (having bed level 4.7 ft. higher than the Panjnad Canal) did not remain practicable. To overcome this situation, yet another risky operation was done by segregating the two regulators with an earthen bund. This permitted independent operation of the two canals through their own regulators *i. e.* Panjnad Canal through its undamaged bays 1 - 7 and Abbasia Canal through the damaged regulator bays.

6.3 **Diversion Channel**

6.31 For permanent repairs to the regulators, the working area is required to be cordoned by erecting earthen coffer dams. This renders the regulators non-operational for a period of about 4 to 5 months. Alternative arrangements to feed the canals were, therefore, required before undertaking the major repair work. This necessitated construction of a diversion channel to atleast cope with the reduced demand of the channels in the winter season which is 2832 cusecs and 426 cusecs for Panjnad and Abbasia Canals respectively.

6.32 As stated previously Abbasia Canal is a high level channel with bed 4.7 ft higher than the Panjnad Canal. To permit water to flow into Abbasia, a control regulator in the diversion channel, therefore, appeared essential. The construction of the control regulator was initially considered to be expensive and liable to take long time in execution. Such a structure designed for a specific discharge was also to limit the passage of flow in the diversion channel. This meant depriving the non-perennial canals of the system from obtaining occasional watering at the time of winter freshets or excessive run off in the river. These factors demanded consideration to excavate diversion channel without an intermediatory regulator which meant that :—

(*i*) Pond level on upstrem of the barrage be maintained varying from RL 328 to 330 depending upon the flow in the river and commanding water level in the Panjnad Canal (water level in the Panjnad Canal is usually 329.5 corresponding to authorised perennial discharge of 2832 cusecs).

(*ii*) Arrangements for pumping perennial discharge of 426 cusecs in Abbasia Canal (from about RL 328 in diversion channel to RL 334 in Abbasia).

Due to general shortage of power in the winter season, it was felt that WAPDA will not be able to supply electricity for pumping of such a big discharge particularly when the demand of power for repairing regulator was also expected to be fairly large. In addition, the pumping units for such a big discharge were not expected to be readily made available and to operate them contineously for 4 to 5 months had many hazards. For better reliability, it was, therefore, decided to cater for the perennial discharge only and regulate supply into the canals by constructing temporary regulators in the diversion channel.

6.33 Alternative alignments of diversion channel were considered and ultimately that shown in plate No. 13 off-taking from Left Guide Bank at a distance of about 1500 - 1700 ft. upstream the weir, joining Abbasia Canal at RD 925 and outfalling into Panjnad Canal at RD 1350 was considered most appropriate. This alignment cuts across Left Marginal Bund and the National Hignway. A temporary baily Pantoon bridge had, therefore, to be constructed over the diversion channel to maintain the normal flow of road traffic.

6.4 Temporary Regulators

6.41 Abbasia being a high level channel can be directly fed from the river pond and required practically no structure to control the supply. However, to check the fluctuations and excessive flow in the canal during winter freshets, a small pucca section having stone pitched approaches was considered desireable and provided for as per location and typical cross-section shown in Plate No. 12. The water-way at the control point was provided a wooden decking supported on detachable iron trussels for facility of crossing and to manupulate wooden needles for regulation. The foundations of the structure being below the sub-soil water level was constructed by dewatering the area. The pumping was of the order of 6 to 8 cusecs and was done by installing 4 shallow tubewells and 2 open pumps. A maximum discharge of about 450 cusecs was passed through this regulator against designed limit of 426 cusecs. The operation of the regulator gave no problem except occasional settlement of stone pitching and apron of the round nose where bifurcation of the discharge between the two canals took place.

6.42 Panjnad is a low level channel with its bed 4.7 ft. lower than the Abbasia Canal. The control structure for a discharge of 2680 cusecs for this channel was thus to withstand a differential head of approximately the same order and had theoretically to be quite massive and strong. However, keeping in view the temporary nature of the work, the design evolved comprised construction of a simple stone weir with shallow concrete curtain walls and the approaches protected by stone pitching. (Refer plate No. 13). The foundation portion of this work which was mostly below the sub soil water table had to be done on dewatering the area by installing 13 shallow tubewells and 2 to 4 open pumps catering for a discharge of about 15 to 20 cusecs.

6.43 On completion of the work, test running was done with a nominal discharge of about 500 cusecs. Soon after opening the regulator settlement in stone pitching along the sides was noticed and the regulator had to be closed immediately for examination and repairs etc. It was observed that the water had developed a free-passage on to the downstream side from underneath the shallow cancrete curtain walls and naturally the structure could not be relied upon for safe operation in that condition. The design was, thereupon, revised to incorporate a deep sheet pile line cut off (refer details in Palte No. 13). The modifications in the structure were incorporated in a record period of abont 10 days and the temporary regulators again put to operation from early January, 1974 (photograph No. 1).

6.44 The temporary regulator of Panjnad Canal was basically designed as a stone weir by adopting a very mild glacis slope of 1 : 15. This did not permit formation of a defined hydraulic jump due to non-existance of a cistern and inadequate water depth on the downstream side. The undissipated energy caused deep scour, side errosion and swirls formation on the downstream side. This created lot of anxiety and to keep the work in tact almost continuous dumping of stone, concrete debris and Killa Bushing had to be resorted to.

6.45 Although a lot of stone can be salvaged from the temporary regulators after the completion of permanent repairs of the main regulators, yet there is no plan to dismantle the same. The thinking is that the works be kept in position and be utilized for diversion of flood water away from the regulators in case the breaches again take place in Left Marginal Bund and God forbid the phenomena of the year 1973 is repeated at any time in future.

6.5 Power Supply

6.51 To carry out permanent repairs and for the construction of temporary regulators, numerous pumping sets, concrete mixers, welding plants, lighting the working area at night and other appliances had to be operated electrically. Continuous operation of the tubewells was necessary to maintain the water table below the working depth. The requirement of power in the initial stages was estimated at 500 and KW gradually reducing to about 250 KW.

6.52 There is an 11 KV transmission line already stretched upto the canal colony where-from low tension line three phase 440 volts goes upto the Barrage. These lines had very small sized conductors and could not possibly take care of the anticipated load. There also existed a few unserviceable generators in the old colony power house which too could not help to ease the situation except to serve as a small stand-by unit. This situation called for tapping some independent and more reliable system which only existed with electricity Department WAPDA.

6.53 It has been experienced that the power supply is never continuous and there are frequent break downs for many hours. The nature of the work required uninterupted continuous power supply round the clock failing which tremendous loss of materials/machinery was liable to take place apart from giving a serious set back to the works in progress. To overcome the situation as far as practicable, alternate sources of power supply from two directions viz. Ahmadpur East (Bahawalpur District) and Alipur (Muzaffargarh Distt.) were tapped and extra high tensionlines were got stretched from WAPDA well in time.

6.54 As a stand-by, two old generators (55 KW & 20 KW) of the colony power house were repaired and put into operation. In addition two mobile generating sets (20 KW capacity each) were arranged from within the department and another of 50 KW capacity (which practically remained out of order) from M.P.O.

6.6 **Enclosing Working Area**

6.61 For permanent repairs to the regulators, the dumped stone, broken floor and other debris had to be removed from the working area upto a level from where the concreting for the new floor was to be laid. This level was approximately 18 ft. below the winter river pond and 13 ft. below the anticipated full supply level in the Panjnad Canal. In order to cordon the working area and also to keep the differential head across the damaged structure within safe limits, a net-work of earthen Coffer Dams (shown in plate 12) were constructed fully compacted (by the movement of MPO dozers/Scrappers) as under :—

(*i*) AT A DISTANCE OF ABOUT 325 FT. BELOW THE PANJNAD REGULATOR

This bund had 25ft. top width, 3:1 slopes on either side and bank top RL 335.0. This gave 5 ft. free-board above the anticipated full supply level in the canal and also covered the Hydraulic Gradient line. Before constructing the bund the stone apron and pitching from both banks of the canal at the junction points were removed with the help of dragline for a secure bond of earth and to obviate development of leaks from an otherwise weak union.

(*ii*) AT A DISTANCE OF ABOUT 350 FT. BELOW ABBASIA REGULATOR

This bund had 25 ft. top width, 3:1 slopes on either side with bank at top R.L 339. This gave a free-board of 4 to 5 ft. above the anticipated full supply level in the diversion channel and also adequately covered the hydraulic gradient line. The stone apron and pitching from both the banks at the junction points were removed similar to Coffer Dam at (*i*) above for obtaining better union. All materials and machinery was brought into the working pit by utilizing this embankment.

(*iii*) AT A DISTANCE OF ABOUT 500 FT. TO 700 FT. UPSTREAM OF THE WEIR LINE IN THE LEFT POCKET.

This bund had a top width of 25 Ft. to 30 ft., side slopes 3:1 and top at RL 340 *i.e.* 5 ft. above the anticipated maximum river pond. A portion of this bund rested on the stone aprons of the left guide bank and along the divide wall. These aprons are placed at low level and the removal of stone in the affected zone could not be done due to peculiar location and being beyond the throw of the dragline bucket. While subjecting the bund to a higher pond (above R.L 334) oozing of water and slight sloughing of earth at the downstream toe was noticed. The downstream slope of the bund had, therefore, to be flattened to I in 8 near the junction of the divide wall and the same effectively supressed the water springs and also the sloughing effect of the earth.

(*iv*) A 15 ft. wide pushta having top RL 333 was laid along the divide wall inside the pocket commencing from the mouth of the fish ladder upto the junction of the main coffer dam as at (*iii*) above. The divide wall having 14.5 ft. base width, resting on shallow wells (8.5 ft. deep) and designed to withstand a differential head of not more than 2 ft. to 3 ft. was otherwise liable to collapse due to pond effect of the river on one side. The slope of this pushta was initially kept at 1:3 but had to be flattened to 1.8 on account of the reasons similar to coffer dam at (*iii*) above.

6.7 Modified Design

6.71 The regulators of Panjnad and Abbasia Canals were constructed in the year 1928-30. The calculations for the original design could not be traced out from the available record in the field or Irrigation Secretariat. The analysis of the existing structure according to Khosla's Theory, however, gave the following results :—

(*i*) The exit gradient of 0.222 giving a factor of safety of 4.5 against the recommended value of 6 for fine sand.

(*ii*) The thicknesses of floor slightly lower than required by Khosla's theory.

The analysis according to Lane's Weighted Creep Theory indicated :—

(*i*) Weighted Creep head ratio of 8.42 against recommended value of 7.0 for fine sand

(*ii*) Floor thicknesses adequate according to uplift pressures on Creep theory

This study revealed that the original design was probably done according to Creep Theory which was widely used for designing the Hydraulic structures prior to inception of Khosla's theory of sub soil flow.

6.72 The small discrepancy in the value of factor of safety against exit gradient or thickness of impervious floor as revealed above does not imply that the structure had been unsafe. These regulators have been in operation for over 40 years and no damage due to undermining or appearance or springs on account of excessive uplift pressures ever came to notice. The damage as described earlier, had been caused by a back flow of considerable magnitude and formation of deep scours by extensive swirling action. These eventualities are generally not considered in the design of such structures as such untoward development occurs very rarely.

6.73 The famous central design office of the Irrigation Department had been abolished at the time of unifying the provinces into One Unit in the year 1958-59. The central record of this office was also divided and transferred to various regions for reference at local level. Since then the training of design engineers in the department, practically, did not take place. Most of the experienced staff managed to go to WAPDA for advancement of their knowledge and then migrated on to National Engineering Service (Pakistan) Ltd. on establishment of this organization