the foundation level is 470 feet. The hydraulic data of the barrages constructed or renovated under Indus basin replacement plan is collected in Table I.VI. The hydraulic data of the link canals taking off from these barrages are listed in Table I.VII. The cross section and plans of Kotri, Taunsa and Guddu barrages of Indus are shown in Fig. 1.19(a,b) and 1.20(a,b) and 1.21(a,b) an for barrages constructed under the Indus basin replacement plan during the period 1962 to 1972 are exhibited in Fig. 1.22-28 (a-b).

1.10.0 HISTORICAL REVIEW OF ADVANCEMENTS IN THE THEORY AND DESIGN OF BARAGES CONSTRUCTED DURING THE PERIOD 1950-75.

In Article 1.8.0, some of the main design, construction, operation and maintenance problems as experienced and their solutions as proposed and adopted in the first half of the century were recounted to the extent permissible in the treatment of the subject under the head historical developments. In the first half of the century, the problems had been mostly pinpointed and the broad basic concepts for sound disign based on the theory of hydraulic jump, seepage flow and sediment transprt were well understood and applied for the construction of barrages on the Indus and other rivers. The design and construction of barrages of Indus and for link canals presented some special problems which had not been encountered to the same extent in the past. Indus river, at Taunsa, Guddu and Chashma, had a river 'Khadir' as wide as 8 to 10 miles and at each site the river had two or three channels, any one of which could become the major active channel in a long period of time. The previous barrage on Indus, the Sukkur Barrage, was located downsteam of Bhukher gorge, above which the river could change its couse considerably, but between the gorge and the Sukkur Barrage it had very limited scope for lateral shift in position. The problem of most suitable location of the barrage and its orientation with respect to the river axis assumed greater impotance and this had to receive due attention. The problem was highlighted and discussed for the first time by the author while the location of the Taunsa Barrage was being decided. The analysis of data on the performance of some of the barrages constructed in the past was made with special reference to the location and orientation with respect to river axis and general principles to be kept in view for the location of a barrage in a wide river 'Khadir' were formulated. These are dealt with in a paper by the author(27) published in Proceedings of Punjab Engineering Congress 1956.

With the rapid developments in the subject of hydrology in the first half of the century, more sophisticated approaches for estimationg the maximum flood discharge became available to the engineers. Previously the different catchment formulae were generally used to approximately determine Q_{max}. The gauge discharge data for the nearest site was then analysed to more specifically fix Q_{max}. The new approaches employ the probability analysis of the data, the unit hydrograph and the flood frequency methods for fixing the Q_{max} for the new hydraulic structures. A comprehensive paper(28) on the subject has since been written by the author and published in Vo1.62 of Pakistan Engineering Congress. In case of barrages and bridges the maximum flood discharge affects the selection of the waterway, but actually it is the dominant flood discharge that determines the shoaling and formation of islands within the guide banks thus determining the effective water way that would be factually available for the passage of maximum flood when it actually occurs. This problem though as yet not solved satisfactorily has been given much attention in the recent past.

A reference to Table I-VII will show that the dischage of the link canals taking off from a pocket of barrages constructed under Indus basin replacement plan are very high as compared to the fully supply discharges of the canals designed and constructed prior to this period. Thus Qadirabad Balloki link taking off on the left side of Qadirabld barrage had a discharge of 18600 cfs and Marala Link and Upper Chenab Canals taking off from the left pocket of Marala barrage had full supply dicharges equal to 22000 cfs and 16500 cfs respectively. At Rasul and Chashma Barrages the full supply discharges of the off taking link canals are 19000 and 21,700 cfs respectively. In the past prior to 1950 for any one canal the maximum full supply discharge for Upper Chenab taking off at Marala was about 12,000 cfs and 13,700 cfs was the full supply discharge of Eastern Nara canal taking off at Sukkur barrage, mostly the canal discharges were less than 10,000 cfs. New problems relating to the optimum width of pocket, necessary length of divide wall and the most suitable height of regulator crest for off-taking channels having high discharges had to be studied in greater detail with reference to all the variables involved. Studies on these problems were made at the irrigation Research Institute, Lahore for each case and the recommendations were generally incorporated in the design.

As discussed in Article 1.8.3 the length of a Stilling Basin and its depth has been corelated with the hydraulic elements of hydraulic jump viz. the length of the jump which in turn is a function of E_{f2} ($= D_2 + v_2 / 2g$). The optimum length and depth of the basin with scour as a pertinent factor had not been studied systematically. this has been done by the author[29] to establish that increase in the length of a stilling basin beyond a particular limit shall not appreciably reduce the scour depth, and that a much shorter length of apron is needed for a given acceptable scour depth if impact and deflector blocks of suitable height and at desired location are provided. In all the new hydraulic structures such staggered blocks have invariably been constructed after hydraulic model studies and are functioning very efficiently.

For high head strucutures where the basin upto the toe can be founded on more stable foundation and downstream bed is semi-erodible, roller or flip bucket type devices have been evolved in American and French Laboratories. For high head spillways at Mangla a twin basin design in which the drop is split into two steps has been used whereas at Tarbela, flip buckets have been used for the Service and Auxiliary spillways. Stilling basins were designed and constructed for the outlet structures of the Irrigation tunnels.

Dealing with the developments on the subject of sediment exclusion devices, it can be said that the performance and efficiency of silt excluders constructed in front of the canal head regulators at Khankı, Trimmu and Kalabagh and the efficiency of the silt ejectors located in Haveli and Thal canals were made a subject of special studies and at the same time further laboratory investigations were made to determine:

(I) The optimum discharge extraction ratio for most efficient functioning of the excluders and ejectors.

(II) The efficiency of individual tunnel of an excluder and the minimum number of bays of the pocket to be used for the excluder.

(III) The layout of tunnel inlets in such a way as to give most efficient excluder.

The above problems and a few others concerning the efficient performance of the silt excluders at minimum discharge extraction ratio and relative merits of conventional and vortex type ejectros were studied by the author[(30),(31)]. Keeping in view the results of these basic studies, silt excluders have been constructed after thorough model testing.

As referred to earlier in Article 1.8.8 the phenomenon of cycles of retrogression and accretion in rivers had been noted and studied by Nickolson and Trench and later by Foy but the method of estimation of expected retrogression as a result of barrage construction was not known. Foy for the first time initiated a method of estimation from the existing guage discharge data the expected retrogression for Kotri barrage. the author[(32)] recommended this method with some modifications to the design engineers for the design of Taunsa barrage. This method has also been adopted for fixing the minimum downstream levels for different specific discharges for the barrages of Indus basin replacement works. With the construction of Dams a change in sediment charge of the rivers is bound to occur. Little information was available which could indicate changes in accretion or retrogressin as a result of change in silt charge. Some work done on methods of computing retrogression in channels due to change in sediment charge is reported in a paper[(33)] submitted to Pakistan Engineering Congress LI, 1969.

In this period, for the first time detailed information on the design and functioning of the different types at fish ladders already constructed on different barrages in Pakistan was collected by the author. Analytical study of the research work done by some premier Institutes abroad was made. The fish ladders work as bye-pass to provide an easy passage across the impediments in the form of barrages placed in the rivers. As a result of these studies some basic principles to be kept in view for the design of fish ladders were discussed and highlighted. Later a new design of the fish ladder removing the defects and limitations of the previous designs was studied in the Irrigation Research Institute for Qadirabad barrages. Detailed discussion of the fish ladders old and new, the reader may refer to Ref. 34.

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TABLE I.II

HYDRAULIC DATA OF WEIRS CONSTRUCTED IN 1870-1900

River		Ganges	Jam	Ravi	Sutlej	Chenab	Jhelum
Name of Weir		Narora	Okhla	Madhopur	Rupar	Khanki	Rasul
Year of Completion		1878	1871	1871	1882	1891	1901
H.F.L.	Upstream	590	667	1146	877	738	724.2
	Downstream	588	664		872.9	735	723.5
Afflux		2.0	3.0		4.5	3.0	0.7
Pond Level		585	662.3		871.26	728	719
Crest Level	Weir	582	659.77	1136.0	866.5	727	711.5
	Undersluice	572	648.2	1129.5	857.0	715	701.0
Width between abutments		2200	2600	2800	2663	4414	4400
Length of Clear Waterway	Weir				2292	4000	3000
	Undersluice	304	96	240	240	240	960
	Total				2532	4240	3960
Length of Weir Along flow		259	250	159	174	324	200
Designed maximum Flood Discharge		320,000	150,000		315,500	750,000	875,000
Slope	Upstream	1:3	1:4	1:3	1:horizontal	horizontal	1:15
	Downstream	Vertical	1:20	1:10	1:15	1:15	
Offtaking Canals	Right Bank	lower Ganges	Agra				
	Left bank			Upper Bari Doeb	Sirhind	lower Chonab	lower Jhelim
Full Supply Discharge (Cusecs)		5100	1500	6900	6000	11530	5280
Crest Level (Head Regulator)		575	652.27	1131.5	859	721	708

TABLE-I.IV
HYDRAULIC DATA OF WEIRS CONSTRUCTED IN 1900-1950

River		Sutlej		Ravi		Chenab		Indus	
Name of Weir		Ferozepur	Sulemanki	Islam	Ballok	Marala	Trimmu	Panjand	Kalabagh	Sukkur
Year of Completion		1927	1926	1927	1913	1912	1939	1932	1946	1932
H.F.L.	Upstrem	651.5	572	457	637.0	813	493.5	341.5	896	201
	Downstreem	648.5	569	455	634.4	809	490.5	338.5	693	198
Afflux		3.0	3.0	2.0	2.6	4.0	3.0	3.0	3.0	3.0
Pond Level		649.5	569	455	632	805.75	492	337.5	692	-
Crest Level	Weir	633.5	560	441	622.41	800	477	325	678	177
	Undersluice	633.5	552	435.5	-	792.1	472.5	325	675	176
Width between abutments		1956	2223	1621	1647	4475	3026	3400	3797	4725
Length of clear Waterway	Weir	1200	1440	921	1400	4000	2220	2820	2520	3240
	Under Sluice	540	480	480	-	240	420	240	833	720
	Total	1740	1920	1401	1400	4240	2640	3060	3353	3960
Lenght of Wair along Flow		190	145	190	228.5	140	140	163	140	190
Designned Maximum Flood Discharge		450,000	325,000	275,000	139,500	718,000	645,000	700,000	950,000	1500,000
Glacis Slope	U/s	1:4	1:5	1:4	1:5	1:6	1:4	1:4	1:4	1:5
	D/s	1:5	1:5	1:5	1:15	1:15	1:4	1:5	1:5	1:10

TABLE I-V

FULL SUPPLY DISCHARGE AND CREST LEVEL DATA OF CANALS OFF-TAKING FROM WEIRS CONSTRUCTED IN 1900-1950

River	Weir		Left Bank Canals				Right Bank Canals	
Sutlej	Frozepur		Bikaner	Estern			Diplapur	
		Full Supply Discharege	2144	3320			6950	
		Crest Level						
	Sulemanki		Sadiqia	Fordwah			Pakpattan	
		Full Supply Doscharge	4917	3366			6058	
		Crest Level	559	561.5			559	
	Islam		Bahawal	Qaim			Mailsi	
		Full Supply Doscharge	5400	558			4883	
		Crest Level	445	446			445	
Ravi	Balloki		Lower Bari Doab				–	
		Full Supply Doscharge	7000					
		Crest Level	627.41					
Chenab	Marala		Upper Chenab				–	
		Full Supply Doscharge	13064					
		Crest Level	795.23/799.23					
	Trimmu		Haveli				Rangpur	
		Full Supply Doscharge	5242				2710	
		Crest Level	481				482	
	Panjnab		Panjnad	Abbasia			–	
		Full Supply Doscharge	9567	1064				
		Crest Level	332.5	330				
Indus	Kalabagh Jinnah		Thal				–	
		Full Supply discharge	8160 with pond level 692 12160 with pond levle 694					
		Crest Level	683					
	Sukkur		East Nara	K.F.East	Rohri	K.F.West	North West	Rice
		E.S.D	13649	2096	10883	1940	5152	10658

TABLE I-VI

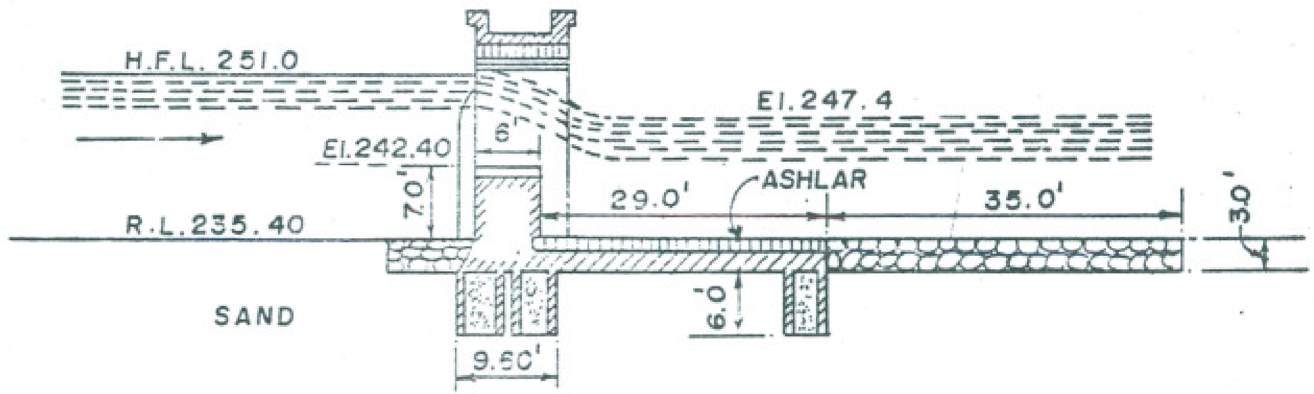
HYDRALLIC DATA OF PARRAGES COSTRUCTED IN 1950-1975

River	Indus			Sutlej	Ravi		Jhelum	Chenab		Indus
Name of Barrage	Kotri	Taunsa	Guddu	Mailsi	Balloki	Sidhnai	Rasul	Qadirabad	Marala	Chashma
Year of Completion	1954	1959	1962	1965	1965	1965	1967	1967	1968	1970
H.F.L. Upstream	72.0	447.	262.0	434.82	638.0	476.3	722.75	704.14	816	640
H.F.L. Downstream	68.5	444	256.2	430.50	635.2	480.0	718.00	700.00		634
Afflux	3.5	3.0	5.8	4.32	2.8	6.3	4.75	4.14	3.3	5.8
Pond Level	68	446	255.5		633	467	719	701	812	642
Grest Level Weir	48	428	236	415.5	624.5	454	703	684.5	800	622
Grest Level undersluice	48	425	234.5			456.0	698.5	680	795	017
With between abutments	3034	4346	4445	1601	1647	712	3209	3373	4475	2356
Length Cear Waterway Weir of	2640	3180	3240	1440	1440	440	2520	2640	3180	2460
Length Cear Waterway undersluice		660	660			160	360	360	780	660
Length Cear Waterway Total	2640	3860	3900	1440	1440	600	2880	3000	3900	3120
Length of Weir along flow	236	233	228.5	216	235	200	262	265	200	340
Designed Maximum Flood Discharge	875,00	750,600	100,000	429,000	225,000	167,000	850,00	900.000	1100,000	950
Glacis Slope upstream	1:5	1:4	1:5	1:5	1:2	1:5	1:12	1:9	1:16	1:12
Glacis Slope Pownstream	1:3		1:3.5	1:4	1:3.67	1:3	1:3	1:3	1:3	1:3

TABLE I-VII

FULL SUPPLY DISCHARG AD CREST LEVEL DATA OF OFF TAKING CANALS FROM DIFFERENT BARRAGES CONSTRUCTED IN 1950-1975

River	Name of arrage	Left Bank Canals				Right Bank Canals	
Indus	Kotri		Pinyar	Fulleli	Akram Wah,	Kalri Begha	
	(8-M) Barrage)	F.S. Discharege	13000	14350	4100	9075	
	Taunsa	Crest level	56	56	58		
			Muzaffargarh	T.P. Link	D.G. Khan		
		F.S. Disharge	8301	14000		8790	
		Crest Level					
			Gbotki Feeder			Desert	Begari
						Canal	Feeder
	Guddu	F.S.Discharge	8490			12945	15494
		Crest level	245.7			243.3	244.3
Sutlej	Mailsi Siphon		Mailsi Bahawal link				
		F.S. Discharge	4000				
		Crest level					
Ravi	Balloki		Lower Bari Doab	B.S. Link			
	(remodelled)	F.S. Discharge	7000	18500			
		Crest levle	627.41	624.84			
	Sidhnai		Sidhnai Mailsi link	Sidhnai Feeder			
		F.S. Discharge	10100	4005			
		Crest levle	458	458			
Chenab	adirabad		Qadirabad Balloki link				
		F.S. Discharge	18600				
		Crest levle	690				
	Marala		Marala Ravi link	Upper Chenab			
		F.S. Discharge	22000	16500			
		Crest levle	802	802			
Jhelum	Rasul		Rasul Qadirabad link	L.J.C. Feeder			
		F.S. Discharge	19000	6600			
		Crest levle	708.5	708.5			
Indus	Chashma		Chashma Jhelum link			Paharpur	
		F.S. Discharge	21700			5000	
	Crestleves	628				626	



COLERUN WEIR

DISCHARGE 284,000 CFT.

LENGTH 2926 FT.

FIG: 1.1

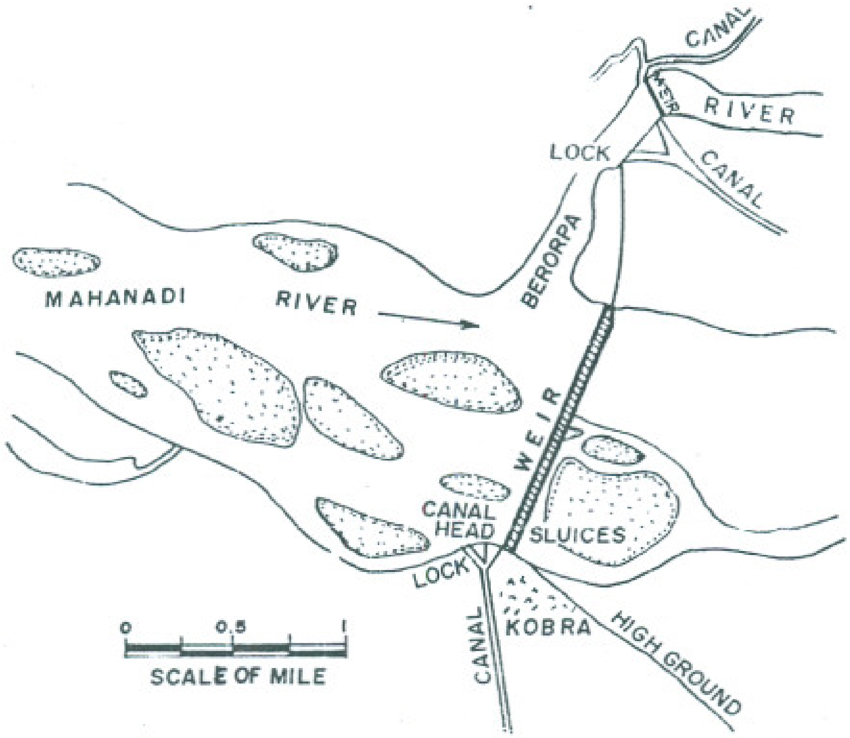


FIG. 1.2 (a) – SITE PLAN OF JOBRA WEIR AT MAHANADI RIVER

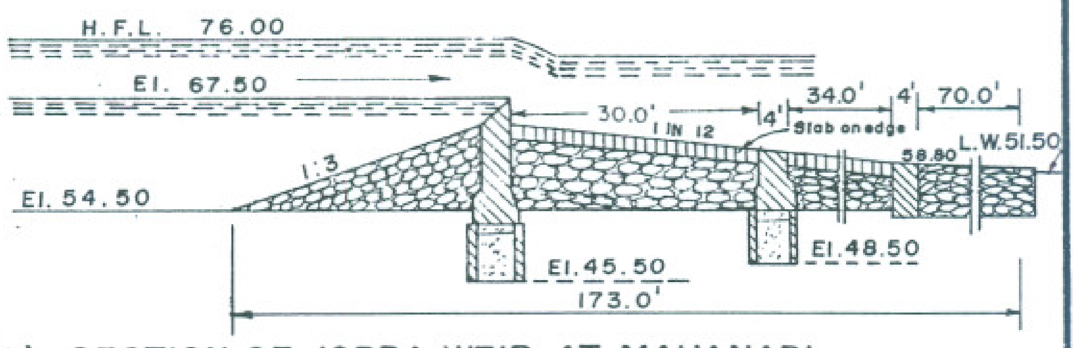
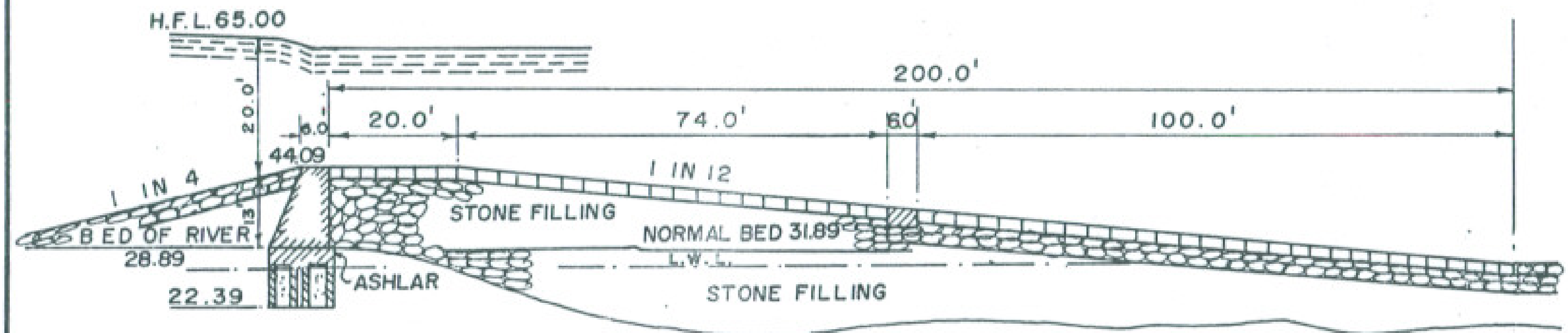


FIG. 1.2 (b) – SECTION OF JOBRA WEIR AT MAHANADI

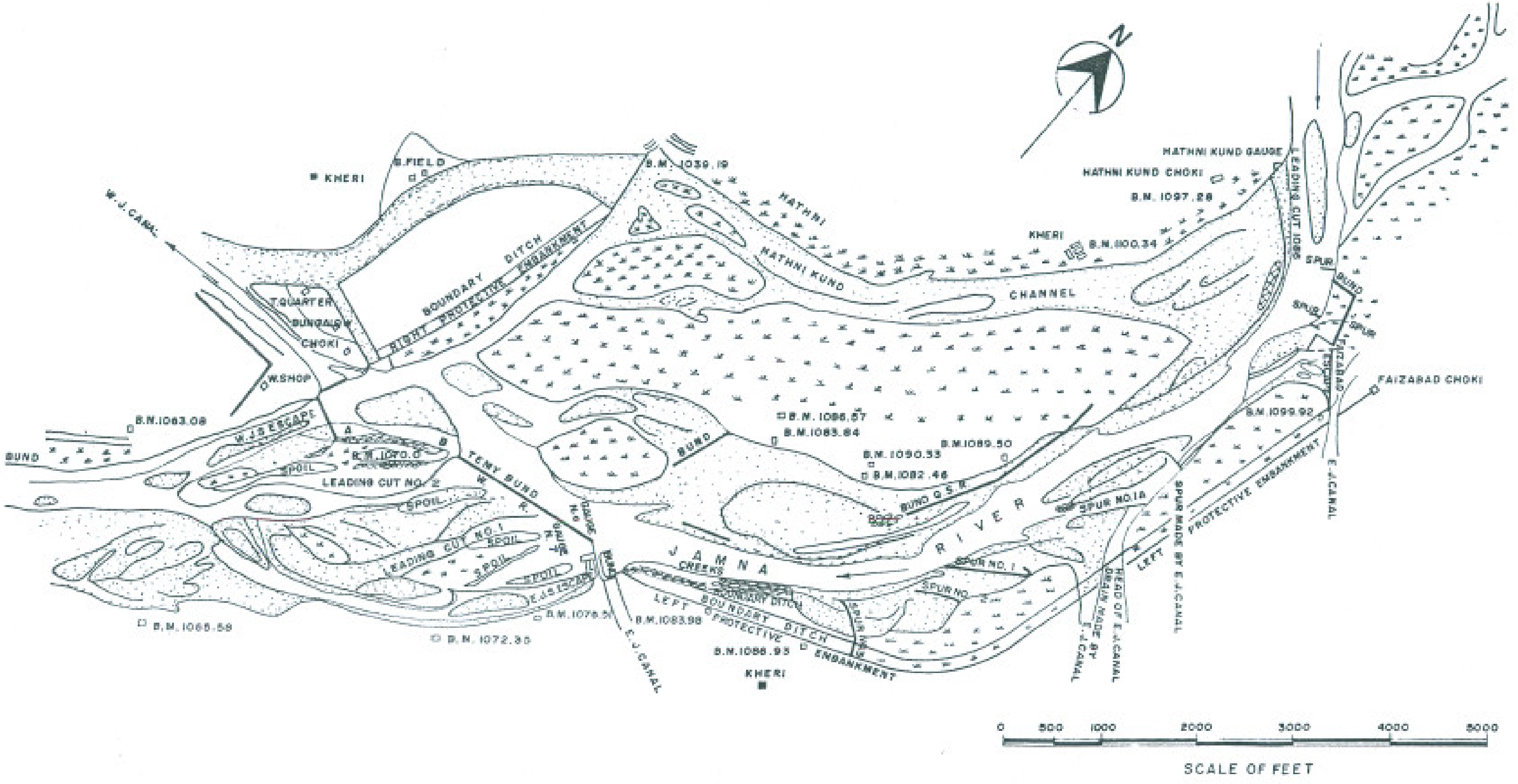


BESWADA ANICUT, KISTNA RIVER, LENGTH 4000 FT.
DISCHARGE 736,000 CFS.

M.R.Ars

Fig: 1.3

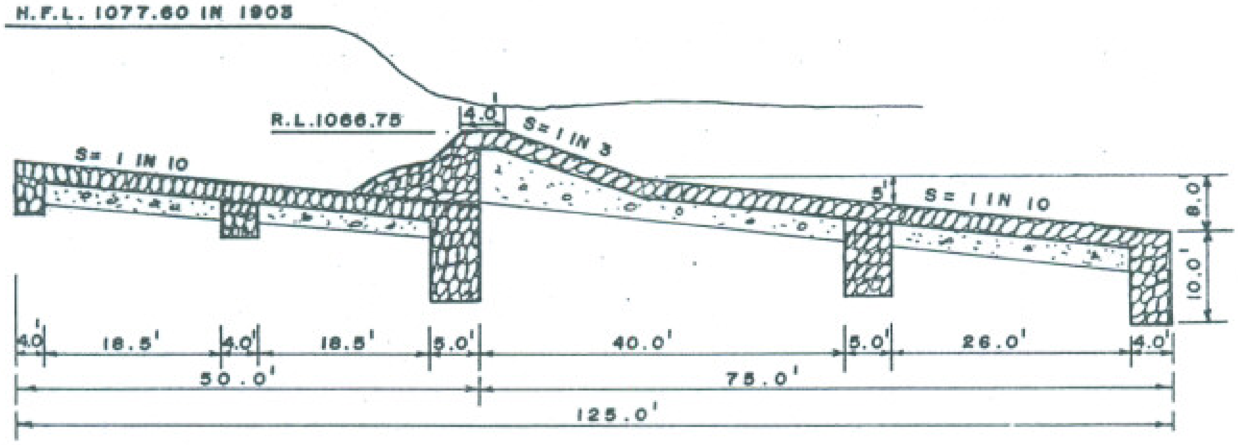
Fig: 1.4 (a)



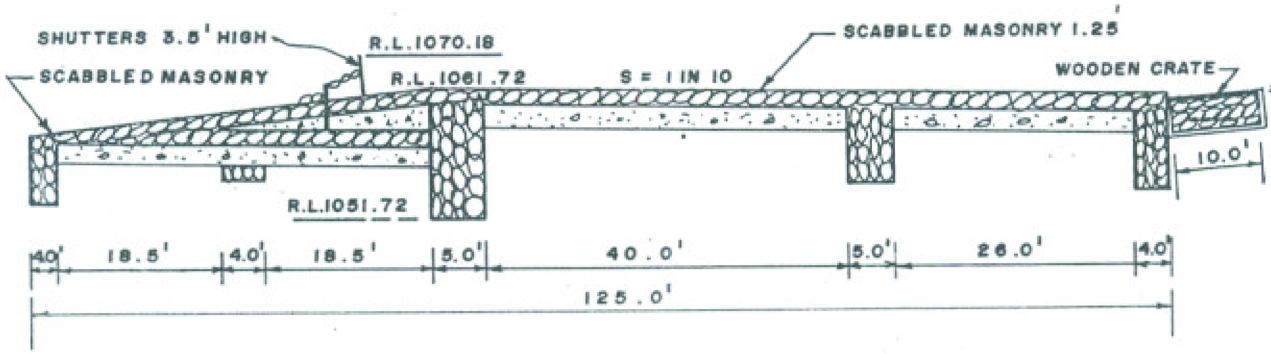
SITE PLAN OF TAJEWALA HEADWORKS

M.R. Arshad

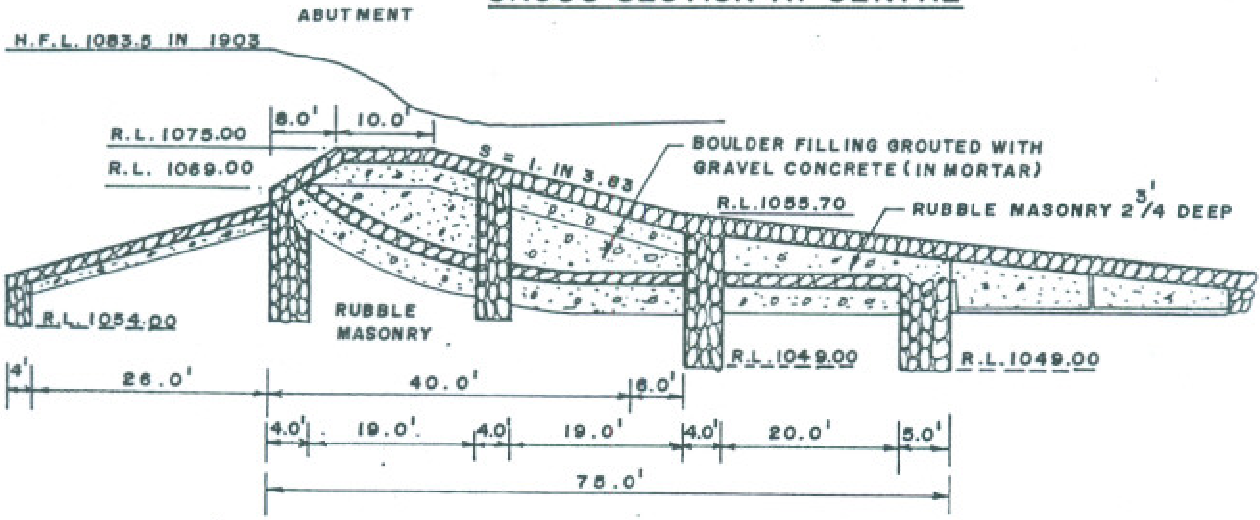
Fig: 1.4 (b)



CROSS SECTION AT POINT A



CROSS SECTION AT CENTRE



CROSS SECTION AT POINT B

SECTIONS OF WEIR AT TAJEWALA

M.R. ARSHAD

FIG: 1.5 (a),(b)&(c)

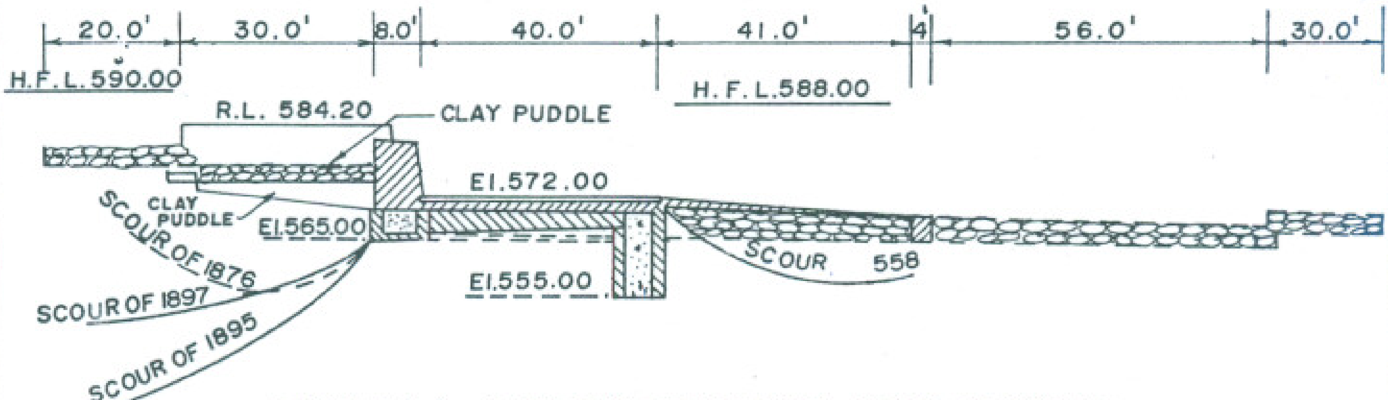


FIG.1.5 (a)– SECTION OF NARORA WEIR SHOWING SCOUR UPSTREAM AND DOWNSTREAM

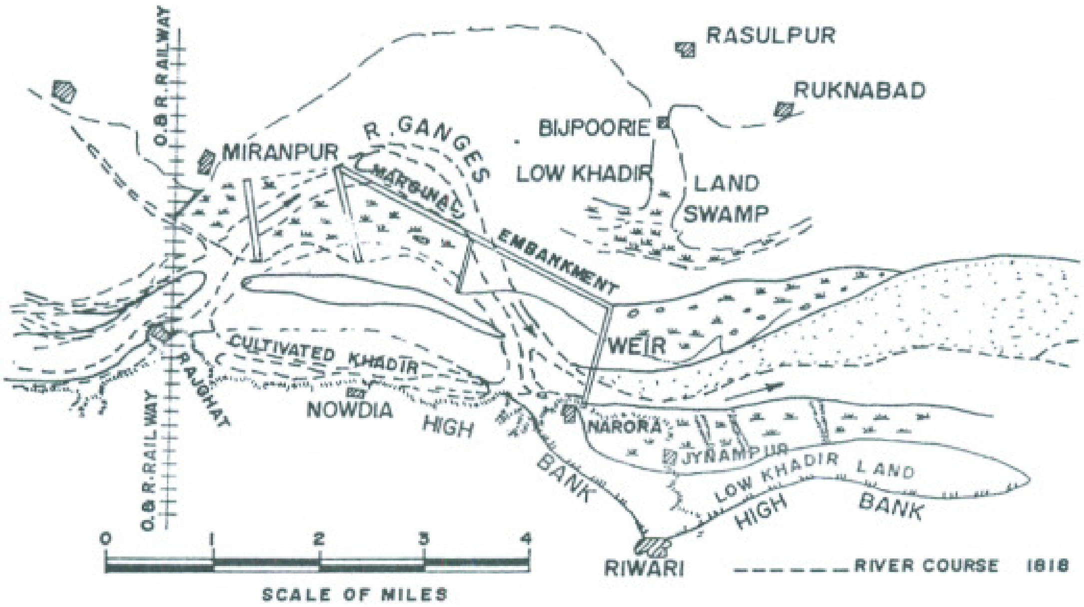


FIG.1.5 (b)–THE GANGES RIVER AT NARORA BEFORE AND AFTER TRAINING WORKS

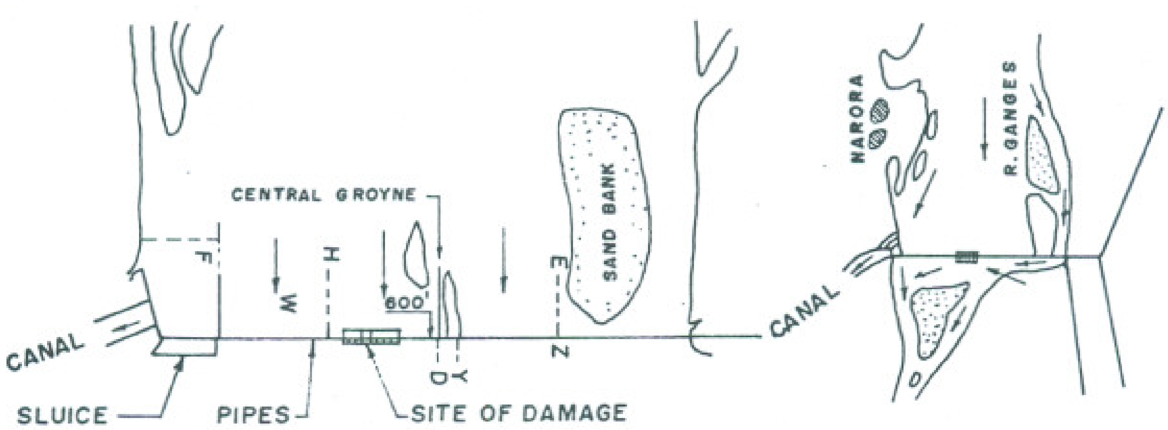
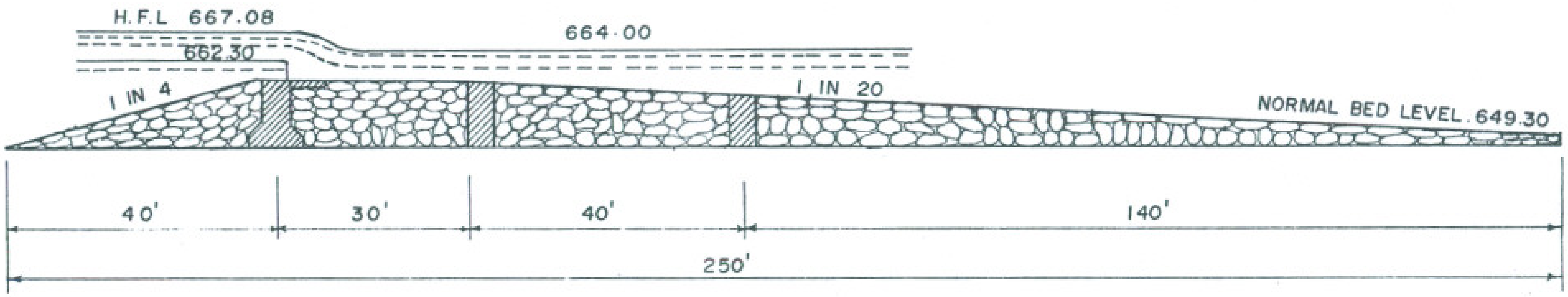


FIG. 1.5(c)– NARORA WEIR IN AUGUST, 1896

M.R.ARSHA

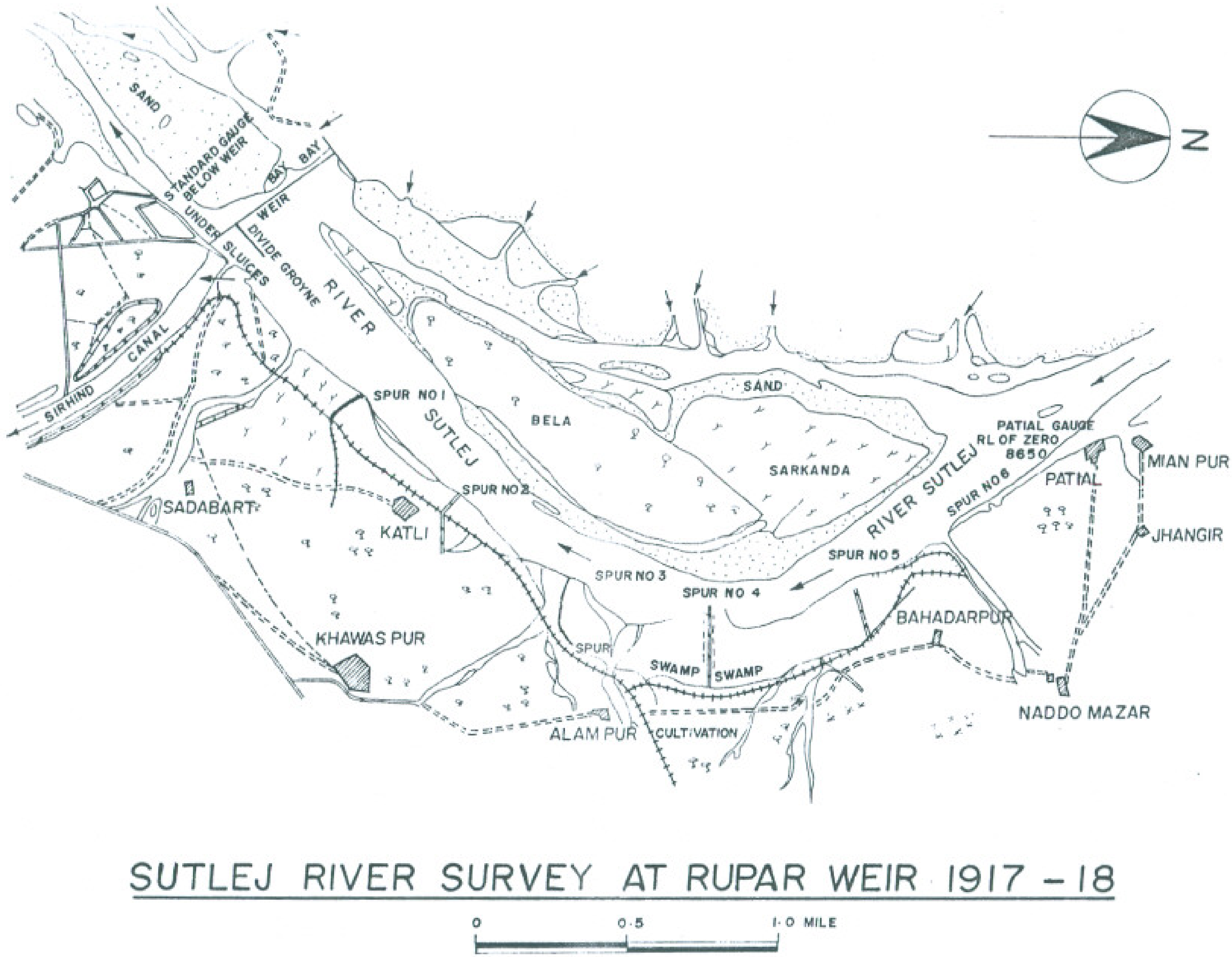


OKHLA WEIR JUMNA RIVER, AGRA CANAL, DISCHARGE 150,000 CFS

LENGTH OF WEIR 2438' SLUICES 16'x6'=96'

Fig. 1·6

Shabbir Ahmad



SUTLEJ RIVER SURVEY AT RUPAR WEIR 1917 – 18

Shabbir Ahmad

Fig. 17(a)

Fig. 1·7 (b)
Fig. 1·7 (c)

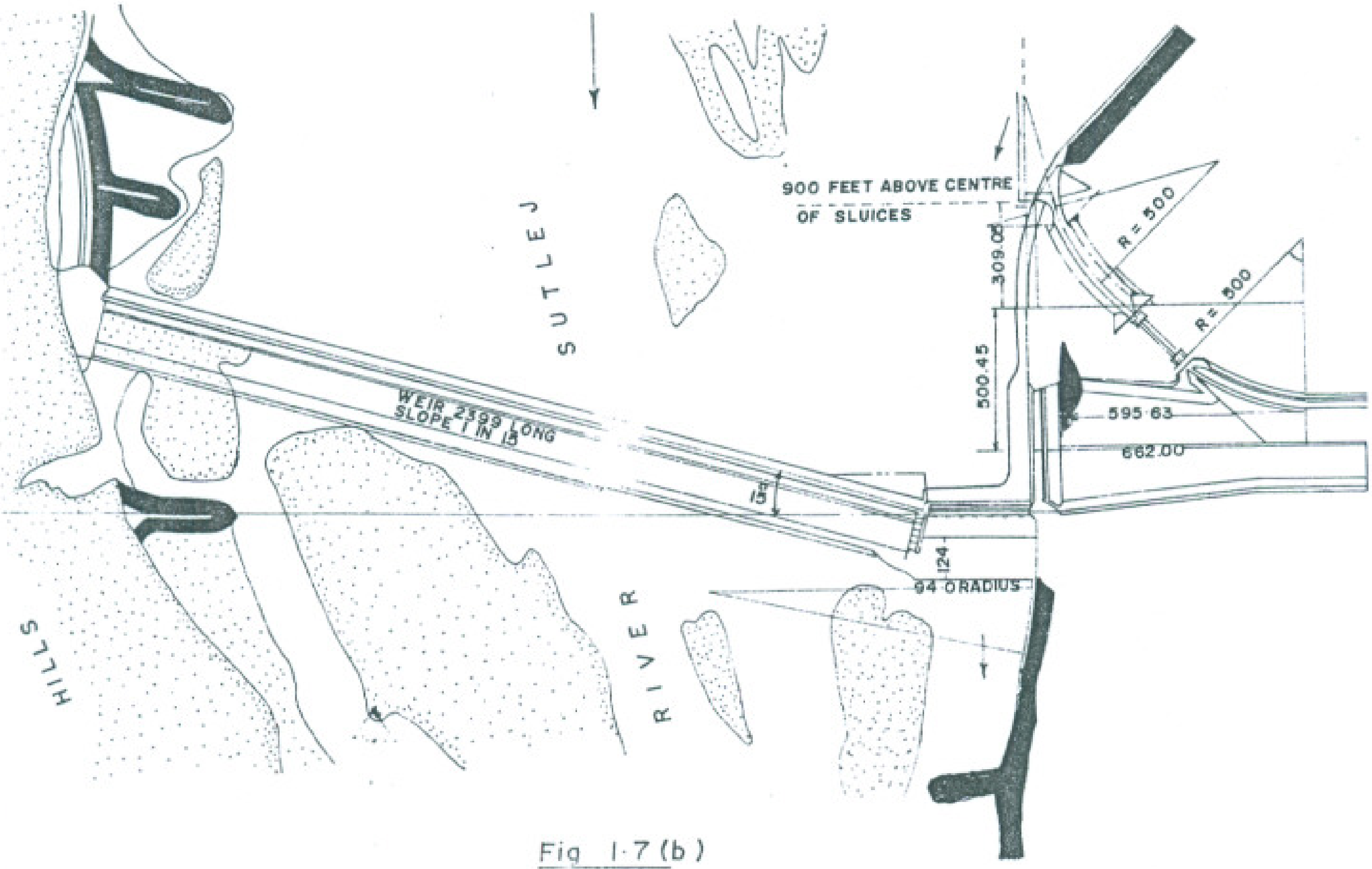


Fig 1·7 (b)

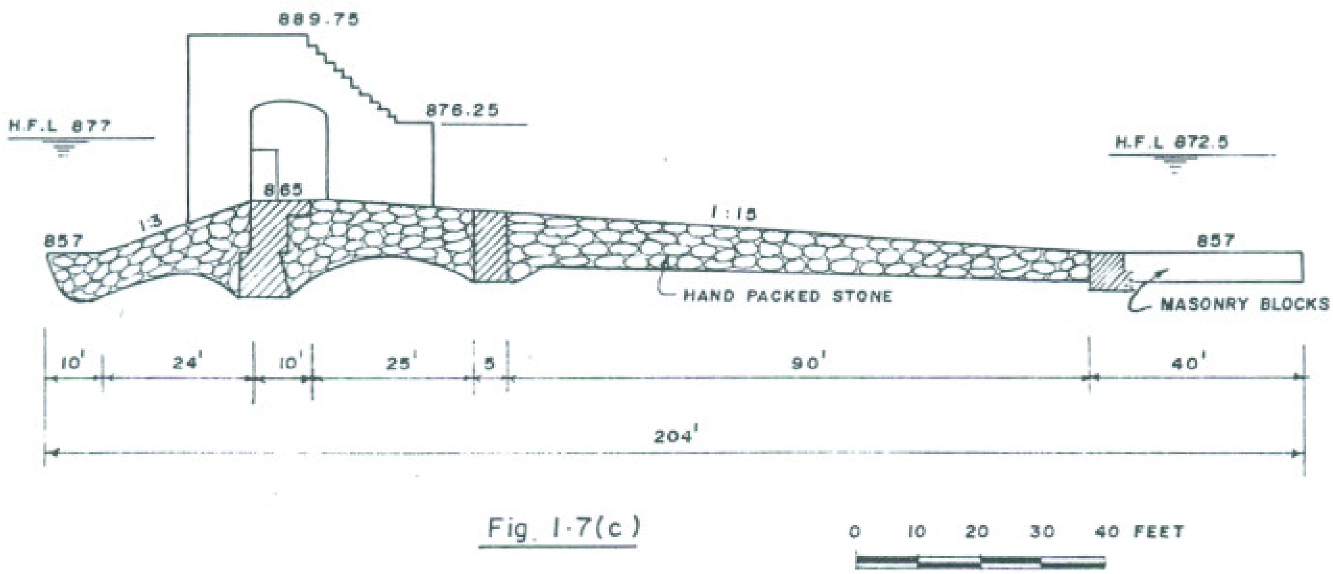
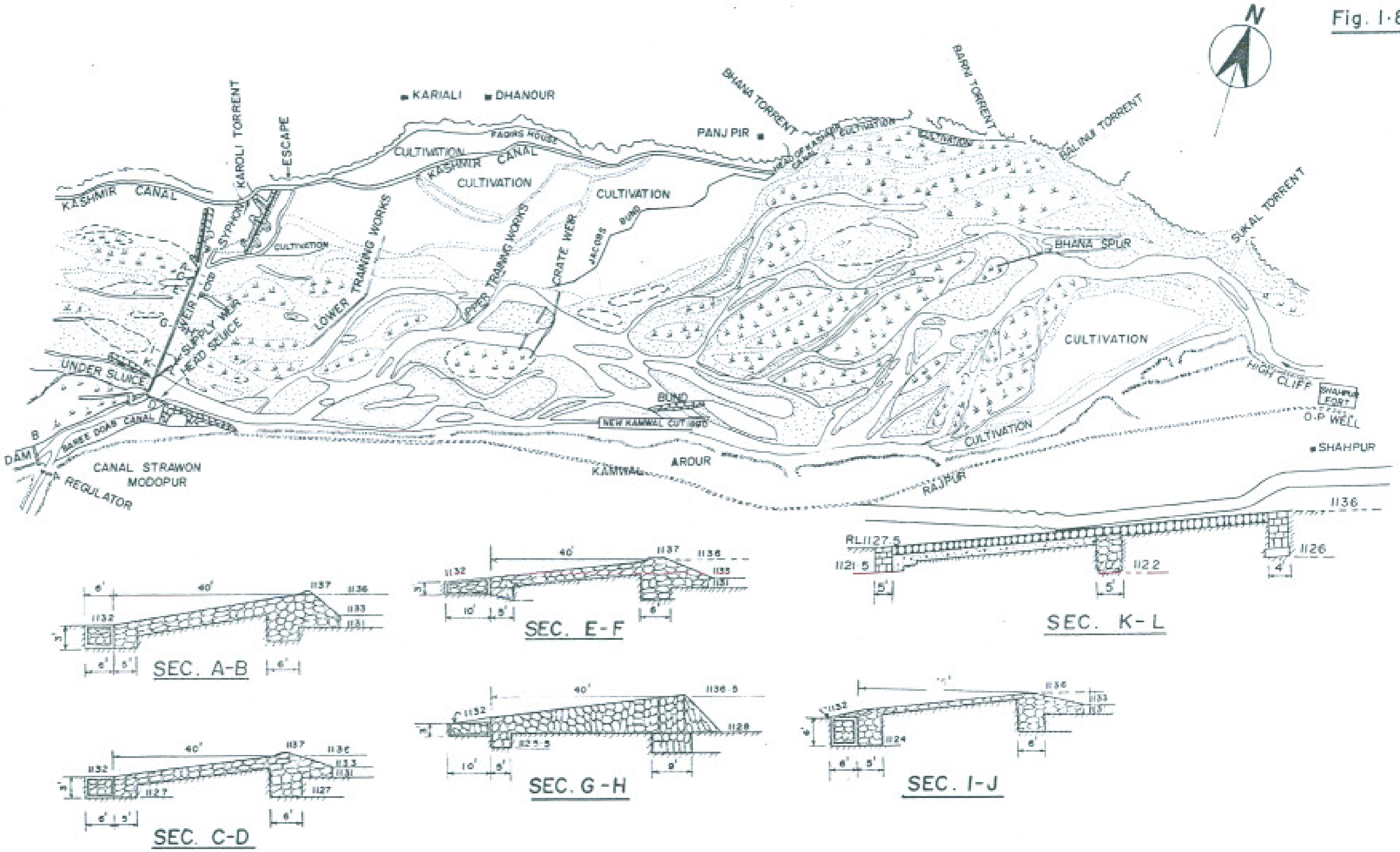


Fig. 1·7(c)

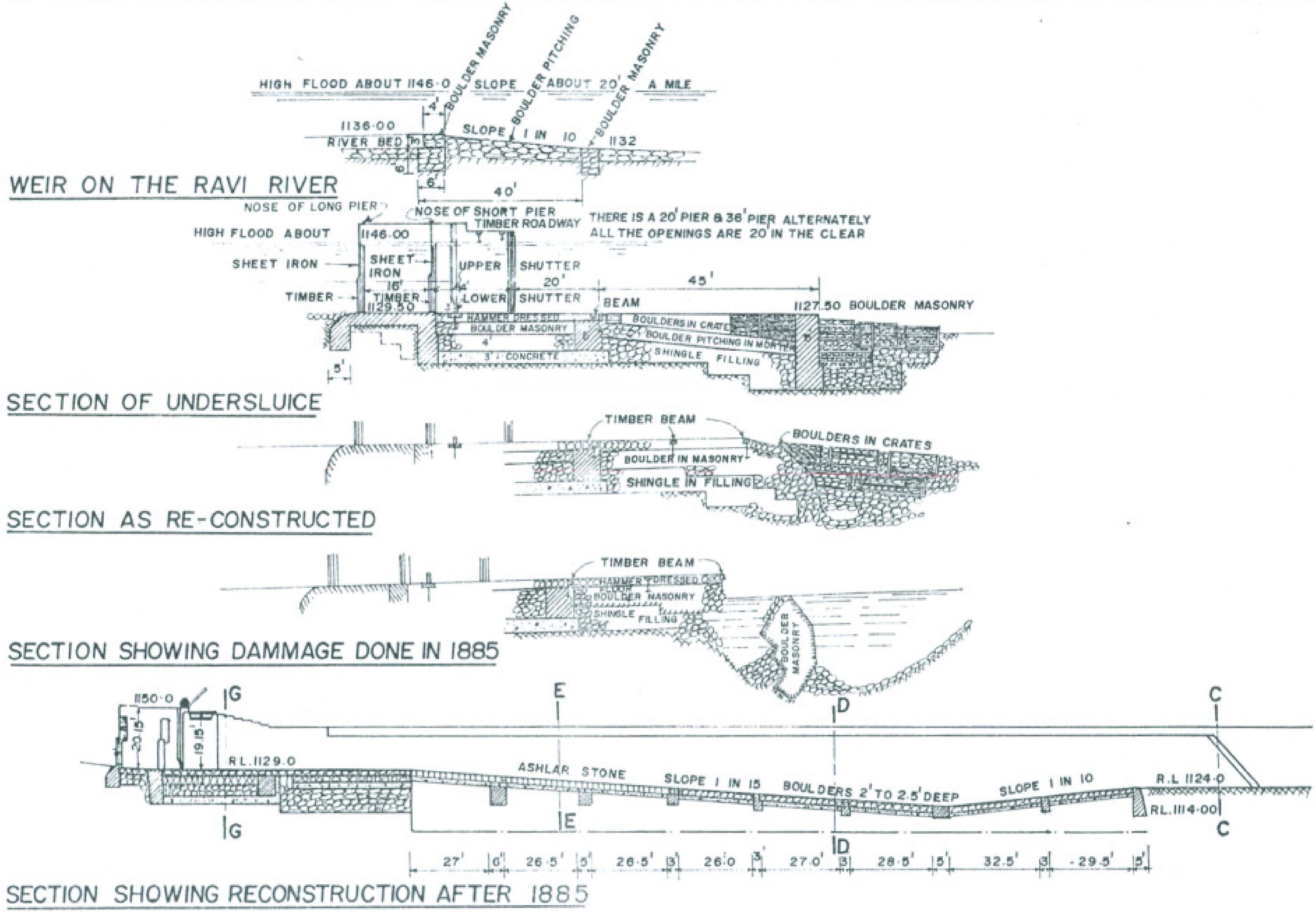
SECTION OF RUPAR HEADWORKS AT SUTLEJ RIVER

Shabbir Ahmad



MODHOPUR AT RIVER RAVI (SURVEY 1890)

Shabbir Ahmad

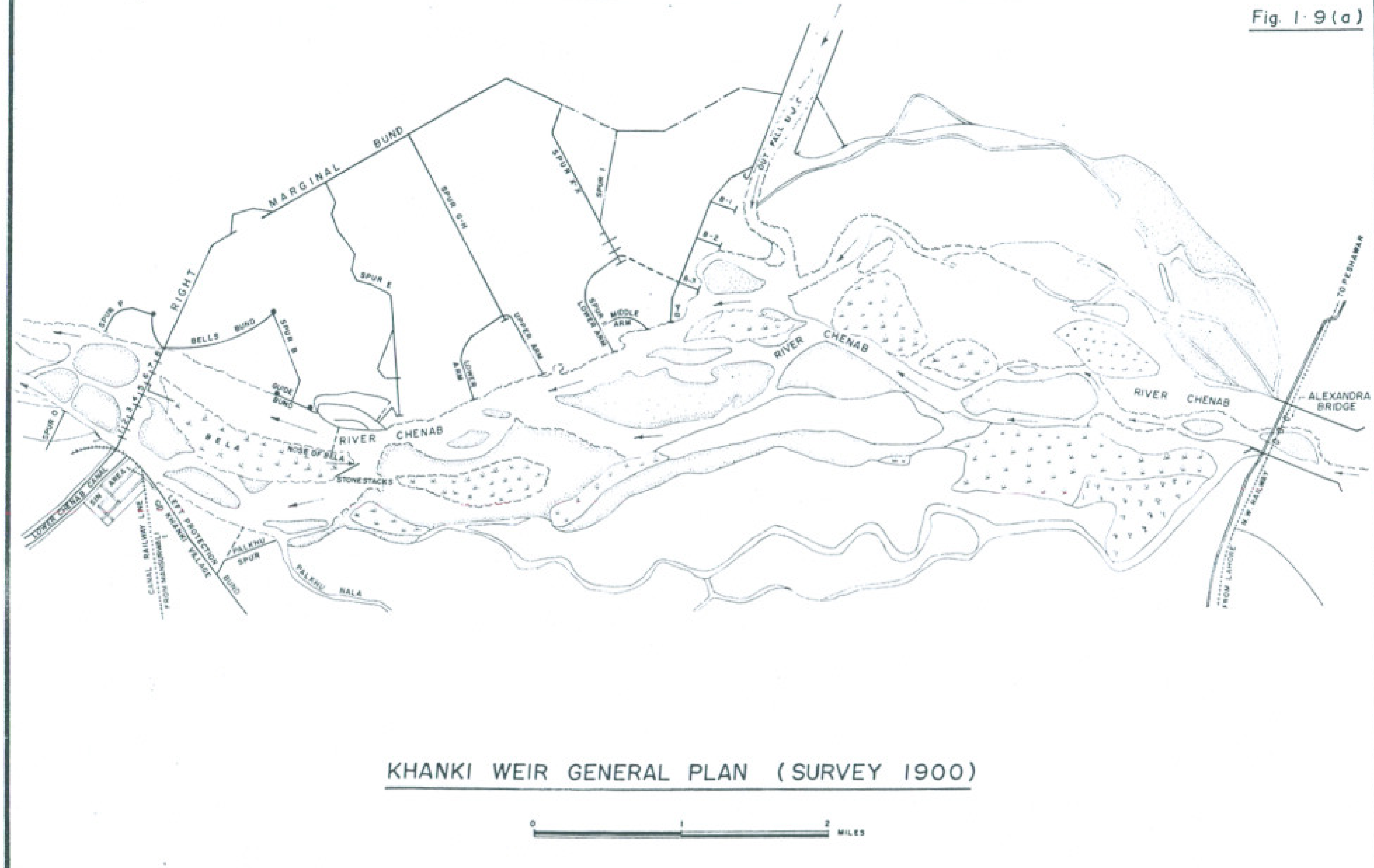


SECTIONS OF MODHOPUR WEIR AND UNDERSLUICES

Fig. 1·8(b)

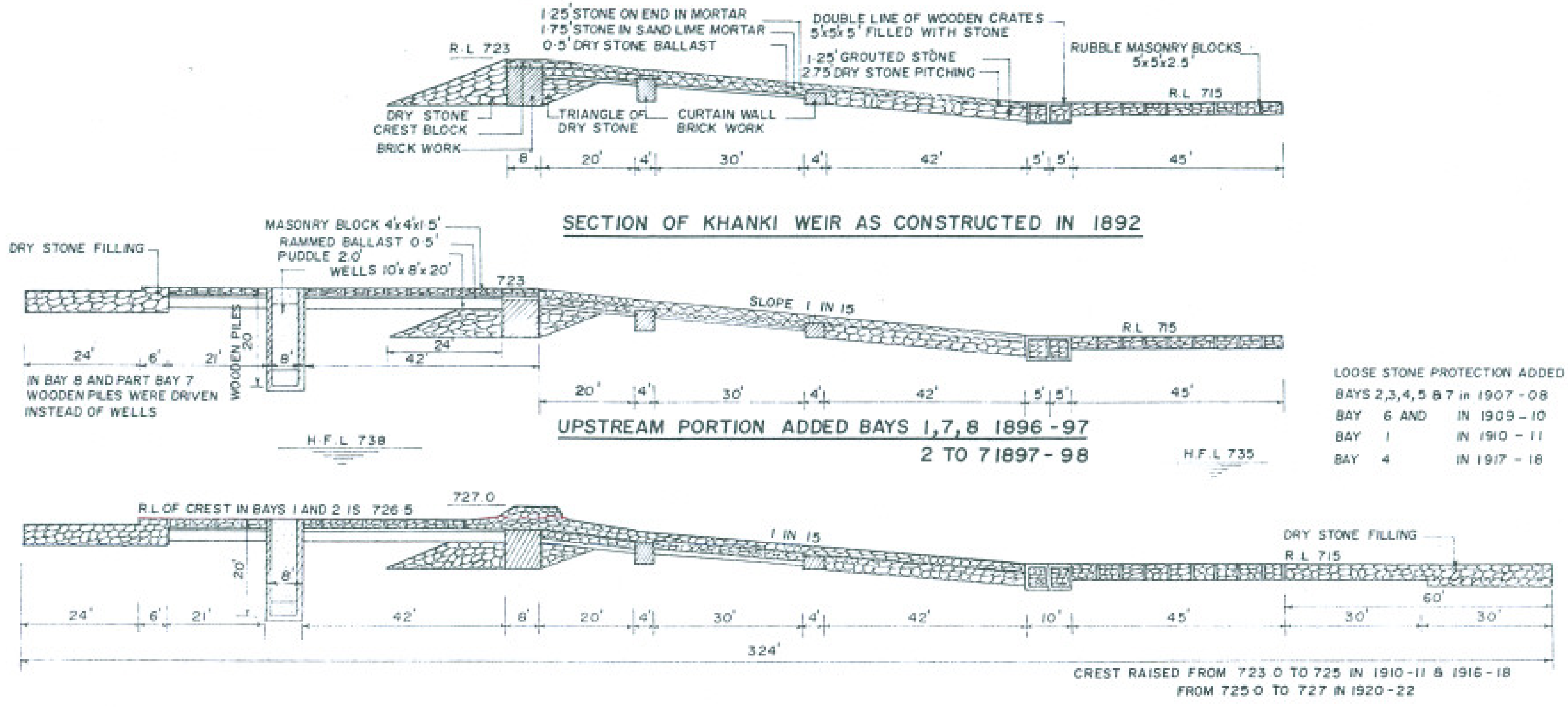
Shabbir Ahmad

Fig. 1·9 (a)



KHANKI WEIR GENERAL PLAN (SURVEY 1900)

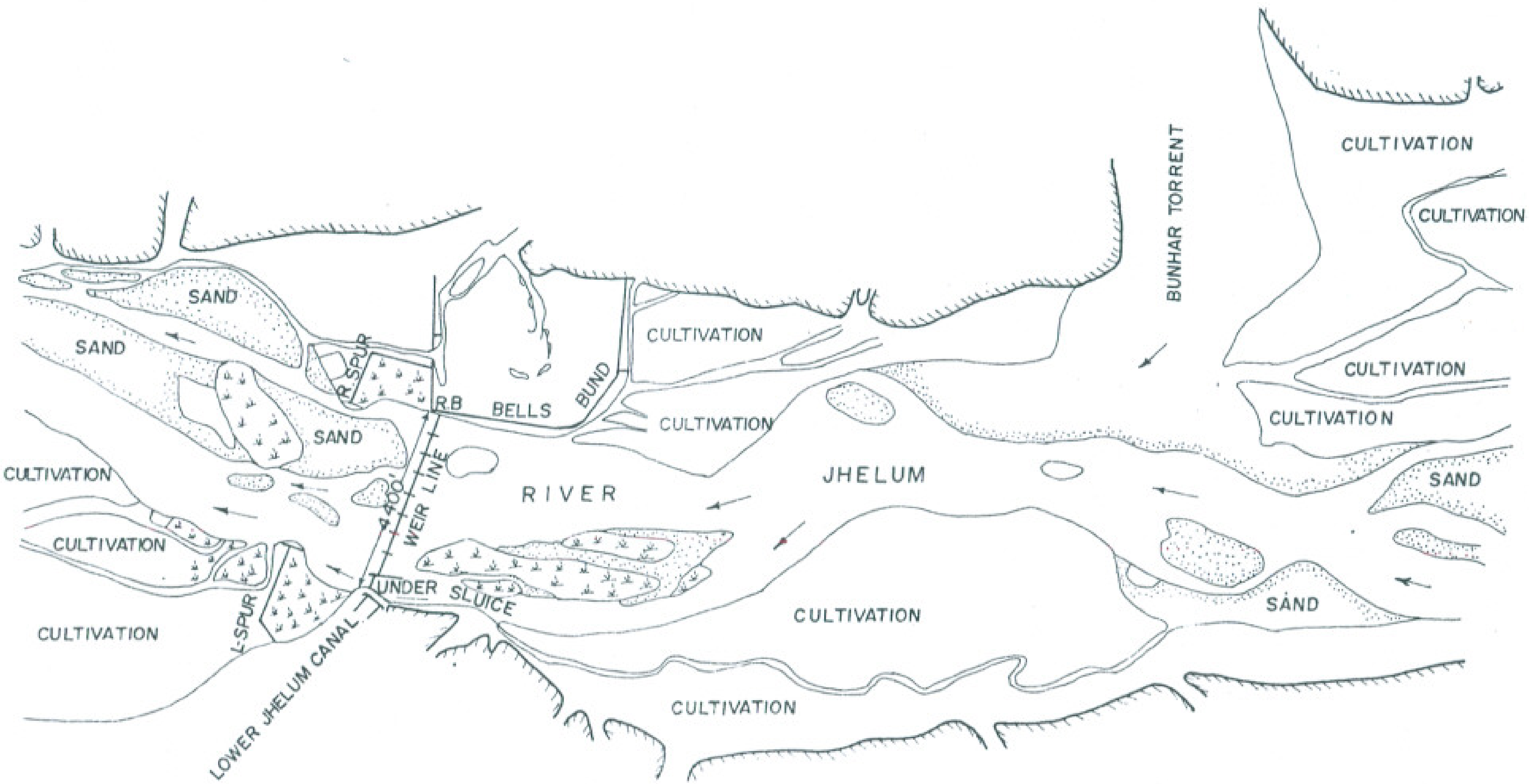
Fig. 1·9 (b)



SECTION OF KHANKI WEIR BEFORE AND AFTER RECONSTRUCTION

SCALE 1 : 250

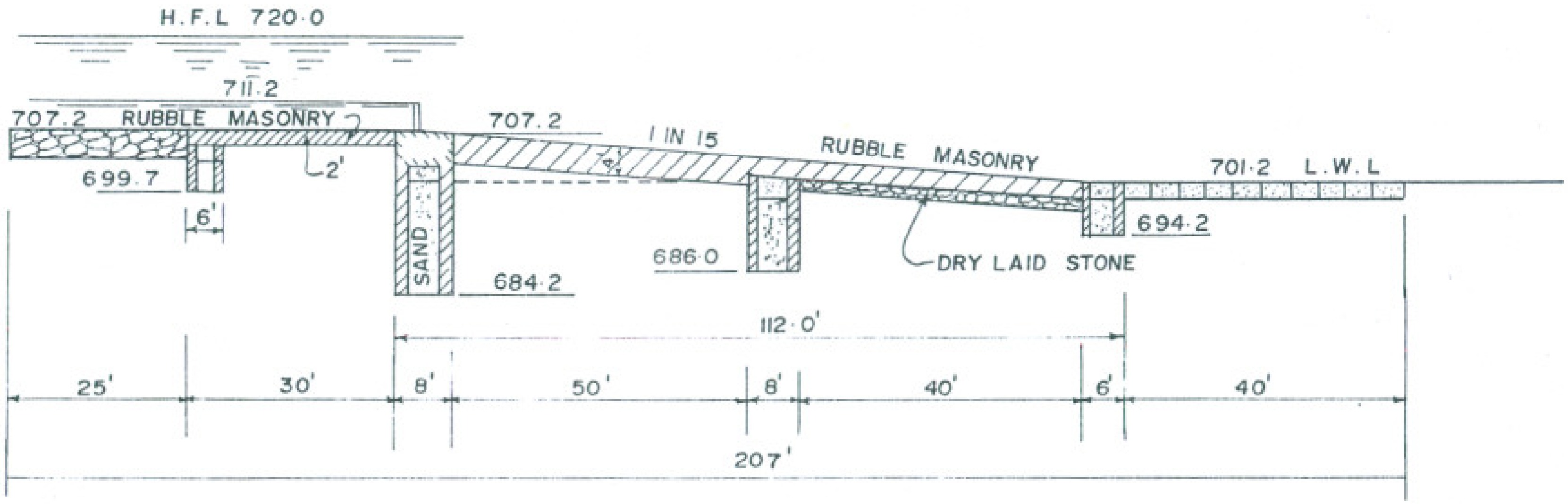
Shabbir Ahmad



SUVEY PLAN OF RIVER JHELUM AT RASUL (1916 -17)

Fig. 1·10 (a)

Shabbir Ahmad



RASUL WEIR, LENGTH 4000 FEET, DISCHARGE 600,000 CUSECS (1912)

Fig. 1·10(b)

Shabbir Ahmad

Fig. 1·11 (a) & (b)

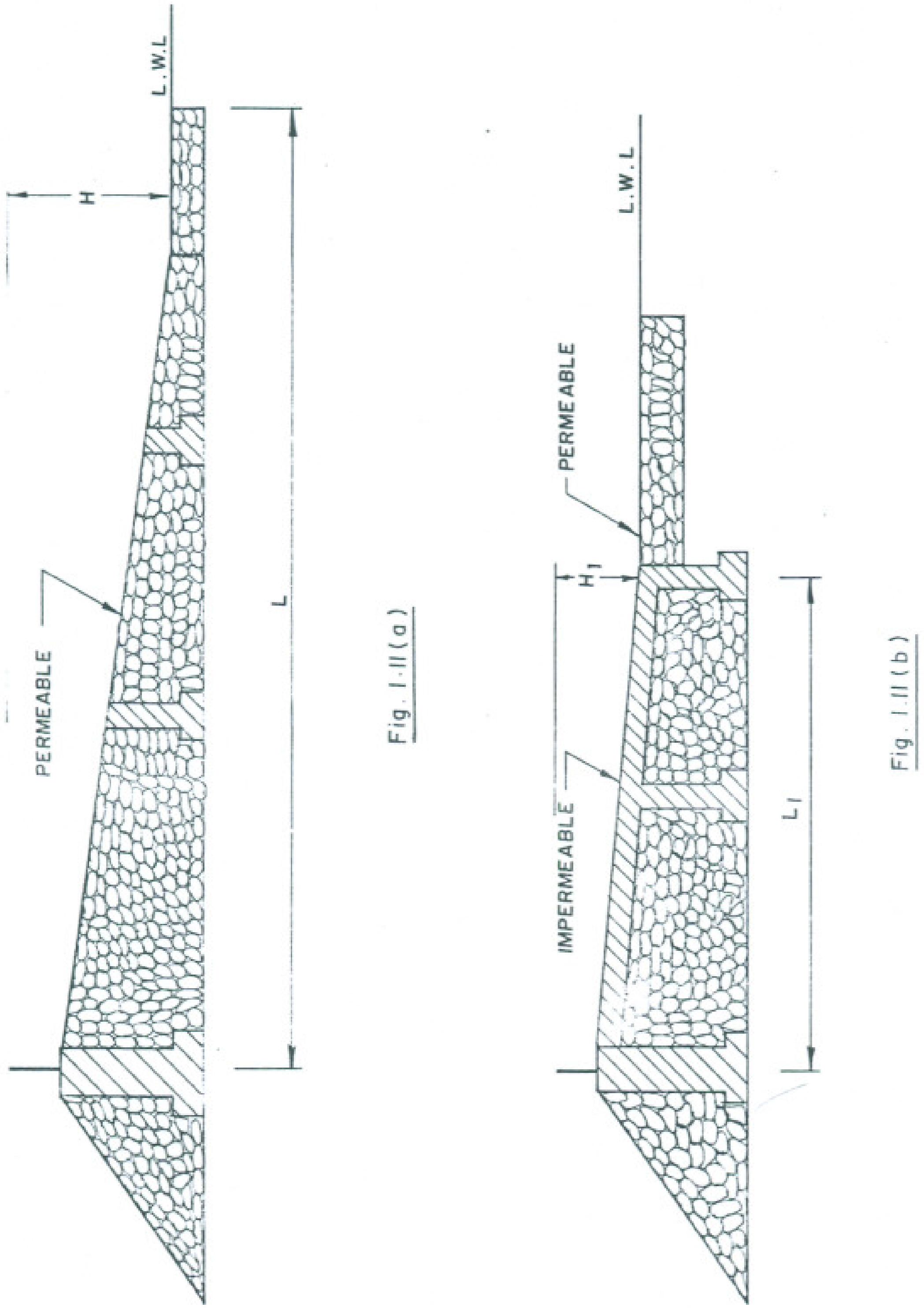
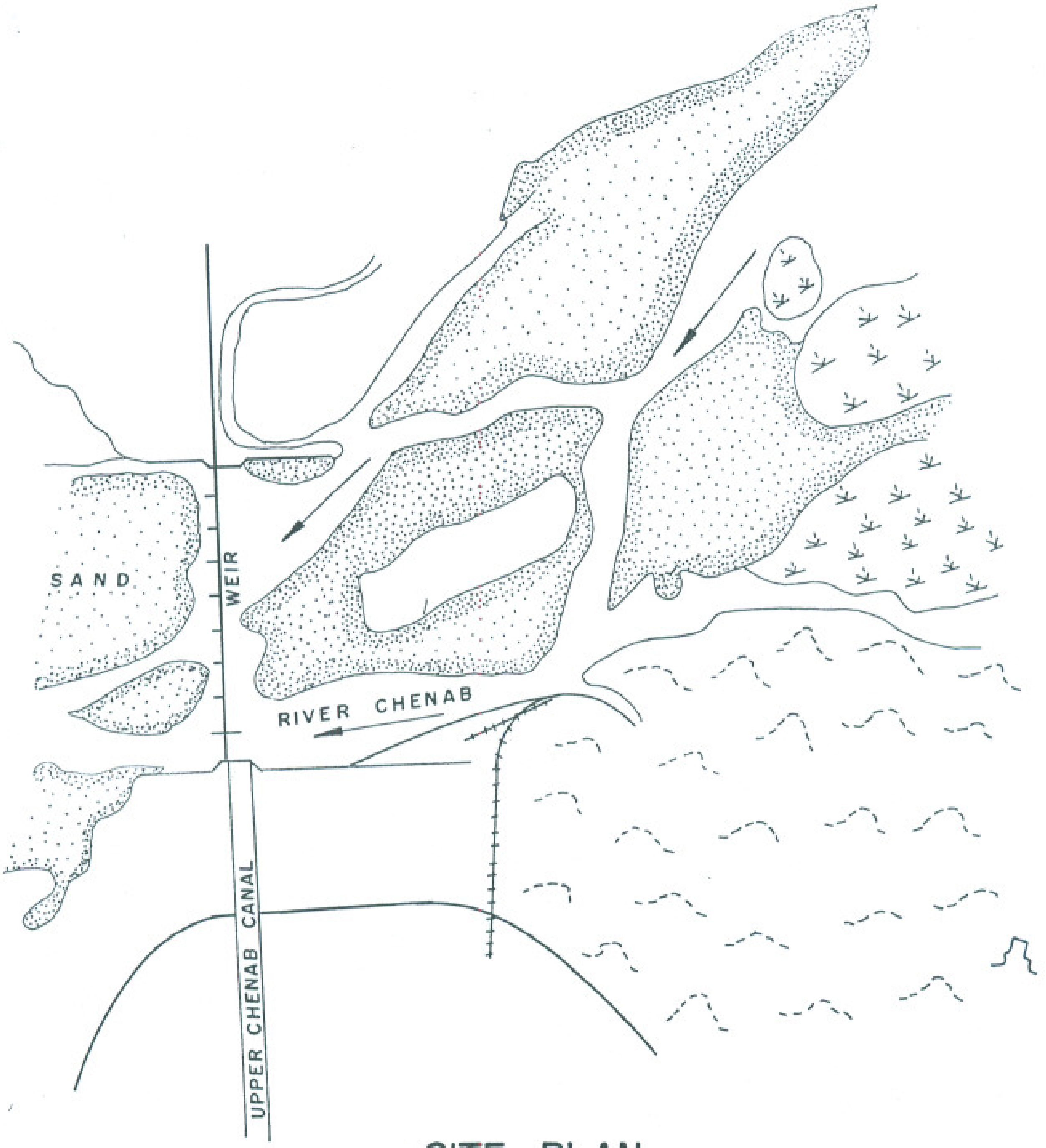


Fig. 1·11 (a)

Fig. 1·11 (b)

Zafar Karim Awan.

Fig. 1.12 (a)



SITE PLAN

OF

MARALA WEIR AT CHENAB RIVER

(SURVEY 1926)

Zafar Karim Awan.