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PERFORMANCE EVALUATION OF EXISTING LINED CANALS IN PAKISTAN AND SUGGESTIONS FOR IMPROVEMENT

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SYNOPSIS

A number of lined canals are in existence in Pakistan. Before independence, the first canal lined was Bikaner off-taking from Ferozepur Barrage now in India. About 84 miles length of the canal was lined in 1924. Its constructional details were given in a paper submitted by Jeffris during 1926 session of the Engineering Congress. Haveli was the second lined canal off-taking from Trimmu Barrage. It was lined in 1937. Its constructional details were given in a paper by R.S. Duncan in the 1939 Annual Session of the Engineering Congress. The problems which appeared on this lined canal were discussed during 1942 by S.N. Kapur. In the 1943 Annual Session of Engineering Congress, there were two papers by S.I. Mahboob on various general aspects of canal lining. Ever since then Pakistan continued to line its major canals such as Thal Main Line Upper, Lower and Mohajir Branch during 1944 to 1950, Akram Wah (lined channel) in 1951-57, Bambanwala-Ravi-Bedian-Depalpur Link in 1953, Balloki-Suleimanki Link in 1955, Sindhnai-Mailsi-Bahawal Link in 1965, Chashma Right Bank Canal (CRBC) Stage-I in 1986-87 and CRBC Stage-II in 1988-1992, Warsak Gravity, Warsak Lift and Lasbela canals during 1985-1992 and few other minor canals, mostly using layers of bricks or cement concrete. However, for the last 47 years the important subject of canal lining, and attainment of the conditions for which the lined canals were constructed has never been taken up very seriously by the Engineering Profession. No serious thought has been given so far to the utmost need of monitoring the performance of any of the existing lined canals in Pakistan. The Authors of this Paper have for the first time inspected the existing lined canals during the winter closure of the year 1991-92 in order to assess the problems and the damages caused to their Lining during the last about 47 years vis-a-vis their typical design details for lining. With their relevant engineering background and experience, the Authors have made their own humble contributions related with the subject of canal lining. Engr. S.N.H.Mashhadi dealt with the recent lining of some Distributaries and Minors under the Command Water Management Project (1985-92) funded by the World Bank in the 64th Annual Session of the Engineering Congress in 1992. In August, 1991 the International Waterlogging and Salinity Research Institute (IWASRI, WAPDA) entrusted Dr. Nazir with preparation of a general write-up indicating the research investigations carried out to-date on the subject of lining of canals in Pakistan. Engr. Amir-ud-Din Qureshi presented his diagnostic analysis of Jamrao and Nara Canal regimes (with particular emphasis on silting problems) done in 1973, in the form of a short technical paper published in IDFCR Council Bulletin, Vol.2, No.2. Later, as a senior Member of the USAID/PRC-Engineering Team, he assisted the Provincial Irrigation Departments of Punjab and NWFP (from 1986 to 1989) in the rehabilitation design of lined and unlined Distributaries and Minors, as part of the Irrigation System Management (ISM) Project (Phase-I), funded by USAID and World Bank. Using their previous experience, combined effort was made by the Authors for this paper, to collect and analyse extensive data pertaining to: various hydraulic design parameters alongwith typical design details of lining for the aforementioned existing lined canals; seepage losses from lined canals; groundwater movement and its behaviour in the vicinity of the lined canals and its impact, in the form of sub-soil hydrostatic pressures exerted on the lining of canals, causing damages to the lining during closure periods; and other soil and water related factors contributing towards the damages to the lining etc.

Based on the data collected from the provincial Irrigation Departments, WAPDA and other related Agencies, an attempt has been made in this paper to study and investigate all aspects of each of the aforementioned existing lined canals in Pakistan. The Study presented comprises details of the typical design for the various types of the Lining; the problems and damages caused to the lining of each canal; the causes of damages; and recommendations for remedial measures and improvements.

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1.0 BACKGROUND

Useful contributions have been made on international level (see bibliographical references 1 through 21) highlighting the need and the techniques for canal lining as well as the multifarious problems involved in the process of lining. Publications based on such contributions were reviewed for purpose of this paper. Throughout this century, the subject of canal lining has engaged serious consideration and attention of eminent irrigation engineers in this sub-continent particularly for salvage of canal seepage losses and eradication of waterlogging of irrigated lands.
The following lined canals have been built in the Indo-Pak Sub-continent during the last six decades:

1. Bikaner Canal
2. Haveli Canal
3. Thal Main Line Upper
4. Thal Main Line Lower
5. Mohajir Branch
6. Bambanwala-Ravi-Bedian-Dipalpur Link
7. Baloki-Suleimanki Link-I
8. Sidhnai-Mailsi- Bahawal Link
9. Head Race Channels of Chichoki Mallian and Shadiwal Hydel Station.
10. Pehur High Level Canal
11. Akram Wah or "Lined Channel"
12. Chashma Right Bank Canal
13. Warsak Gravity Canal
14. Warsak Lift Canal
15. Lasbella Canal

The Authors during their life time service in Irrigation Department, WAPDA and/or other semi-government and private organizations engaged on water resources engineering works, had a chance to casually inspect these lined canals and notice the deteriorating conditions of their lining. An idea was mooted to have their detailed investigation during annual closures and write a paper describing their design features, problems and damages having been caused to the lining, causes of the damages, present state of repairs, and suggestions for remedial measures. This has been done for all the lined canals in chronological order in the subsequent paragraphs:

2.0 BIKANER CANAL

As this was the first major canal lined in the Sub-continent, we have put-forth

brief information about its construction. This canal was taken off from Ferozepur Barrage during construction of Sutlej Valley Project in 1926. It was to carry a discharge of 2,144 cusecs through 84 miles of its length to irrigate about 0.775 million acres of Bikaner State. The parameters of the canal were: bed width 52 feet; depth 8 feet ; and side-slope 1:1. Assuming a frictional coefficient equal to 0.013. the velocity attained was worked out to be 4.51 feet per second. The 6 inches thick lining comprised lime concrete which was prepared out of Kankar (calcium carbonate nodules) existing in large quantity in Bikaner at site called Darbari. These nodules were burnt to yield Hydraulic lime used as cement. Suitable sand was not available nearby, so very fine portions of the nodules were used in place of sand. The gravel part constituted the coarse grade of the nodules. Hydraulic lime was produced at many sites along the canal where stock of other material was collected. The mix ratio of the concrete was: one part hydraulic lime, one part of very fine nodules in place of sand and six parts of coarse nodules. This concrete of 1:1:6 mixture was rammed with pneumatic rammers to make the 6 inches thick concrete. For expansion joints Y-shaped pieces of wood, one inch at top and 1/2 inch at base, were used. A free-board of one foot was provided.

A few specimen of lining were tested for permeability in a laboratory. These gave a seepage order of 1.47 to 4.93 cusecs per million square feet. Its average absorption was assumed equal to 1.5 cusecs per million square feet.

3.0 HAVELI CANAL

The Haveli Canal was taken-off from the left flank of Trimmu Barrage during its completion in 1937-38. This canal at the time of construction was 45 miles in length to carry its main supplies to Sidhnai Barrage on the Ravi river. Its design data was:

Discharge Capacity	= 5,224 cusecs.
Bed Width	= 84 feet.
Depth	= 12 feet.
Side-Slope	= 1:1
Longitudinal Slope	= 1 in 10, 500
Manning's 'n'	= 0.0149

During its construction the compaction of the soil fill was not carried out. The cross-section of the canal was dug and, wherever needed, the soil was filled and dressed to a slope of 1 in 1. It was then overlain by 1/2 inch thick layer of 1:6 cement-sand plaster. This was followed by

12" x 5 7/8" x 2 1/2" inches tiles laid over the 1:6 cement-sand mix, and pointed with 1:6 cement mortar. The surface of the tiles was plastered with 1/2 inch thick layer of 1:3 cement-sand mortar. Two-way steel reinforcement comprising 1/4 inch diameter bars placed 12.5 inches C/C was also introduced in the 1/2 inch thick cement plaster. Later on in the bottom layer the C/C spacing of steel was increased from 12.5 to 24.5 inches. On the surface of the reinforced plaster, the second layer of tiles of the same size as the bottom layer was laid and pointed with 1:3 cement-sand mortar. This design and details of lining are shown in Figure-1. In 1939 R.S. Duncan explained the constructional details of Haveli Canal[3]. This lined canal on operation became a source of several troubles. S.N. Kapur who operated the canal was faced with many problems. He also explained all these problems in a technical paper published in 1942 [5].

3.1 The Problems Caused to Haveli Canal

Haveli canal was provided with one foot free- board. It was quite insufficient and resultantly even a wind-storm of low intensity caused water to spill over the lining. This water seeped at the back of the lining and the uncompacted back-fill became slushy and subsided causing hollows behind the lining. Pressure of water and wet soil caused buldging of lining which had to be rebuilt. The Manning's coefficient of roughness of 0.0149 was found to be too low. In actual condition it rose up to 0.02. Another source of trouble was appearance of some insects which roughened the lining and thus increased the frictional coefficient. Very soon the reinforcement at some places showed corrosion. A committee of expert engineers and scientists was appointed to find a solution to this problem of insets appearance and corrosion of reinforcement. It was decided to give up the use of reinforcement in the future lining projects.

3.2 Estimation of Seepage Loss From the Lined Canal

In 1938 absorption tests on Haveli lined canal were carried out in reaches R.D. 13+000 to R.D. 14+000 and R.D. 212+000 to R.D. 213+000. Soil embankments were constructed in the canal section at these two sites and by filling the ponds with canal water, seepage and evaporation losses were determined. The observation gave an absorption of 0.1 and 0.25 cusec per million sq.ft. of wetted perimeter. It was then decided to fix a loss of 20 to 40 cusecs in cold weather and 40 to 50 cusecs in hot weather from the full length of the canal. A loss of 38 cusecs which corresponded to about 1.5 cusecs per million sq.ft. was thus assumed.

3.3 Depth of Groundwater along Haveli Canal before its Construction and at Present

As said earlier, Haveli canal takes off from Trimmu Barrage located at the confluence of Jhelum and Chenab rivers. It carries its water across the Rechna Doab to Ravi river at Sidhani Barrage. For a study of the groundwater levels within a few miles on either side of the canal, the elevations of groundwater in the wells along each Well Line were studied. Figure-2 shows the Well Lines and the location of the wells within close distance of the canal, as also shown in Table-1.

TABLE-1

Sr. No.	Well Line	Well No.	Distance from Canal in miles	
			Left Side	Right Side
1-	NP VIII	20	-	1.5
	NP VIII	21	3	-
2-	Circle Line	XV 131	-	-
	Circle Line	XV 132.	3	-
	Circle Line	XV 133	3.5	-
3-	Line VII	1	-	2
	Line VII	2	1.5	-
	Line VII	3	3	-
4-	Line VI	1	-	2
	Line VI	2	-	1.5
	Line VI	3	-	-
	Line VI	4&5	2	-
5-	CL XVI	2	-	3
	CL XVI	3	-	1.5
6-	No. V	4	-	2.5
	No. V	5	-	-

Records of Wells on all these Well Lines are incomplete. Whatever data could be found from the Basic Data Release No.3 of WAPDA[13] has been studied. The observation on some of the wells is available for the years 1900, 1905 and 1943. As the Haveli Canal was completed in 1938, we have checked the well records up to 1940 and during 1956/ 1959 when the lined canal was in operation for about 18 to 20 years. These records are shown

in Table-2. It seems that before the construction of Haveli Canal the annual rise of groundwater was very slow which after construction increased by about three times. The depth of groundwater below natural surface as studied for the few wells is given in Table-3. This Table indicates that by 1959, the groundwater existed at an average depth of about 13 feet.

TABLE NO-2

RECORDS OF WELLS AT DIFFERENT PERIODS AROUND HAVELI CANAL

DATA FOR DIFFERENT YEARS

Well Line	Well No.	Year	RLs of G.Water Depth	Year	RLs of Depth	Rise in Groundwater G.Water Level (ft.)
NP XIII	20 and 21	Not available				
CL XV	131	Year	RLs of G.Water Depth	Year	RLs of Depth	Rise in Groundwater G.Water Level (ft.)
CL XV	131	1900	470.70	1940	475.70	5 ft. in 40 years
CL XV	131	1905	460.90	1940	471.00	10 ft. in 35 years
CL XV	131	1905	458.10	1940	467.50	9.4 ft. in 35 years
Well Line VII	1	1943	472.10	1957	473.70	1.6 ft. in 14 years
Well Line VII	2	1943	468.60	1958	472.00	3.4 ft. in 15 years
Well Line VII	3	1943	465.30	1959	469.10	3.8 ft. in 16 years
Pipe Line VI	1	1943	468.80	1959	478.05	9.3 ft. in 16 years
Pipe Line VI	2	1943	461.50	1959	463.50	2 ft. in 16 years
Pipe Line VI	3	1943	456.20	1959	462.50	6.3 ft. in 16 years
Pipe Line VI	5	1943	455.80	1956	463.10	7.3 ft. in 13 years

TABLE NO-3

DEPTH OF GROUNDWATER BY 1959

Well Line	Well No.	Natural Surface RLs	ELs of G.Water in 1959	G.Water Depth (ft.)
CLX V	132	488.80	475.80	13.00
CLX V	133	485.70	472.90	12.80
Well Line VII	2	481.80	472.00	9.80
Well Line VI	3	483.50	469.10	14.40
Pipe Line VI	2	476.20	463.50	12.70

3.4 Depth of Groundwater Checked from other Sources

Haveli Canal is located near the confluence of the Chenab and Jhelum rivers. This area has always been marked with high groundwater. In some wells observed groundwater depth during October, 1982 was noted. The position of wells with respect to canal and its head-regulator and the depths of groundwater were as below:

Distance from the Regulator of the canal in miles	Depth Observed (feet)	Position of point on Right or Left side of canal
5	6.5	Near Canal
5	7.0	2 miles on Right Side
13	5.6	1.5 miles on Right Side
13	13.6	2 miles on Right Side
19	12.2	Near Canal
20	7.0	2 miles on Right Side

The June values may be 2 or 3 feet deeper. Another check was carried out from the groundwater depth map prepared by WAPDA's Central Monitoring Organization for the period of June, 1990. Study of this map indicated that in 1990, about 90 percent of the areas around Haveli had groundwater within 3 to 5 feet.

3.5 Changes in Groundwater after the Construction of Trimmu-Sidhnai Link

In about 1966, Trimmu-Sidhani Link was constructed to carry a discharge of 11,000 cusecs. It was aligned 350 feet away on left side of Haveli. Hydraulic data of this canal as compared to Haveli Canal was as under:-

		Trimmu-Sidhnai Link	Haveli Canal
i)	Discharge	11,000 cusecs	5,224 cusecs
ii)	Water Depth	12 ft.	12 ft.
iii)	Elevation of water surface at Intake	491.16	489.0

iv)	Elevation of Bed at Intank	479.16	476.87
v)	Elevation of water surface at Tail	467.0	467.0
vi)	Longitudinal Slope	1 in 10,500	1 in 10,500
vii)	Groundwater Depth during Construction	RD. 10 at bed; RD. 50,4 ft. below bed; RD.100, 10 ft. below bed; and RD. 155 at bed .	

Water surface in Trimmu-Sidhnai Link intake was 2 feet higher than that in Haveli. It remained higher up to the tail at R.D. 220. The water delivered into Sidhnai Barrage was at the same elevation of 467 in the two canals. The lined portion of Haveli extends up to R.D. 180 after which it was constructed as unlined canal up to R.D. 225, the unlined portion of Haveli having a reduced depth of 9 feet. This change was necessary as the old Sidhnai Barrage was abandoned and new one was constructed some distance upstream. The 350 feet wide land strip lying between the two canals remained nearly saturated due to seepage from the two canals.

3.6 Estimation of Seepage Losses from T.S. Link and Haveli Canal

Tipton and Kalmbach estimated water loss from T.S. Link equal to 400 cusecs during Kharif and 300 cusecs during Rabi. T.S. Link has no canal command, so its seepage is not recorded alongwith the rest of 24 canal commands. Here for Haveli the diversion is given equal to 0.5 MAF (690.5 cusecs) and length of main line is 49 miles. Length of Branches is not given whereas for distributaries it is indicated as 133.3 miles for which the loss per mile was estimated equal to 0.342 cusec. At present the difference between canal water surface and groundwater is comparatively low. The seepage may not be very high due to the small water head.

3.7 Inspection of Lining during January,1992

Haveli Canal was closed for winter annual repairs in January, 1992. A visual inspection of lining was undertaken by the authors on 16th January. The inspection

bank lies on left side of the canal towards T.S. Link. The right side of the bank and the bed was quiet visible. The sides at many locations seemed to have been repaired often by big size cement concrete blocks as exhibited in Photos 1 and 2 . The tiles seemed to have been damaged in a width of 3 to 4 feet just below the canal water surface. The free-board appeared to have been extensively repaired and the tiles deteriorated by salts of capillary water. The pointing material appeared to have been removed out of bricks. Another serious defect was the growth of bushes and weeds in the top three or four feet of lining near water surface. As shown in Photo-3, this growth must have penetrated its roots through the crevices of the cement pointing down to the soil formation. The top salt-affected free-board was also visible. Another serious visible damage was the lifting of the reinforced lining in the bed due to hydrostatic pressure. This type of damage was often found after almost every five R.Ds. Only three instances of bed and side damages are shown in Photos 4, 5 , 6 . The water pressure particularly during canal closures caused these damages and removed the cement pointing out of tiles. On the whole this lining was less damaged as compared to a few other lined canals. Its lined section has remained intact during the last 54 years, and, even during the last 26 years after the construction of T.S.Link which has its F.S.L. 2 ft. higher than that of Haveli canal.

3.8 Some Suggestions to Improve the Lining of Haveli Canal

Stability of lining in Haveli Canal is affected by the pressure of high groundwater and wet soil. The canal was constructed in the area with generally high groundwater which was rising at a very slow rate. The construction of Haveli increased the rate of rise and very soon it attained a position beyond which rise became slower. After about 28 years of its construction T.S.Link carrying 11,000 cusecs discharge and with its full supply level 2.0 feet higher than the full supply level of Haveli, was constructed 350 feet away on the left side[119]. Seepage from the new unlined Link Canal further raised the groundwater. As to the programme of canal closure, T.S.Link needs to be closed at least for about 15 days before the closure of Haveli. During this period some of the water from within the 350 feet wide strip of land can flow towards T.S.Link. If this type of closure is practiced there are less chances of damages to lining of Haveli Canal.

The lining is not much damaged. It seems that due to water pressure from T.S.Link, the pointing material seemed to have been removed out of tiles. Even the damages to bed lining seem to have worked as pressure- release devices. It is thus suggested that during all repair programmes of the lining, weep holes 6 inches square (with proper filters at the back), about 3 feet above the lined bed of canal and every 10 feet apart, may be provided for release of pressure.

3.9 Suggestion to use Land Strip between Haveli and T.S Link

This strip of land between the two canals is without a spoil bank. The land is nearly level. Its depressions remain filled with seepage water, and salt accumulation exists on vast areas as shown in Photo No.-7. This land was acquired by Government during construction of T.S. Link. It has ample fresh water source. If an interceptor drain at about 50 feet away from the left bank of Haveli is constructed with a sump hole every one mile apart, a strip of land 200 to 250 ft. wide and about 1000 ft. long constituting about 2.25 sq. miles, i.e. about 1440 acres of fertile land would become available with usable water for agriculture production. The economics for development of this land with appropriate means of drainage needs to be examined. Use of very shallow tubewells about 15 feet deep with multiple-strainers may be another alternative to irrigate the strip of land for irrigated agriculture and simultaneously to reduce the sub- soil water pressure on Haveli Canal. While repairing the salt deteriorated tiles on the free-board, it is suggested to use one layer of bitumen impregnated tiles at the bottom. It will stop the rise of salts. No other counter measures to protect the lining of Haveli Canal appear to be economically feasible due to peculiar conditions of site.

4. LINING OF THAL CANAL AND ITS MOHAJIR BRANCH

4.1 Thal Main Line Upper

Kalabagh Barrage, now called Jinnah Barrage, was completed by 1942. Thal Main Line Upper taking off from its left side was constructed as a lined canal. Its hydraulic design data are as under:

i)	Discharge at head	= 7,500 cusecs
ii)	Bed width	= 71 feet
iii)	Full supply Depth	= 17.3 feet
iv)	Bed Elevation	= 656.38
v)	Full Supply water surface Elevation	= 674.18

Lining of Thal Main Line Upper was undertaken in 1944. The length to be lined was 31 miles. As ample deposits of shingle and sand were available nearby, lining was constructed using 4 inches thick 1:3:6 cement concrete. The sub-grade formation at filling was compacted for the first time. Another change introduced was in the side-slopes which were kept 1 vertical to 1.25 horizontal. Unlike Haveli canal the lining of Thal Canal was constructed in panels, each 15 feet wide, ends of panels resting on profile walls called "Dhomalies". The lining worked satisfactorily for about 16 years. Then damages appeared on a few panels near Paikhel area at about

RD.60. Here the canal is in digging. The groundwater had risen considerably and at the time of annual closure a few specific panels were found damaged. The problem was referred to the Irrigation Research Institute (IRI) which had already recommended remedial measures for protection of the side lining of Kalari Feeder in Sindh. The lining of Kalari Feeder was observed to be damaged at few sites where water accumulated outside the Feeder. Its protection was possible by installing a filter with weep holes which released the excess moisture. The same advice was tendered for Thal Canal. It was also suggested to renovate the surface drain which existed between the spoil and the Mianwali-Kalabagh road so that the seepage water could flow through syphons after removing their choaking. Another suggestion was to close the canal very slowly in one or two days to release the pressure from saturated soil behind the lining. Unfortunately IRI's suggestions were not adopted with the result that the lined panels kept suffering from damages during closure every year. Thus the damages to lining kept multiplying with the passage of time.

On 30th January, 1992 inspection of the canal was carried out. From Mianwali towards the Barrage at R.D. 80, both sides of the canal lining were found heavily damaged. The sides of the canal are now provided with stone pitching using large size stones (about one foot square). Photo No.8 shows stone pitching being built at R.D.76. The stones were rolled along the sides from the top of the banks towards the bed. The labourers standing down on the bed laid the stones one above the other. No cement pointing and/or cement mortar was used to fill the crevices and/or the joints. One example of the stones laid as such is shown in Photo No.9. During rolling of stones from top to bottom the natural soil which was refilled without proper compaction, was disturbed. This type of stone protection extended upto R.D. 20. The problem with this type of stone pitching is that the flowing water in the canal sucks the wet soil behind the stones and the whole stone protection falls down into the canal. At places big embayments have been formed. One instance of embayment is shown in Photo No.10 With the passage of time the stones often slipped down onto the bed and the process of stone-laying was repeated . At many sites several layers of stones were visible as shown in Photos No.11 and 12. A few sites where the crevices and interstices in between stones were filled with plaster, the pitching behaved satisfactorily (Photo No.13). The damage which had started from Paikhel extended both upstream and downstream. The original damage started on the left side but now the right side is equally damaged. Description of some more details about the causes of damages and a few remedial measures is given in the subsequent sub-paragraphs.

4.1.1 Estimation of Seepage Loss from Thal Main Line Upper

Very recently Hydrology Directorate of Irrigation Department (Punjab) in compliance to the S.E. Thal Canal's request dated 20th September, 1992 observed the discharge

of this Canal at four sites viz:

i) Up-stream of bridge at R.D. 10,800.
ii) Up-stream of bridge at R.D. 64,000,
iii) Down-stream of bridge at R.D. 77,000 and,
iv) At the tail regulator, R.D. 156,000.

During these observations discharge at the canal head regulator was kept constant equal to 7,255 cusecs. The observed discharge was as under:

1) **Observation for site (i) and (ii)**

Between R.D. 10,800 to R.D. 64,000 i.e. for a distance equal to 10.64 canal miles:

- Average Discharge at R.D. 10,800 = 7,413 cusecs
- Average Discharge at R.D. 64,000 = 7,302 cusecs
- Withdrawal of Paikhel/ Bokhari Distributaries and 3 Direct outlets. = 60 cusecs
- Actual difference of Discharge = 51 cusecs (loss)
  Loss per canal mile = 4.79 cusecs per mile

2) **Observation for Site (ii) and (iii)**

- Average Discharge at R.D. 64,000 = 7,302 cusecs
- Average Discharge at R.D. 77000 = 7,247 cusecs
- Loss = 55 cusecs
- Distance = 2.6 canal miles
- Loss per canal mile = 21.15 cusecs

3) **Observation for site (iii) and (iv)**

- Average Discharge at R.D. 77,000 = 7,247 cusecs
- Average Discharge at R.D. 156,000 = 6,971 cusecs
- Withdrawals in the reach = 231 cusecs
- Actual loss = 45 cusecs
- Distance = 15.8 canal miles
- Loss per canal mile = 2.85 cusecs

Sites (i) and (ii) are located in partly damaged lined portion of the canal . The seepage loss in this reach (R.D. 10,800 to R.D. 64,000) is 4.79 cusecs per mile. This is equivalent to 7 cusecs per million sq.ft. of wetted perimeter. The sites (ii) and (iii)

are located in completely damaged lined portion. It is noteworthy that the loss in these badly damaged reaches is 21.15 cusecs per mile length of canal which is exceptionally high, even much higher than in unlined canals. This portion of canal is in deep digging, and the seepage loss is very high. The seepage loss from the third site where the lining is generally undamaged is 2.85 cusecs per mile length which is equivalent to 4 cusecs per million sq. ft. of the wetted perimeter. This is also a considerable loss.

4.2 Lining of Mohajir Branch

The Thal Main Line Upper ends near Mianhwali where a complex multi- diversion system has been constructed. At this site Thal Main Line Lower, Mohajir Branch, Dullewala Branch, Kundian and Tibbi Distributaries and also an escape channel have been constructed. The hydraulic data of Mohajir Branch is as under:-

i)	Discharge	=	1,463 cusecs
ii)	Bed width	=	37 feet
iii)	Depth	=	9 feet
iv)	El. of bed	=	661.61
v)	El. of water surface	=	670.61
vi)	The head regulator has three bays, each ten feet wide.		

The first seventeen miles of this canal upto R.D. 85 are lined. Its design features are explained in Figure -3. The lining was of cement concrete of mix ratio 1:3:6. On the bed the lining is 4 inches thick and on the sides it is 5 inches thick. The side slopes are 1 horizontal to 1.25 vertical. The concrete slabs/panels of 15 feet width had Dhomalies under the end joints between them. Mahajir Branch follows along the salt range. Its alignment is balanced i.e. neither too much in digging nor much in filling. The lining is heavily damaged. Photo Nos. 14 and 15 show the condition of damaged panels. At many sites during its 47 years of existence the lining seems to have been repaired at many sites. Generally repair has been done by plastering the old lining with certain thickness of cement sand as shown in Photo Nos.16 and 17. This plaster having no bond with previous lining was lifted up and got removed. Another characteristic of the damages to this lining is that the whole depth of panel from top to bottom was damaged. In other lined canals the damage is usually at the point of maximum pressure, generally 3 or 4 feet above the toe of sides. During repairs, the dismantled portion has been allowed to remain in the bed of the canal as shown in Photo No.14.

4.3 Constructional Details of Lining for Thal Main Line Lower

The lining of Thal Main Line Lower comprises the following three different designs:

i) **R.D. 0+00 to R.D.5+000**

The lining upto the first five R.Ds. was constructed using two layers of ordinary bricks with impregnation of 0.50 inch thick 1:3 cement-sand plaster in between. It was similar to the design of Haveli Canal except that instead of 2 inches thick tiles, normal bricks of 9"x4 1/2"x3" size were used. The portion of this lining has remained in perfect condition during the last 46 years, inspite of unfavourable groundwater conditions.

ii) **R.D. 5+00 to R.D. 68+000**

Another type of lining starts from R.D. 5 and extends upto R.D. 68. This lining was constructed after dressing the soil formation and providing a first layer of 0.5 inch thick layer of 1:10 cement-sand plaster. Another layer of 4 inches thick 1:6 cement-sand plaster was spread on the first layer. Each panel of 15 feet rested on "Dhomalies". This plaster is now in a very bad shape. Its surface has become rough and irregular (full of pitting) throughout. Although no serious damage to the lining has occurred but the surface has become irregular as shown in Photo No.18. The canal from R.D. 5 to R.D. 68 is generally in filling with land surface below the full supply level. The filling material is composed of sandy soil of pervious nature. There seems no problem of high groundwater. So far repair seems to have been carried out by replastering the damaged surface of the previously laid cement-sand plaster (Photo No.19). For repairs, a plaster 2 inches thick of 1:4 cement-sand mix is generally spread on surface without arranging for any bond with the old plaster (Photo No.20). This is liable to be lifted up. During the short winter closure, the channel does not get completely dewatered so that the bottom 3 to 4 feet of panels are left without plaster as shown in Photo No.21.

iii) **Lining of Thal Main Line Lower Beyond R.D.68**

The design of lining starting from R.D. 68 was again changed. The changed design is shown in Figure -4. Its main feature was the replacement of bottom layer of tiles by 1.5 inch thick 1:6 cement-sand plaster. This was laid on compacted formation having a thin blinding layer of 1:10 cement-sand mix. The surface of 1.5 inch thick plaster was coated with 3/8 inch thick 1: 3 cement-sand mix. This plaster was then provided with a layer of 2.0 inch

thick tiles. Thal Main Line Lower extends from R.D.68 to R.D.375. Its section in this reach is generally in cut and fill. The land around is lower than the full supply level and is sandy in nature. This is one main reason for the safety of this lining, since the hydrostatic pressure behind lining, instead of bursting the lining, is dissipated into the porous soil behind.

4.4 Stability of Thal Canal System with Respect To Depth of Groundwater

4.4.1 Thal Main Line Upper

Data of groundwater records along the canal was studied. This information is available in Basic Data Release No.6 of 1961, edited by Muhammad Ashraf Mughal, Sabir Ali and Nadir Khan of WAPDA[13]. Along the canal on its right side a few Well Lines referred as KI, KIII to KIX were established in 1935. Each Well Line has generally three observation wells. There are no observation wells on left side of the canal. The records of the Well Line of K series are quite incomplete. Elevation of surface is given for a few wells. The observations of many wells are also missing. Study of available records indicates depth to groundwater at about 10 feet below surface. The Indus River flows a few miles away almost all along this canal. It appears that the groundwater on right side of Thal Main Line Upper had remained even shallower than ten feet. At the time of construction of the canal several syphons were provided to convey the water of surface run-off from rains across the canal which got choaked after a few years. Most of the alignment of canal in digging obstructed the rain water which caused groundwater to rise. Thus after a period of 16 years the groundwater attained a level detrimental to the lining. The deterioration started near Paikhel from 1960 onwards. The areas of high groundwater on this side has continued to extend upstream and downstream of the canal.

4.5 Some Suggestions to Protect the Lining of Thal Main Line Upper

4.5.1 Lowering of High Groundwater

One obvious counter measure is to lower the groundwater. This is possible by renovating the open drain which flows along the canal near the toe of the spoil. The syphons need to be cleaned up to carry the drain and rain water. This may be affective on the area where the canal is not too deep. Another suggestion is to study the possibility of installing drainage wells as per design of Figure-5. A three to four-inch dia bore pipe, 100 to 200 feet in length with 10 feet long strainers every 25 feet apart may be installed. The pumped water can be used for irrigation. These wells may particularly start operating in October and continue till the canal's annual closure or afterwards as per requirement of water for agricultural use. As the

lining is getting damaged on both sides, this type of counter measure needs to be installed along both sides of the canal.

4.6 Type of Lining to Withstand High Water Pressure

The present practice of providing stones could have been effective if installed scientifically and methodically by cementing of joints. It was necessary to dress the sides and to lay 2 or 3 inches thick stabilized sand of 1:30 cement- sand mix . It was to be followed by another 2 or 3 inches thick layer of pie-size gravel of 2 to 4 mm size. This filter may finally be protected by the stones which exist at site. The stones fallen on the bed can also be used. This type of lining would withstand any amount of water pressure, but the value of Manning's "n" shall be about 0.025 as against 0.018 for concrete-lining. So the discharge carrying capacity of the channel with stone lining shall be reduced.

4.7 Causes of Damages to Lining of Mohajir Branch

Mohajir Branch flows nearly parallel to the foot hills of salt range. Only seventeen miles of its length is lined. In a map prepared by Discharge Division of Irrigation Department in October, 1982, the depth of groundwater is recorded as 40 feet. In the area of unlined reach of this canal the original groundwater existed at 46 feet. These were the depths to groundwater along right side of the canal. There are no observation points on the left side of the canal. Along the right side of the canal, wells of provincial Line "V" are located as shown in Figure-6. Their observations have been recorded since 1935. The observed levels are given in Basic Data Release No.6 of WAPDA upto 1960. The canal operation started in about 1947. In Table-4 records of ten wells are tabulated. Elevation of natural surface and water depth during 1935 , 1950 and 1960 are given. The groundwater during 1935 to 1950 was rising at a rate of 0.7 ft. per year. In fifteen years it rose by about 10 feet. From 1950 to 1960 the average rise increased to 2.5 feet per year, giving a total rise of 25 feet. Thus by 1960 about 35 feet rise of groundwater brought the water depth to within 8 to 10 feet from surface. This was the condition for the lined portion of the canal. The wells of line No.V extend further to the unlined portion. Their earliest depth, the rate of rise from 1935 to 1950 and from 1950 to 1960 is also given in Table-4 below.

TABLE-4

CHANGES IN GROUNDWATER LEVEL ALONG LINED MOHAJIR BRANCH
STUDY OF WELLS ALONG PROVINCIAL WELL LINE NO.V

Well No.	Earliest Depth G.W. (ft)	El. of N.Surface	El. of Water Depth in different Periods 1935	1950	Rise per year during 1935 to 1950 Per year	Total	1960	Rise in G.W. Levels (1935-60)	Rise in G.W. Levels (1950-60)	Total Rise of G.W. (1950-60)	Depth to G.W. Table (1982 (Oct.)
1.	28.00	664.00	625.00	633.0	0.55	8.25	649.40	24.40	1.62	16.20	11.30
2.	37.00	659.40	617.70	627.40	0.65	9.75	648.40	30.70	2.10	21.00	7.00
3.	45.40	656.60	613.70	624.50	0.72	10.80	645.90	32.20	2.14	21.40	-
4.	41.00	646.10	607.10	618.00	0.73	11.00	640.00	32.90	2.20	22.40	-
5.	41.00	631.00	598.50	607.00	0.57	8.60	626.50	28.00	2.80	28.00	8.10
6.	47.00	630.50	592.00	599.00	7.00		622.40	30.40	2.30	23.40	-
7.	48.00	629.00	582.50	592.00	9.5		616.50	34.00	2.40	24.50	5.90
8.	46.00	620.00	577.00	584.00	7.00		611.50	34.50	2.75	27.50	0.80
9.	45.20	618.90	574.00	582.00	8.00		608.40	34.40	2.64	26.40	8.20
10.	32.00	612.40	580.60	587.70	7.10		607.20	26.60	1.95	19.50	2.70

The water depth for October, 1982 from the map of Irrigation Department is also given. The rise was slightly more than the lined portion of the canal. In 1982 it existed very near the surface. Groundwater level is expected to be higher on left side of canal. Usually damage to lined canal occurs a few feet above the toe of sides which is the point of maximum pressure. However, the damage to lining of Mohajir Branch has been observed throughout the depth of the side panel i.e. from top to bottom. This is most probably due to very high position of groundwater.

4.8 Suggestions for Improving the Lining of Mohjir Branch

Damage to Lining of Mohajir Branch has resulted from pressure of water and wet soil. The groundwater has risen so high that its decline seems to be no easy job. The lining is so much damaged that its repair is not possible during the short period of canal closure. The difference between the water surface of the canal and groundwater is so small that the seepage loss is expected to be very low. Lining is only useful to maintain the present section of the high water pressure. If this lining is repaired as per practice of spreading thick low permeability plaster, and even if a bond is created with the old lining, the pressure release filter must still be provided. Thus it is concluded that no major repair to the existing lining will be useful or even possible. The present seepage needs to be checked. For checking excessive leakages from the damaged linings Asphalt Grout lining is adopted in USA which has been found to be very effective. The correct composition for the mastic depends on the size of cracks, angle of slope and water temperature. Since the sand-mastic mixture has a specific gravity of more than 2.0, it will sink rapidly through water and fill the cracks and damaged portions of the lining into a single mass.

4.9 Measures to Improve the Lining of Thal Main Line Lower

Referring to Figure-6, there are a number of Circle Well Lines and three Provincial Well Lines No. V,VII and VIII. Provincial Well Line No.V is along Mohajir Branch and its well records have been examined. Well records of Circle Lines are very irregular and unsatisfactory, and conclusive results cannot be drawn . The wells of Provincial Well Lines VII and VIII have been properly recorded and their records are quite regular. For this reason, eleven wells of line VII and VIII close to the canal were studied. These are given in Table-5. The earliest groundwater existed 40 feet deep. From 1935 to 1950 there was some rise of groundwater. The data upto 1960 also indicates very slow rise. The groundwater level recorded by Irrigation Department for October, 1982 indicates depth of groundwater still at 20 to 28 feet below surface which is quite lower than the bed level of the canal. This is one very important reason for the safety of Thal Main Line Lower which is much less deteriorated. The condition of alignment of the canal, and the type and elevation of land around are two major factors for its stability. In 32 years the groundwater depth has not attained a damaging position. Some drainage measure may be adopted to safeguard the canal against any future rise of groundwater. The deep groundwater recorded by wells of Provincial Links No.VII and VIII is questionable as extensive waterlogging exists in Thal Doab particularly along Chashma-Jhelum Link.

TABLE-5

CHANGES IN GROUNDWATER LEVEL ALONG MAIN LINE LOWER RECORDED IN WELLS OF PROVINCIAL WELL LINE NOS VII AND VIII

Well No.	Earliest Depth to G.Water (ft.)	El. of Natural Surface	El. of Water Depth in Different Periods 1935	1950	Rise between 1935 to 1950	1960	Rise between 1950 to 1960		Depth G.W. below N.Surface (Oct. 1982) (ft.)
	Provincial Well Line VII								
1.	40.50	628.70	588.00	598.00	10.00	601.00	3.00		27.30
2.	41.10	633.00	592.00	595.00	3.00	604.00	9.00		19.00
3.	42.50	634.00	594.40	600.00	7.60	618.40	18.60		15.60
4.	48.50	633.70	584.00	590.80	6.80	612.30	11.50		-
5.	51.00	624.70	573.90	576.50	2.60	599.21	22.70		-
6.	62.10	635.30	574.70	578.50	3.80	604.20	25.70		-
7.	48.20	622.30	573.00	578.20	4.80	597.50	19.30		-
8.	43.60	611.00	567.60	574.20	6.40	590.30	16.10		1.10
9.	49.50	607.00	556.50	560.10	1.50	577.90	13.70		-
10.	49.50	607.00	556.50	560.10	3.60	566.70	6.60		5.40
11.	49.20	599.00	561.80	564.30	2.50	573.00	8.70		12.90
	Provincial Well Line VIII								
1.	26.40	594.00	567.50	565.70	-1.80		568.50	2.80	24.40
2.	41.00	602.00	559.00	561.00	2.00		570.00	9.00	28.20
3.	44.00	596.30	549.00	552.00	3.00		562.00	10.00	15.00
4.	47.50	590.10	540.60	541.80	1.20		549.82	8.02	17.80
5.	59.30	598.20	537.90	540.50	2.60		546.60	6.10	33.50
6.	56.20	603.20	547.00	541.90	-5.10		549.00	7.10	-
7.	65.40	606.70	541.30	544.80	3.50		546.70	1.90	-
8.	59.00	606.20	543.20	542.20	-1.00		550.00	7.80	-
9.	63.60	602.60	539.00	543.00	4.00		545.50	2.50	38.20
10.	62.70	596.40	533.70	538.30	4.60		541.40	3.10	38.60
11.	60.20	596.40	535.20	537.60	2.40		538.80	1.20	43.10

5.0 BAMBANWALA-RAVI-BEDIAN-DIPALPUR LINK

5.1 General Background Information

This canal is an extension of old Raya Branch which originated from Upper Chenab Canal at Bambanwala Head Regulator. Originally it ended within Rechna Doab. At the time of independence in 1947, India severed supplies in all canals originating from the three eastern rivers-Ravi, Beas and Sutlej. Pakistan had to make some alternative arrangements to feed the distributaries and branches which originally were a part of Upper Bari Doab Canal. It was then decided to increase the capacity of Raya Branch, and extend it across the Ravi river, to feed the canals originally receiving water from Upper Bari Doab Canal. For this purpose a syphon was constructed to carry the canal across the Ravi[14]. The canal emerging out of the syphon had the following hydraulic features:-

- Discharge ———— = 4,863 cusecs
- Bed Width ———— = 52 to 56 ft.
- Average depth ———— = 16 to 14 ft.
- 'n' value adopted ——— = 0.018
- Water surface slope —— = 1 in 8,000 to 1 in 13,400

As the canal emerged out of the syphon at R.D.260, it had to cross a considerable portion of Ravi flood plains. It was thus decided to line it, and the lining was started in 1952. The design of the lining was similar to that for Thal Main Line Lower (beyond its R.D.68). Lining was carried out upto R.D.372 near the village Bedian. Its total length was about 22 miles. For a part of the length of lined canal the side-slope was kept 1 vertical to 1.25 horizontal, while for a remaining length it was flattened as 1 vertical to 1.5 horizontal.

5.2 Condition of Lining Observed During Winter Closure of 1992

A visual survey of the condition of lining was carried out during the winter closure of January 1992. The inspection bank lies on the left side of canal. The right side has a high spoil. The condition of lining particularly on right side was quite visible. The free-board seemed to have been raised by 3 to 4 feet. The lining near the position of water surface showed extensive weed growth (see Photo No.22). The lining in general was satisfactory except minor damages at a few sites. At places, cement pointing had been removed out of joints as shown in Photo No.23. This defect was quite extensive. At a few sites the lining was buldging outward due to hydrostatic or soil pressure from beneath.

5.3 Study of Groundwater Depths

The area now commanded by this Link used to be irrigated through Upper Bari Doab in remote past. The irrigation was started in 1886. The records of

groundwater started to be collected in 1895, when certain Well Lines were fixed. The Well Lines and their observation wells, a few miles along the Link were:-

i) CL XIX
ii) CL XVII
iii) CL XVIII
iv) NPL II
v) NPL III

Number of wells on these well lines close to the Link was as given in Table-6. Information for each well included the measurement of elevation of natural surface and that of water depths during 1895, 1951 and 1959 or 1960. Water depths with respect to natural surface were worked out. The rise of groundwater from 1895 or 1920 upto 1950, was 1 to 3 feet only. Data of 1951 to 1959/60 when the link had already been lined also showed no significant change. The present groundwater depth was checked at two sites. The groundwater existed at 15 to 20 feet. This lined canal has been in existence for the last 40 years. Its lining has remained generally undamaged mainly due to the existing groundwater level deeper than its bed level. No portion of lined canal exists in digging. The canal in general is higher than the level of the land in the surroundings. The soil formation except in the zone close to flood plain is of low permeability.

TABLE NO-6

WELL RECORD OF GROUNDWATER LEVELS IN VICINITY OF LINED PORTION OF B.R.B.D. LINK

Well Line	Well No.	Location (miles,R or L of Canal)	Elv.of Natural Surface	Elv. of G.Water Depth (1895)	G.Water Depth (1895) (ft.)	Elv. of G.Water Depth (1951)	Rise in G.Water (1895-1951) (ft.)	Elv. of G.Water (1959/60	Rise of G.Water (1951-1959/60 (ft.)
CL XVII	2	2,L	726.00	709.00	16.40	710.70	1.10	709.90	-0.80
CL XVII	3	2.5L	724.70	714.80	9.90	714.20	0.60	712.30	-1.90
CL XVII	4	3,L	726.50	713.00	13.50	778.00	-	713.00	0.00
CL XVII	5	5,L	722.60	708.00	14.60	711.00	3.00	709.00	-1.70
CL XVIII	1	2,R	718.10	706.40	11.60	700.00	6.40	695.60	-0.40
CL XVIII	2	1,L	724.50	705.30	19.20	707.00	1.70	710.00	3.00
CL XVIII	4	2,R	707.80	697.00	10.80	700.30	2.70	690.60	-9.40
CL XVIII	5	3.5,L	710.40	697.00	13.40	697.00	0.00	689.00	-8.00
CL XVIII	6	4,L	714.10	701.00	13.10	700.40	-0.60	700.40	0.00
CL XIX	1	Near River	-	-	-	-	-	-	-
CL XIX	2	6,L	708.60	686.60	22.00	686.00	0.00	687.80	2.20
N PL II	53	On Canal	715.30	693.60	21.70	694.80	11.20	693.30	-1.50
N PL II	55	2,L	714.10	691.60	22.50	-	-	-	-
N PL II	59	3,L	727.20	712.20 (1920)	15.00	717.20	0.00	713.00	-4.20
N PL II	59	4,L	722.10	709.40	12.70 (1920)	711.00	1.60	709.30	-20.0
NPL III	63	R&L	685.40	675.20	10.20 (1920)	675.30	0.10	-	-
NPL III	64	End of Lahore	700.50	678.50 (1920)	10.20	628.40	3.90	683.70	1.30
NPL III	67		701.10	687.30	13.80	684.30	3.00	686.30	2.00
NPL III	69		704.70	692.00	12.70	695.20	2.80	699.20	4.00
NPL III	70		703.70	691.10	12.70	700.00	8.90	-	-
NPL III	71		697.00	688.10	9.00	689.20	1.10	691.80	2.60
NPL III	73		696.00	689.60	6.40	692.20	2.60	693.00	0.80
NPL III	74		701.30	690.00	11.30	693.10	3.00	693.80	0.70

6.0 BALLOKI-SULEIMANKI LINK NO.I (B.S.LINK-I)

In 1955, it was planned to undertake construction of B.S.Link-I offtaking from Balloki Headworks for conveying 15,000 cusecs to Suleimanki Headworks. The design data of this Link Canal is as below:-

- Discharge Q ———— = 15,000 cusecs
- Designed bed width ———— = 112 ft.
- Depth ———— = 15 ft.
- Side-Slopes ———— = 1 vertical to 2 Horizontal
- Manning's roughness ———— = 0.017
- Coefficient 'n' (assumed).
- Longitudinal slope ———— = 1 in 8,000
- Free-Board ———— = 1 ft.

After construction of B.S-II Link & remodelling of B.S-I Link, an earthen channel takes off from the Balloki Headworks and carries a total discharge of 18,000 cusecs i.e. 12,000 cusecs for B.S.Link-I, and an additional 6,000 cusecs for B.S.Link-II upto R.D. 73. From Rd.73 to RD. 266 i.e. the B.S.Link-I for a length of 39 miles has a lined section. B.S.Link-II also takes off from RD.73 as an unlined channel[17]. Lining of B.S.Link-I was completed in 1955. On operation it was found that the assumed value of 'n' was too low and even with the encroachment of the entire one ft. free-board, it was not possible for the channel to carry the F.S. discharge. Thus the design was revised to pass a discharge of 12,500 cusecs at a depth of 18 ft. and the revised 'n' value was adjusted at 0.02.

During construction of B.S.Link-I the bottom fill formation was well compacted. Main features of its design are shown in Figure-7. On the section of the channel 1/2 inch blinding layer of 1 in 10 cement-sand was trovelled. This was followed by 3 inches thick layer of pit-sand mixed with cement in the ratio of 1 : 30. The first layer of 2 inches thick tiles was laid on this cement-sand filter. The 12x6 inches tiles were pointed with 1:6 cement-sand mortar. The surface of the tiles was provided with 3/8 inch thick 1:3 cement-sand plaster. It was followed by the second layer of tiles laid on 1/8 inch thick 1:3 cement mortar. The pointing of the tiles was also done with 1:3 mortar. Another change introduced in this lining was that the side-slope was kept as 1 vertical to 2 horizontal. The 1:30 cement-sand drainage filter was connected to a 9 inches bore-hole drilled as deep as groundwater and filled by materials similar to drainage filter. Such drainage bore-holes were drilled 30 to 50 feet apart and constructed on both sides of the lined canal in a staggered position. The lining had 15 feet wide panels which ended upon "Dhomalies" in brick-work.

6.1 Alignment Characteristics of the Link and its Effect on Stability of Lining

At RD.73, i.e. the bifurcation point of B.S.Links I and II, the elevation of water surface was at R.L. 622.11. It was slightly reduced to El.620.62 at the start of the Link-I. The original bed level of El.608.11 was kept nearly the same, i.e. at El.607.90. At this site the natural surface was at El. 647 i.e. about 40 feet above bed level of the Link. The depth started to decline along the canal and at RD.106 its height was reduced to El. 633. Beyond this point due to an escarpment in the topography the ground level suddenly dropped to El. 613 creating a drop of about 20 ft. in natural surface. Thus at RD.106 a Fall of 14 feet had been provided. From this point onward upto the tail of the Link at RD.266 the natural surface remained nearly level so that near the outfall at RD.266 its elevation was 583. The position of natural surface, water and bed level of Link at various RDs. and the position of groundwater is exhibited in Figure-8. The obvious conclusions are that:-

(i) in the length between RD.73 to 106, the natural surface was much above the water surface level of the Link;

(ii) the alignment of the Link generally remained in deep digging upto RD.106;

(iii) the groundwater in the portion from RD.73 to 106 existed 5 to 12 feet below bed level of the Link;

(iv) from RD.106 to Tail the surface water of the Link was a few feet higher than the natural surface. This portion of the Link was generally in filling;

(v) The groundwater existed either at bed level or a few feet higher.

6.2 Hydraulic Changes After the Construction of B.S.Link-II

B.S.Link-II was also taken off at R.D.73 of B.S.I Link. It was an earthen channel with a capacity of 6,000 cusecs. It was aligned parallel to B.S. Link-I at a distance of about 350 feet. Due to similar topographical conditions it had also to be provided with a Fall and its other characteristics about position of natural surface and water level were similar to B.S. Link-I. Its construction created a zone of high groundwater in the full 350 feet width of the land strip between the two Links. These two Links created a new source of recharge which caused the groundwater level to rise. Between R.D.73 to R.D.106 in a length of 6.6 miles, the bed level of the lined Link existed 30 to 35 feet deep below the natural surface. The rise of groundwater played a disastrous role to damage the lining. Whatever programme for annual closure of canals is adopted it can never be possible to decrease the pressure of the water or that of wet soil alongside the lined Link. A visual survey of the lined B.S.Linl-I was carried out in January, 1992. The condition of the lining was noticed

to be horrible. A few photographs depicting the condition of the lining existing on the left side towards Link-II are putforth as Photos No.24 & 25 . The inspection bank is on the right side of the canal. On the downstream of each bridge, damage to lining was noticed as shown in Photo No.26. The cause of this damage can also be attributed to the reduced section at bridges by fluming and its expansion on downstream side. Another design mistake is steepening of side-slope near bridges from normal 2:1 to 1:1 from economic considerations. Almost all the steep slopes along bridges have been damaged. Another serious fault is the pressure of 20 to 40 feet high spoil, just at the left side of the lined canal. During construction of both the Links in very deep digging, the spoil accumulated at the sites as depicted in Photo No.26. Yet another serious cause of damage was the growth of bushes, weeds and small trees on about 3 to 4 feet width of lining near the water surface. Accumulation of salts on the free-board deteriorated the tiles (see Photo No.27). The portion of the lined canal downstream of R.D.106 was generally stable and intact. There was no pressure of spoil there. The canal is generally in filling, and the damages were very minor . These were due to the inflow of rain water and lack of proper drainage of the canal roads from where water seeps down to damage the lining.

6.3 Variation of Groundwater Along the B.S.Link-1

The changes in groundwater levels at some distance along the canal can be recorded with reference to Well Lines and their Wells. In this connection Figure-9 shows the Well lines near and along the Link as NPL V, NPL VI and NPLXII. Some other Well Lines generally start from the middle of the Doab and reach the Sutlej River near Suleimanki. Observations of the records of wells of these Well Lines are available in WAPDA's Basic Data Release No.6. The early records of some of these wells pertain to 1909, 1920 and 1935. Water levels upto 1960 are available for the Well Line NPLXII. These are given in Tables 7,8 and 9. Table-7 gives the observations of 8 wells of NPLV during 1920, 1950 and 1960. Groundwater in 1920 existed at depths of 30 to 35 feet. From 1920 to 1950 i.e. in 30 years, the rise was about 5 to 7 feet. In the next ten years from 1950-1960 the rate of rise increased, resulting in rise of the same order as during the earlier 30 years.

TABLE-7

DATA FROM WELL RECORDS ON WELL LINES IN THE VICINITY OF BALLOKI-SULEIMANKI LINK-I
WELL-LINE NPLV

Well No.	R.L. of Natural Surface	R.L. of G.Water Depths (1920)	G.Water Depths (1920)	R.L. of G.Water Depths (1930)	Rise in G.Water (1920-30)	R.L. G.Water Depths	Rise in G.Water (1920-50)	R.L. of G.Water Depths (1950)	R.L. G.Water Depths (1960)	Rise in G.Water (1950-60)
60.	638.00	598.60	39.40	603.00	12.60	607.00	8.40	613.40	24.60	6.40
61.	631.00	595.00	35.00	599.00	4.00	602.70	7.70	606.90	24.10	4.20
62.	630.80	597.00	33.80	599.00	2.00	603.00	6.00	607.40	23.40	4.40
63.	605.50	590.00	15.50	594.00	4.00	595.00	5.00	600.70	4.80	5.70
64.	622.70	590.00	32.70	617.00	-	592.70	2.70	595.10	27.60	2.40
65.	607.90	591.00	16.50	596.00	5.00	593.60	2.60	597.40	10.50	3.80
66.	-	592.00	-	596.50	4.50	593.70	1.70	596.00	-	2.30
67.	606.80	594.10	12.70	600.00	6.00	-	-	595.00	11.80	-

In Table-8 results of ten wells of NPLXII are shown. Their observation started from 1935 when the original depth was 15 feet. In 1950 during 15 years the rise of groundwater was 3 ft. and between 1950 to 1990, the rise increased considerably. Hydrology Directorate of Punjab Irrigation Department has produced two maps in which the position of groundwater observed at various depths during October, 1977 and October, 1982 is given. Assuming Suleimanki Head as the starting point, the distance of each observation point was checked in miles. Their depths are given in Table-8. From Suleimanki to about 20 miles upstream the order of depth was 5 to 7 feet in 1977 and it increased by about half foot in 1982. At a few points the deepest groundwater was also recorded. The main inference is that now groundwater generally exists at a depth of 5 to 6 feet. In the zone of canal between R.D. 73 to R.D. 106 with 30 feet of digging the lining is under a high pressure of groundwater. There is no record of water depth within the 350 feet wide distance between the two Links. Here not only the head of water must be very high, but the problem of pressure from 30 to 40 feet high surcharge was also faced. The alternative to decrease the water pressure does not appear to be an easy one. The lining is so much damaged that the canal is behaving just like an unlined channel. The difference between the full supply of the link and groundwater is quite small. One can expect very low order of percolation. It is thus suggested to leave this length of lined canal in its present condition. Repair to lining will be a waste of resources.

As to the portion between R.D.106 to tail R.D. 266 the lining is safe. Groundwater is not rising any further. Steps may be taken to carefully dispose off the rain water by maintaining lined catch water drain, collecting sumps & connecting R.C.C. pipes for drainage back to canal.

TABLE NO-8

WELL RECORDS ALONG BALLOKI-SULEIMANKI LINK-I
WELL-LINK NPL XII

Well No.	R.Ls of Natural Surface	R.Ls of G.water Depths (1935) (ft.)	G.Water Depths (1935) (ft.)	R.Ls of G.Water Depths (1950) (ft.)	Rise in G.Water (1935-1950) (ft.)	Rise of G.water Depths (1960) (ft.)	Rise in G.Water (1950-60) (ft.)
65	594.40	580.00	14.40	582.70	2.70	584.00	1.30
64	593.40	581.00	12.40	583.00	2.00	584.70	1.70
63	591.80	578.00	13.80	580.40	2.40	581.70	1.30
62	589.00	574.00	15.00	576.50	2.50	580.20	3.70
61	593.50	577.70	15.70	572.50	- 5.20	585.30	12.80
60	587.70	576.00	11.70	572.90	- 3.10	580.40	7.50
59	586.00	572.00	14.00	571.60	- 0.40	579.40	7.80
58	579.40	576.00	3.70	569.20	- 5.80	580.20	11.00
57	598.00	568.00	10.00	570.50	2.50	578.60	8.10
56	579.40	568.00	11.40	571.70	3.70	574.00	2.30

TABLE NO-9

GROUNDWATER DEPTHS OBSERVED IN THE VICINITY OF LINED PORTION OF BALLOKI-SULEIMANKI LINK-I ON THE RIGHT SIDE OF THE LINK

(SULEIMANKI IS TAKEN AS POINT OF START)

OBSERVATION IN OCTOBER, 1977				OBSERVATIONS IN OCTOBER, 1992			
Distance of observed points from Suleimanki Headworks (miles)	Depth of Groundwater (ft.)		Deepest Observation & distance	Approximate Distance of observed points from Suleimanki Head		Groundwater Depth recorded (ft.) Works (miles)	
2.5	7.0		-	-		-	
4.0	7.9		-	4.0		5.0	
5.0	7.5		-	-		-	
9.0	7.8		-	-		-	
10.0	10.5		-	11.0		8.2	
12.0	10.0		-	-		-	
13.0	7.8		-	13.0		4.3	
14.0	7.7		17.1/04	14.0		6.3	
16.0	4.1		-	15.0		6.5	
17.0	4.7		-	16.0		4.3	
18.0	4.1		-	18.0		6.3	
19.0	2.0		-	20.0		0.7	
22.0	2.2		12/11.4	-		-	
23.0	1.3		9/8.3	23.0		2.5	
25.0	8.0		-	-		-	
29.0	0.8		13.5/3.5	29.0		1.5	
33.0	3.6		-	-		-	
34.0	3.8		-	34.0		3.0	
36.0	3.2		-	36.0		3.5	
37.0	4.0		-	37.0		5.4	
48.0	3.8		-	38.0		3.5	
53.0	21.8	41.0		44.0	20.3	47.7	
57.0	19.0		-	47.0	21.9	45/14	
58.0	18.8		-				

7.0 SIDHNAI-MAILSI-BAHAWAL LINK

Sidhnai-Mailsi-Bahawal (SMB) Link was constructed in 1965 as a part of Indus Basin Project. It takes off from the new Sidhnai Barrage which receives supplies from Haveli Canal and Trimmu-Sidhnai Link. The SMB Link has to feed a few canals before reaching the Sutlej River which is crossed by the Link through a syphon to feed the Bahawal Canal[16]. From the Barrage to R.D.76, it is unlined while from R.D. 76+0 to tail R.D. 376 it is lined. Its discharge capacities in different reaches along its length are as given in Table-10 below:

TABLE-10

HYDRAULIC DATA OF SIDHNAI-MAILSI-BAHAWAL LINK

R.D. of Reach	Discharge (Cusecs)	W.S. Slope (1 in)	Water Depth (ft.)	Bed Width (ft.)	Mean Velocity (ft/sec)	Top Width (ft.)
76 to 96	10,100	10,700	18.00	100	4.13	172
96 to 249	8,900	10,300	17.60	90	4.03	160
249 to 283	4,700	9,600	15.80	50	3.64	113
283 to 376	4,000	9,300	15.60	40	3.60	102

The construction details of its lining are shown in Figure-10. While constructing the link, the filling portion of the section was compacted and the whole section was dressed with 0.5 inch thick 1:6 cement-sand plaster . One layer of tiles, 2 inches thick (12 inches x 6 inches) was laid over the 1:6 cement plaster and pointed with 1:6 cement-sand mortar. The surface of the tiles was again coated with 0.50 inch thick 1:3 cement-sand plaster. On its surface a layer of 1/8 inch thick bitumen was sprayed. It was then provided with another layer of same size tiles pointed with 1:3 cement-sand mortar. This design of lining was different from the earlier linings . A side-slope of 1 vertical to 2 horizontal was adopted and a frictional coefficient equal to 0.02 used. No drainage filter and bore holes as constructed for the B.S Link-I were provided below the lining. Layer of bitumen was used for the first time.The SMB Link from RD.76 to RD 140 was in total cutting and thus its full supply level is equal to the level of natural surface. From RD.145 to Tail at RD 370 the natural surface was below the full supply of the canal. The canal in this reach was thus partly in cut & partly in fill. The nature of the soil along the Link appeared to be sandy and pervious . Throughout the length of the canal, there was no growth of bushes or weeds at the level of water surface, which is a very common phenomenon in other lined canals. There was no high spoil. It seems that the excavated soil was used in the construction of high banks. The depth of groundwater at the time of canal construction existed generally 20 feet below the land surface.

7.1 Study of Rise of Groundwater along the SMB Link

The location of Well Lines and their Wells along the Link are shown in Figure-11. Their position on right and left side of the Link are shown in Table-11 below:

TABLE-11

Sr. No.	Well Line	Well Number and their Location
1.	NPLX	22, 23, and 24 about 4 miles on left Side.
2.	NPLXIV	17 and 18 on Right Side 11, 12, 13, 15, 16, 17 on left side.
3.	NPL XI	23, 24, 25, 26,28, 29, 30, 31, 33, 34, 35 on right side.
4.	CLXIX AND CLXX	have a number of wells of each line close to the Link.

Hydrology Division of the Irrigation and Power Department has produced two Maps showing position of groundwater observed during October, 1977 and 1982. The sites of these observations are not mentioned. Their distance from the Sutlej River was worked out using the scale of the Maps. The depth below natural surface is given in Table-12. In October, 1977 the groundwater existed at a depth of 18 to 33 feet. After five years in October, 1982 there was some minor change but the same is un-perceptible. It seems that the groundwater is still deep after about 28

years of safe operation of the canal. The lining is in perfect condition. The reasons for the safety of the lining against any damages, are obvious as explained above.

TABLE NO-12

DEPTH OF GROUNDWATER AS PLOTTED BY HYDROLOGY DIVISION OF IRRIGATION AND POWER DEPARTMENT (PUNJAB) (INVICNITY OF S.M.B.LINK)

OCTOBER-1977 Distance from Canal (miles)	Depth of G.Water (ft.)	OCTOBER-1982 Distance from Canal (miles)	Depth of G.Water (ft.)
1	-	1	9.70
2	-	2	12.70
3	-	3	11.50
6	18.00	6	-
8	18.00	8	-
-	-	9	20.00
12	33.00	13	35.00
18	33.20	18	33.20
29	20.10	29	18.20
29	28.80	-	-
36	34.20	-	-
-	-	40	25.60 Right Side
-	-	40	30.20 Left Side
-	-	40	22.00 Right Side
44	31.00	-	-
-	-	47	28.60 Right Side
56	19.00 Right Side	-	-
56	27.00 Left Side	59	23.00 Right Side

8.0 HEAD RACE CHANNELS OF CHICHOKI MALLIAN AND SHADIWAL HYDEL STATIONS

Chichoki Mallian Hydel Station was constructed in the years 1954. By that time the results of tests on various designs of lining were available. It had been noted that lining with 0.5 inch thick 1:3 cement-sand plaster, yielded seepage under a head of water from 10 to 15 feet. Laboratory experiments had indicated that a layer of 1/8 inch thick 30/40 grade bitumen layer was very helpful to reduce percolation. The Engineers planning the construction of the Hydel Station decided to conduct a few experiments on different lining alternatives at the Chochoki Mallian Hydel Channel. They found that the type of double- tile lining with impregnation of 1/2 inch thick 1:3 cement-sand layer and with a layer of 1/8 inch thick bitumen was very stable. They, however,introduced two more variations. One of the variations was a 3 inch thick 1:3 cement-sand plaster layer; the other was bore holes filled with sand to drain the seepage behind lining into the underground formation. Mr. Farrent who was then Director, Irrigation Research Institute and had returned after lining of Thal Canal, supported the idea. The final design of the Lining thus evolved is shown in Figure-12. Later on this very design was adopted for the lining of B.S. Link-I without the use of the impregnated bitumen layer. Without considering the implications of providing bore-holes for drainage it has been used in all lining projects designed by WAPDA including part of the Chasma Right Bank Canal Stage I&II, and some other lining/drainage projects.

9.0 PEHUR HIGH LEVEL CANAL

Pehur High Level Canal is located in the Mardan District of NWFP. It takes off from the right bank of Tarbela Dam. It is a lined canal with hydraulic data as under:-

i) Discharge	=	750 cusecs
ii) Bed width	=	10.75 ft.
iii) Depth	=	10.76 ft.
iv) Water Surface Slope	=	1 in 5,000
v) Flow Velocity	=	6.5 ft./sec.
vi) 'n' value	=	0.015

Nineteen miles of this canal are lined. Its design is identical to Haveli Canal without reinforcement i.e. double layer of brick tiles.

10.0 AKRAM WAH OR "LINED CHANNEL" (IN SINDH)

This canal takes off from the left bank of Indus river, upstream of Ghulam Mohammad (Kotri) Barrage. With a Full Supply Discharge (F.S.D.) capacity of 4,100 cusecs, the 'Lined Channel' serves a perennial Culturable Commanded Area of 4,87,000 acres. The canal, with a total length of 76 miles, was lined in its first 38 miles in the head reaches to reduce the seepage losses and to control waterlogging in the most fertile and irrigated areas.

The lining partly comprised plain cement concrete, 4 inches thick on the bed and 5 inches thick on the sides; and partly brick-tiles. The lined section was designed for a Manning's 'n' = 0.016 for cement concrete and 0.018 for brick lining. The construction work on the lined canal was started in 1951 and it was opened for irrigation in Rabi season of 1957. Previously there used to be no Rabi cultivation in the tracts of the commanded land at all but later assured perennial supplies brought large areas under improved agriculture.

Towards the middle of sixtees, the lined panels of Akram Wah Canal, particularly those at the site of digging, were observed to be highly damaged. Full concrete slabs were completely disintegrated and dislodged. The main cause of this damage was the high groundwater table, a typical and common problem in the deltaic areas of Sindh. This problem particularly in the areas adjacent to this canal caused saturated sub-soil water pressure on the lining,which resulted in damage to panels.
During the canal closures (1992), the damaged portions were seen repaired by loose stone pitching and also by pressing loose bushes. Since no appropriate measures were adopted to check or intercept the sub-soil water pressures, the damage continued to escalate in intensity with the passage of time and consequently almost whole of the lined portions were damaged. At present almost the entire lined portion of this canal is covered with stone-pitching. It is not known if any programme for repairs to this lined canal has been finalized.

11.0 CHASHMA RIGHT BANK CANAL

As its name implies the Chashma Right Bank Canal (CRBC) takes off from the right flank of Chashma Barrage located on the Indus River with a head capacity of 4,879 cusecs. The canal, as a part of the Chashma Right Bank Irrigation Project (CRBCIP) is presently under implementation according to a 3-staged construction programme. The Stage-I of the canal upto the first 52 miles length alongwith the associated distribution system, stands completed and commissioned since Feb. 1987. The distribution system under this stage covers a CCA of 140,000 acres in the D.I.Khan District of the NWFP, and essentially comprises the remodelled Paharpur Canal and four new distributaries.

Execution of CRBC Stage-II extending over the next 24 miles has been completed in July, 1992. This stage is proposed to serve a CCA of 90,000 acres by virtue of a distribution system comprising 11 distributaries. The main canal and the related distribution system has been commissioned with effect from May, 1993.
Stage-III comprising the remaining 94 miles is still in the design stage. It is likely to be started in September, 1993 & completed by the end of the year 2000.

11.1 Design features-Stage-I & Stage-II

The main canal has been designed as unlined channel from RD. 0+000 to RD. 120+000. The reach from RD.120+000 to RD. 210+000 has been lined with double-layer 12"x 6"x2" brick tiles. The reach from RD. 210+000 to RD. 378+5000 is mostly designed as a fully concrete lined channel.
The unlined canal section in the above mentioned reach is basically designed on Lacey,s Regime Theory. A silt-factor of 0.97 was used after study of the design parameters for the C.J. Link offtaking from Chashma Reservoir on the left bank of Indus River in addition to other data.

The lined sections of the CRBC have been designed on Manning's formula with:

'n'	= 0.016
D	= 16 ft.
B/D	= Varying from 3.5 to 2.95
L.Slope	= 1 in 14,000 for the reaches RD. 120+000 to Tail RD.378+500.

Side-Slopes

The original section of the canal had a side-slope of 1.5:1 from RD. 0+000 to RD. 135+000 and 2:1 from RD. 135+000 to RD. 846+000 as per PC-I Proforma (Draft) of October, 1979. It was, however, changed to a uniform side-slope of 1.5:1 as per instruction of the High Level Technical Committee (GOP) as a cost reduction measure and the same was adopted for the canal sections incorporated in the revised PC-I Proforma of May, 1981. However, in the canal reach from RD. 210+000 to RD.

260+000, side-slope of 2:1 was retained since the works in this reach had been awarded and made substantial progress prior to formation of the High Level Technical Committee.

11.2 Canal Alignment

In view of the peculiarities of the terrain traversed by the canal and the canal safety, it was decided to align the canal so that the FSL was more or less at the same level as the NSL. In other words the water prism in the canal was set mostly in cut except in the depressions where the canal would be in filling.

11.3 Type of Lining

Double-layer brick tile lining with 1:3 cement-sand plaster has been adopted from Rd.135+000 to RD.210+000 while concrete lined section has mostly been adopted for the rest of the canal i.e. RD.120+000 to RD.135+000 and from RD.210+000 to RD.378+500 except for two short reaches of 13,360 ft. (between RD.260+000 and RD. 273+360) and 8,679 ft. (between RD. 244+721 and RD. 253+400) wherein brick tile lining had been placed prior to the decision for adopting fully concrete lined section in accordance with the recommendations of the various Specialists.

The design of brick tile lining for CRBC was firstly kept similar to Balloki-Suleimanki Link-I. Its main features are exhibited in Figure-13. The soil formation used in filling was compacted as per practice, over which 3 inches thick sand stabilized with cement (1:3 cement-sand mix) was used as the sand filter. This was coated with 1/4 inch thick 1:8 cement-sand plaster. The first layer of tiles 12x6x2 inches size was laid and pointed with 1:8 cement-sand mortar. The previous practice was to use a 1:6 cement-sand mix both for plaster and pointing. The impervious layer as usual was 0.5 inch thick layer of 1:3 cement-sand mix. A second layer of tiles of the size similar to first layer was laid on this plaster and pointed with 1:3 cement-sand mortar. At the toe of the sides a sand stabilized layer similar to that laid below the lining was spread throughout its length. The size of this deposit of sand was 9-inches wide and of the same depth. Every 100 feet apart a 9-inches diameter hole was drilled 50 to 70 feet deep to reach the sand bed. This hole drilled without casing was then filled by pie-size gravel to work as pervious medium as to carry the seepage water down to the sand deposit. This design of lining was implemented from RD.260 to RD.263 and from RD.265 to RD.268/269.

The procurement of suitable tiles became a problem and,therefore,it was decided to eliminate both the layers of tiles as well as the 1:3 cement-sand plaster. Instead, 1:3:6 cement concrete was laid on the stabilized layer of 1:30 cement-sand filter. The provision of horizontal filter medium at the toe of the sides and the bore-holes was maintained as in the pervious design.

11.4 Some Problems Noticed During the Lining of CRBC Stage-II

In the beginning of 1989, an inspection of the lining was carried out. The lined panel near RD.262 from bottom to a height of about 3 to 4 feet along the sides was observed to be quite wet. On inspection of the area, it was noticed that the source of seepage causing the wetness was a small water course about 110 feet away from the lining which was constructed by the Contractor to carry water for construction. Examination of the sub-soil formation indicated it to be relatively a low permeable medium below the bed of the lining. It appeared that the seepage could not move down into the formation. Even the existence of horizontal filter along the toe of the sides and the drainage bore holes were not effective to dispose off the seeping water, appearing below the lining, down to deeper formation. During field visits it was also noticed that at RD.273, wet soil was slipping down with oozing of water. The soil was slipping and accumulating on the bed of canal. A labourer who moved towards the wet soil, got his foot sunk into the soil. This condition is exhibited in Photo No.28. It was noticed that the Contractor had built a small water tank near this site and water was seeping into the formation from this source. At this location the lining had yet to be constructed. The wetness conditions were witnessed by WAPDA Soil Experts, Drainage Engineers and the Consultants to WAPDA. Different proposals to replace the slushed unconsolidated soils were putforth. The proposals were still under examination when in September,1989 it was reported that cracks appeared on the lining. These were examined in the month of October, the same year. It was noted that:

i) Cracks existed on both types of lining with concrete and tiles;

ii) Their usual height was 3 to 5 feet above the toe of the sides;

iii) The cracks were horizontal extending from one end of panel to the other;

iv) Their usual width was 1/32 to 1/16 inches and extended down into the thickness of the lining. In Photo Nos.29 and 30 the cracks on both type of lining are shown. In Table-13, the number of panels,their position and type of lining are recorded. Construction of tell-tale on some cracks was installed. Their examination after a few months showed re-appearance of cracks. The Asian Development Bank Mission during their Mission also noticed these cracks and proposed to get guidance from experts of U.S. Bureau of Reclamation on Soils and Lining.

TABLE NO-13

LOCATION OF CRACKS ON LINED PANELS, AND TYPE OF LINING ON THE DAMAGED PANELS (CHASHMA RIGHT BANK CANAL-CRBC)

Sr. No.	R.D.	RIGHT SIDE		LEFT SIDE			
		No. of Panel With Cracks	Distance of Crack above Toe of Lining (ft.)	Type of Lining	No. of Panel With Cracks	Distance of Crack above Toe of Lining (ft.)	Type of Lining
1.	260-261	17-27 (11)	4 to 6	Tile	15-27 (13)	4	Brick Tile
2.	261-262	1-67 (68)	3 to 5	Tile	1-67 (68)	3 to 3.5	Brick Tile
3.	262-263	1 (1)	3	Tile	85-87 (2)	15.75	Concrete
4.	263-264	-	-	-	6-59 (16)	4 to 5	Concrete
					98-100 (2)	3.5	Concrete
5.	264-265	2-8 (4)	4	Concrete	1-85 (13)	3.5	Concrete
6.	265-266	23-24 (2)	4	Concrete	13-16 (3)	3.5	Concrete
7.	268-269	16-30 (13)	4 to 5	Concrete	31-39 (4)	3.5	Brick Tile

11.5 Arrival of USBR Experts from United States

Mr. William Cowan and Paul C.Knoddl of U.S. Bureau of Reclamation (U.S.B.R.) arrived in Pakistan in August, 1990. They were provided with complete data about the type of lining carried out. They visited the site and became acquainted with the site and the problems of the lining. They travelled along the lined CRBC Stage-I and via Chashma Barrage also drove along the lined Thal Main Line Lower and Upper to see its damaged lining. The Consultants were satisfied with the excellent studies performed in Pakistan by various engineers and organizations and felt no necessity for any further investigations.

11.6 New Design of Lining For CRBC

The advice of the USBR experts on which construction was immediately started included:

i) Construction of lining with 4 inches thick 1:2:4 cement concrete panels/slabs to be laid directly on dressed soil, eliminating the sand filter under the lining (Figure-14);

ii) Each panel/slab was to be 10 feet wide and about 33 feet long (along the sloping sides of canal);

iii) The ends of the two panels were to lie one in front of the other i.e. just adjacent to each other with no bottom support of Domalies to be provided under these panel joints, i.e. the two panel ends would rest directly on soil formation;

iv) No expansion joints were to be provided in the lining;

v) Although the results of the analyses of internal friction and cohesion of the

soil were provided to the Experts, they still recommended a side-slope of one horizontal to 1.5 vertical.

vi) The provision of sand filter below the panels was considered unnecessary. Instead, it was recommended to dig in the middle of the panel a hole 2.5 ft. wide, 2.5 ft. high and 2 ft. deep into the soil. it was to be provided with 3 inches thick layer of sand. The remaining portion was to be filled with pie-size gravel. In the center of this filter a G.I.Pipe, 2.0 inch diameter with drilled round holes was to be provided. The pipe projected about 3 inches beyond the surface of the concrete slabs. A stainless steel flexible flap valve was to be provided on this pipe . The size of the drainage hole and the projecting end of the G.I. Pipes are shown in Figure-14.

11.7 Possible Problems with the Revised Design of Lining for CRBC

As soon as recommendation for the alternative design of the lining were received, these were implemented at site without consideration of their advantages and/or disadvantages towards the solution of the problems.
A few points about this new type of lining are laid as under:

i) There are no Dhomalies at the end of concrete panels. The ends of panels lie together without any joints. The hair cracks of the panels will be a source of seepage. The soil under-neath may become wet. The flowing water will suck out this wet soil and after some time cavities can form under the joints of the panels (see Photo No.31).

ii) Each panel is 10 feet wide and 30 to 33 feet long without any expansion joint. The top two feet free-board during summer will attain a temperature of 140°F while the lining under water will have a temperature of 50°F. This differential of temperature may result in cracks.

iii) The serious problem is the stability of lining under the back pressure of water and wet soil. Will the small drainage hole of two inches dia. size release the pressure when the canal is suddenly closed?

iv) The water and wet soil pressure may damage concrete panels. One such damage is exhibited in Photo No.32.

v) The relative strength of the 4-inch thick concrete panels made from either 1:3:6 or 1:2:4 concrete needs examination under water pressure from behind the lining under worst saturated condition when the canal is empty and full depth of canal is exposed to damage.

vi) Although the results of the analyses of internal friction and cohesion of the soil provided to the soil experts suggested side-slopes even flatter than 1 to

2, yet they still recommended a side-slope of 1 horizontal to 1.5 vertical. It is considered that this side-slope of 1:1.5 may not warrant stability of canal against worst condition of floods and/or high groundwater with the resulting pressure from saturated zone behind the canal lining.

Unfortunately problem have been observed even on the CRBC lining constructed as per revised design under advice of the USBR experts. Site visits to examine the lined panels were carried out following the completion of lining and a number of cracks and damages were noticed on the unlined and lined panels as indicated in Photo No.33.

12.0 LINED CANALS ON WARSAK DAM SYSTEM (NWFP)

Kabul River Canal getting diversion through a tunnel from the Warsak Dam lake on Kabul river bifurcates into Warsak Gravity Canal and the Warsak Lift Canal (Figure-15). A brief account of lining of the two canals follows:

12.1 WARSAK GRAVITY CANAL

12.1.1 General

The Warsak Gravity Canal traversing through the city of Peshawar is about 29 miles long and has been a constant source of seepage causing waterlogging in the areas on its both sides. Foundations of several houses and building in the adjoining areas were reported to be severely impaired causing collapse of some and cracks in others. The NWFP Irrigation Department had, therefore, plans to line this channel and also to beautify it from recreational point of view since it passes through the city.
Lining of Warsak Gravity Canal from RD. 58+000 to RD. 82+000 was carried out in two phases. In first phase reach between RD.78+000 and RD.82+000 was undertaken during one annual closure. In second phase reach between RD.58+000 to RD.74+000 was tackled in two annual closures. Salient features of lining are:

12.1.2 First Phase RD.78+000 To RD.82+000

a) **Bed and Slopes**

In this reach, 1:3:6 P.C.C. lining was adopted having a thickness of four inches. Side slopes were kept as 1.5:1.

b) **Treatment of Slope above the F.S.L.**

In certain reaches, channel is passing through deep cutting and rain wash from high banks enters into the channel and thus adversely affects its efficient operation. Certain proposals were pondered over to combat this menace and these included:

i) Turfing
ii) Providing Shrubs
iii) Providing Soil Cement (1:10) Cover and
iv) Covering of slopes with boulder-pitching (in cement mortar).

It was decided to pitch cover the slopes with uniform and small size boulders which treatment gave a good look and also checked the side-erosion.

12.1.3 Second Phase RD.58+000 To RD.74+000

a) Reach RD.58+000 to RD.67+000

This reach passed through heavy cutting and it was decided to provide it with lining and cover it with arches so that gardens could be grown on the levelled top of these arches and these provide recreational facilities to the inhabitants of the area. In this reach P.C.C. lining, 4-inch thick, was provided in the bed whereas vertical abutments, in bricks, were constructed on the side so that arches could be supported on the same.

b) Reach RD.67+000 to RD.74+000

In this reach the lining comprised 4 inches thick 1:3:6 P.C.C. with side-slopes of 1.5:1, and treatment to the slopes above F.S.L. being replicated as narrated in para 12.1.2(b).

12.2 WARSAK LIFT CANAL

Warsak Lift Canal, with a perennial discharge of about 200 cusecs at its head, had also to be lined in certain reaches under the Command Water Management Project (CWMP). The topography and setting of the canal was such that diversion could not be built for lining the existing channel in dry and perforce the work had to be done during the winter annual closures of about 30 days. After closure the canal would take about 7 to 8 days to dry up and for lining the earthen section had to be tightened. Tightening of the section with compacted earth over the wet bed and sides of the channel resulted in slushy conditions and lining over such surface would settle and crack. To overcome this difficulty, an idea was mooted to try river/nullah pit gravel stabilized by mixing with cement in a ratio of 1 cement to 20 pit gravel containing sand for tightening the channel section. This innovation worked very well and was welcomed because of the cheapness and availability of pit gravel in abundance in the NWFP and is now being adopted almost everywhere on the lining of distributaries and minors in the province. A typical section showing the arrangement adopted at site is shown in Figure-16, and various design parameters given in Table-14.

TABLE NO.14

STATEMENT SHOWING PARTICULARS OF LINING ON WARSAK LIFT CANAL

SR. NO.	NAME OF SUB-PROJECT	NAME OF CHANNEL	DISCHARGE AT BEGINNING OF LINED REACH (cusecs)	LENGTH OF LINING (canal miles)	TYPE OF LINING	TOTAL SURFACE AREA OF LINING (sft.)
1.	Warsak Lift	Warsak Lift Canal from RD.39+100 to RD. 64+400	172	5.06	P.C.C. (1:3:6)	7,917
		Warsak Lift Canal from RD.101+100 to RD.153+000	95	10.38	P.C.C. (1:3:6)	10,064

13.0 LASBELA CANAL

Lasbela Canal takes off from the Hub Main Canal which itself draws supplies from the Hub Dam Located 35 miles North of Karachi on the Hub River. The Hub Main Canal bifurcates into two canals namely-" Karachi Water Supply Canal" and the "Lasbela Canal" (Figure-17). Hub Dam reservoir has a live storage of 760,000 acre-feet. The planned annual release is of the tune of 193,000 acre-feet. It provides 89 MGD drinking water to the Karachi city and irrigation supplies to 1000 acres of land in Sindh Province, besides 15 MGD water to Hub Industrial Estate and irrigation supplies to 21,000 acres of land in the district of Lasbela of Balochistan Province through Lasbela Canal.

Both Karachi Water Supply Canal and Lasbela Canal were provided with precast concrete 12"x6"x2" double-layer tile lining with a sandwitch layer of 1:3 cement plaster and bituman paper. However, the quality of precast tiles was very poor and were structurally porous, being manufactured with coarse sand and cement (and not real concrete). Lasbela Canal with a designed discharge of 142 cusecs at head is 22 miles long (RD.0-106) with a C.C.A. of 21,000 acres. The canal received its first water delivery in 1988. Its nine minors were stone-lined (with open joints) to resist erosion by excessive velocities. The lining of main canal proved to be porous and leakage therefrom and also from the minors soon resulted in serious waterlogging of the command area. To overcome these problems the canal and its minors were included in the World Bank-financed Command Water management Project (CWMP) (1985-92) and the following treatments were given to the Main Canal and Minors:

i) The bed lining of the canal was overlaid by 2-inch thick P.C.C. 1:2:4 mix with sulphate resistant cement (to safeguard against salinity of soils).

ii) The open joints of the lining were properly racked and pointed with 1:3 cement-sand mortar in the reach RD. 0 to 73+500. The lining surface was

sack-rubbed with neeroo (cement-slurry) to seal the voids.

iii) In the Reach RD.73+500 to RD.106+000 the P.C. tile lining was overlaid by layer of 2-inch thick concrete with sulphate resistant cement.

iv) Lining in sides was raised by 1 foot, with 1:2:4 P.C.C.

v) Six out of nine minors were provided with new 1:2:4 P.C.C. Lining with S.R. cement since the soils in Project area were heavily salt-affected.

vi) Minor No.1 was provided with precast R.C.C. pipe lining during two annual closures.

As a result of all these remedial measures the standing water ponds all along the canal were dried up which proved the efficacy of these improvements.

14.0 SUMMARY OF DISCUSSION ABOUT THE DESIGN, PERFORMANCE AND IMPROVEMENT OF LINED CANALS IN PAKISTAN

14.1 Main Inference From this Study regarding Purpose of Lining Vis-A-Vis Achievements.

The lining of canals has been carried out in Pakistan to reduce seepage, to control water-logging and to improve their hydraulic efficiency. However, sufficient information is still not available about the water saved by lining of canals. The condition of all lined canals has determine the existing order of seepage from each lined canal.

As regards the control of waterlogging, the groundwater at many sites has risen so high that it has damaged the lining thus impairing control on water-logging. In order to provide relief to lining against the rising groundwater, the methods adopted are questionable. These have rather caused quick rise of groundwater. The methods adopted to repair the damaged lining of different lined canals have to be considered in accordance with the site conditions in vicinity of the canals in order to achieve meaningful success. Few suggestions to this effect have been put forth in relation to various lined canals analysed in this paper.

14.2 Outline of Structural Design of Lined Canals

The first lined canal constructed in the area now comprising Pakistan was the Haveli Canal in years 1937-38. In this paper information is given for the existing lined canals so far completed. The canals which are mainly meant for conveying supplies from one river to another are Balloki-Suleimanki Link-I with a discharge capacity of 12,000 cusecs, Sidhnai-Mailsi-Bahawal Link with a discharge capacity of 10,100 cusecs, and Haveli Canal with a capacity of 5,200 cusecs. The lined canals which are mainly used for direct irrigation, include Thal Main Line Upper of 7,500 cusecs,

Thal Main Line Lower of 4,500 cusecs, Mohajir Branch of 1,459 cusecs, Bambanwala-Ravi-Bedian Dipalpur Link of 4,863 cusecs and Chashma Right Bank Canal of 5,000 cusecs. During the last few years some other small canals, distributaries and minors carrying low discharges have also been lined under CWMP & Irrigation System Rehabilitation Project (ISRP). Haveli is the first canal which was constructed with double layer of tiles impregnated with 0.5 inch thick 1:3 cement-sand plaster. Tiles were available at the site alongwith cheap labour to lay the tiles. This type of lining was used for Balloki-Suleimanki Link-1, Sidhnai-Mailsi-Bahawal Link and part of the Chashma Right Bank Canal (CRBC) Stage-I. For certain sites proper tiles were not available. At those sites the bottom layer was constructed with 1:6 cement-sand plaster followed by a layer of 0.5 inch, 1:3 cement-sand plaster and top layer of tiles. This design was adopted for Thal Main Line Lower and Bambanwala-Ravi_Bedian-Dipalpur (BRBD) Link. Thal Main Line Upper, Mohajir Branch, CRBC Stage-II, Warsak Gravity, Warsak Lift and Lasbella are the only canals where cement concrete has been used because the ingredients needed for this type of lining were easily available close to the canal.

14.3 Purpose of Lined Canals

Out of several purposes served by lined canals, the two main advantages of lining are: reduction in seepage and hence saving of water; and prevention of waterlogging of irrigated lands.

It is very unfortunate that after a canal was lined, seldom an attempt was made either to monitor its performance or to estimate its seepage. This is not true only for Pakistan but for India also which has 25 lined canals. Many canals in Indian Punjab are lined with the type used on Haveli canal and CRBC, but no information is available regarding their seepage losses. When lining of Haveli canal was completed ponding tests were carried out at two sites on the canal, but the results were not very conclusive.

Recently lining of minors and small distributaries has been undertaken mainly to reduce seepage losses. A few distributaries and minors have been lined by building new channels along the old ones. After constructing the new lined canals the flows were diverted into the new channels. Ideal conditions were thus available to estimate the seepage loss both from a lined and unlined distributaries under identical site conditions. But serious thought was not given to this important aspect.

The second purpose of lining was to stop chances of groundwater rise, and to control waterlogging. Unfortunately this aim has also not been achieved. Actually the major damages to lining are due to rise in groundwater. Highly damaged linings are those where the groundwater rose so high as to exert hydrostatic and wet soil pressure on the lining during closure of canals.

The purpose of lining would be defeated if the performance of lined canal is not closely monitored in order to assess the benefits accrued from lining and also for proper maintenance of the lined channels.

14.4 Present Damages to Lined Canals and their Causes

14.4.1 Highly damaged portions of lined canals have been observed on Thal Main Line Upper from R.D. 20 to R.D.70. This length of canal started getting damaged after about 17 years of its construction. The sites which were in digging attained high groundwater which continuously caused damage to the lining during the annual canal closures. This condition continued to extend and now about 6 miles of the canal length is highly damaged. Mohajir Branch is another lined canal offtaking from Thal Main Upper. Seventeen miles of this canal are severely damaged. The groundwater before the construction of the canal was 40 feet deep. The construction of canal caused quick rise of groundwater and after about fifteen years, its lining started collapsing due to pressure of high groundwater. At present about 80 percent of the lining is damaged. The lining of both these canals was constructed with 1:3:6 cement concrete.

14.4.2 Yet another instance of highly damaged lining is the seven miles reach of Balloki-Suleimanki Link-I. This portion of the canal is dug 33 ft. below natural surface. After ten years of its construction the B.S.Link-II (an unlined channel) was constructed about 350 feet away from B.S.Link-I. This saturated the land strip in between the two canals which became a high groundwater source to damage the lining of about seven miles of B.S. Link-I from R.D. 73 to R.D. 106. The condition became aggravated due to the 30 to 50 feet high spoil between the two Links, excessive growth of weeds in the top 3 to 4 feet of water surface, improper design of bridge sections which were reduced and then expanded downstream thus creating eddies resulting in further damages to the lining. The natural surface suddenly dropped by about 20 feet at RD.106 so that the condition of the canal changed from digging to filling and the natural ground at places became lower than full supply level of the canal. The lining from R.D.106 to R.D.266 (near tail) is much less damaged inspite of the B.S.Link-II flowing parallel to it at the distance of 350 ft.

14.4.3 Haveli canal lining was completed in 1938. Its groundwater was not too deep. It was, however, rising very slowly. The construction of canal increased the rate of rise and by 1965, when it had been in operation for about 27 years the average groundwater existed at 10 to 13 feet below the natural surface. There used to be minor damages due to high position of groundwater, growth of weeds and small trees at the water surface and deterioration of bricks in the capillary zone. But after the construction of Trimmu-Sidhnai-Link parallel to Haveli at a distance of 350 feet and with its Full Supply Level 2.0 feet higher than that of Haveli, the groundwater position aggravated. The water pressure lifted the lining of the bed of Haveli and the cement pointing was pushed out from the tile joints. Haveli canal is still flowing under these conditions.

14.4.4 Nineteen miles of lined Bambanwala-Ravi-Bedian-Dipalpur (BRBD) Link was constructed 40 years back. It has remained in much better condition because through all these years the groundwater has existed at 15 to 20 feet below natural surface. The long life of its operation has, however, caused removal of the cement pointing from the tile joints. At some places the lining is buldging due to pressure of wet soil.

14.4.5 Out of all the old lined canals, Sidhnai-Mailsi-Bahawal Link has worked most satisfactory for the last 27 years. The main reason for this has been deep groundwater during construction and even now. This can also be contributed to good compaction of embankments and high quality of construction of lining and also provision of bitumen layer between the tiles. There is no growth of weeds at the water surface, and no pressure of spoil. The full length of canal is generally located with water surface either equal to natural surface or higher.

14.4.6 Another instance of undamaged lined canal is Thal Main Line Lower particularly below R.D.68. In this portion the groundwater has remained deeper than the bed level during all the past 42 years and the canal is mainly in filling, being slightly higher than the sandy soil around.

15.0 RECOMMENDATIONS FOR INTRODUCTION OF SOME CHANGES TO IMPROVE LINING PERFORMANCE

15.1 Use of Bitumen in Double Tile Lining

Various designs of lining have continued to be tested in Laboratory. It was found that double tiles with impregnation of 0.5 inch thick 1:3 cement-sand plaster gave lesser seepage under water head of 10 to 15 feet. However, it has been noticed that provision of a thin coat of 1/8- inch thick bitumen considerably reduced the seepage even under high water-heads. The bitumen layer was thus provided in the lining of Sidhnai-Mailsi-Bahawal Link, which turned out to be the only canal in which the lining is still intact in good condition. It is worthwhile to give serious thought for introduction of such bitumen impregnated layer in the lining of future canals.

15.2 Drainage Measures for Release of Water Pressure

In order to provide drainage relief against high water pressure a 3 inch thick pervious layer of sand stabilized by mixing with one part cement and 30 parts sand was considered very appropriate for release of water pressure. A pipe filled with gravel and located as shown in Figure-18 could be of help in the drainage of the sandy filters. The pipe has a flap to close under water pressure and open during drainage. Instead of this device, a bore hole of 9 inches in diameter and reaching the water table or sandy bed was provided every 50 or 100 feet apart along the toe of the sides in some canals. This arrangement was tried under the Head Race

Channel of Chichoki Mallian and in the lining of Balloki- Suleimanki Link-I. It was adopted in some projects of WAPDA such as CRBC Stage-I and part of CRBC Stage-II and also other Drainage Projects such as SCRAP-VI. This arrangement has the main disadvantage that it provides a means for the seepage water from the lined canals to directly contribute to underground formations. Thus the purpose to drain out the water during canal closure is defeated. During the operation of the canal, seepage continues to be added to the underground formation causing quick rise of groundwater. This arrangement needs to be discouraged in future.

15.3 Use of Dhomalies Under the Panal Joints

Construction of a lined canal, is divided into panels generally 10 feet wide. Previously the ends of the panels rested on Dhomalies usually 9 to 13 inches wide with one brick at top. It was soon realized that this type created two hair cracks. Top brick was therefore removed to reduce the hair cracks to one as shown in Figure-19.

Recently U.S. Experts in their revised design for CRBC Stage-II have completely eliminated the Dhomalies so that the ends of every two panels now directly rest on the soil. The possibility of development of hair cracks exists due to absence of Dhomalies. Water will seep through the cracks at the panel joints, and the same will wet the soil underneath which in turn will be sucked by flowing water in canal, thus resulting in formation of cavities. It would be safe and advantageous to revert back to use of Dhomalies.

15.4 Minimization of Present Seepage Loss from Lined Canals

It has already been pointed out that in some of the canals lining is so highly damaged that the canals are behaving like unlined channels. The seepage is being controlled by the soil formation which is now subjected to a lower water head as the difference between canal full supply levels and the groundwater level is very small. There are so many organizations conducting research on many aspects of irrigation. This is an important problem, research on which will clarify the present loss of water from the damaged lined canals. Use of sealing materials in flowing water my prove effective and should be tried in checking the seepage.

16. A FEW SUGGESTIONS TO RECTIFY DAMAGED LINED CANALS

It has been mentioned that highly damaged linings are:-

(i) Thal Main Line Upper-R.D.20 to R.D.70;

(ii) Mohajir Branch-full 17 miles of Lining.

(iii) Balloki Suleimanki Link No.1-from R.D.73 to R.D.106.

(iv) Haveli canal-full length.

Considering their site conditions and the causes of damages, some suggestions for their rectification are put forth as under:

16.1 Repair to Lining of Thal Main Line Upper

(i) Lining of this canal is highly damaged from R.D.20 to R.D.70. So far its repair has been carried out by lining the damaged panels by stone- pitching with large size (one cubic foot) stones on the sloping side (see Photo Nos.8 and 9). The joints and crevices in between the stones were not properly filled and cemented with cement-sand mortar of proper and/or required specification to provide sufficient bond between the stones. The stones kept falling on the bed. It is suggested that the sites where the original concrete lining has been highly damaged, may be provided with a 3 inches thick layer of 1:3 cement-sand plaster. It may then be followed by 3 inches thick layer of 2 to 3 mm gravel, which may be followed by placement of stones already used at site. Thus stones lying in the bed of the canal may also be used. This type of filter under the stones will release the high water pressure. Further improvement is also possible by renovating the choaked drain existing between the spoil of the canal and the Mianwali-Kalabagh road. All the choaked syphons may also be cleaned up.

(ii) Another effective suggestion is to install a system of shallow tubewells. Its design is given in Figure- 6. A 4-inch diameter horizontal pipe 100 ft. long connected to multiple vertical strainers each 10 ft. long and 20 ft. apart from the other , may be installed 2 to 3 feet below water surface (at the same depth below natural surface). A pumping set will withdraw groundwater from the sub-soil formation in the vicinity of canal. A similar tubewell may be installed towards downstream of the canal and both these pumped by the same pumping set. The water pumped may be used for irrigation of the adjoining lands. Two such tubewells can be effective in a length of one mile. Installing this system on both sides of the canal may be very useful. These wells may operate during the period approaching the canal closure.

16.2 Repair to Lining of Mohajir Branch

The full 17 miles length of lining of this canal is highly damaged. The present site conditions include high pressure of groundwater causing damage to the lining. Any portions of undamaged lining can be saved by providing extensive weep holes. Actually this canal needs full investigation before a counter measure can be suggested.

16.3 Protecting Lining of B.S.Link-I From R.D.73 to R.D.106

The canal from R.D.73 to 106 is very deep below natural surface and groundwater

is so high that no simple device will protect the lining. Provision of extensive system of weep holes to reduce water pressure may prove of some help. Use of under-water lining is being tried in U.S.A. which could also be tried in Pakistan. Present condition of lined canal needs detailed investigations.

16.4 Protecting Lining of Haveli

This lined canal is subjected to high pressure of groundwater under the influence of T.S. Link flowing close by its side. It is worthwhile to examine the possibility of installing an interceptor type tubewell as shown in Figure-5 about 50 feet from the Haveli canal along its spoil. This device will lower the high groundwater and reduce the damages. This lining also needs intensive drainage by weep holes.

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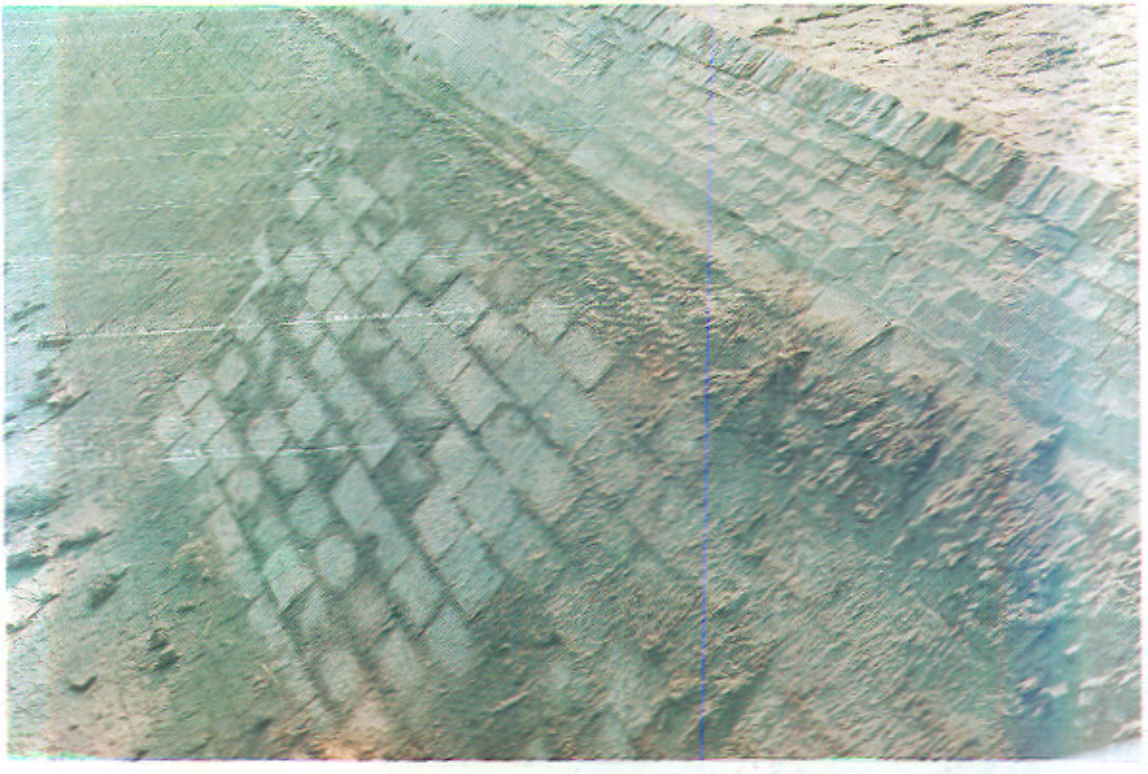
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HAVELI CANAL

Photo No.1: Extensive Weeds Growth-Concrete Tiles Used for Repair.



HAVELI CANAL

Photo No.2: Damages Repaired by Tiles



HAVELI CANAL

Photo No.3: Damage at 1/3 depth of Sides. Filler Material Removed, Weed Growth and Free Board Damaged



HAVELI CANAL

Photo No.4: Lining of Canal Bed is Lifted.

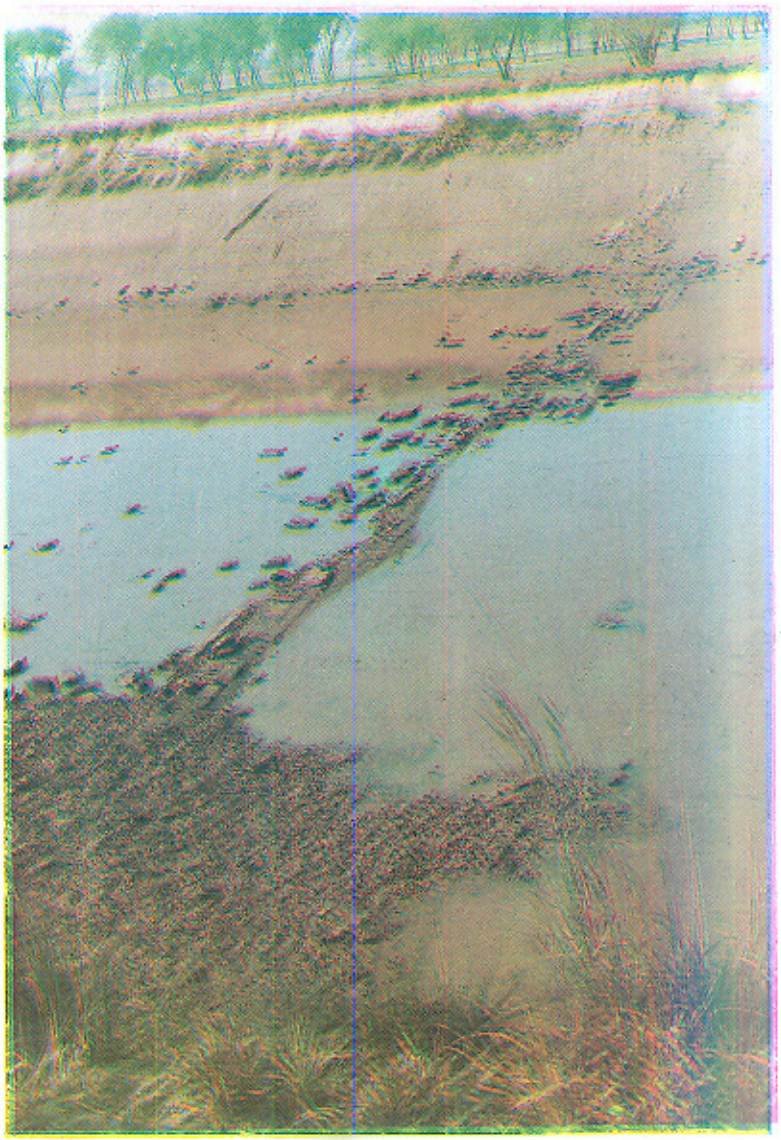


HAVELI CANAL

Photo No.5: Water Pressure Damaged the bed as well as the sides. Damages by Weeds growth and Soil Salinity.

HAVELI CANAL

oto No.6: Damaged Lining at 1/3
es, Weeds Growth, Bed Lining
naged by Upward Pressure.





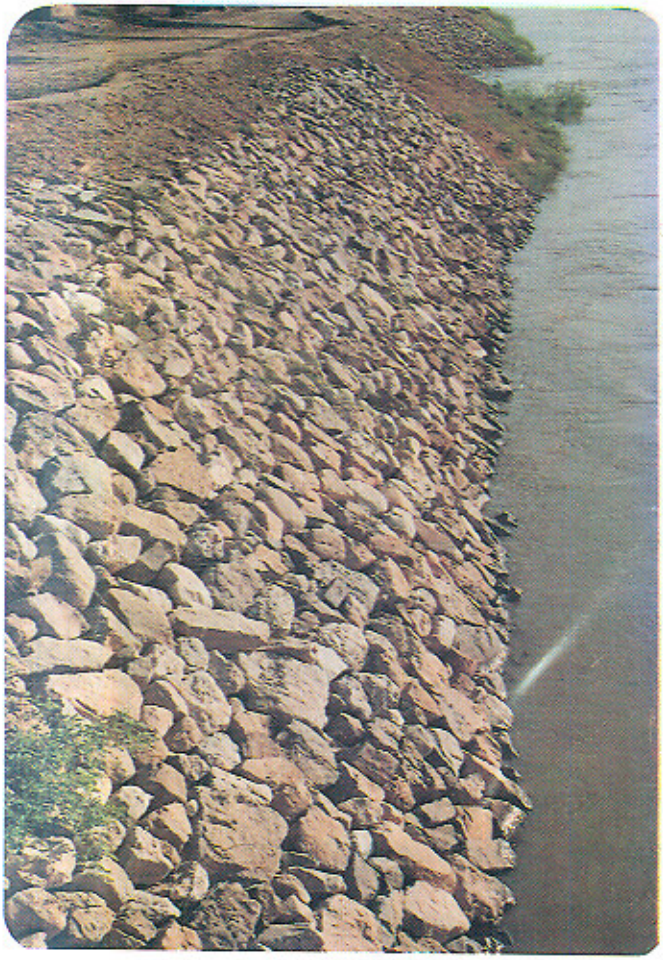
HAVELI AND T.S.LINK

Photo No.7: Land Between Haveli and T.S.Link is 350ft wide and Highly Waterlogged/Salinized



THAL MAIN LINE UPPER

Photo No.8: Stone Pitching along sides is in Progrss



THAL MAIN LINE UPPER

Photo No.9: Large size stones pitched on sides without filler materials.



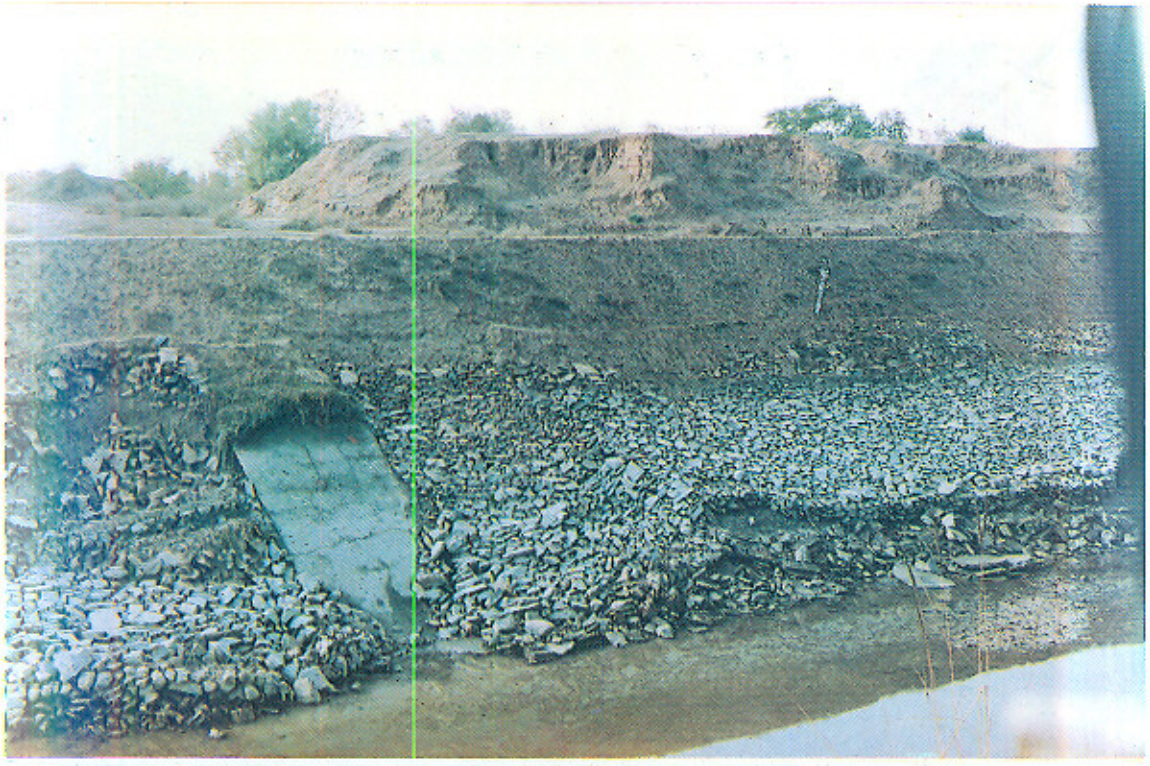
THAL MAIN LINE UPPER

Photo No.10: Big Embayments formed along sides. Dumped Stone Slipping in the Bed of Canal



THAL MAIN LINE UPPER

Photo No.11: Several Layers of Stone Visible



THAL MAIN LINE UPPER

Photo No.12: Pitching of Sides with Cut Stones without pointing



THAL MAIN LINE UPPER

Photo No.13: Pointed Stones do not generally get damaged



MOHAJIR BRANCH

Photo No.14: Nearly 80 percent of lined panels are damaged from top to bottom. Canal is partly in filling and digging.



MOHAJIR BRANCH

Photo No.15: i) All panels are damaged
ii) Damage Extends from top to toe of the Lining
iii) Damage at top of panel is extensive



MOHAJIR BRANCH

Photo No.16: Damaged Panels



MOHAJIR BRANCH

Photo No.17: Repaired Panels Again Damaged



THAL MAIN LINE LOWER

Photo No.18: The Plastered surface of Lining was quite irregular with cuts and depressions



THAL MAIN LINE LOWER

Photo No.19: Plastering of Surface seemed to be an old Practice. This plaster is also erroded.



THAL MAIN LINE LOWER

Photo No.20: Two and a half inch cement sand plaster, mix ratio 1:4 spread on surface of earlier plaster without any provision of its bond with the old plaster.



THAL MAIN LINE LOWER

Photo No.21: During closure the canal always contains some water, the lower three to four feet is kept unrepaired



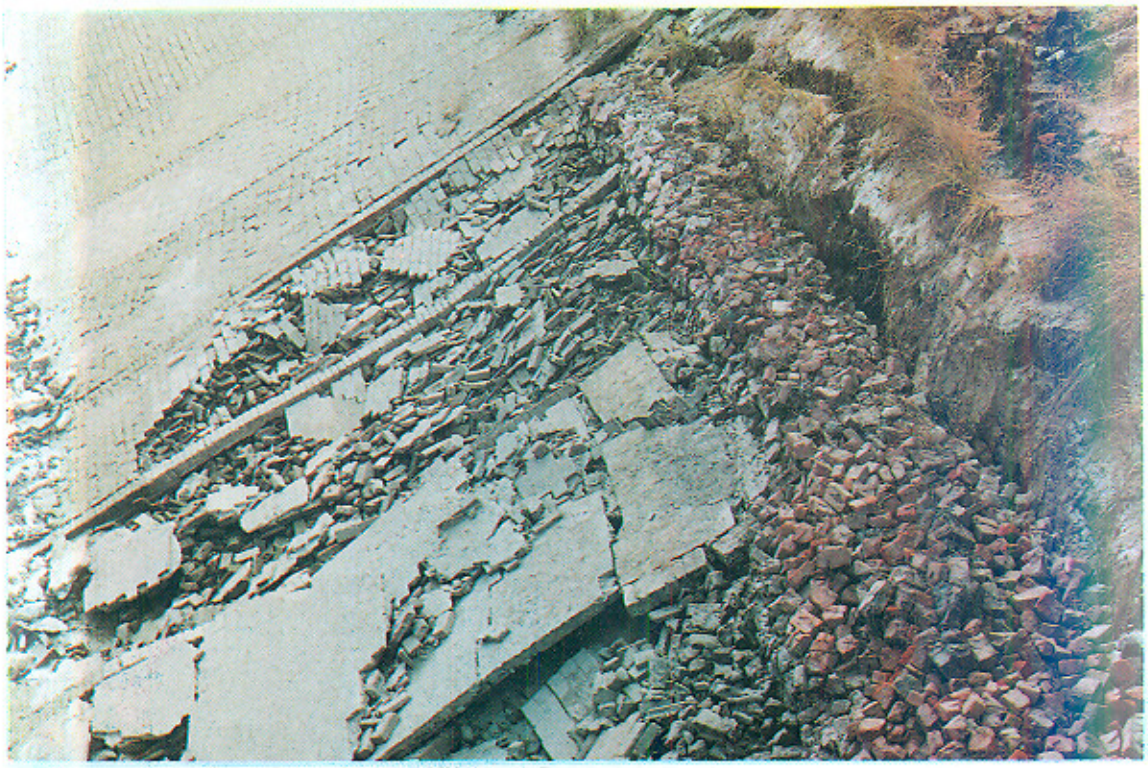
B.R.B.D.LINK

Photo No.22: Damaged Lining with Growth of Weeds near Free Board



B.R.B.D.LINK

Photo No.23:Buldging/Removal of Pointing, Damage at about 1/3 height of Lining.Weeds Growth,salt-affected tiles on the free-board.



BALLOKI SULEMANKI LINK NO.1

Photo No .24 : Damaged Panels of Lining by Soil Water Pressure.



BALLOKI SULEMANKI LINK NO.1

Photo No.25 : Damaged Panels of Lining by Soil Water Pressure.



BALLOKI SULEMANKI LINK NO. 1

Photo No.26: Damages to Lining Downstream of Bridges due to expansion of width of Canal. Excessive pressure of high spoil and high sub-soil water.



BALLOKI SULEMANKI LINK NO.1

Photo No.27: Weeds growth and fungus formation combined with rainfall water causing deterioration of lining.



C.R.B. CANAL

Photo No.28: Slushed Side Wall of C.R.B.Canal due to Seepage



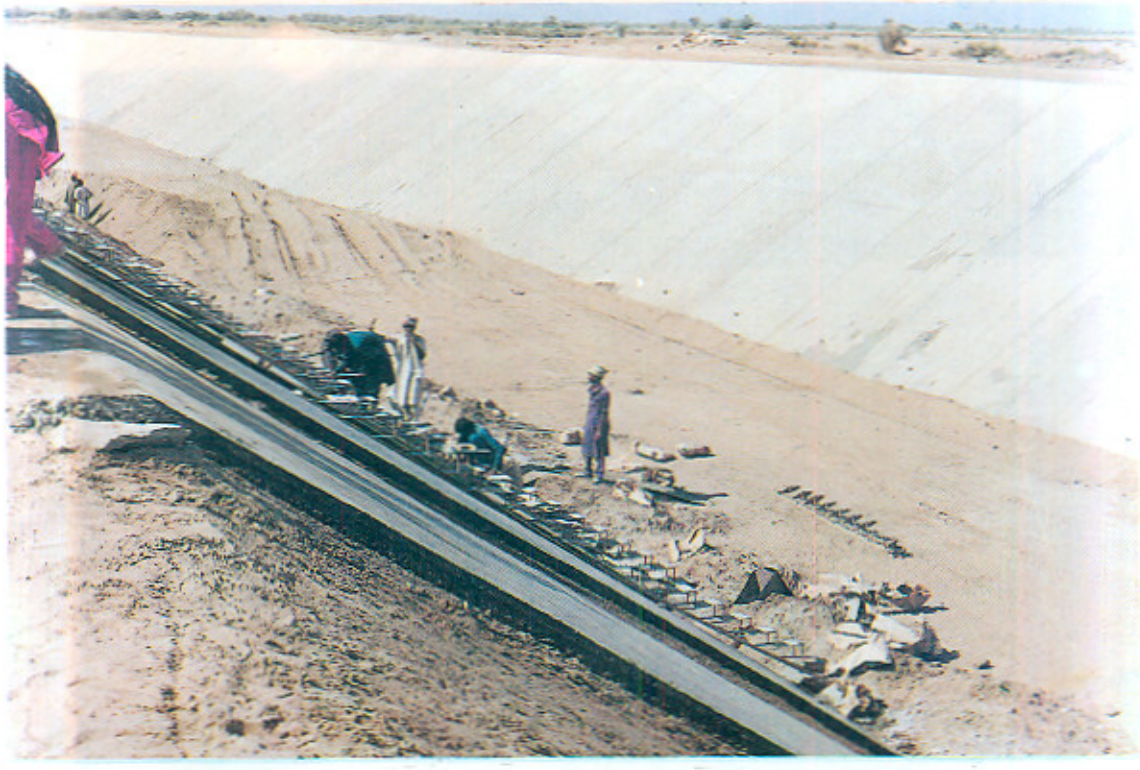
CRBC STAGE-II

Photo No.29: Crackson Concrete Lining of CRBC.



CRBC STAGE-II

Photo No.30: Cracks on Tiles Lining of CRBC.



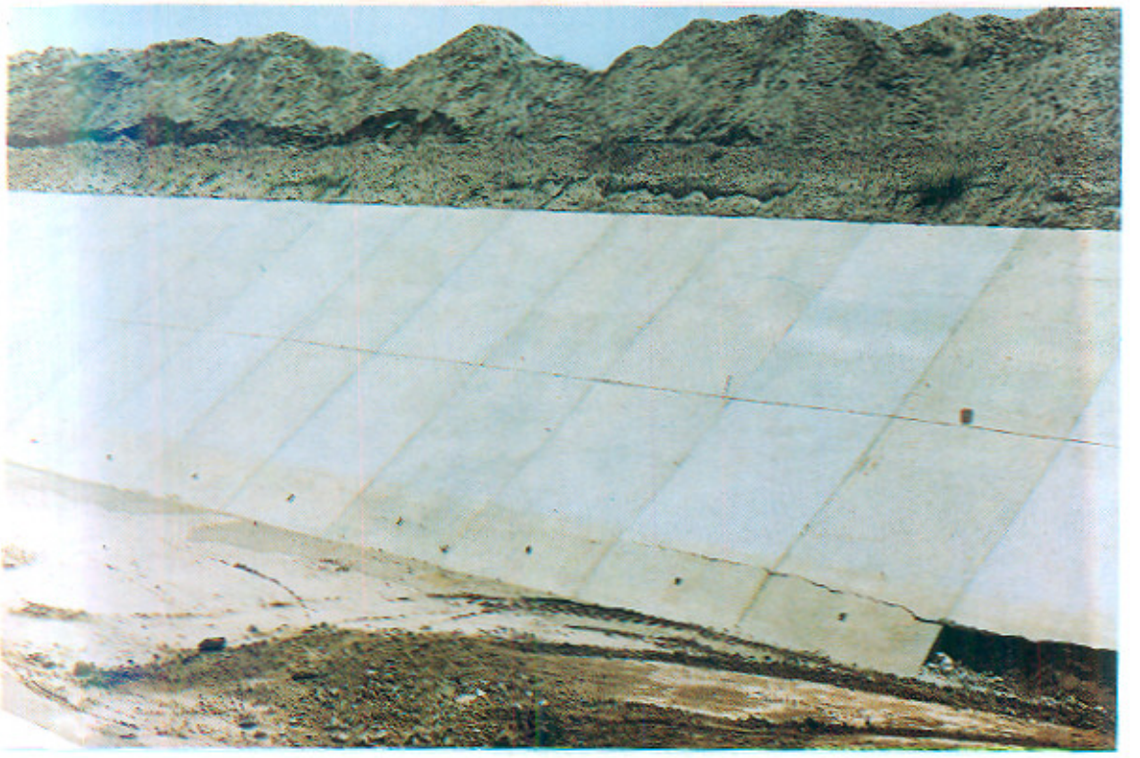
CRBC STAGE-II

Photo No.31: Panels being constructed without Dhomalies



CRBC STAGE-II

Photo No.32: Lining Damaged by Soil Water Pressure

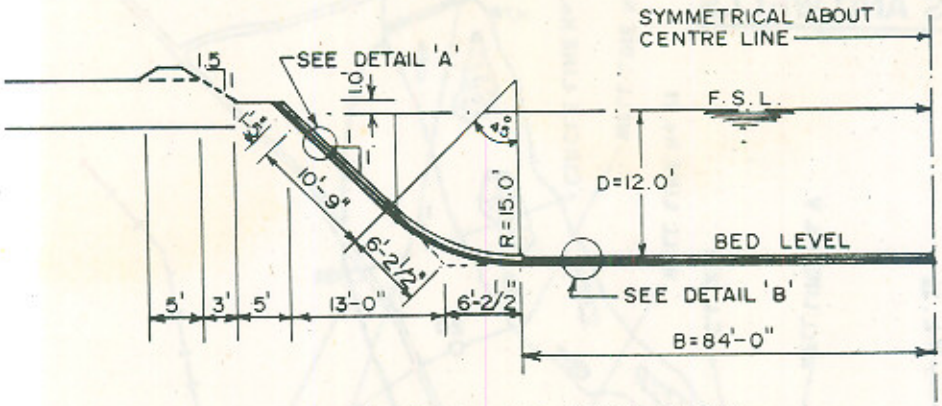


CRBC STAGE-II

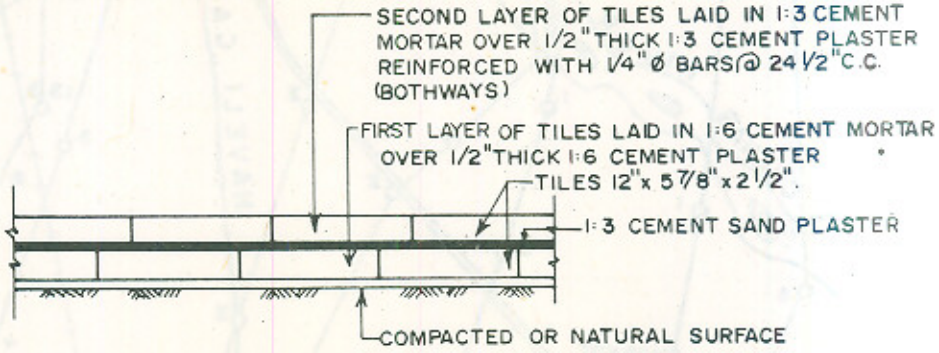
Photo No.33: Cracks Appearing at Drainage Holes

FIGURE-1

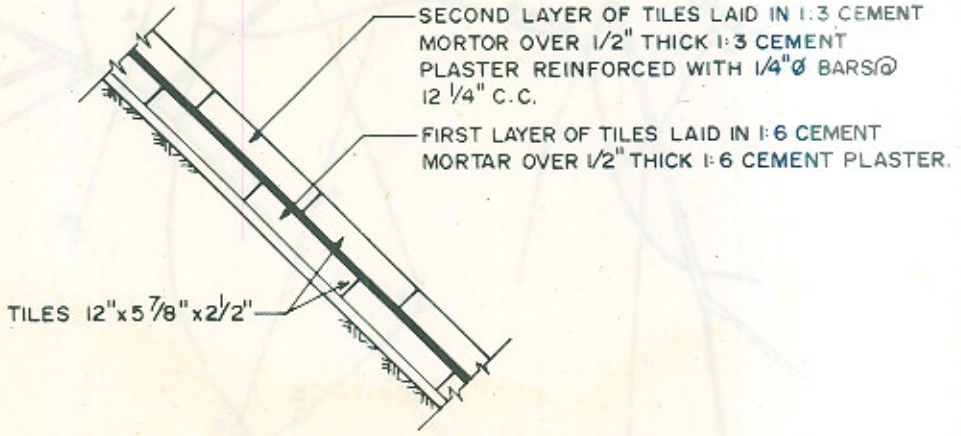
DETAILS OF BRICK LINING
HAVELI MAIN LINK CANAL



X-SECTION OF MAIN CANAL



DETAIL AT 'B'



DETAIL AT 'A'

FIGURE-2

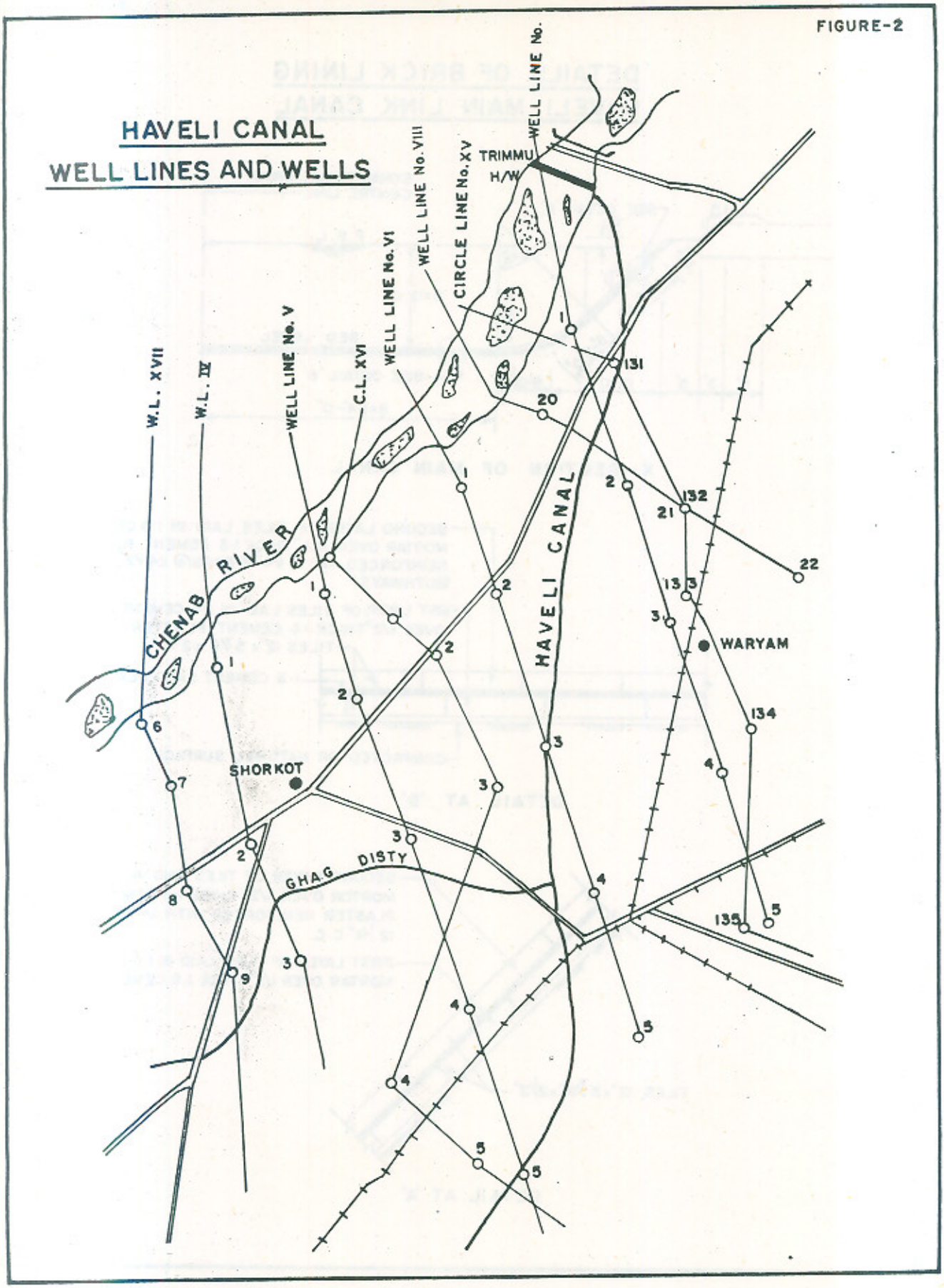
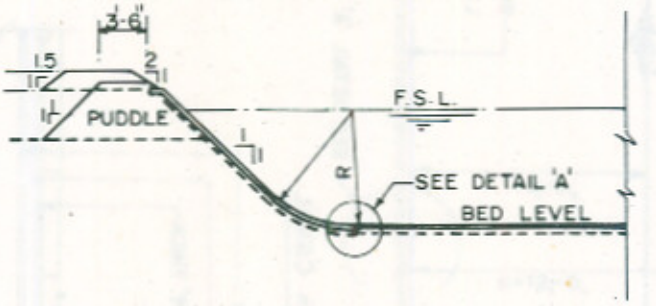
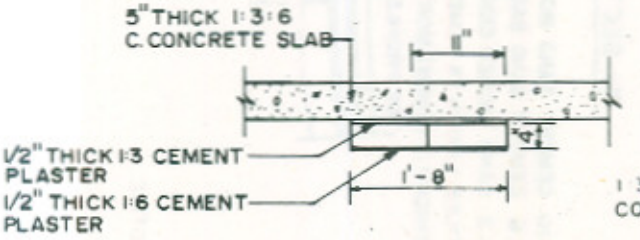

HAVELI CANAL
WELL LINES AND WELLS
WELL LINE No.
TRIMMU H/W
WELL LINE No. VIII
CIRCLE LINE No. XV
WELL LINE No. VI
C.L. XVI
WELL LINE No. V
W.L. IV
W.L. XVII
CHENAB RIVER
HAVELI CANAL
SHORKOT
WARYAM
GHAG DISTY
131
132
134
135
20
21
22

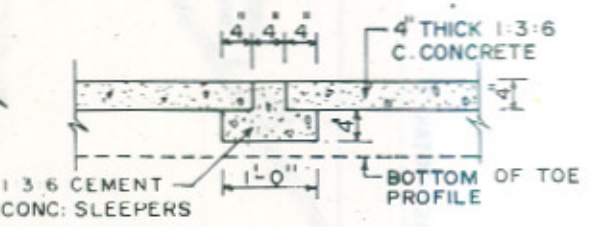
FIGURE – 3

DETAILS OF CONCRETE LINING
MUHAJIR BRANCH

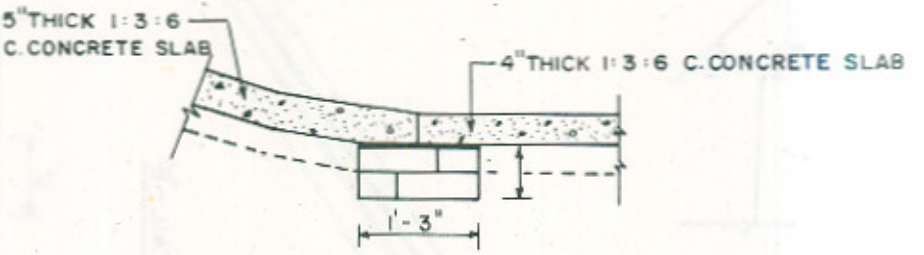




DETAIL OF PROFILE
ON SIDE SLOPES
(AT 15'-0" O.C.)



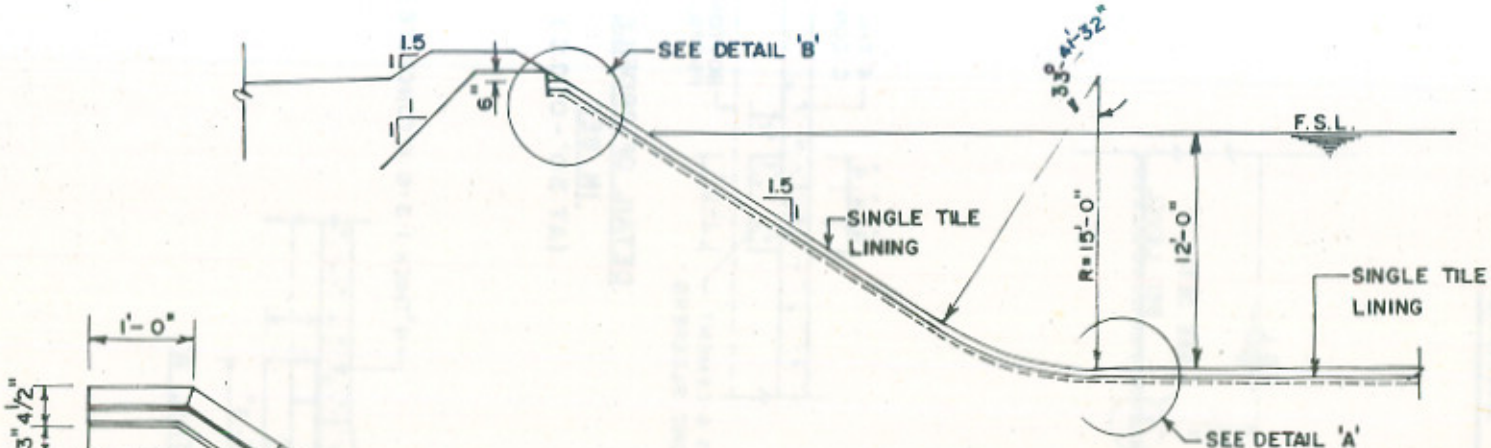
DETAIL OF PROFILE
IN BED
(AT 30'-0" O.C.)



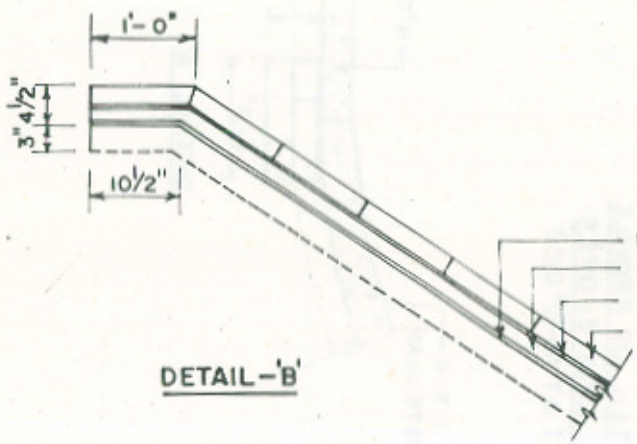
DETAIL 'A'

DETAILS OF BRICK LINING-THAL MAIN LINE LOWER

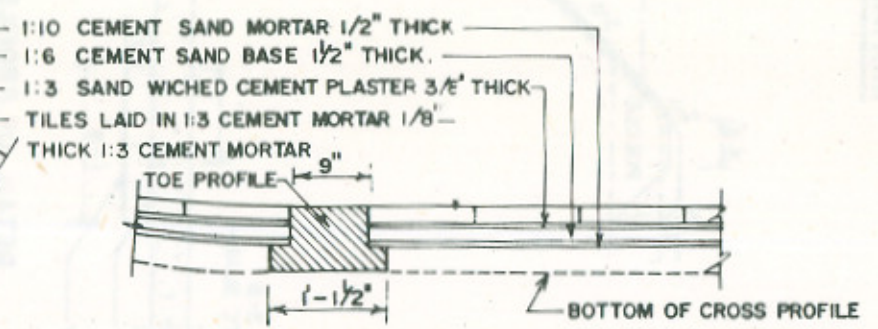
R.D. 68+500 TO TAIL



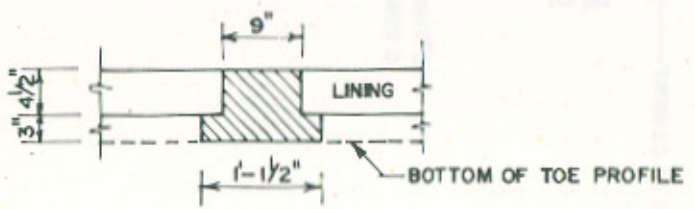
X-SECTION OF MAIN CANAL



DETAIL-'B'



DETAIL-'A'



CROSS PROFILE
(AT 25'-0" O.C.)

FIGURE-4

SYSTEM OF DRAINAGE WELLS

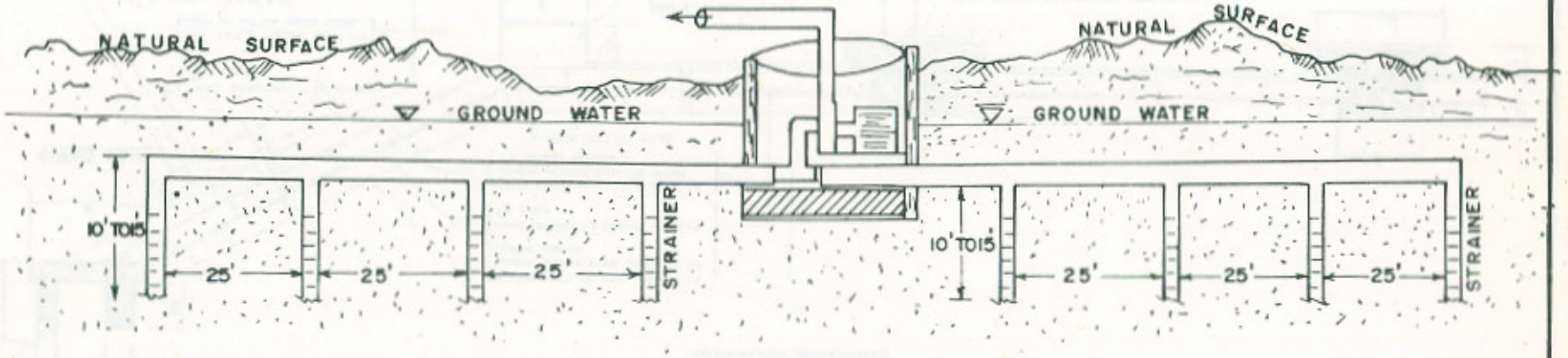
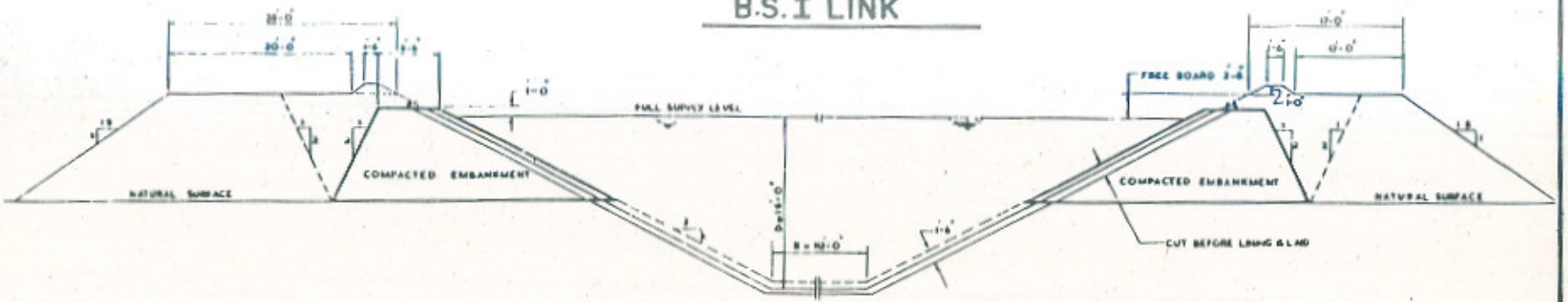
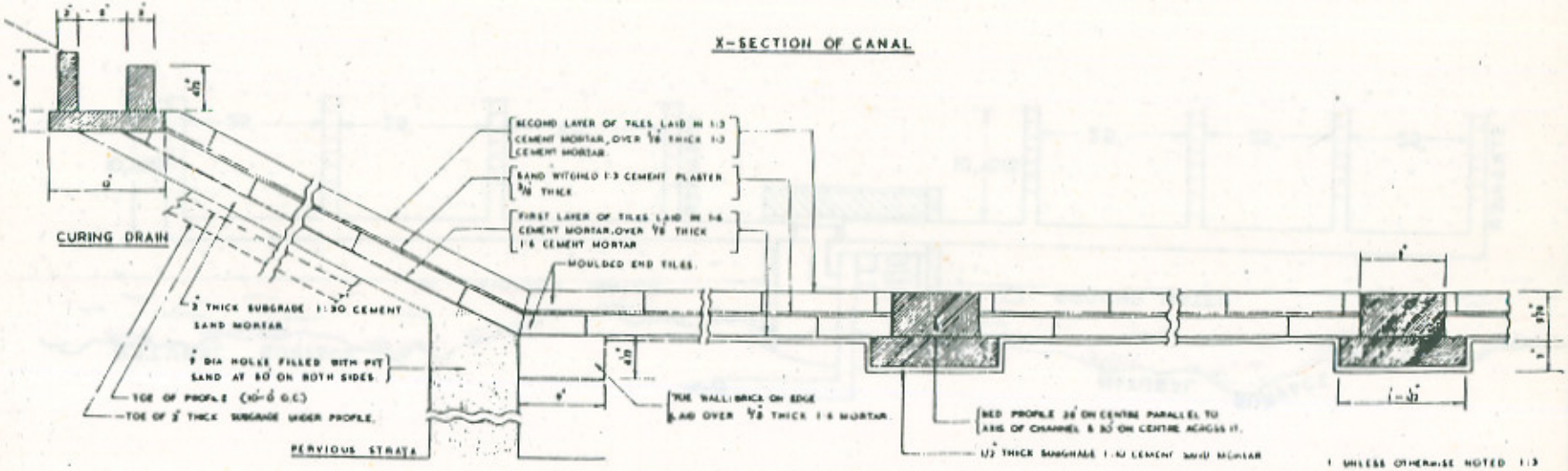


FIGURE-9

TYPICAL SECTION OF BRICK LINING B.S.I LINK



X-SECTION OF CANAL

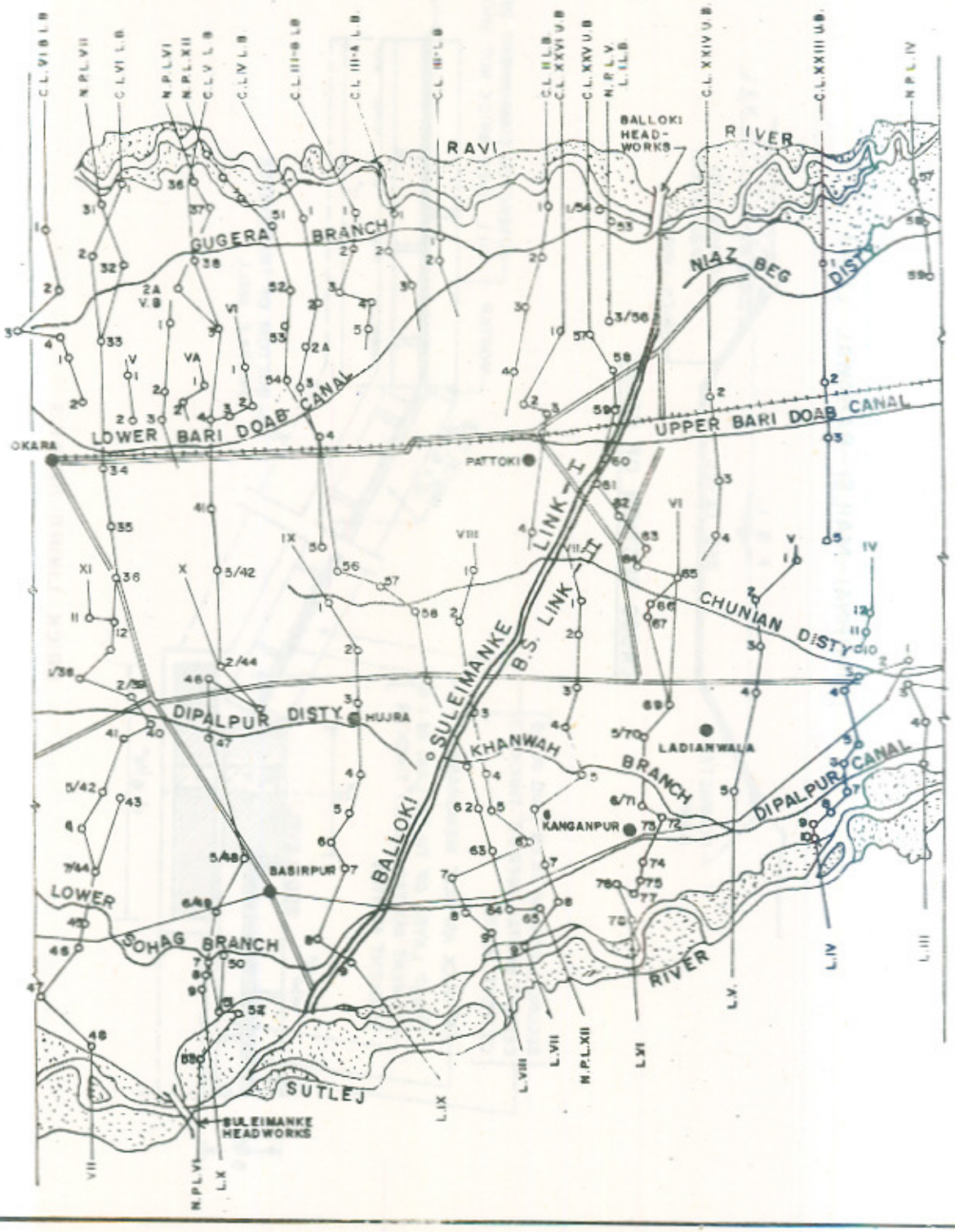


DETAIL OF LINING

FIGURE-7

FIGURE-9

WELL LINES ALONG B.S. LINK NO.I AND NO.II

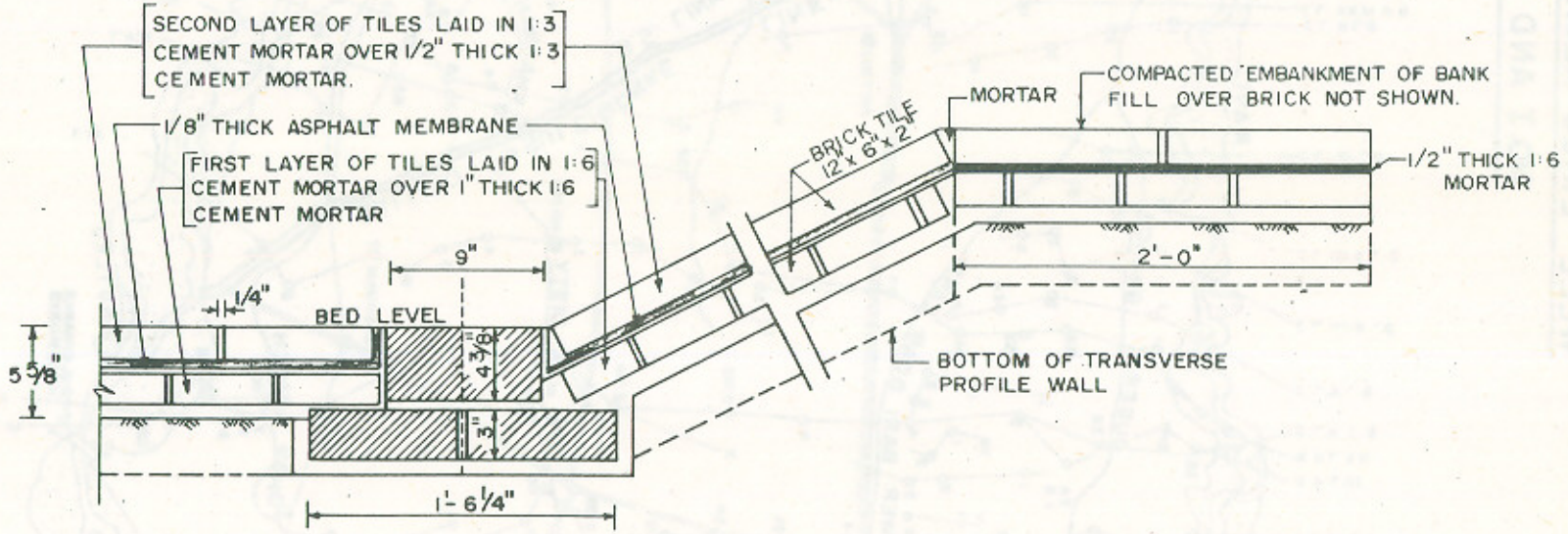


TYPICAL SECTION BRICK LINING

(SINDHNAI - MAILSI - BAHAWAL LINK)



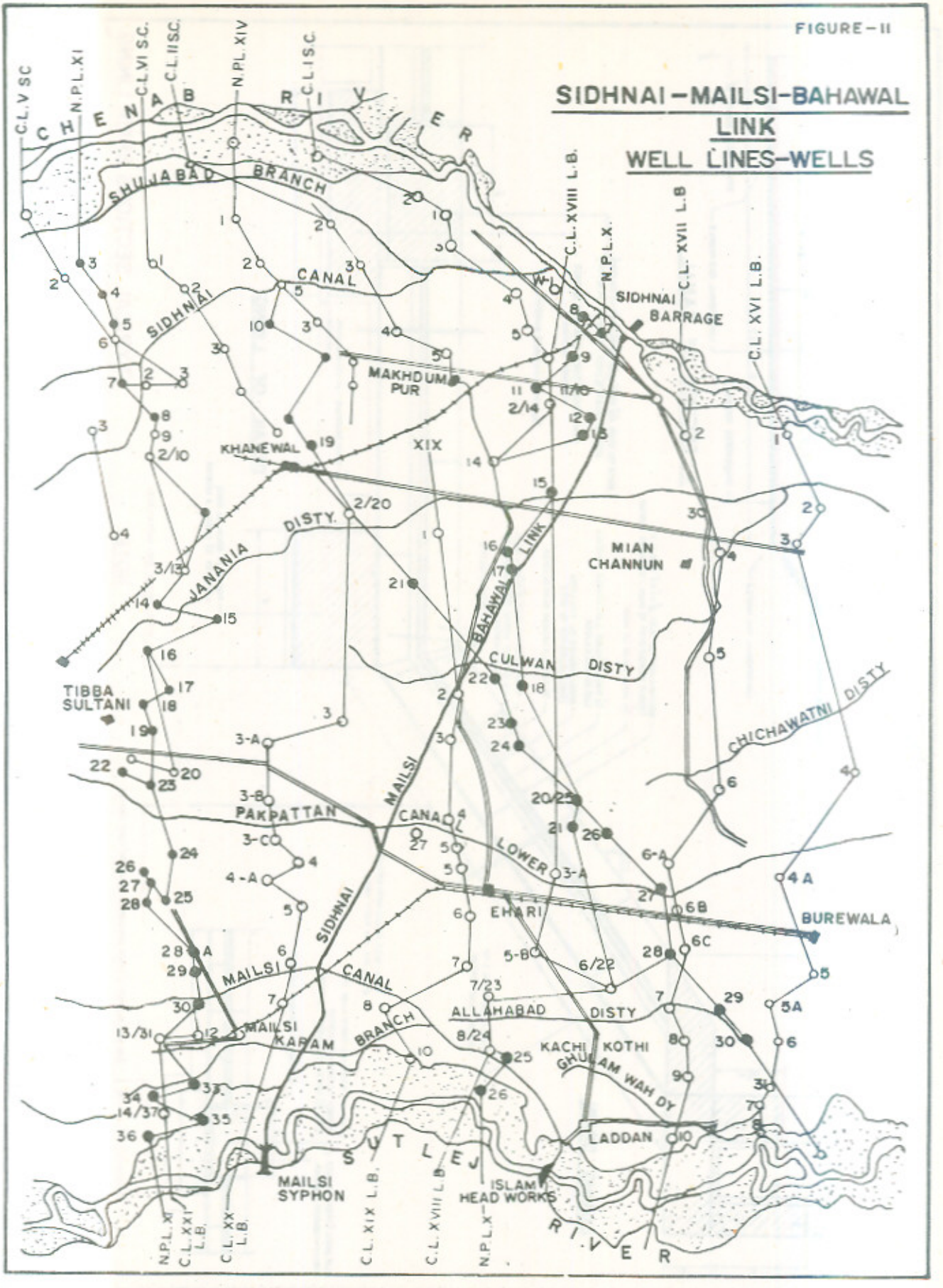
CROSS SECTION OF CANAL

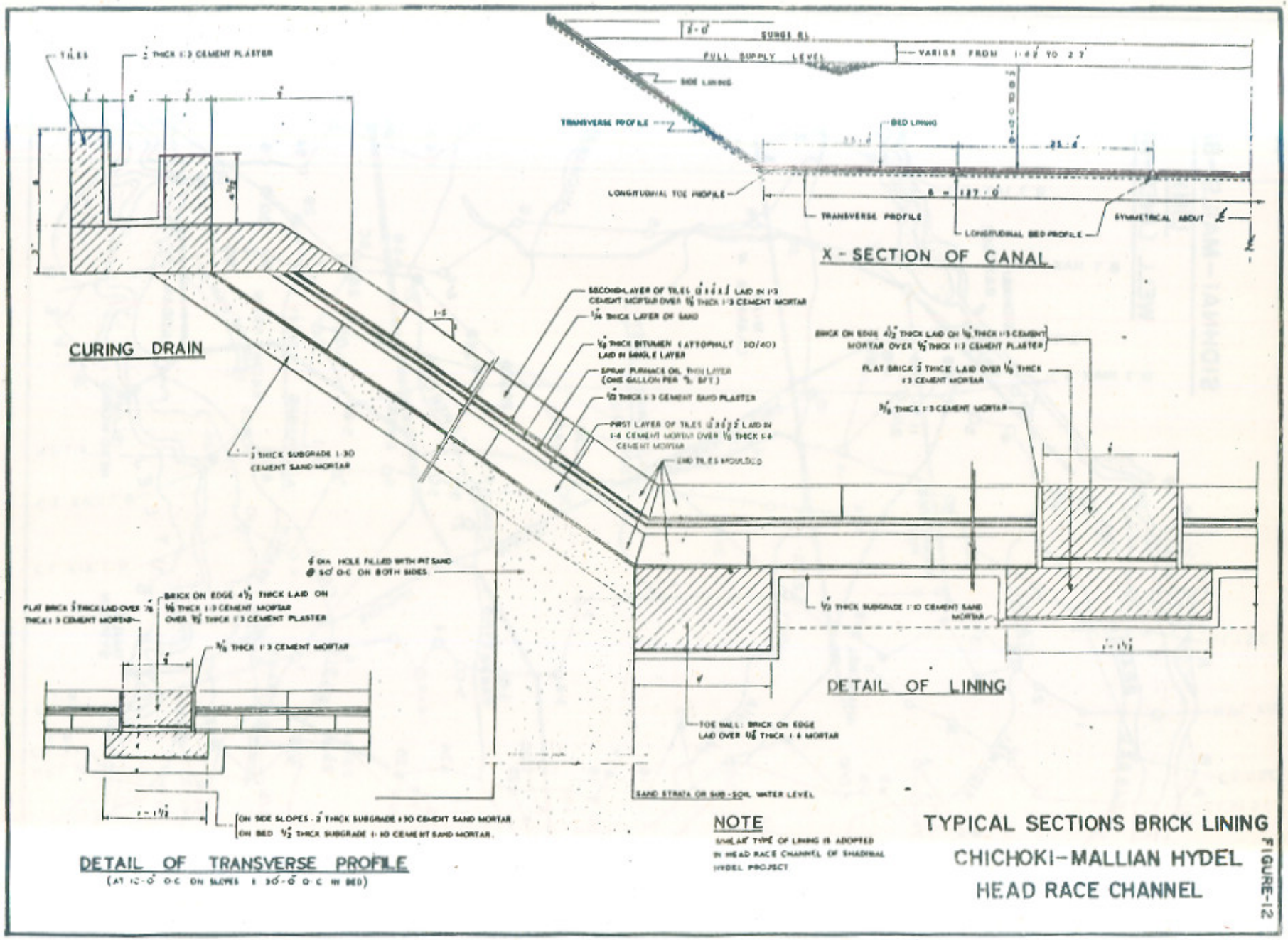


BRICK LINING DETAILS

FIGURE-10

FIGURE – II

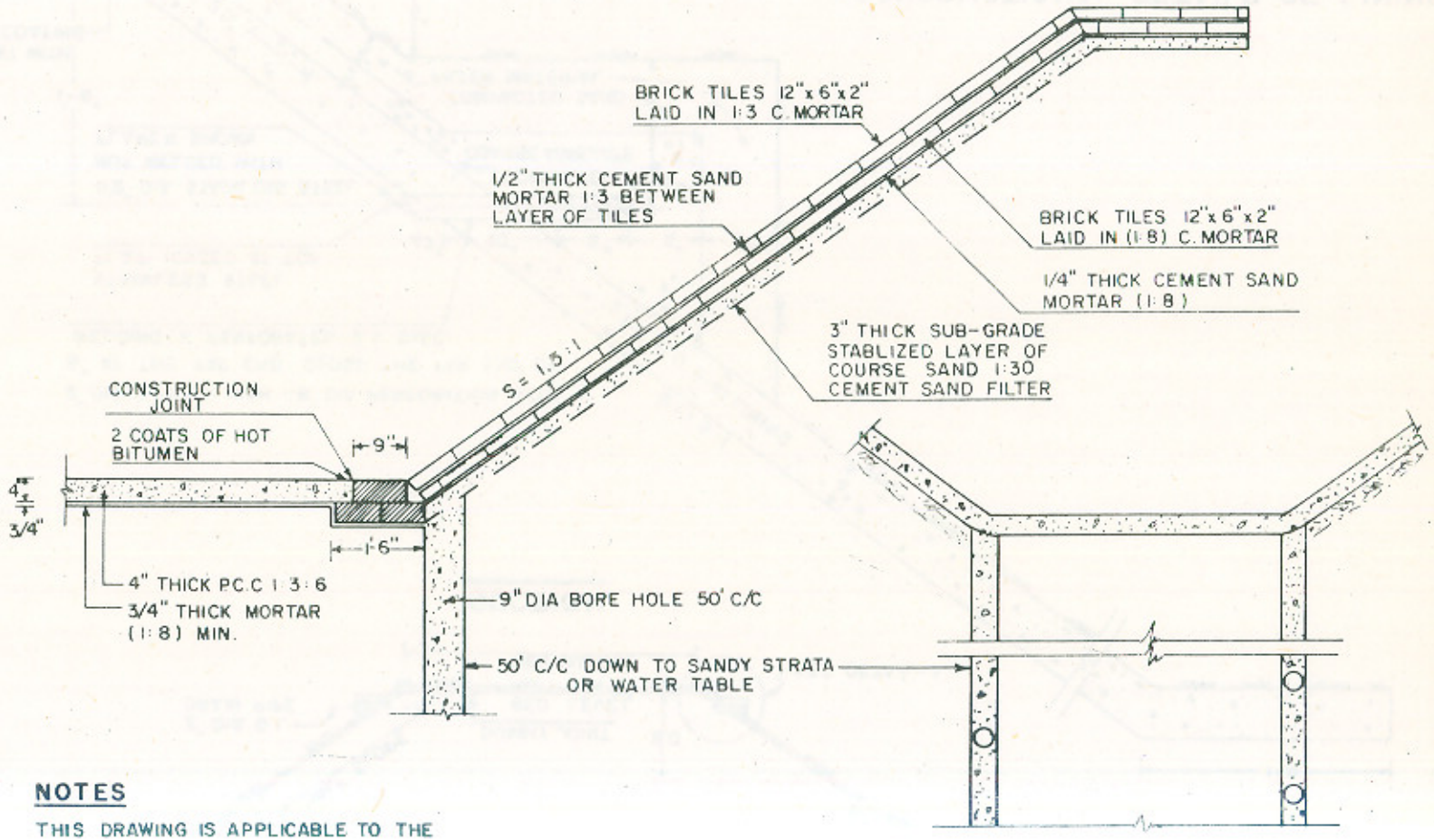

SIDHNAI – MAILSI – BAHAWAL LINK
WELL LINES – WELLS
CHENAB RIVER
C.L. V SC
N.P.L. XI
C.L. VI SC.
C.L. II SC.
N.P.L. XIV
C.L. I SC.
SHUJABAD BRANCH
SIDHNAI CANAL
SIDHNAI BARRAGE
C.L. XVIII L.B.
N.P.L. X.
C.L. XVII L.B.
C.L. XVI L.B.
MAKHDUM PUR
KHANEWAL
XIX
JANANIA DISTY.
BAHAWAL LINK
MIAN CHANNUN
CULWAN DISTY
CHICHAWATNI DISTY
TIBBA SULTANI
PAKPATTAN CANAL
MAILSI SIDHNAI LOWER
EHARI
BUREWALA
MAILSI KARAM BRANCH
MAILSI CANAL
ALLAHABAD DISTY
KACHI GHULAM WAH DY
KOTHI
LADDAN
SUTLEJ RIVER
MAILSI SYPHON
ISLAM HEAD WORKS
N.P.L. X
C.L. XXI L.B.
C.L. XX L.B.
C.L. XIX L.B.
C.L. XVIII L.B.
N.P.L. X


TILES
THICK 1:3 CEMENT PLASTER
SURGE BL
FULL SUPPLY LEVEL
VARIES FROM 1:4 TO 2:1
SIDE LINING
TRANSVERSE PROFILE
BED LINING
LONGITUDINAL TOE PROFILE
TRANSVERSE PROFILE
LONGITUDINAL BED PROFILE
SYMMETRICAL ABOUT
X - SECTION OF CANAL
CURING DRAIN
SECOND LAYER OF TILES LAID IN 1:3 CEMENT MORTAR OVER THICK 1:3 CEMENT MORTAR
THICK LAYER OF SAND
THICK BITUMEN (ATTOPHALT 30/40) LAID IN SINGLE LAYER
SPRAY FURNACE OIL THIN LAYER (ONE GALLON PER SQ. FT.)
THICK 1:3 CEMENT SAND PLASTER
FIRST LAYER OF TILES LAID IN 1:4 CEMENT MORTAR OVER THICK 1:4 CEMENT MORTAR
END TILES MOULDED
THICK SUBGRADE 1:30 CEMENT SAND MORTAR
BRICK ON EDGE THICK LAID ON THICK 1:3 CEMENT MORTAR OVER THICK 1:3 CEMENT PLASTER
FLAT BRICK THICK LAID OVER THICK 1:3 CEMENT MORTAR
THICK 1:3 CEMENT MORTAR
DIA HOLE FILLED WITH PIT SAND @ C/C ON BOTH SIDES
THICK SUBGRADE 1:10 CEMENT SAND MORTAR
TOE WALL: BRICK ON EDGE LAID OVER THICK 1:6 MORTAR
DETAIL OF LINING
SAND STRATA OR SUB-SOIL WATER LEVEL
FLAT BRICK THICK LAID OVER THICK 1:3 CEMENT MORTAR
BRICK ON EDGE THICK LAID ON THICK 1:3 CEMENT MORTAR OVER THICK 1:3 CEMENT PLASTER
THICK 1:3 CEMENT MORTAR
ON SIDE SLOPES - THICK SUBGRADE 1:30 CEMENT SAND MORTAR
ON BED THICK SUBGRADE 1:10 CEMENT SAND MORTAR.
DETAIL OF TRANSVERSE PROFILE
(AT C/C ON SLOPES & C/C IN BED)
NOTE
SIMILAR TYPE OF LINING IS ADOPTED IN HEAD RACE CHANNEL OF SHADIBAL HYDEL PROJECT
TYPICAL SECTIONS BRICK LINING
CHICHOKI-MALLIAN HYDEL
HEAD RACE CHANNEL
FIGURE-12

C.R.B.C. STAGE-II

CONSTRUCTIONAL DETAILS OF LINING WITH TILES

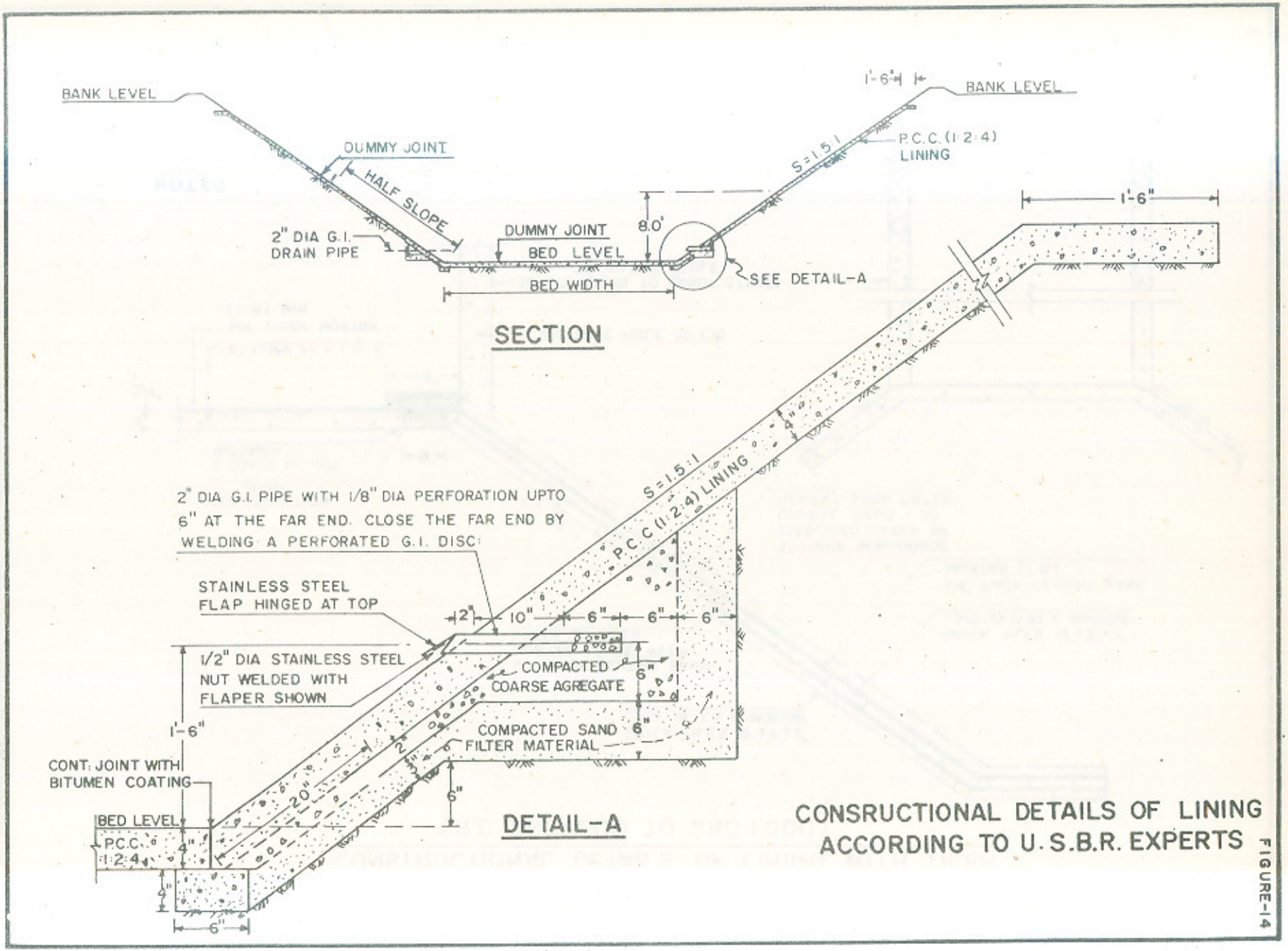
(R.D. 260+000 TO 280+000)



NOTES

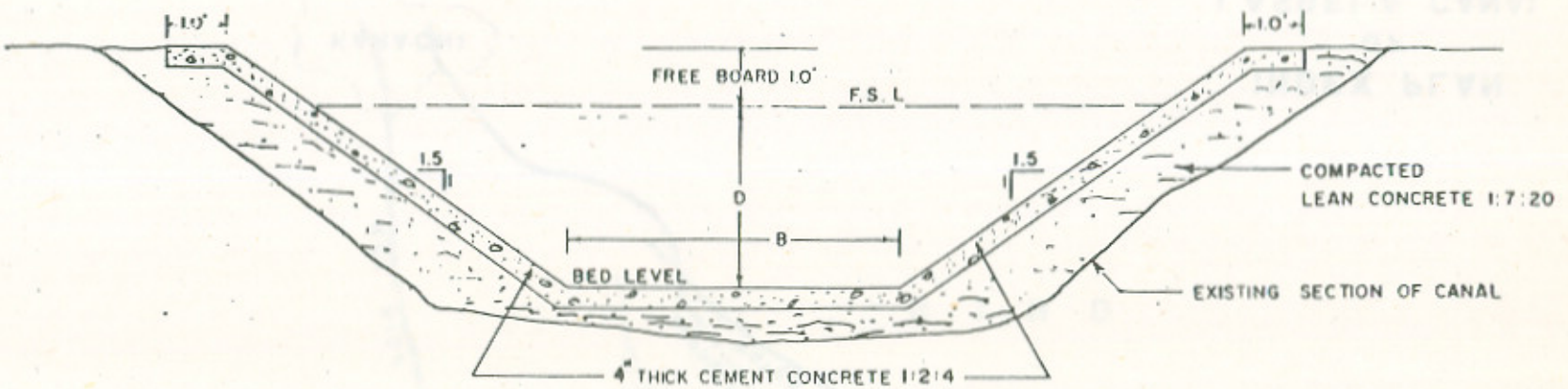
THIS DRAWING IS APPLICABLE TO THE REACHES WHERE BRICK LINING HAS BEEN DONE.

FIGURE-13



CONSRUCTIONAL DETAILS OF LINING ACCORDING TO U.S.B.R. EXPERTS

FIGURE-14



LINING OF WARSAK LIFT CANAL

TYPICAL SECTION

FIGURE-16

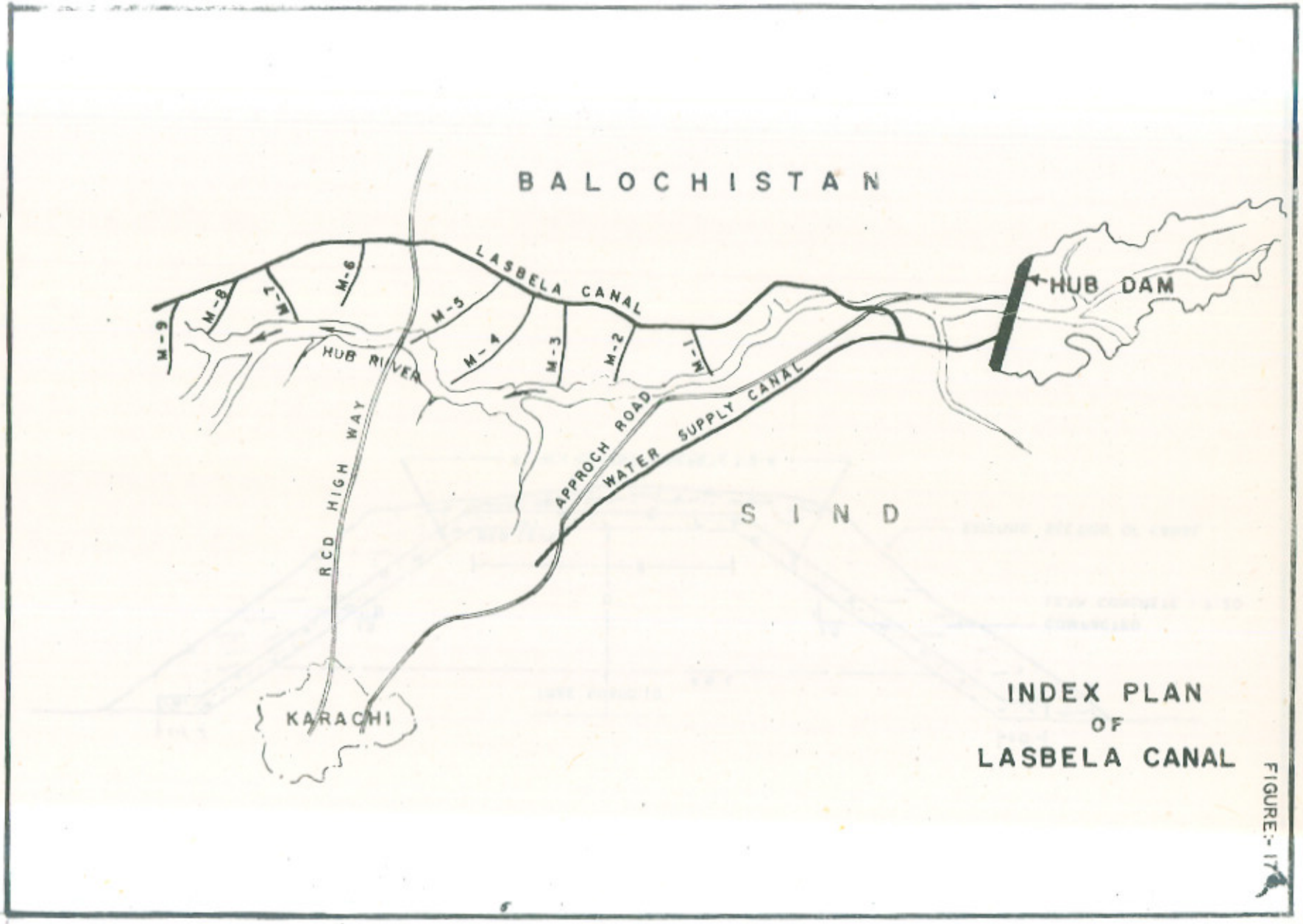

BALOCHISTAN
LASBELA CANAL
HUB DAM
M-9
M-8
M-7
M-6
M-5
M-4
M-3
M-2
M-1
HUB RIVER
RCD HIGH WAY
APPROCH ROAD
WATER SUPPLY CANAL
SIND
KARACHI
INDEX PLAN
OF
LASBELA CANAL

FIGURE:- 17

FIGURE – 18

DRAINAGE ARRANGEMENT FOR LINING IN SOILS WITH POOR PERMEABILITY.

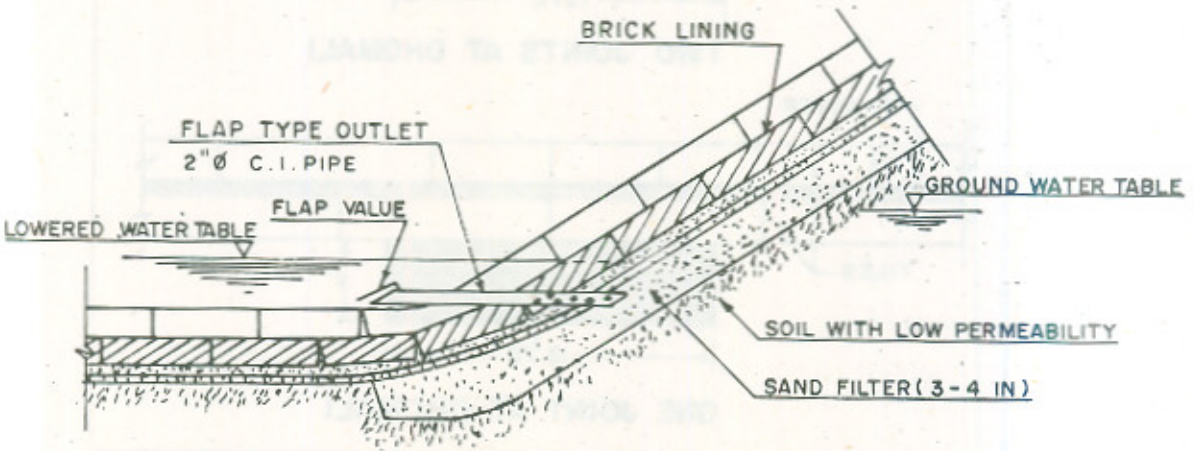
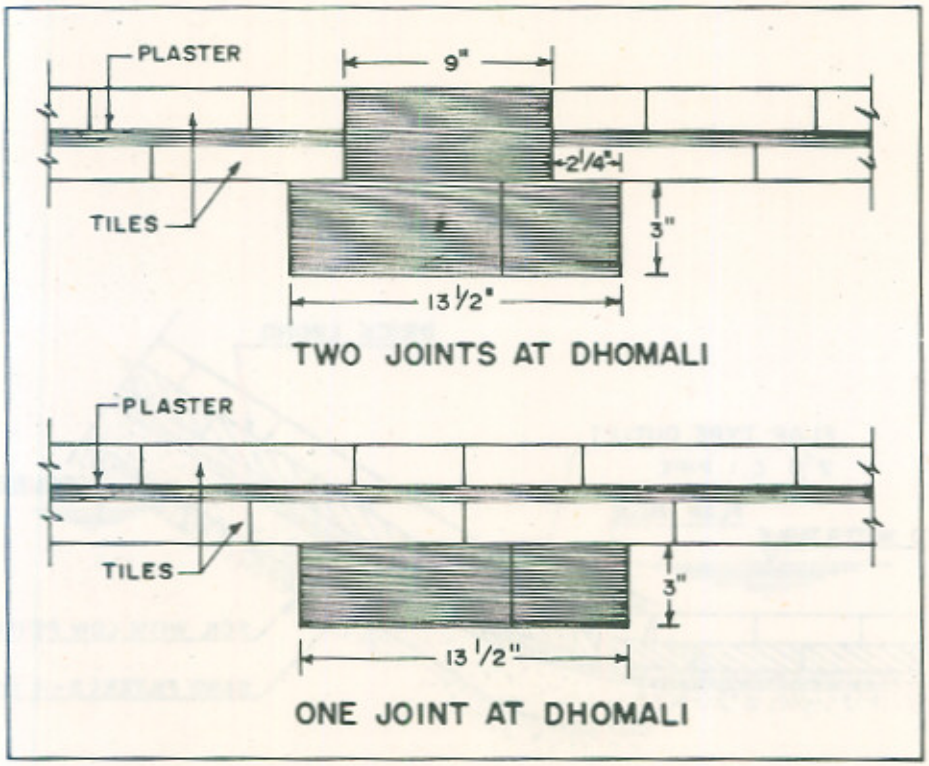


FIGURE-19


PLASTER
9"
2¼"
TILES
3"
13½"
TWO JOINTS AT DHOMALI
PLASTER
TILES
3"
13½"
ONE JOINT AT DHOMALI