(5) Regarding the samples on the sand bar, grain size distributions of No. S1 ~ No. S3 at old sand bar and No. S4 ~ No. S6 at new sand bar are different. The latter is biased to the coarser side. However, the percentage of grains under d = 0.075 mm is small for both cases as seen in the bed material. It is presumed that finer material is being washed away by the current.

(6) As shown in Fig. 5.13, in general, the value of $\sqrt{d84/d16}$ becomes larger and the range of grain size distribution increases as d50 becomes smaller. At the sampling points composed of fine material, widely-distributed sizes up to coarse component are contained because gradation by current is not performed.

(7) Specific gravity of samples No. C1 to No. C12 ranges between 2.65 and 2.78. The average is 2.73.

In conclusion, the soil at each sampling point is primarily composed of fine material, d = 0.02 ~ 0.2 mm, and does not contain material of the size d > 0.3 mm. Further, the mean grain size of material that affects river bed fluctuation is around d = 0.1 mm based on the distribution curves. As for this size, its critical tractive velocity and settling velocity are equivalent to about 1 cm/sec. Therefore, the proportion of suspended load composed in transported sediment is high. On the other hand, silt components smaller than d = 0.02 mm are contained in small amounts in the samples on the river bank that represents characteristics of cohesive material. However, it might be the material which cannot be compacted and is liable to be fluidized under saturated condition.

5.7 Proposed Alignment and Area of Bank Protection at Comilla Side

Based on the result of the study on the present river condition, as well as the output of two-dimensional flow simulation that is discussed subsequently in Chapter 6, an appropriate alignment of the bank protection by stone embankment to protect the abutment and approach road is proposed along the line connecting the toe of left abutment of the bridge (to be included the existing damaged revetment downstream of the Bridge) to the ferry ghat (to be included the upstream shoreline of the ferry ghat).

Advantages of the proposed alignment are as follows:

(1) Since the small bay in front of the existing revetment is to be filled and a smooth shoreline will be created from upstream of the old ferry ghat toward the left abutment, the water surface profile upstream of the Bridge will be made steady

without unfavorable turbulence and vortexes. In this aspect, the existing scour pool will possibly be buried gradually by silt transported from the upstream side.

(2) The upstream shoreline of the ferry ghat should be protected by the riprap to protect against scouring. However, as clarified in Section 5.3, in the meantime scouring of the left bank upstream of the old ferry ghat will continue. Even in case that sliding occurs again and water outflank behind the new stone embankment, additional stone dumping and extension of the protection works can be duly provided because the damage will not directly affect the stability of the abutment of the Bridge.

Although the river bank on the Comilla side will be strengthened as abovementioned, continuous monitoring of river bed fluctuation and local scouring near the old ferry ghat must be made after construction of the proposed works. The method of monitoring and maintenance works is recommended in Chapter 8.

5.8 Design Values for Proposed Bank Protection

5.8.1 Design Flow Velocity

As described in Section 4.3, the maximum surface flow velocity of 1.60 m/sec at the Meghna Bridge was recorded on Aug. 1, 1989 when the water level was R.L +4.50 m. Further, the simulation study by the two-dimensional flow model in this study showed 1.58 m/sec as an average flow velocity in front of the left bank at the Bridge section.
The point flow velocity underwater in the vicinity of the foot and slope of the proposed stone embankment will be smaller than the above velocity. However, considering the complex mechanism of local current of fluid specially during floods, it is presumed that higher flow velocity might occur near the ferry ghat. Further, the fact of appearance of the deep scour pool and the active geomorphlogical change of the river channel near the ferry ghat implies that considerable high velocity will happen adjacent to the area. Thus, taking account of safety factor to be given, the design flow velocity is decided to be 3.0 m/sec for examination of stability of the proposed riprap.

5.8.2 Appropriate Size of Stone for Riprap

In order to determine an appropriate size of the stone riprap against the design flow velocity, the tractive force theory is generally applied. Required condition of the stability of soil particle on the river bed is that the tractive force τ* (or the friction velocity, u*) shall be smaller than the critical tractive force τ* (or the critical friction velocity, u*) which can be derived from a particular river section and concerned grain size.

The parameters, u* and τ*, can be expressed as below:

$$u^* = \sqrt{g\ R\ ie}\ ,\ \tau^* = \frac{U^{*z}}{Sgd} = \frac{Rie}{Sd}$$

where,

s	:	Specific gravity of soil in water
g	:	Gravity acceleration
d	:	Grain size
ie	:	Energy gradient
R	:	Hydraulic radius

The hydraulic radius, R, corresponding the design velocity is estimated by the Manning's formula as below :

$$v = \frac{1}{n} R^{2/3}\ ie^{1/2}$$

The energy gradient was approximated by water surface gradient, which is 1/15,000 in the stretch between No. U10 and No. D4, estimated based on the result of the simulation in the case of R.L 4.00 m at the Bridge site in this study.

v=3.0 m/sec, n=0.03, ie=1/15,000

Thus,

R=36.6 m, u^*=15.46

On the other hand, the critical friction velocity, u^*c, is given by Iwagaki as follows:

$$u^*c = 80.9\ d\ \ (\text{for } d>0.303\text{cm})$$

The required minimum grain size is obtained as bellow:

$$d > \frac{U^{*2}}{80.9} = \frac{15.46^2}{80.9}$$

$$= 3.0\ \text{cm}$$

It is theoretically revealed that stones having about 3 cm in diameter will not move under the hydraulic condition above.

However, it should be noted that a number of failures due to erosion are caused by structural defects and insufficient material. At the Bhairab Bazar railway bridge, considerable large size of boulders, approximately 30 to 50 cm, are being utilized for the bank protection. In the stockyard beside the bridge, a huge quantity of boulders are now stored for the extented river training works in the vicinity of the Bridge. Further, since most of the proposed construction works on the Comilla side will be obliged underwater, the construction of the stone embankment and riprap aiming to meet a strict specification as designed will be practically very hard in terms of appropriate mixture of different size and its accurate placement. Thus, taking account of the uncertainity of the construction, the minimum size of stones required for the proposed works is determined to be 30 cm in diameter.

5.8.3 Design Maximum Scouring Level

In the Feasibility Study on Meghna, Meghna-Gumti Bridges Construction Project, the scouring depth was estimated at the proposed two bridge sites by various methods. The results are presented in Appendix of the said Report (Page AP.2-24). After comparison of the results, the maximum value of 11.0m estimated by Laursen's method among total 12 methods was finally applied at the Meghna Bridge site. Then, the scouring level was set at R.L -22.0m referring the lowest river bed of R.L -11.0m to design the pile foundation of the bridge piers.

On the other hand, the deepest scour pool has been observed R.L -30.0m near the ferry ghat when the river survey was carried out in November 1989. The latest river bed level was measured R.L -26.0m in June 1992. by the present study In respect of on this local scouring near the ferry ghat, detailed description is given in Section 5.4.

As the result of examination on the above, the design maximum scouring level is determined to be R.L -30.0m for designing the foot protection of the proposed bank protection on the Comilla side in the subsequent studies.

CHAPTER 6 HYDRAULIC ANALYSIS NEAR MEGHNA BRIDGE BY THE TWO-DIMENSIONAL FLOW MODEL

CHAPTER 6 HYDRAULIC ANALYSIS NEAR MEGHNA BRIDGE BY TWO-DIMENSIONAL FLOW MODEL

6.1 Objective of Simulation

In order to grasp the hydraulic characteristics mathematical model in the vicinity of the Meghna Bridge and to create a basis for elaboration by means of further accumulated topographic and hydrological data in the future, a mathematical simulation by two-dimensional flow model was conducted. Although hydraulics and inundation features during flood are not yet clarified in detail in the Meghna River basin due to shortage of available data, a mathematical model was established with reasonable and simplified boundary conditions that represent the river stretches near the Meghna Bridge.

Computation for two water levels, H = 4.00 m and 6.29 m, at the Meghna Bridge were carried out to assess hydraulic conditions during flood. The results of simulation were evaluated in view of the relationship between hydraulic characteristics and scouring of the river bank.

6.2 Applied Simulation Model

6.2.1 Principal Equations

The principal equations of the Two-dimensional Flow Model, composed of Theories of Energy Conservation and Mass Conservation, are expressed as follows:

$$\frac{\partial h}{\partial t} + \frac{\partial M_j}{\partial x_j} = 0 \tag{1}$$

$$\frac{\partial M_i}{\partial t} + \frac{\partial}{\partial x_j}\left\{M_i u_j - \varepsilon\left(\frac{\partial M_i}{\partial x_j} + \frac{\partial M_i}{\partial x_j}\right)\right\} = -gh\frac{\partial H}{\partial x_i} - \frac{T_{bi}}{\rho} \tag{2}$$

where,
- t : Time coordinate
- χi : Cartesian coordinate plane
- h : Water depth
- Mi : Discharge flux (= μih)
- μi : Vertical mean velocity
- g : Gravity acceleration
- H : Water level
- ε : Eddy viscosity coefficient
- ρ : Density of fluid

Further, Tbi means tractive force on the channel bed. In that case, the Friction Theory of Manning is usually applied:

$$T_{bi} = \frac{\rho g n^2 u_i \sqrt{u_k u_k}}{h^{4/3}} \tag{3}$$

where, n : Manning's roughness coefficient

Equation (2) is assumed by static water pressure as for vertical distribution of pressure. Since such assumptions are applicable to relatively shallow flow condition, this equation is called the "Shallow Water Flow Condition". Generally, as boundary conditions, the following three relations are considered.

$$M_i = \hat{M}_i \qquad S \in S_1 \tag{4}$$

$$r_i = \left\{ \varepsilon \left(\frac{\partial M_i}{\partial x_j} + \frac{\partial M_j}{\partial x_i} \right) \right\} = n_i \hat{r}_i \qquad S \in S_2 \tag{5}$$

$$h = \hat{h}_i \qquad S \in S_3 \tag{6}$$

In the above, ri: χi Coordinate of force on surface, ni: Cosine element of unit vector acting outside of boundary, ^: Initial value at boundary. In addition, boundary "S" is constant of S_1, S_2, and S_3. S_1 and S_2 are not to be duplicated and S_3 is to be a part of S_2.

In analysis of the Two-dimensional Flow Model, it is required that a function of distributions of flow velocity and water depth be obtained which satisfies the group of the principal equations above under the boundary conditions. However, to get an analytical solution is almost impossible except in very few situations, practically an approximate solution by numerical analysis is required.

6.2.2 Algorithm

Methods of numerical analysis are classified as FDM, FEM and BEM by the discrete method. Among them, FEM is most commonly utilized. In FDM, the equation of dispersion is basically formulated by variables on the regular lattice. On the other hand, FEM has only few limitation on setting nodes for computation and has advantages when computating of flow areas with irregular boundary shapes. Considering application to the two-dimensional flow simulation, the advantages of setting nodes freely are essential because real topography is usually used.

Therefore, FEM was considered the most appropriate method in this study. Several analytical methods to solve the shallow flow equation by FEM have been studied. As for discretion of spacial dimension, Galerkin's method was used and as for discretion of time dimension "Two-stepped Positive Method" which treats up to secondary terms in Taylor's expansion was used. Two-stepped Positive Method is an algorithm suitable for large-scale analyses, because computation proceeds without solving simultaneous equations.

The two-stepped positive finite element equations are written as follows, where suffix α, β and γ express the respective apexes and the superscript n expresses a step of computing time.

(First step)
$$\bar{A}_{\alpha\beta} M_{\alpha\beta}^{n+1/2} = \bar{A}_{\alpha\beta} M_{\beta i}^{n} - \frac{\Delta t}{2}\{B_{\alpha\beta j\gamma} u_{\beta j}^{n} M_{\gamma i}^{n} + C_{\alpha\beta\gamma j} u_{\beta j}^{n} M_{\gamma i}^{n} + S_{\alpha i\beta j} M_{\beta j}^{n} + F_{\alpha\beta\gamma i} h_{\beta}^{n} H_{\gamma}^{n} - \tilde{A}_{\alpha\beta} \lambda M_{\beta i}^{n} - \Omega_{\alpha i}\} \quad (7)$$

$$\bar{A}_{\alpha\beta} h_{\beta}^{n+1/2} = \bar{A}_{\alpha\beta} h_{\beta}^{n} + \frac{\Delta t}{2} G_{\alpha\beta i} M_{\beta i}^{n} \quad (8)$$

(Second step)
$$\bar{A}_{\alpha\beta} M_{\alpha\beta}^{n+1} = \bar{A}_{\alpha\beta} M_{\beta i}^{n} - \Delta t\left\{B_{\alpha\beta j\gamma} u_{\beta j}^{n+1/2} M_{\gamma i}^{n+1/2} + C_{\alpha\beta\gamma j} u_{\beta j}^{n+1/2} M_{\gamma i}^{n+1/2} + S_{\alpha i\beta j} M_{\beta j}^{n+1/2} + F_{\alpha\beta\gamma i} h_{\beta}^{n} H_{\gamma}^{n} - \tilde{A}_{\alpha\beta} \lambda M_{\beta i}^{n+1/2} - \Omega_{\alpha i}\right\} \quad (9)$$

$$\bar{A}_{\alpha\beta} h_{\beta}^{n+1} = \bar{A}_{\alpha\beta} h_{\beta}^{n} + \frac{\Delta t}{2} G_{\alpha\beta i} M_{\beta i}^{n+1/2} \quad (10)$$

where,
$$A_{\alpha\beta} = \int_V (\Phi_\alpha \Phi_\beta) dV, \quad B_{\alpha\beta j\gamma} = \int_V (\Phi_\alpha \Phi_{\beta,j} \Phi_\gamma) dV, \quad C_{\alpha\beta\gamma j} = \int_V (\Phi_\alpha \Phi_\beta \Phi_{\gamma,j}) dV,$$

$$S_{\alpha\beta\gamma j} = \int_V \varepsilon(\Phi_{\alpha,k} \Phi_{\beta,k}) \delta_{ij} dV + \int_V \varepsilon(\Phi_{\alpha,j} \Phi_{\beta,i}) dV,$$

$$F_{\alpha\beta\gamma j} = \int_V g(\Phi_\alpha \Phi_\beta \Phi_{\gamma,j}) dV, \quad G_{\alpha\beta i} = \int_V (\Phi_\alpha \Phi_{\beta,j}) dV,$$

$$\lambda = \frac{g n^2 \sqrt{M_{\alpha k}}}{h^{10/3}}, \quad \Omega_{\alpha i} = \int_{S_2} (\Phi_\alpha \hat{r}_i) dS$$

Further, $\bar{A}$ means a concentrated coefficient matrix given by accumulation of a diagonal term and asymmetric term, and $\tilde{A}$ is the modified concentrated coefficient matrix defined by,

$$\tilde{A}\alpha\beta = e\ \bar{A}\alpha\beta + (1-e)\ A\alpha\beta \quad (11)$$

6.3 Assumptions and Results of Simulation

Two-dimensional flow simulation was conducted by means of a two-stepped positive finite element method in the area of the river which stretches approximately 10 km from cross section No. D4 to No. U10. Through the simulation, the hydraulic condition of the surface flow in the vicinity of bank protection area was assessed. Peak discharge of 12,000 m^3/sec which was estimated at Meghna Bridge as the peak discharge in July 1988 was applied for simulation.

6.3.1 Assumptions

(1) Division of Finite Elements

Division of finite elements were made; 620 nodes and 1,121 elements were produced as shown Fig. 6.1. The interval in the detailed sounding area adjacent to the Bridge is set at 50 m and 100 m for all other area based on the survey result in July 1992.

(2) Topographic Condition

The third dimensional coordinates of the river bed at each node for computation were based on the coordinates of the control points and results of the cross-section survey. Further, those at interpolated sections between measured ones were set by means of the contour map of the river bed.

(3) Boundary Conditions

Water depth and discharge flux are given at the downstream and upstream ends of the project area. Condition of slippery wall are applied to the lateral boundary. The water level at the downstream end was R.L. 3.88 m while at the Meghna Bridge it was R.L. 4.00 m and thus no gradient is assumed in lateral direction of the flow.

The discharge flux at the upstream end is distributed to each node so that the discharge volume crossing each section will be 12,000 m^3/sec. The ratio of distribution was estimated by assuming that it is proportionate a power of the water level. Flow direction is set in the direction of normal.

As for the initial conditions at each section, water depth and discharge flux are given by the same methods as for the boundary conditions through water surface profile computation by non-uniform flow analysis.

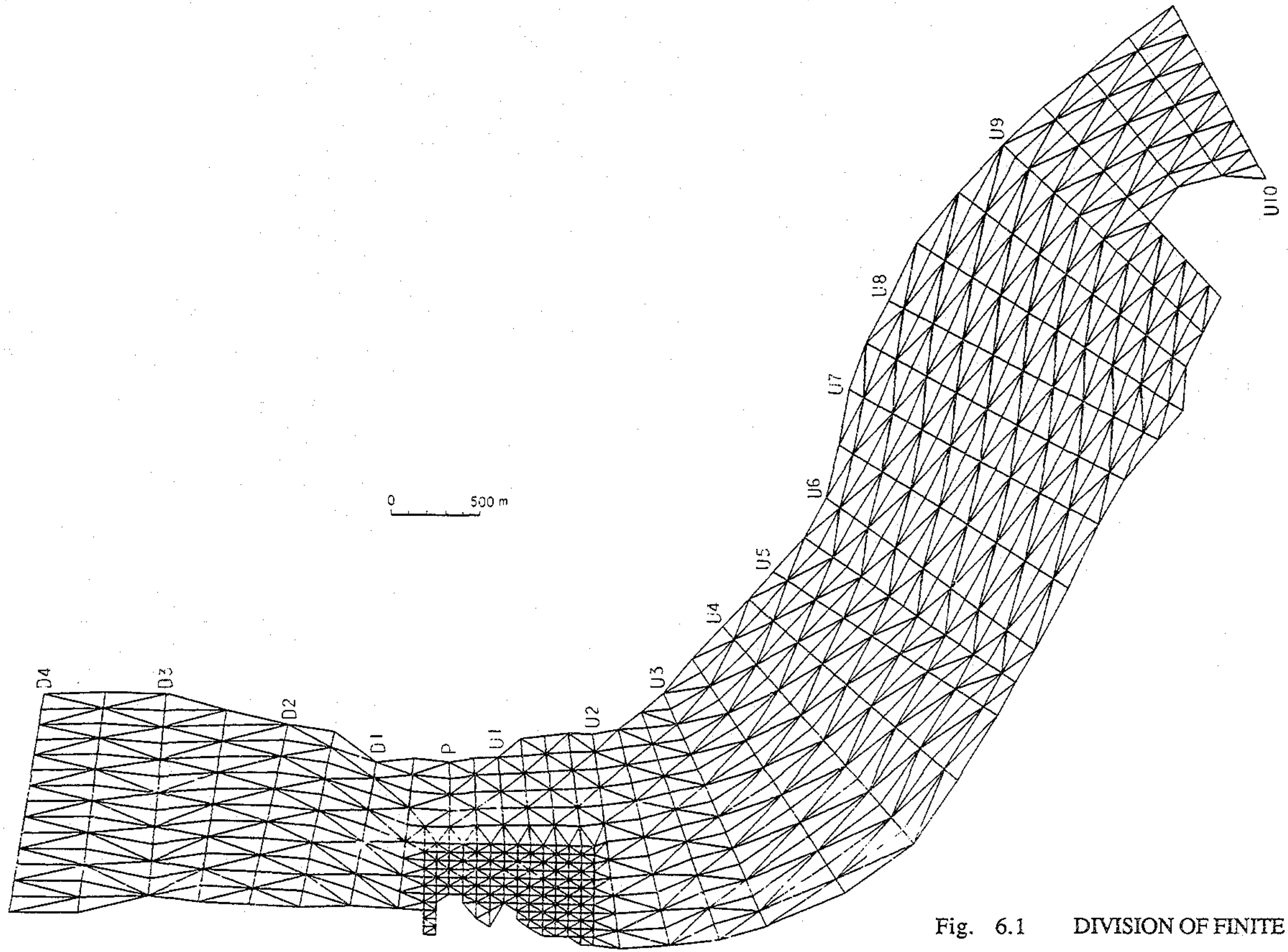


Fig. 6.1 DIVISION OF FINITE ELEMENT

(4) Other Assumptions

Other assumptions applied in the simulation are as follows:

- Interval of computation (Δt) : 0.05 sec
- Adjustment factor (e) : 0.7
- Manning's roughness coefficient : 0.030 sec $m^{-1/3}$ (for all section)

6.3.2 Results

By means of the assumptions described above, two-dimensional flow simulation was conducted. Computation was started from the initial condition and was repeated up to the water level. The discharge flux at all nodes in the project area for analysis converged to a constant value. The results for H = 4.00 m and H = 6.29 m are illustrated in Figs. 6.2 and 6.3 respectively.

6.4 Evaluation of Simulation Results

In order to clarify the relationship between flood characteristics and scouring of the river bank near the Meghna Bridge, the magnitude of the vectors of current inside, the channel approximately 100 m from the control points, are plotted based on the simulation results shown in Fig. 6.4. The following preliminarily findings were obtained through the figure:

(1) The distribution of flow velocity along the river course is similar for H = 4.00 m and H = 6.29 m. As a whole, the magnitude of vector becomes larger going downstream along both sides of the river bank.

(2) The peak velocities appear at No. U9, No D1, and No. D4 for the right bank and at the Bridge site for the left bank. In comparison of the magnitude of both banks at the respective points, a large difference is found at No. U9. It is judged that this phenomenon is a common characteristic at transition points of meandered channels.

(3) The largest velocity in the stretch from No. U10 to No. D4 occurs at the Bridge section for H = 4.00 m and H = 6.29 m. Considering the width and flow area of the respective sections compared, this phenomenon is recognized as common feature of hydraulics in open channels.

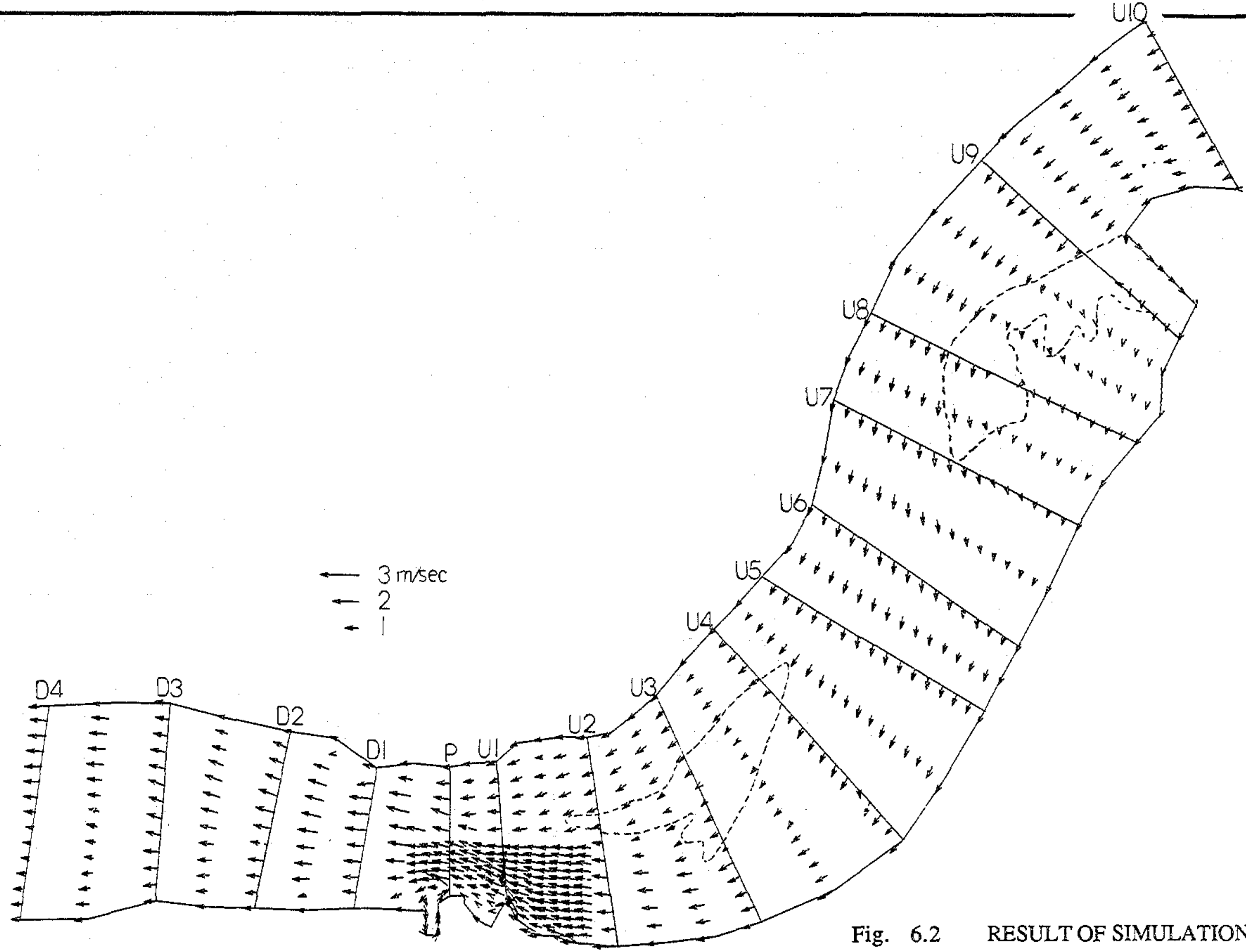


Fig. 6.2 RESULT OF SIMULATION (Hbg = 4.00 m)

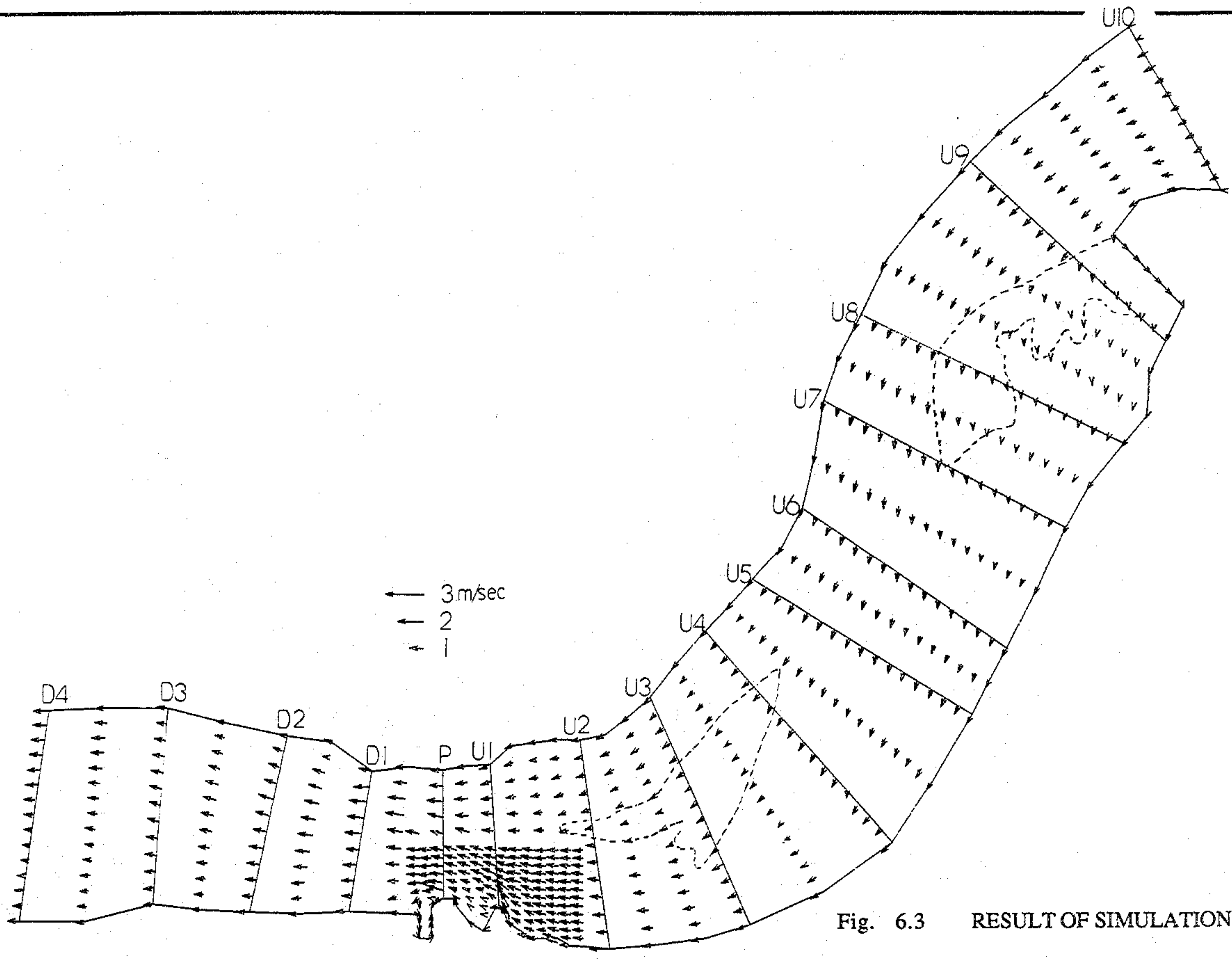


Fig. 6.3 RESULT OF SIMULATION (Hbg = 6.29 m)

(4) After comparison of the distribution of magnitude along the river course between the right and left banks, a turning point is revealed within the stretch from No. U4 to U5. This is caused by the explained current flowing into the branched channel at the sand bar just upstream of the Meghna Bridge If the branched channel on the right side of the sand bar did not exit, a large difference of velocity at No. U9 must occur similarly between No. U5 and No. U3.

It is deemed, of course, that the magnitude of flow velocity in the vicinity of river bank is not the sole index representing scouring of river bank, but slope angle and soil conditions are also concerned. The numerical analysis contains limitations in clarification of the physical mechanism of scouring in connection with flood characteristics. However, as a whole, the results of simulation by the two-dimensional flow model, abovementioned, appropriately represents the flood characteristics in the aspect of scouring at river banks. It should be noted that the boundary conditions herein must be reviewed and elaborated based on the further accumulation of basic hydrological data of the Meghna River.

6.5 Result of Flow Velocity and Direction Survey

As described in Section 5.1, surface flow velocity and flow direction were observed during second field reconnaissance in September 1992. The results of the observation are illustrated in Fig. 6.5 with the distances between control points and their coordinates and elevations. In comparison of Fig. 6.2 and Fig. 6.5 it can be judged that the simulated flow directions show fairly good approximation of the actual hydraulic characteristics in the surveyed river stretches.

Further, the results of field measurement of the flow velocity are presented in Table 6.1 with the simulation results. The water level at the Meghna Bridge fluctuated between R.L +3.80 m to +4.00 m when the survey was carried out from Sept. 5 to Sept. 13, 1992. Thus, the observed water level is almost the same as given condition in the simulation, which is R.L +4.00 m at the Bridge site.

The observed values show around one half to one third of the calculated ones as a whole. It means that the actual discharge could be same magnitude of the proportion of the flow velocity. As for the simulation, the boundary conditions were set assuming a flood discharge of 12,000 m^3/sec. The flow velocity widely varies at certain water levels at the Bridge site as shown in Fig. 4.8. Therefore, it is noted that the hydraulic condition of the field measurement in September 1992 is different from the provided condition in the simulation and thus evaluation of the simulation result by means of the field measurement records is not available.

The measurement results of the point velocity underwater are presented in Fig. 6.6.

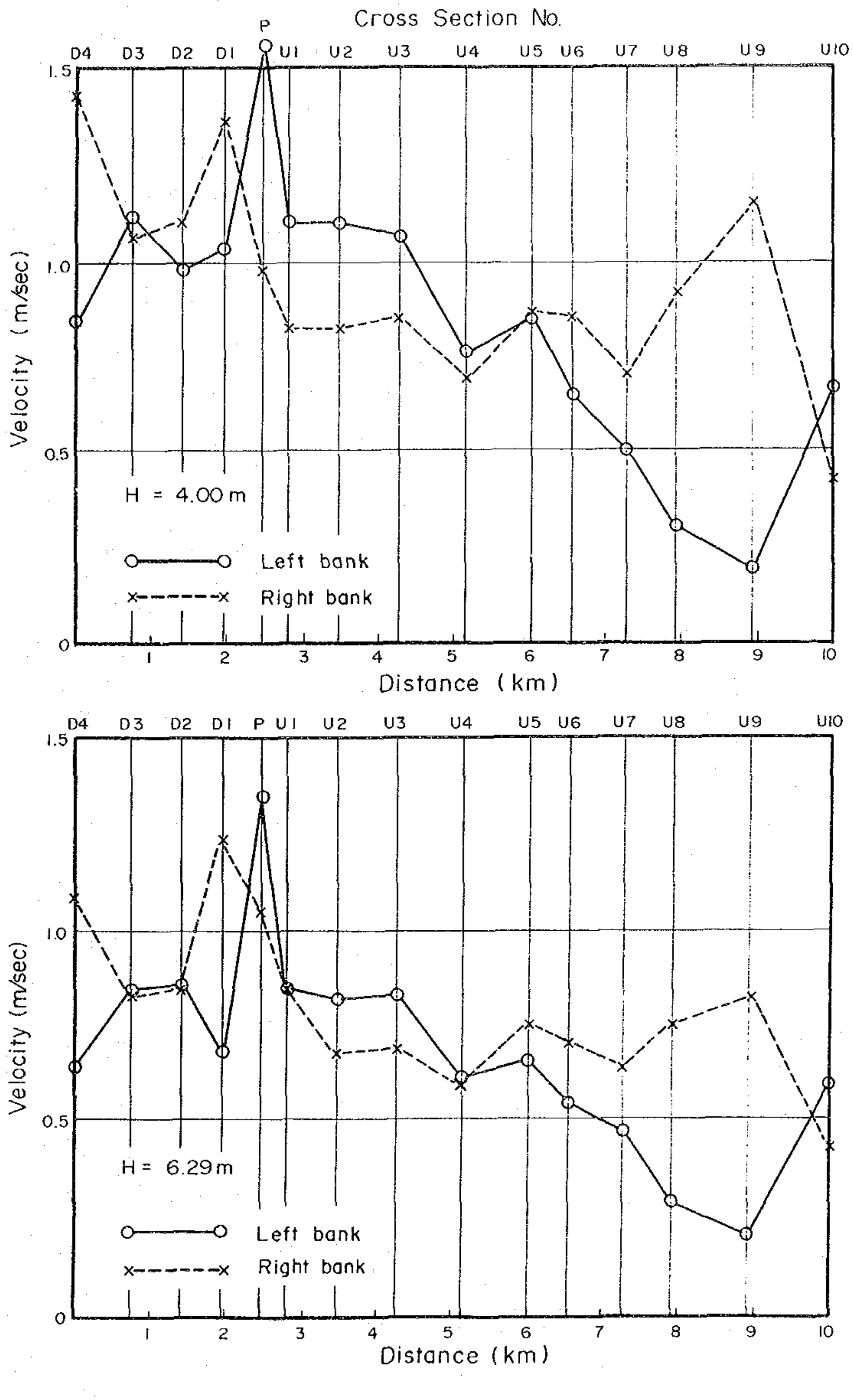
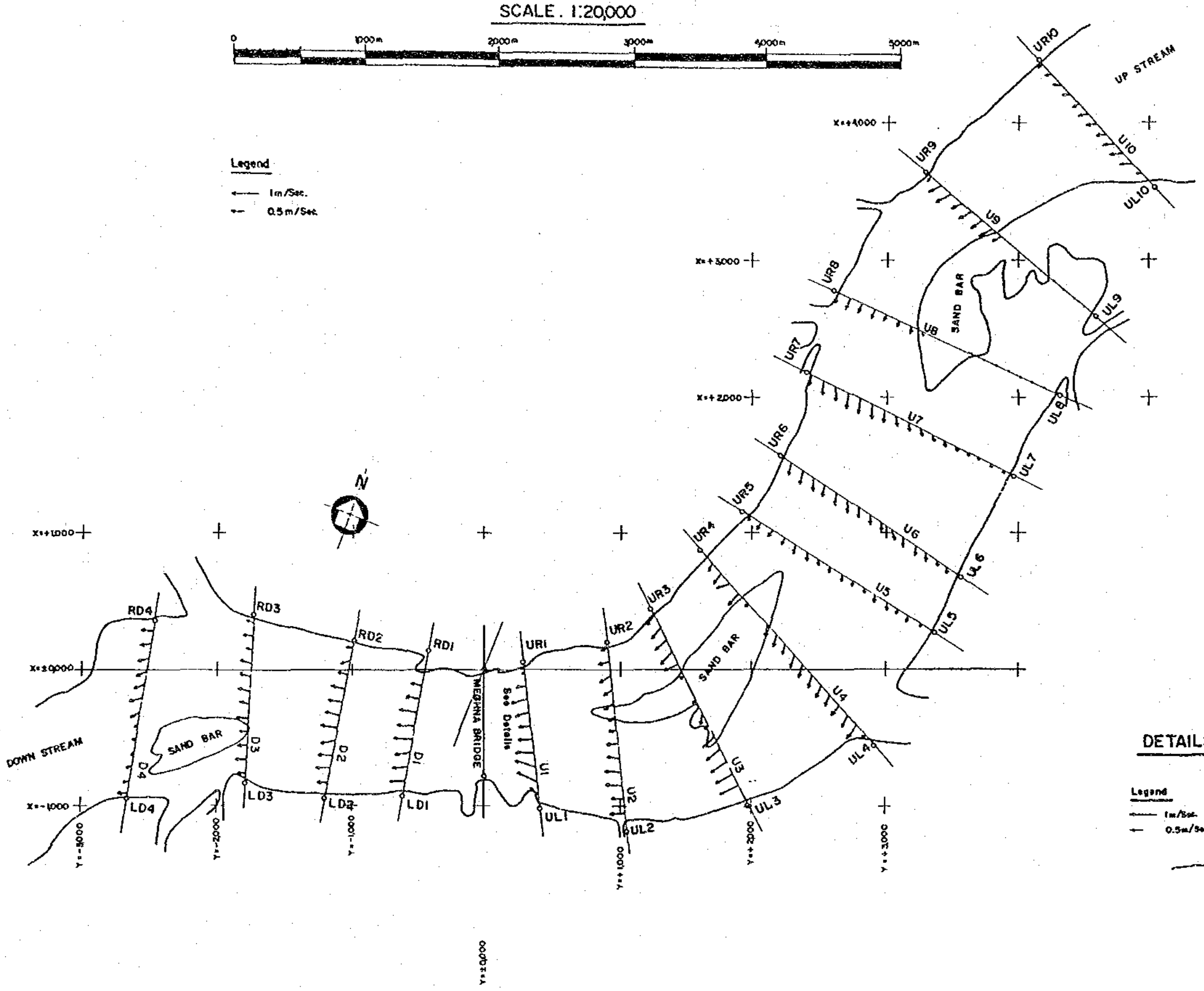


Fig. 6.4 FLOW VELOCITY DISTRIBUTION OBTAINED BY SIMULATION OF TWO-DIMENSIONAL FLOW MODEL

FLOW VELOCITY AND DIRECTION

AT MEGHNA RIVER
IN SEPTEMBER, 1992



Point	Distance (m)
D4	1,392.624
D3	1,278.497
D2	1,175.419
D1	1,040.995
UA1	907.787
UA2	1,032.632
UA3	972.222
U1	950.918
U2	1,402.058
U3	1,604.103
U4	1,869.279
U5	1,645.277
U6	1,568.688
U7	1,734.555
U8	1,875.438
U9	1,656.939
U10	1,220.582

CO-ORDINATES AND ELEVATIONS OF CONTROL POINTS

September-1992			
POINT	Xi (m)	Yi (m)	ELEVATION
P1	0.000	0.000	+18.300
UR1	38.056	296.053	+ 6.568
UR2	207.659	865.433	+ 3.600
UR3	476.054	1,279.936	+ 4.220
UR4	900.046	1,609.045	+ 4.684
UR5	1,171.002	1,955.948	+ 4.560
UR6	1,626.837	2,269.322	+ 4.520
UR7	2,283.292	2,419.579	+ 3.050
UR8	2,912.675	2,656.184	+ 3.950
UR9	3,772.100	3,354.778	+ 5.397
UR10	4,631.146	4,377.711	+ 4.878
URD1	128.328	- 421.729	+ 5.992
URD2	202.154	- 991.718	+ 4.057
URD3	389.555	-1,739.850	+ 3.480
URD4	394.699	-2,486.502	+ 4.035
P10	0.000	- 783.000	+18.333
UL1	- 909.985	369.979	+ 5.837
UL2	-1,181.142	1,057.785	+ 3.497
UL3	-1,017.137	1,866.048	+ 3.800
UL4	- 489.515	2,859.376	+ 3.290
UL5	313.481	3,360.083	+ 3.344
UL6	732.586	3,558.158	+ 3.052
UL7	1,474.922	3,954.252	+ 3.993
UL8	2,010.551	4,300.399	+ 3.300
UL9	2,649.113	4,573.116	+ 3.262
UL10	-3,563.518	4,969.313	+ 4.470
UL11	3,572.508	5,852.434	
ULD1	- 897.008	- 601.609	+ 4.305
ULD2	- 948.346	-1,232.468	+ 4.115
ULD3	- 885.226	-1,837.263	+ 5.494
ULD4	- 983.154	-2,688.796	+ 4.370
RA1	29.787	75.228	+ 6.043
RA2	17.033	171.001	+ 6.400
RA3	28.934	216.990	+ 6.458
LA1	- 877.727	97.495	+ 5.824
LA2	- 1,015.279	196.746	+ 6.099
LA3	- 938.539	312.971	+ 7.884

DETAILS BETWEEN BRIDGE AND U1

Scale. 1: 10,000

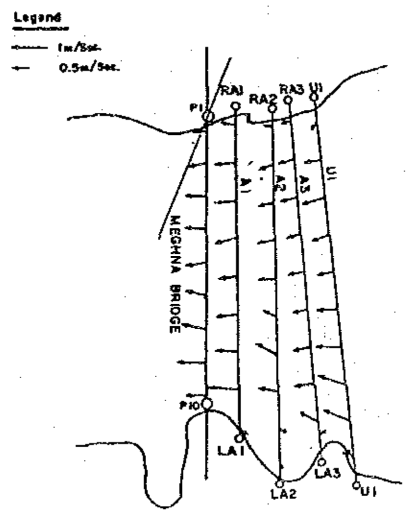


Fig. 6.5 FIELD MEASUREMENT RESULT OF FLOW VELOCITY AND DIRECTION (SEPTEMBER 1992)

Table 6.1 COMPARISON ON OBSERVED AND CALCULATED FLOW VELOCITIES (1/3)

Sec. No. D4

No.	Observed	Calculated
1	0.52	1.70
2	0.51	1.44
3	0.46	1.39
4	0.41	1.35
5	0.46	1.32
6	0.54	1.27
7	0.40	1.11
8	0.08	0.86
9	0.11	0.56
10	0.16	0.62
11	0.26	0.56
12	0.26	0.74
13	0.36	0.85
14	0.46	0.85
Ave.	0.36	1.04

Sec. No. D3

No.	Observed	Calculated
1	0.31	1.20
2	0.36	1.07
3	0.41	1.14
4	0.46	1.25
5	0.46	1.28
6	0.48	1.36
7	0.41	1.19
8	0.44	1.23
9	0.34	1.22
10	0.40	1.29
11	0.41	1.16
12	0.41	1.12
13	0.31	1.01
Ave.	0.40	1.19

Sec. No. D2

No.	Observed	Calculated
1	0.27	1.11
2	0.36	1.15
3	0.36	1.28
4	0.56	1.56
5	0.64	1.49
6	0.61	1.38
7	0.66	1.37
8	0.56	1.28
9	0.56	1.10
10	0.56	0.98
11	0.41	0.92
Ave.	0.50	1.24

Sec. No. D1

No.	Observed	Calculated
1	0.22	1.06
2	0.30	1.37
3	0.32	1.77
4	0.47	1.66
5	0.44	1.66
6	0.44	1.30
7	0.43	1.31
8	0.51	1.21
9	0.62	1.03
10	0.46	
11	0.25	
Ave.	0.41	1.37

Sec. No. P

No.	Observed	Calculated
1	0.44	0.98
2	0.50	1.24
3	0.56	1.51
4	0.62	1.32
5	0.60	1.44
6	0.61	1.23
7	0.74	1.32
8	0.82	1.44
9	0.66	1.80
Ave.	0.62	1.36

Sec. No. A1

No.	Observed	Calculated
1	0.41	-
2	0.56	-
3	0.58	-
4	0.60	-
5	0.51	-
6	0.56	-
7	0.58	-
8	0.84	-
9	0.26	-
Ave.	0.54	-

Sec. No. A2

No.	Observed	Calculated
1	0.27	-
2	0.44	-
3	0.44	-
4	0.46	-
5	0.46	-
6	0.39	-
7	0.66	-
8	0.56	-
9	0.21	-
10	0.09	-
Ave.	0.40	-

Sec. No. A3

No.	Observed	Calculated
1	0.26	-
2	0.43	-
3	0.45	-
4	0.44	-
5	0.44	-
6	0.46	-
7	0.50	-
8	0.60	-
9	0.62	-
10	0.28	-
Ave.	0.45	-

Sec. No. U1

No.	Observed	Calculated
1	0.14	0.82
2	0.46	0.99
3	0.66	1.02
4	0.51	1.14
5	0.46	1.31
6	0.56	1.39
7	0.71	1.44
8	0.81	1.64
9	0.81	1.56
10	0.36	1.53
Ave.	0.55	1.28

Table 6.1 COMPARISON ON OBSERVED AND CALCULATED FLOW VELOCITIES (2/3)

Sec. No. U2

No.	Observed	Calculated
1	0.26	0.88
2	0.41	0.81
3	0.51	0.93
4	0.41	0.96
5	0.51	0.95
6	0.26	0.68
7	0.31	0.78
8	0.41	1.00
9	0.46	1.20
10	0.66	1.22
11	0.61	1.22
12	0.51	1.10
13	0.66	1.94
14	0.16	
Ave.	0.44	1.05

Sec. No. U3

No.	Observed	Calculated
1	0.51	0.65
2	0.56	0.85
3	0.68	0.89
4	0.71	0.88
5	0.68	0.81
6	0.16	0.71
7	sand bar	0.30
8	0.14	0.49
9	0.46	0.70
10	0.15	0.83
11	0.66	0.55
12	0.71	1.30
13	0.71	1.04
14	0.71	1.01
15	0.76	1.07
16	0.61	1.60
Ave.	0.55	0.86

Sec. No. U4

No.	Observed	Calculated
1	0.41	0.55
2	0.54	0.68
3	0.61	0.92
4	0.66	0.94
5	0.21	0.97
6	sand bar	0.63
7	0.50	0.00
8	0.56	0.74
9	0.46	0.87
10	0.56	0.96
11	0.58	0.89
12	0.56	0.99
13	0.56	1.04
14	0.51	0.63
15	0.51	1.15
16	0.56	1.02
17	0.66	0.77
18	0.21	1.43
Ave.	0.51	0.84

Sec. No. U5

No.	Observed	Calculated
1	0.21	0.85
2	0.36	0.94
3	0.41	1.05
4	0.36	1.01
5	0.31	0.91
6	0.36	0.94
7	0.31	0.91
8	0.31	0.92
9	0.36	0.95
10	0.26	0.94
11	0.36	0.86
12	0.34	0.92
13	0.36	0.87
14	0.26	0.92
15	0.31	0.84
16	0.11	1.06
Ave.	0.31	0.93

Sec. No. U6

No.	Observed	Calculated
1	0.54	0.84
2	0.52	0.85
3	0.51	0.97
4	0.49	1.00
5	0.49	1.09
6	0.47	1.04
7	0.42	0.99
8	0.43	0.89
9	0.41	0.89
10	0.41	0.83
11	0.38	0.77
12	0.40	0.69
13	0.37	0.73
14	0.36	0.68
15	0.28	0.64
16	0.26	0.54
Ave.	0.42	0.84

Sec. No. U7

No.	Observed	Calculated
1	0.41	0.94
2	0.54	0.81
3	0.56	1.01
4	0.64	1.04
5	0.61	1.06
6	0.59	1.10
7	0.51	1.12
8	0.41	1.03
9	0.40	0.85
10	0.36	0.74
11	0.30	0.51
12	0.26	0.45
13	0.18	0.36
14	0.14	0.41
15	0.12	0.55
16	0.07	0.50
17	0.00	0.39
Ave.	0.36	0.76

Table 6.1 COMPARISON ON OBSERVED AND CALCULATED FLOW VELOCITIES (3/3)

Sec. No. U8

No.	Observed	Calculated
1	0.41	1.19
2	0.46	0.92
3	0.41	0.95
4	0.39	0.99
5	0.32	0.98
6	0.26	0.95
7	0.31	1.05
8	0.16	0.91
9	sand bar	0.53
10	sand bar	0.00
11	sand bar	0.12
12	0.00	0.34
13	0.00	0.35
14	0.00	0.38
15	0.00	0.37
16	0.00	0.44
17	0.00	0.39
18	0.00	0.30
19	0.00	0.28
Ave.	0.34	0.60

Sec. No. U9

No.	Observed	Calculated
1	0.26	1.15
2	0.56	1.06
3	0.76	1.33
4	0.51	1.21
5	0.56	1.07
6	0.61	1.06
7	0.56	1.19
8	0.41	0.61
9	sand bar	0.00
10	sand bar	0.00
11	sand bar	0.16
12	0.00	0.16
13	0.00	0.18
14	0.00	0.24
15	0.00	0.19
16	0.00	0.04
Ave.	0.53	0.60

Sec. No. U10

No.	Observed	Calculated
1	0.26	0.52
2	0.31	0.42
3	0.31	1.07
4	0.31	1.29
5	0.26	0.86
6	0.41	0.86
7	0.41	0.86
8	0.36	0.84
9	0.46	0.85
10	0.51	0.78
11	0.46	0.76
12	0.21	0.66
Ave.	0.36	0.81

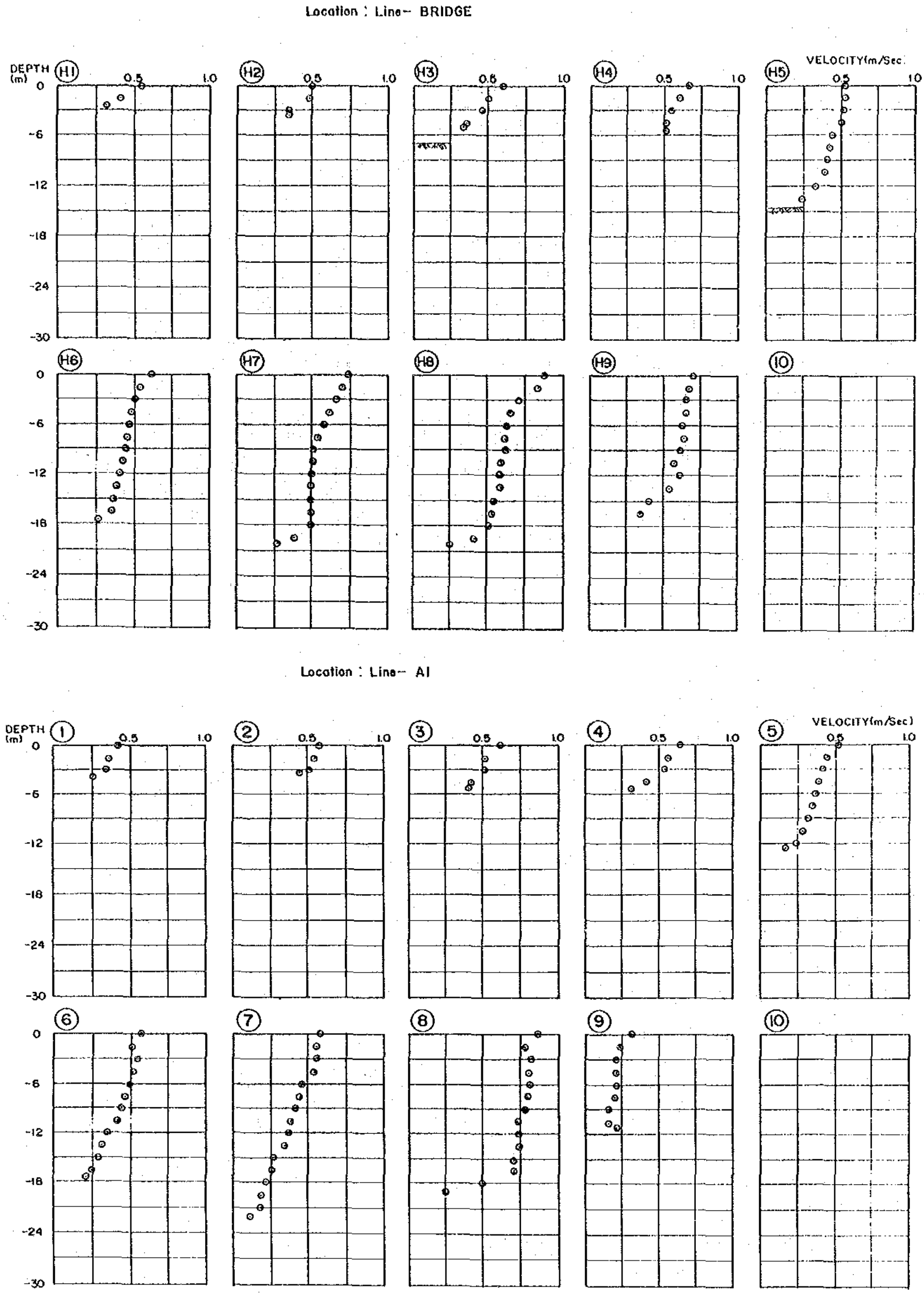
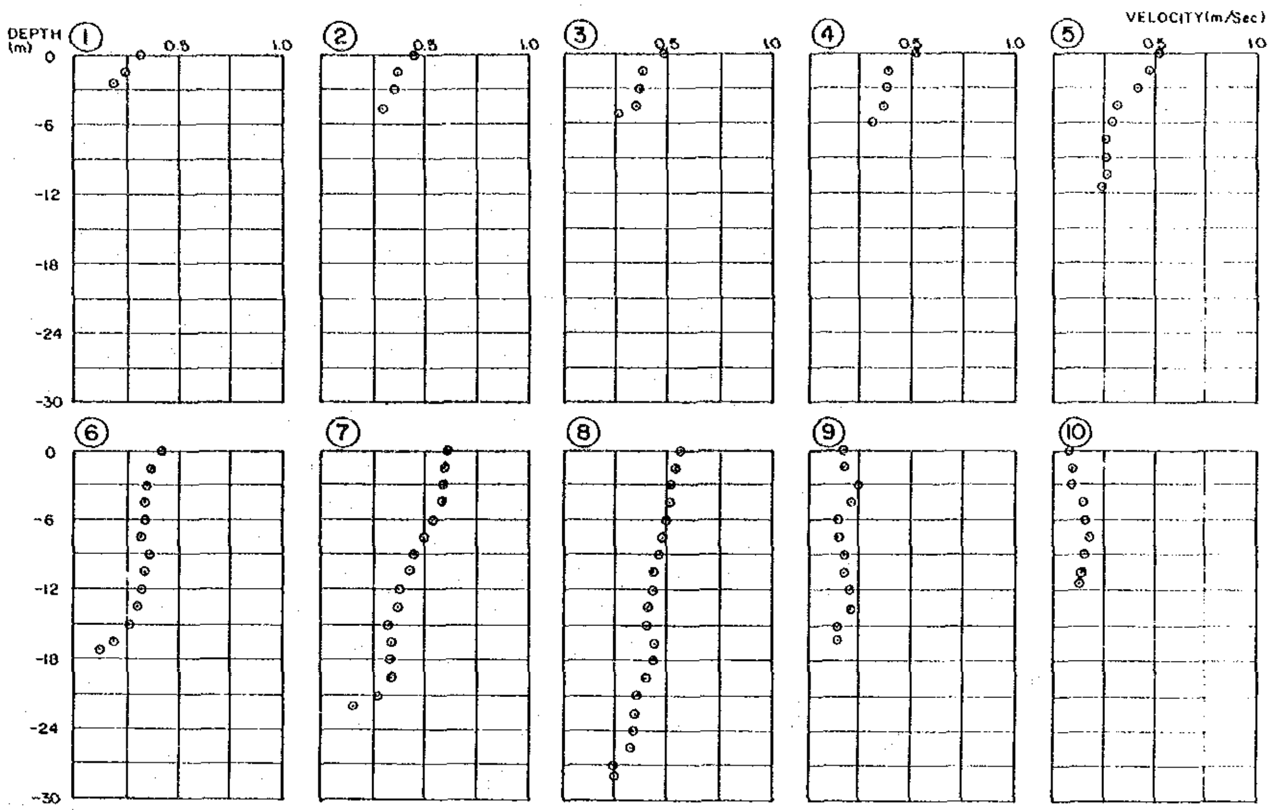


Fig. 6.6 DIAGRAM OF VERTICAL FLOW VELOCITY (1/3)

Location : Line- A2



Location : Line- A3

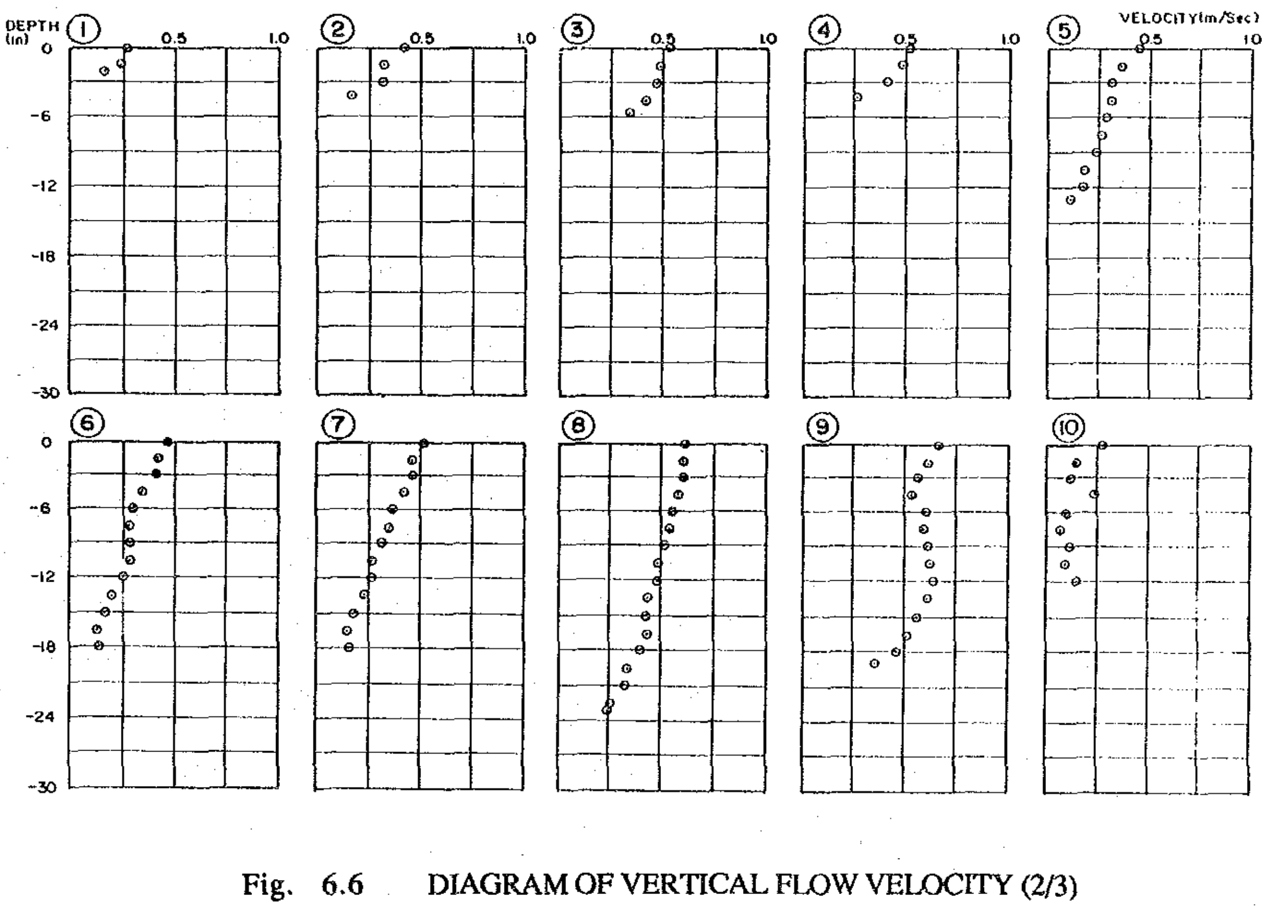


Fig. 6.6 DIAGRAM OF VERTICAL FLOW VELOCITY (2/3)

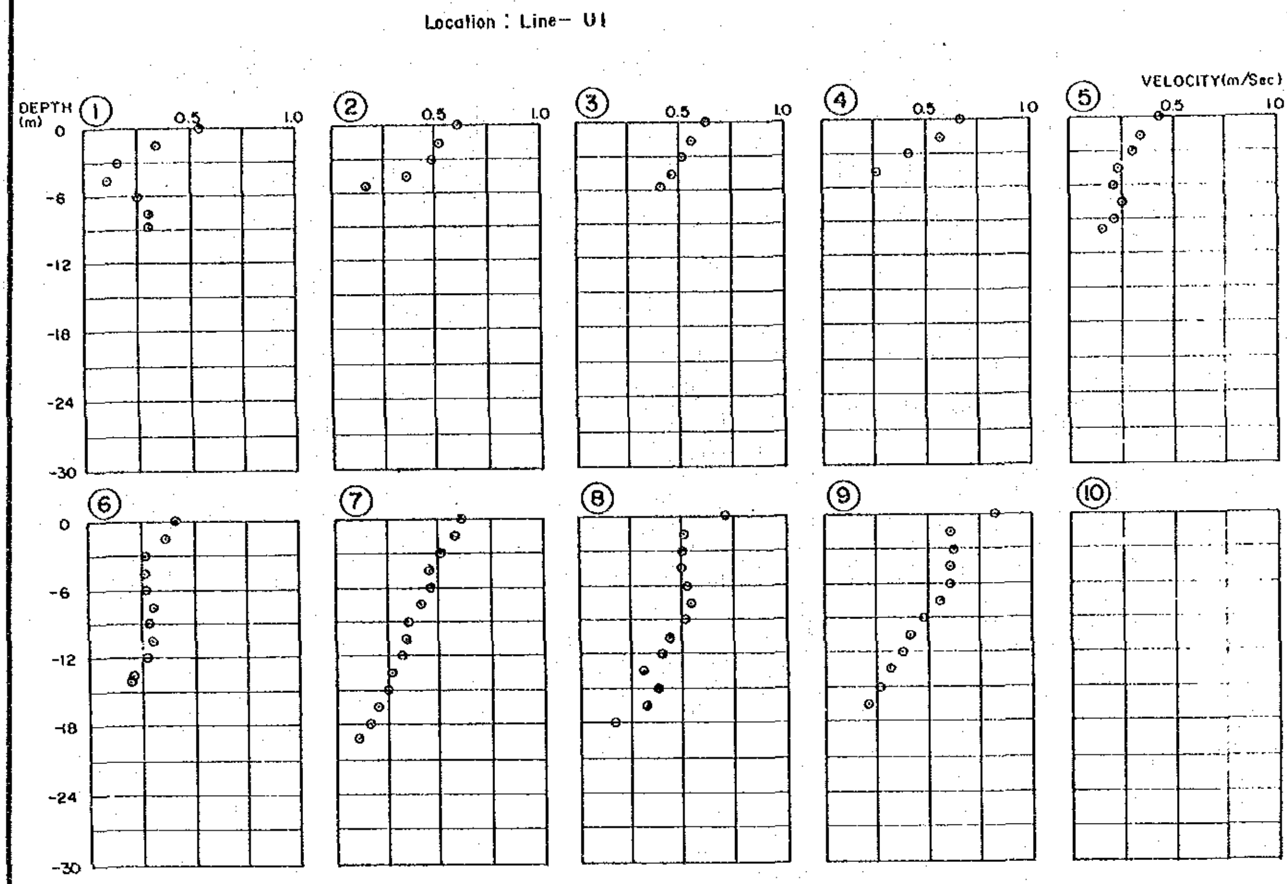


Fig. 6.6 DIAGRAM OF VERTICAL FLOW VELOCITY (3/3)

CHAPTER 7 BASIC DESIGN

CHAPTER 7 BASIC DESIGN

7.1 Design Policy

Meghna River is a large scale river as described in 4.1 General Feature of Meghna River, and it is very difficult to predict the river flow direction.

The repair to the damaged Comilla side banks in Dec., 1991 and the protection by gabion placing in June-Sept, 92, were made as emergency measures under the Meghna Bridge Project. However the protection measures were meant to reduce further damage.

This project proposes to make additional protection to take care of further erosion to the river banks near the Bridge based on the results of the investigations performed at the site.

The basic design will be performed with the following considerations:

(1) The structures for protecting revetments will be designed based on the results of field investigation and accumulated river data up to the present.

(2) The purpose of the basic design will be for the protection of the foundation, and access roads on the Comilla Side of the Meghna Bridge, and the extent of protection works will be kept to a minimum upon consideration of the natural waterways of the Meghna River flows and the topographic features.

(3) The structures to protect the revetments consists of the materials produced in Bangladesh as much as possible in order to minimize the construction and the maintenance costs. The structures shall be designed to avoid technical difficulties.

(4) The implementation of the plan shall be completed within one dry season because the existing river banks should be protected from collapse during the rainy season. Therefore, the construction methods shall be determined carefully.

7.2 Study and Examination of Design Criteria

The basic design conditions for this project were decided after performance of field investigations were made in the field as follows:

(1) Determination on the Bank Area to be Designed:

Based on the results of the investigation of the river bed, together with the results of the simulation by the Two-Dimensional Flow Model described in Chapter 6, the Area to be designed is proposed to be the section from the bridge site to the old ferry ghat. The zone to be provided with bank protection will be from the downstream of the bridge abutment to immediately upstream of the old ferry ghat.

The reason for the above are described in paragraph 5.7, Proposed Alignment and Area of Bank Protection at Comilla Side.

(2) The Depth of Scouring by Natural Water Flows:

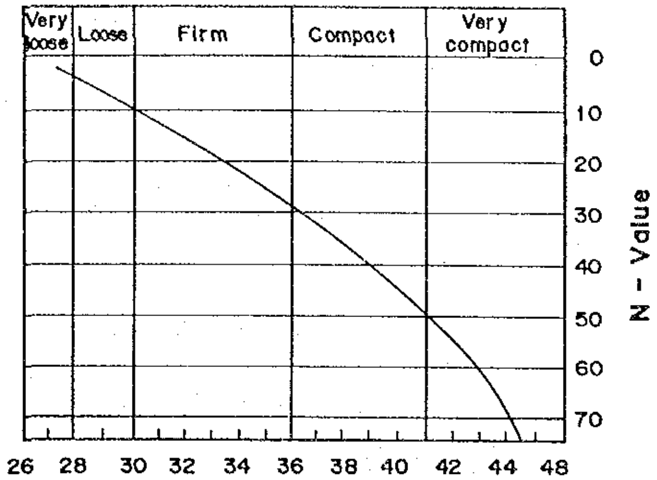
As described in paragraph 5.4, Local Scouring Near the Old Ferry Ghat, the depth caused by scouring of the river bed is estimated to be RL-30 m, and this value will be used as the basic design depth for the scouring depth.

(3) Soil Conditions:

Taking into consideration the results of the soil boring conducted on the land side, and the results of soil borings taken for the detailed design for the Meghna Bridge, the soil conditions used for the stability calculations of the bank protection are as follows:
(refer to Fig. 7.1 and Table 7.1)

Soil Layer	Thickness (m)	γt	N-Value (N)	Internal Friction Angle Ø	Cohesion t/m²
Earthfill	-	1.80	-	30	-
Rubble, Crushed Gravel, Tile	-	2.00	-	37.5	-
River Bed:					
Layer #1	9.5	1.80	15	32°	-
Layer #2	8.0	1.80	18	33°	-
Layer #3	9.5	1.80	30	36.5°	-
Layer #4	-	1.80	50	41.0°	-

Fig. 7.1 RELATIVE CHART FOR N-VALUE AND INTERNAL FRICTION ANGLE



INTERNAL FRICTION ANGLE
(DEGREE)

TABLE 7.1 WET DENSITY OF SOIL

Soil		Condition of Soil		Wet density(t/m^3)	Symbols
Embakment	Sand mixed gravel	Compact		2.0	GW, GP
	Sand	Compact	good gradation	2.0	SW, SP
			No good gradation	1.9	
	Sandy soil	Compact		1.8	SM, SC
	Cohesive soil	Compact		1.7	ML, CL, (MH, CH)
	Volcanic cohesive soil	Compact		1.4	VH
Natural ground	gravel	Compat or good gradation		2.0	GW, GP
		Loose or no good gradation		1.8	
	Sand mixed gravel	Compact		2.1	GW, GP
		Loose		1.9	
	Sand	Compact or good gradation		2.0	SW, SP
		Loose or no good gradation		1.8	
	Sandy soil	Compact		1.9	SM, SC
		Loose		1.7	
	Cohesive soil	hard		1.8	ML, CL
		soft		1.6	
	Silt	hard		1.6	ML
		Soft		1.4	
	Clay	hard		1.7	CH, MH
		Soft		1.5	
	Volcanic cohesive soil			1.4	VH

7.3 Basic Design

7.3.1 The Alternative Study on the Construction Method

There is the possibility of the danger of damage to the Dhaka - Chittagong Roadway by erosion of the Meghna River Banks. The following two measures are considered to maintain the function of this roadway.

1) The new protecting revetment will be constructed to keep the existing flow of the waterway, within the river channel.

2) If the natural waterways of the Meghna River are kept without the construction of the protecting revetment, the direction of water flow may shift to the approach road. The function of the road will be kept by expanding the PC girder bridge in the longitudinal direction along the approach road.

The construction method of protecting the revetment will be conducted by the alternative study regarding above mentioned method (1).

(1) Examination of Construction Methods:

The following three methods have been considered for protection of the river banks:

A. All Protection by Continuous Steel Pipe Piling
B. All Protection by Rock-Fill Dike and Gabion
C. Combination of (A) and (B)

A comparison of the 3 methods are given in Table 7.2.

Method "B" is recommended as the most suitable construction method for the following reasons;

a) Construction cost is low.

b) It is possible to start the construction most earliest by utilizing local materials, therefore, the construction can be completed within the coming dry season.

c) Construction method B is not technically difficult.

d) Maintenance and operation are easy.

e) The riprap works proved the effectiveness of the protection for erosions by investigating Hardinge Bridge Bank Protection and by surveying the river bed conditions of Pier 6, 7 and 8 of Meghna Bridge.

(2) Examination of Construction Methods Other Than Bank Protection

The function of the Bridge and its access road can be protected by way of extending the PC Bridge Beam and the Bridge Deck (refer to Fig. 7.9). This method has the following merits and demerits:

Merits:

- Since only land facilities are involved, it will not be constrained by time as required for the bank protection of the river as mentioned in item (1).
- In the short term, the number of additional spans are small and construction cost seems to be less.

Demerits:

- The number of additional spans are difficult to determine. It is stipulated that additional spans will be required in the immediate and long term life of the bridge.
- As the bridge abutment will further shift to the Comilla side, the navigational course of the river will be difficult to maintain.
- The roadway will need detouring during construction, and the road traffic will be affected.
- Huge land will be damaged by the river erosion.

Therefore, the extension of bridge span is unfavorable comparing with the protection of the river bank.

Table 7.2 Protection Method of Meghna Bridge from Erosion of River Bank

	(A) All Protection by Continuous Steel Pipe Piling	(B) All Protection by Rock-Fill Dike and Gabion	(C) Combination of (A) and (B)
General Description of Construction Method	The main protection structure will be steel pipe piling with steel waling and tie-rods. This will be changed into three attenuate methods as the material may have to be changed in the field for the components. Type 1 will be around the perimeter of the bridge foundations, and will begin from the river banks starting from the existing steel sheet piling, tie-rods, steel pipe sheet piling, tie-rod, steel sheet piling, in this order. Similarly, type 2 will be between the bridge foundation and the old ferry ghat inlet core will be steel pipe sheet piling, tie-rod, steel pipe sheet piling. Type 3 will be at the old ferry ghat, and will be composed of steel pipe sheet piling, tie-rod, steel sheet piling. Steel pipe sheet piling: 1,016 mm dia., wall thk. = 12 mm, length = 35 ~ 45 m Steel Sheet Piling: VL hollow type, l = 20 mm See Figs. 7.2 ~ 7.5 Description of work: 1) Driving of steel pipe sheet piling. 2) Construction of RC Pile Cap. 3) Driving of diagonal steel sheet piling. 4) Install tie-rod. 5) Grading of earthwork (fill work). 6) Install gabion slope protection. 7) Pitch stone in front of sheet piling.	Protection of dike will consist mainly of rock fill. See Figs. 7.6 ~ 7.7. Description of work: 1) Level river bed. 2) Pitch rock fill dike. 3) Fill with earth. 4) Protect slope with rock fill. 5) Pitch rock fill at toe.	The method combines Methods (A) and (B). (A) to be performed around circumference of bridge foundation. (B) to be performed upstream of bridge foundation. See Fig. 7.8. Description of work: Refer to (A) and (B)
Construction Cost	Not economical (X)	Most economical (O)	Economical to some degree (Δ)
Principal Features	Merits: • Operation and maintenance free. • Construction cost (materials) high. Demerits: • Materials will have to be imported from 3rd countries (Japan), and delivery will take time. • Construction in vicinity of bridge foundation is difficult. • Construction in vicinity of existing sheet piling will be difficult.	Merits: • Construction cost is low. • Construction is not technically difficult. • Can cope with changes in waterways. • Materials (rock) will be procured locally, and contributes to the local economy Demerits: • Operations and maintenance cost high. • Large amounts of rock not easy to maintain.	Refer to (A) and (B)

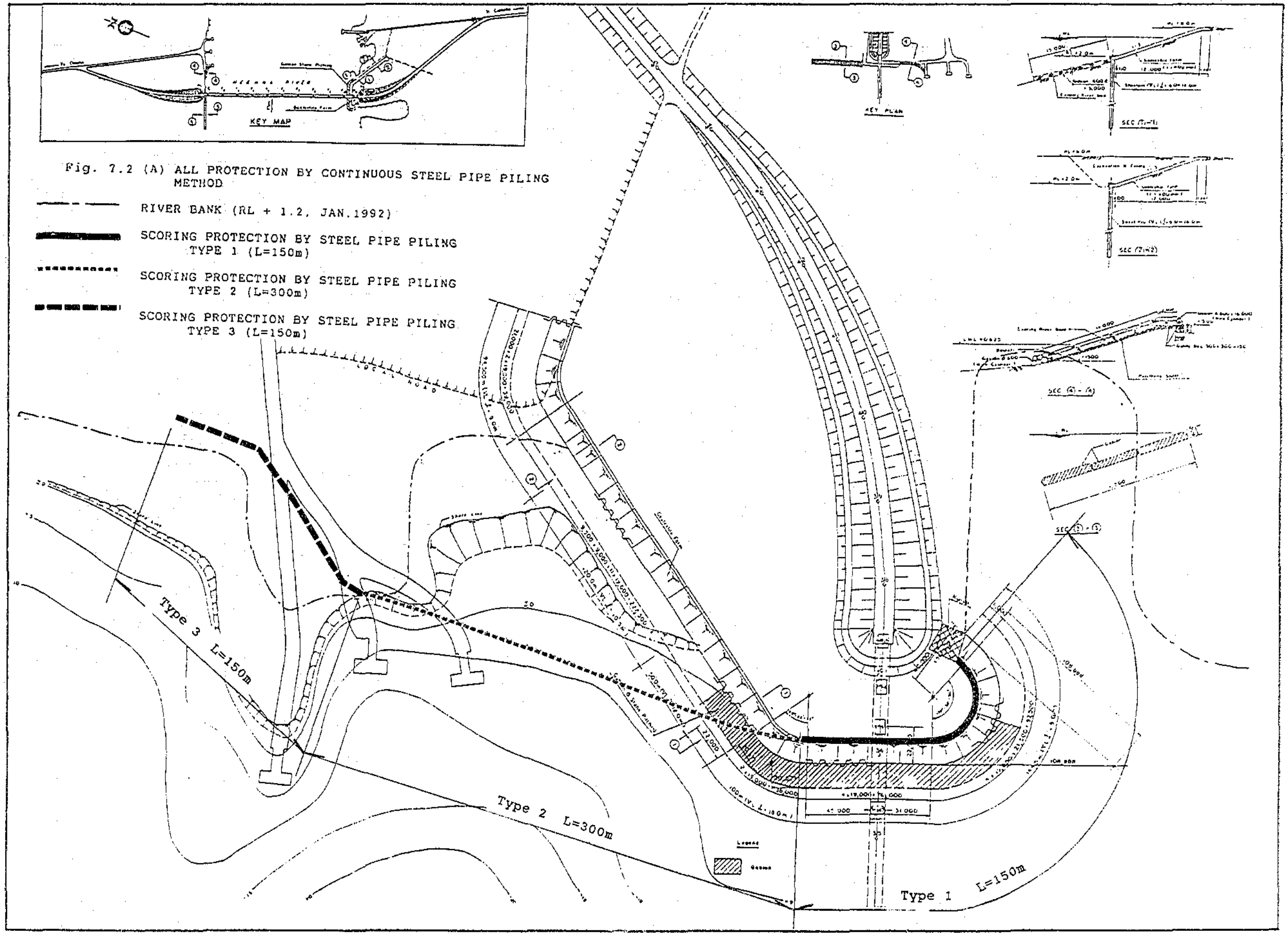


Fig. 7.2 (A) ALL PROTECTION BY CONTINUOUS STEEL PIPE PILING METHOD

Fig. 7.3 Continuous Steel pipe Pilling Method (TYPE I)

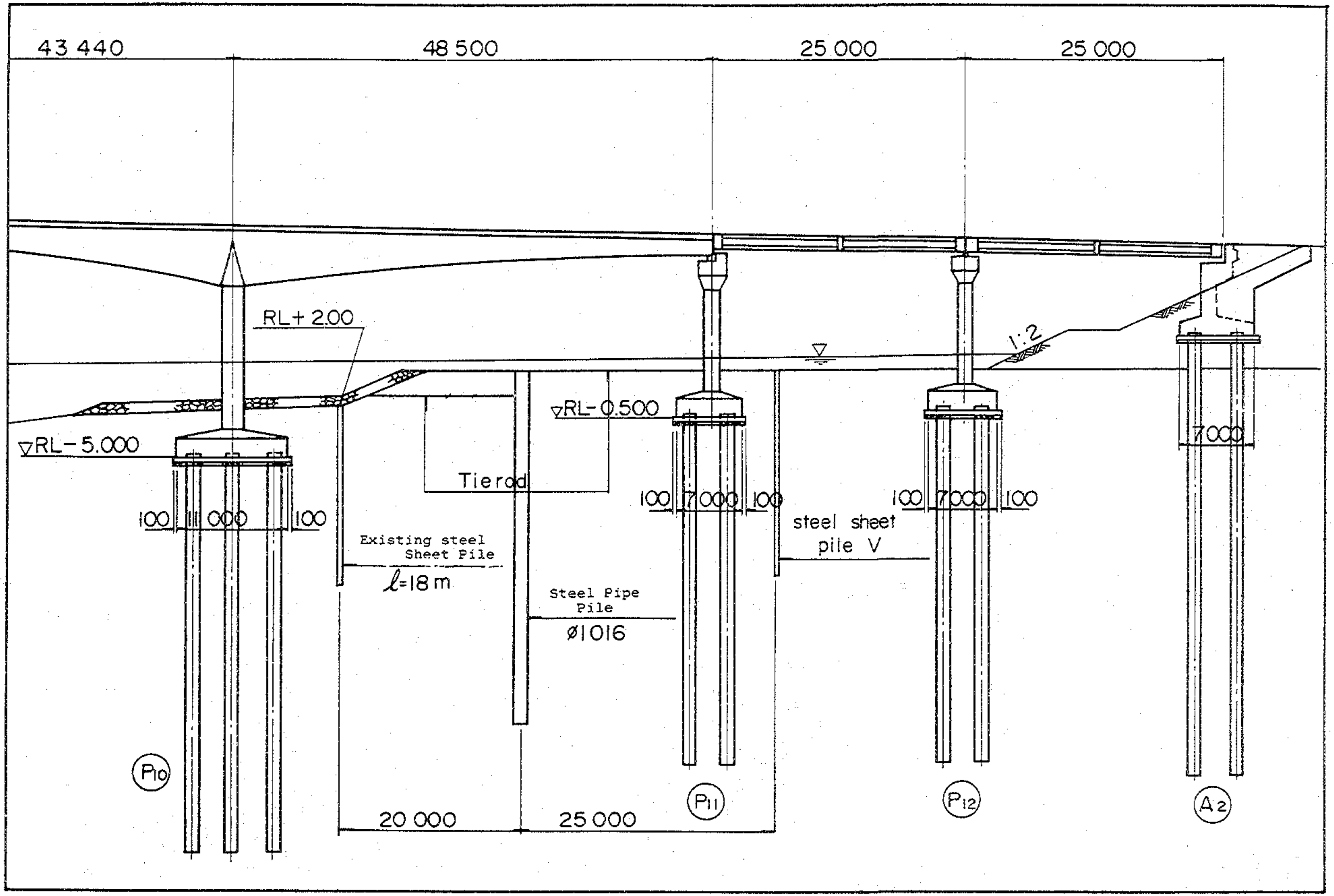


Fig. 7.4 Continuous Steel pipe Piling method (TYPE 2)

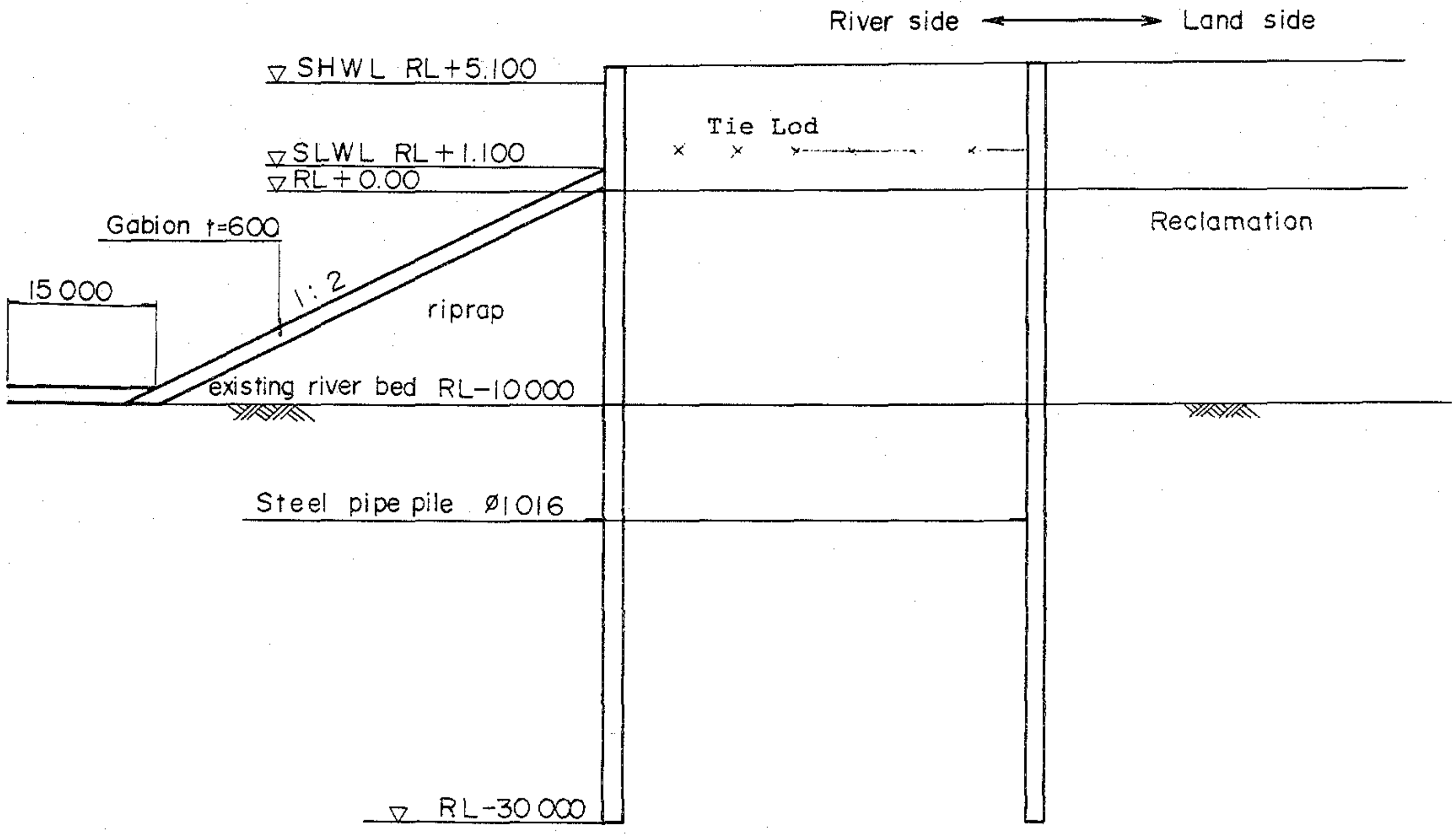
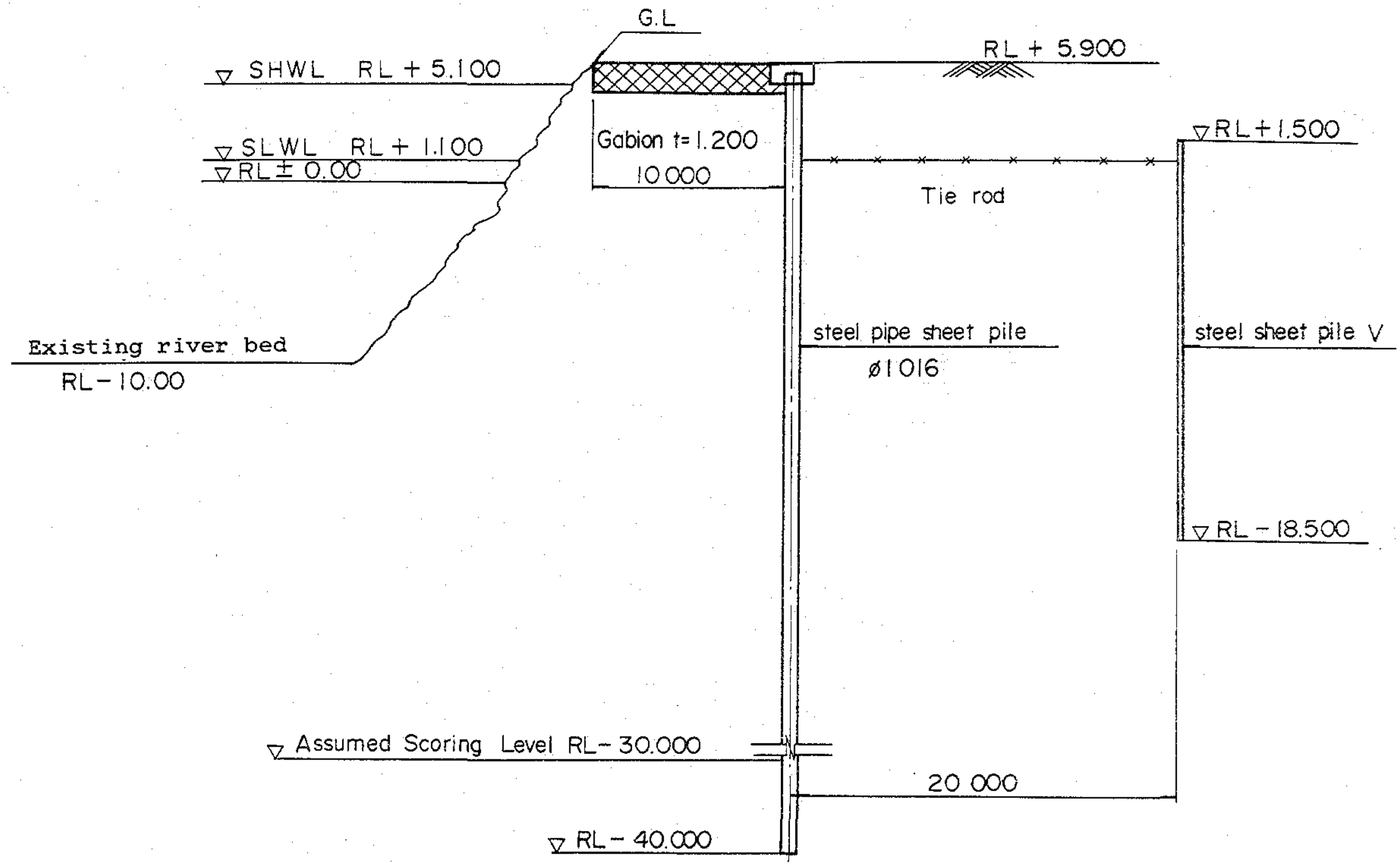


Fig. 7.5 Continuous Steel pipe Piling method (TYPE 3)



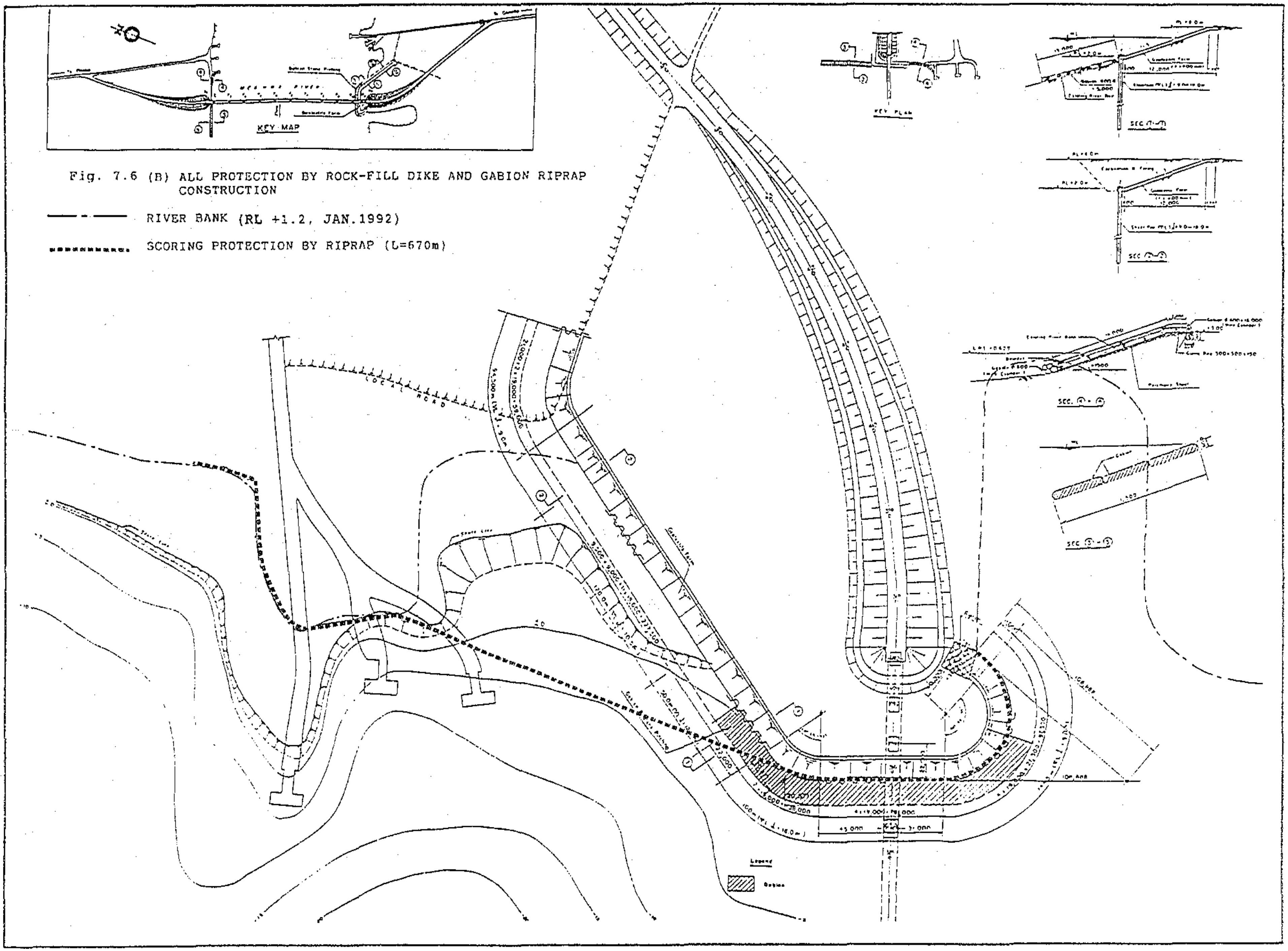


Fig. 7.6 (B) ALL PROTECTION BY ROCK-FILL DIKE AND GABION RIPRAP CONSTRUCTION

— - — RIVER BANK (RL +1.2, JAN.1992)

▪▪▪▪▪▪▪ SCORING PROTECTION BY RIPRAP (L=670m)

Fig. 7.7 Rock-fill Dike and Gabion Riprap method

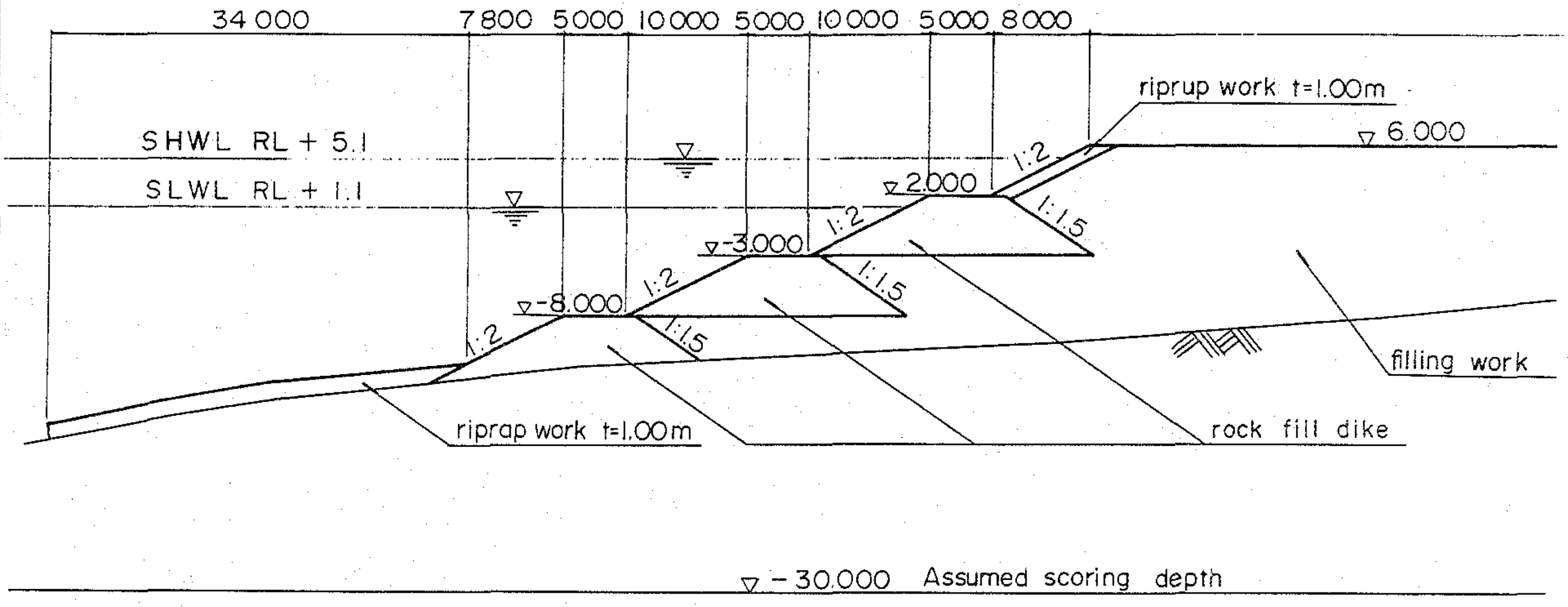


Fig. 7.8 (C) PROTECTION BY TYPE 1 OF METHOD A & METHOD B

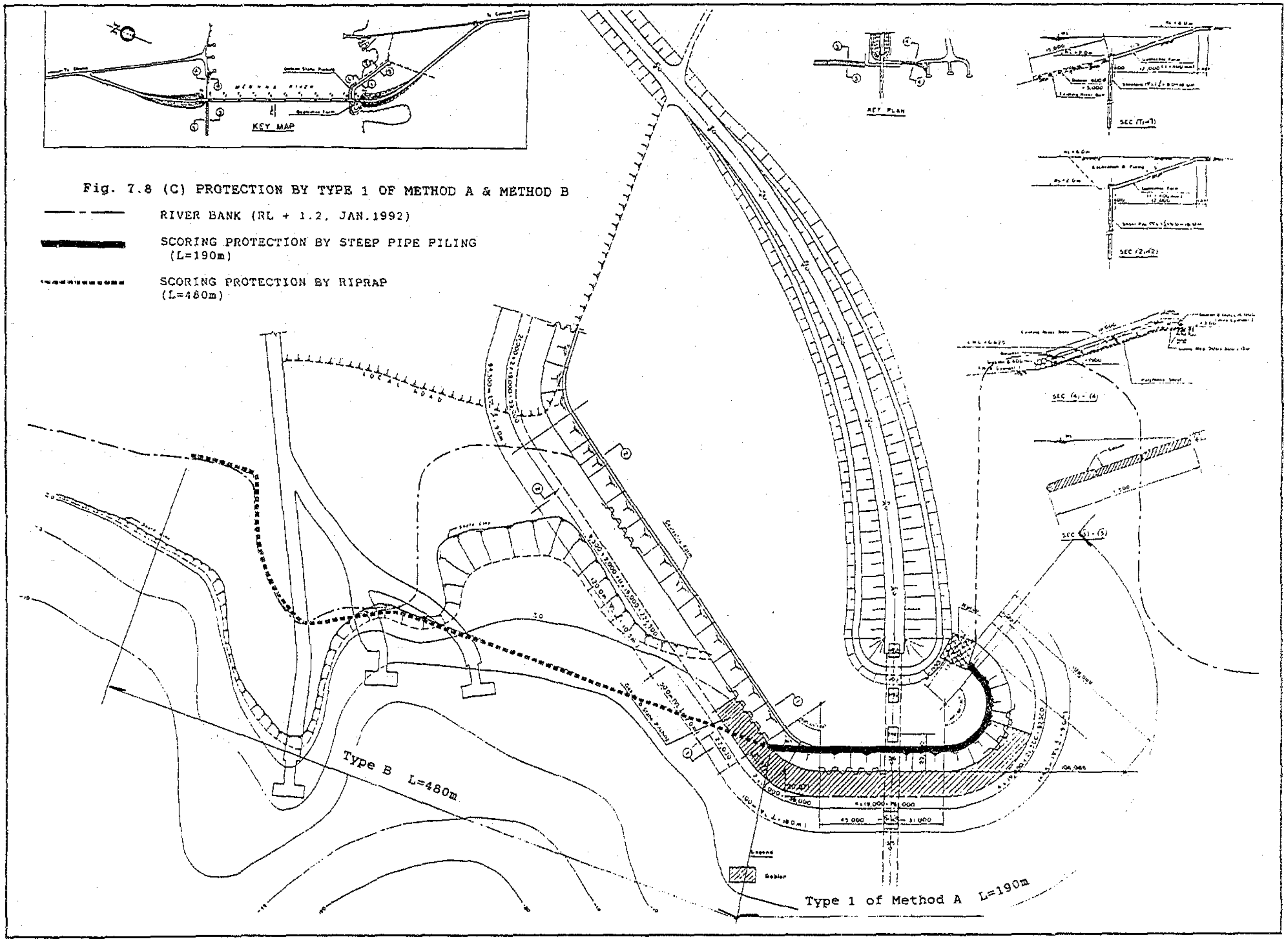
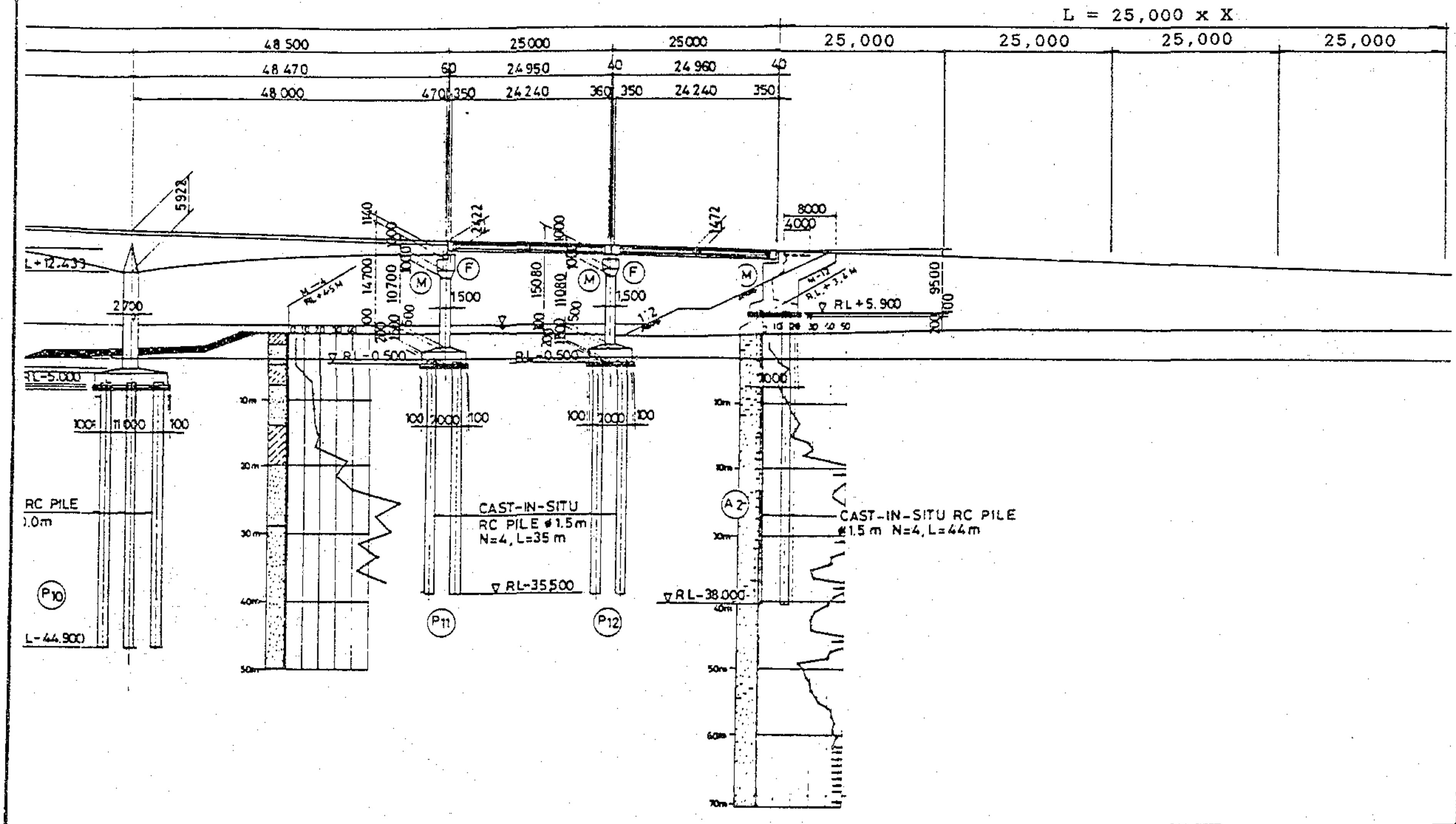


Fig. 7.9 EXTENTION PLAN FOR SIDE SPAN PC BEAM



(3) Examination of the Alignment:

The alignment of the protection works was examined. The extent of the protection area discussed and agreed to with the Bangladesh side at the time of field investigation is given in Figs. 7.10 to 7.15.

From the point of economy it will be advantageous to install pitched stone with the alignment of Alternative 1. But in order to prevent occurrence of local vortex and to stabilize water surface profile at just upstream of the Meghna Bridge, it will be better to provide the alignment from the tip of the old ferry ghat to the front of the bridge footing. Accordingly Alternative 2 was selected. Summary of the examination is shown in Table 7.3 for comparative purposes.

TABLE 7.3 Examination of Alignment

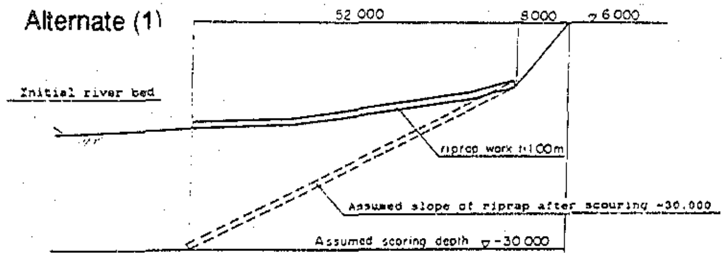
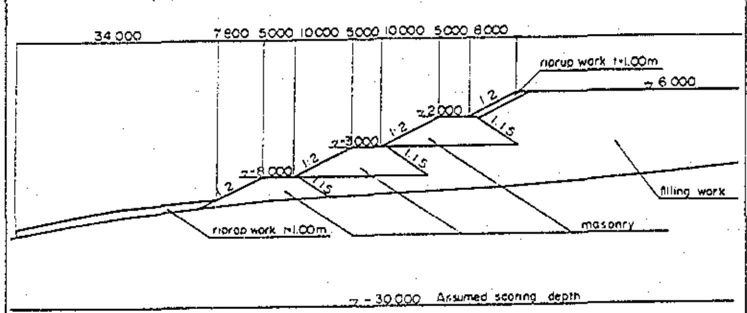
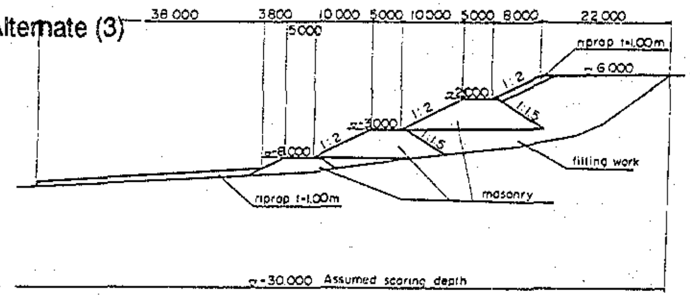
Representative Cross Section (B-B)	Characteristics of Alternatives
Alternate (1)  	• The assumed scouring depth is assumed at -30 m. • Corresponds most closely to existing dike. (Minutes of meeting (1)). • Rock will be cast on existing river bed. The extent will be for scoured depth to -30 m, and a dike slope of 1 : 2. • Estimated Quantities: Pitched rock, approximately 29,000 m³. • Construction is simpler compared to Alternate (2), but is close to the bridge road.
Alternate (2)  	• The assumed scouring depth is -30 m. • Is the farthest from the present dike. (Corresponds to Minutes of meeting (2)). • Estimated Quantities: Rock Work : Approx. 48,000 m³ Earthwork : Approx. 230,000 m³ Pitched Rock : Approx. 25,000 m³ • The construction cost (and period) is more expensive than Alternate (1), however this method excels Alternate (1).
Alternate (3)  	• The assumed scoured depth is -30 m. • This method ranks between Alternates (1) and (2). • Estimated Quantities: Rock Work : Approx. 44,000 m³ Earthwork : Approx. 56,000 m³ Pitched Rock : Approx. 21,000 m³

Fig. 7.10 Plan of Alt - 1

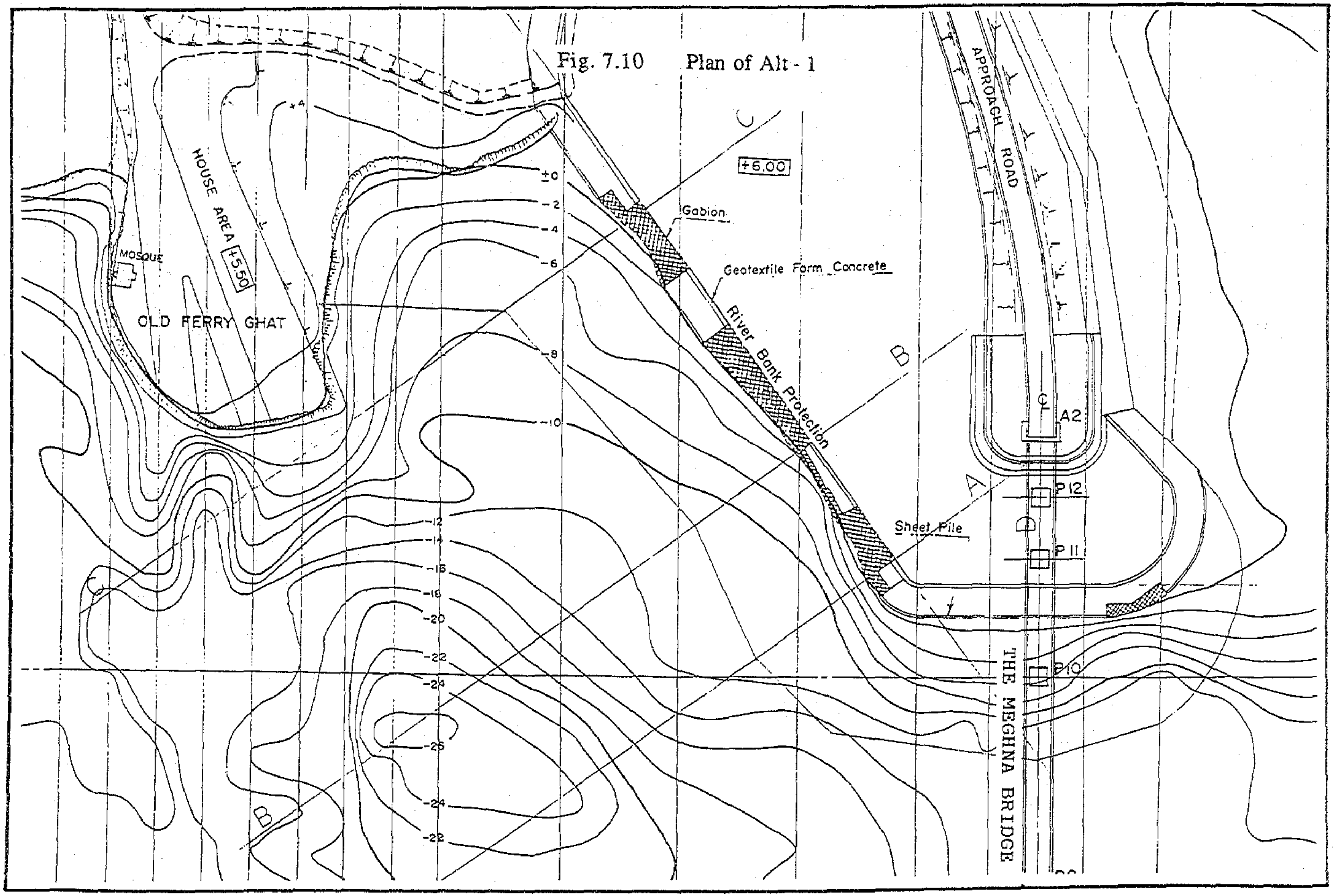


Fig. 7.11 Alt - 1 Gabion Riprap Method

Typical cross section (B - B) S=1/500

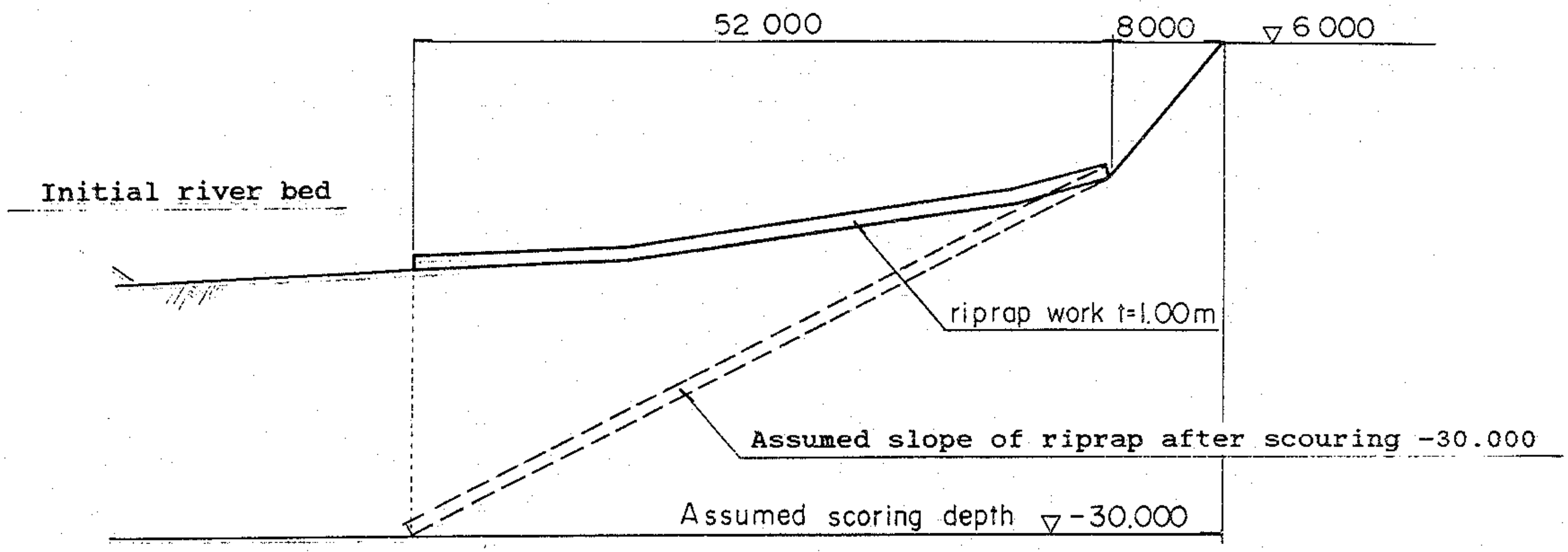


Fig. 7.12 Plan of Alt - 2

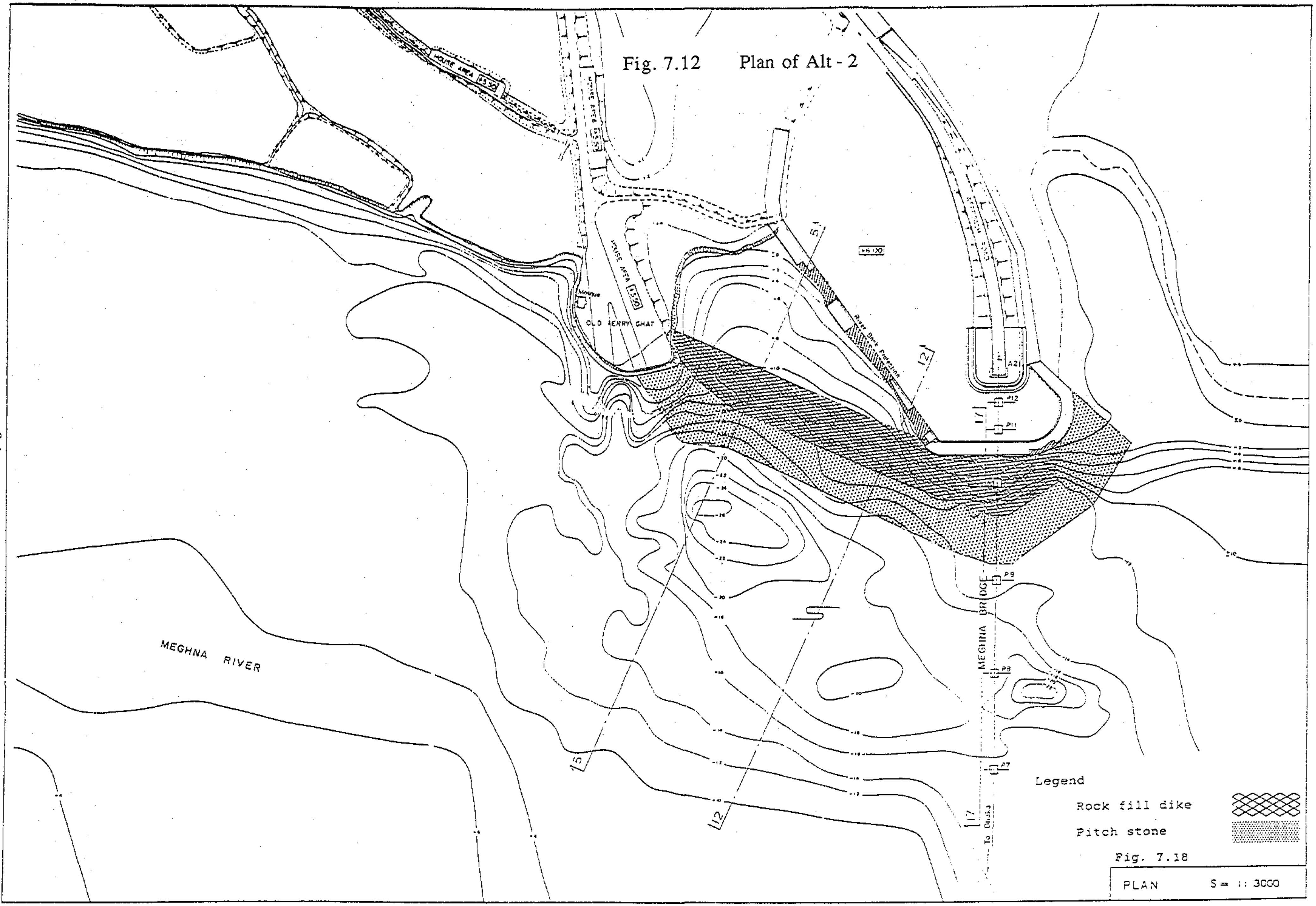


Fig. 7.13 **Alt-2 Masonry filling and riprap method**

Typical cross setion (B-B) S=1/500

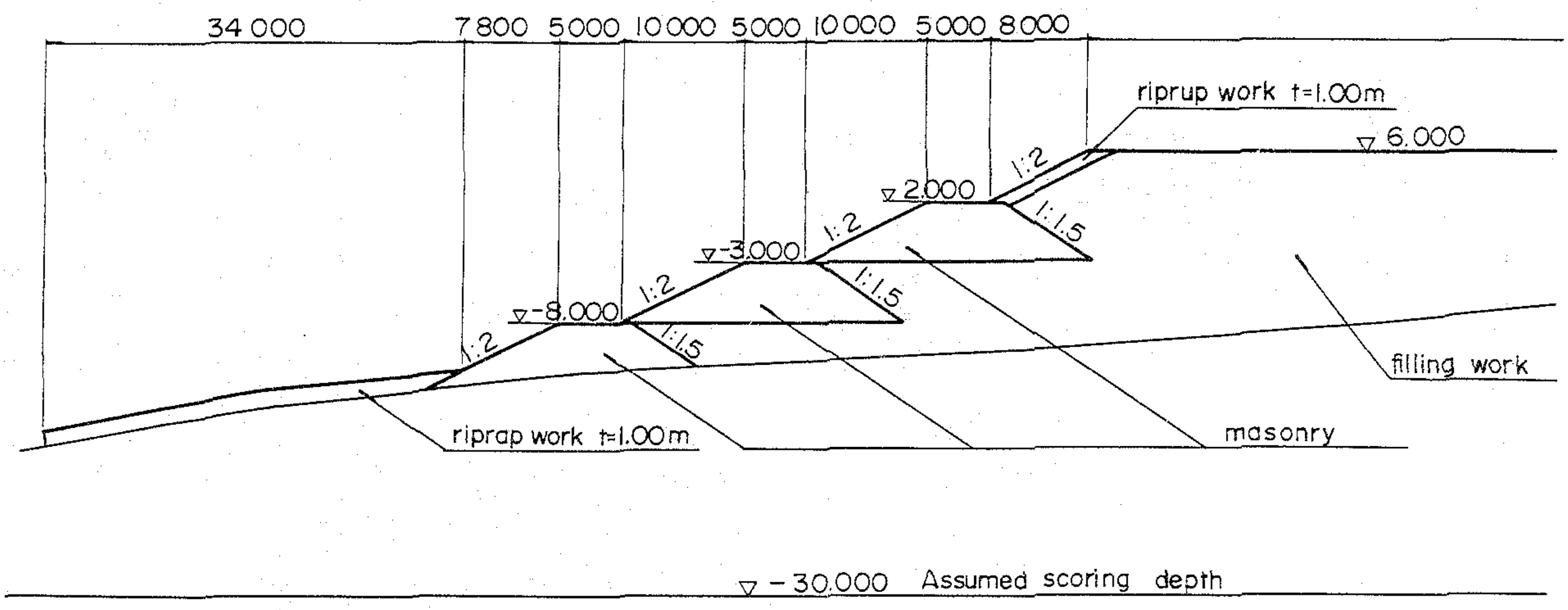


Fig. 7.14 Plan of Alt - 3

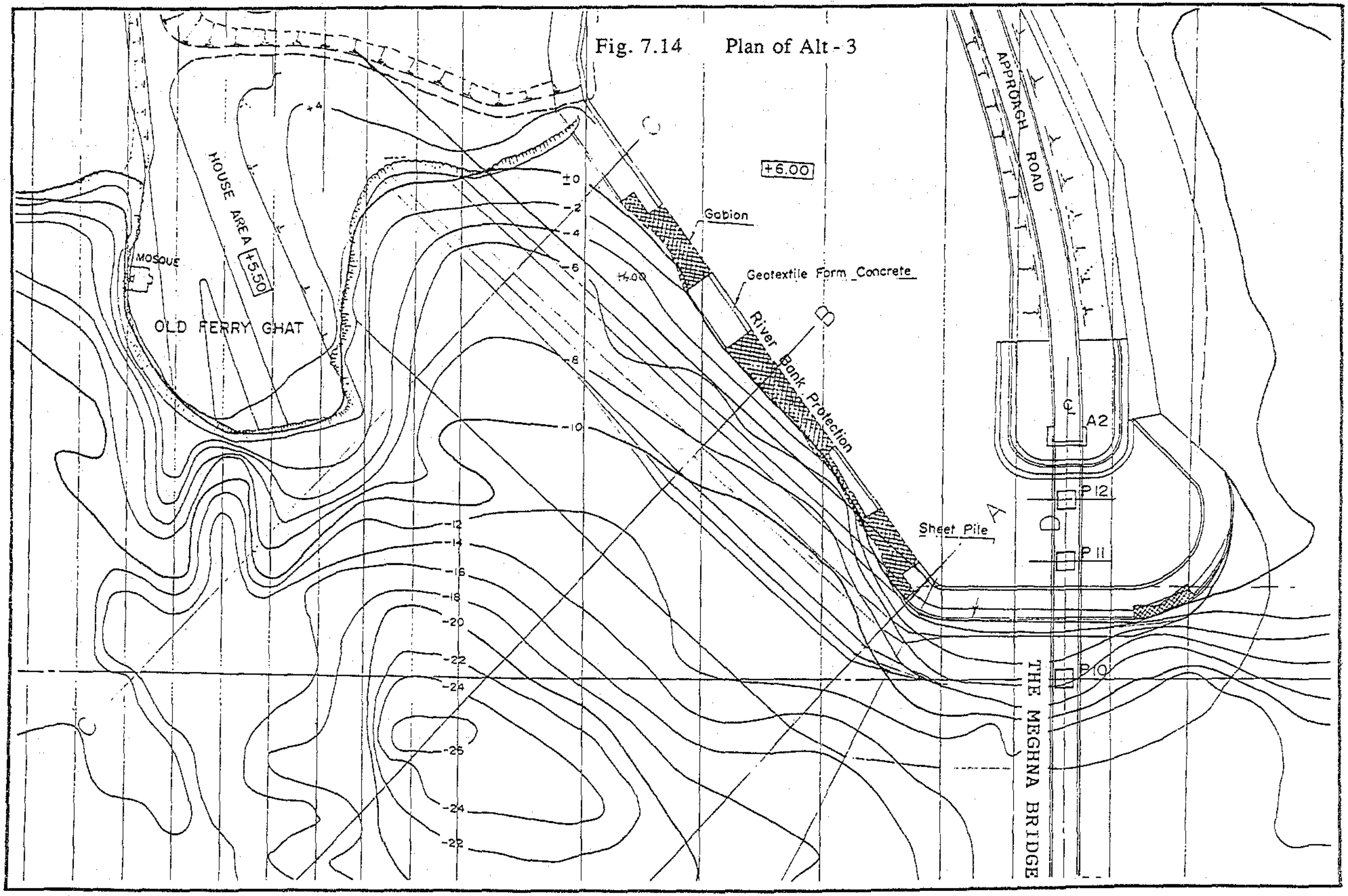
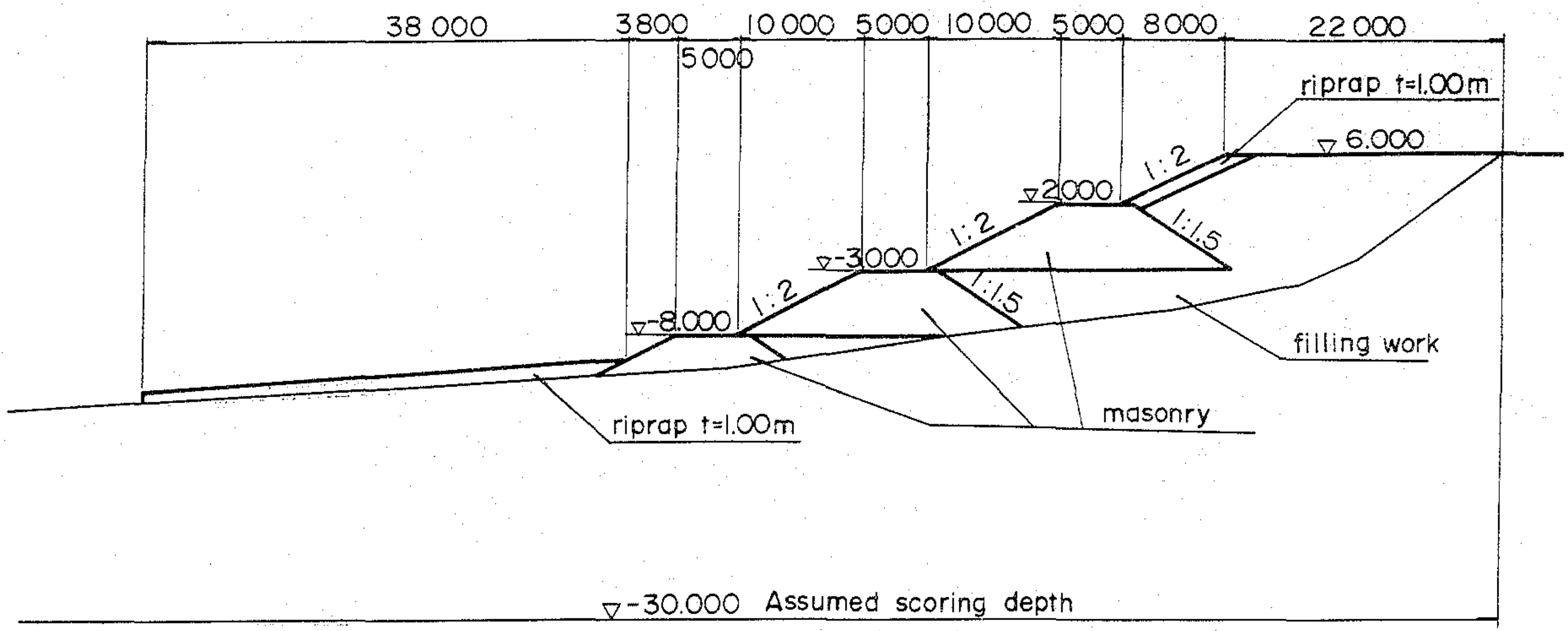


Fig. 15 Alt−3 Mansonry filling and riprap method

Typical cross section (B− B) S=1/500



7.3.2 Stability Calculation for Slope Protection:

A stability calculation has been performed for Rock-Fill Dike Protection, and performed slope sliding plane as shown in Fig. 7.16 and 7.17.

The factor of safety of the former is 1.2, and 1.3 for the latter. The structure is stable.

7.3.3 Basic Design

The plan and standard cross sections are shown in Fig. 7-18 ~ Fig. 7-19.

	X (M)	Y (M)	R (M)	FS	MR (T.M/M)	MS (T.M/M)
1	90.00	75.00	40.00	1.280	5335.33	4169.63

* SOIL CONDITION & SEISMIC COEFFICIENT

	GAMMAT (T/M^3)	GAMMAS (T/M^3)	GAMMA (T/M^3)	PHAI	C0 (T/M^2)	K	Y0 (M)	KH	KV
1	1.800	1.900		30.00	0.000	0.000	0.0		
2	2.000	2.100		37.50	0.000	0.000	0.0		
3	1.800	1.900		32.00	0.000	0.000	0.0		
4	1.800	1.900		33.00	0.000	0.000	0.0		
5	1.800	1.900		36.50	0.000	0.000	0.0		
6	1.800	1.900		41.00	0.000	0.000	0.0		

* C = C0 + K (Y0−Y)

Bank protecting works for Meghna river case−1

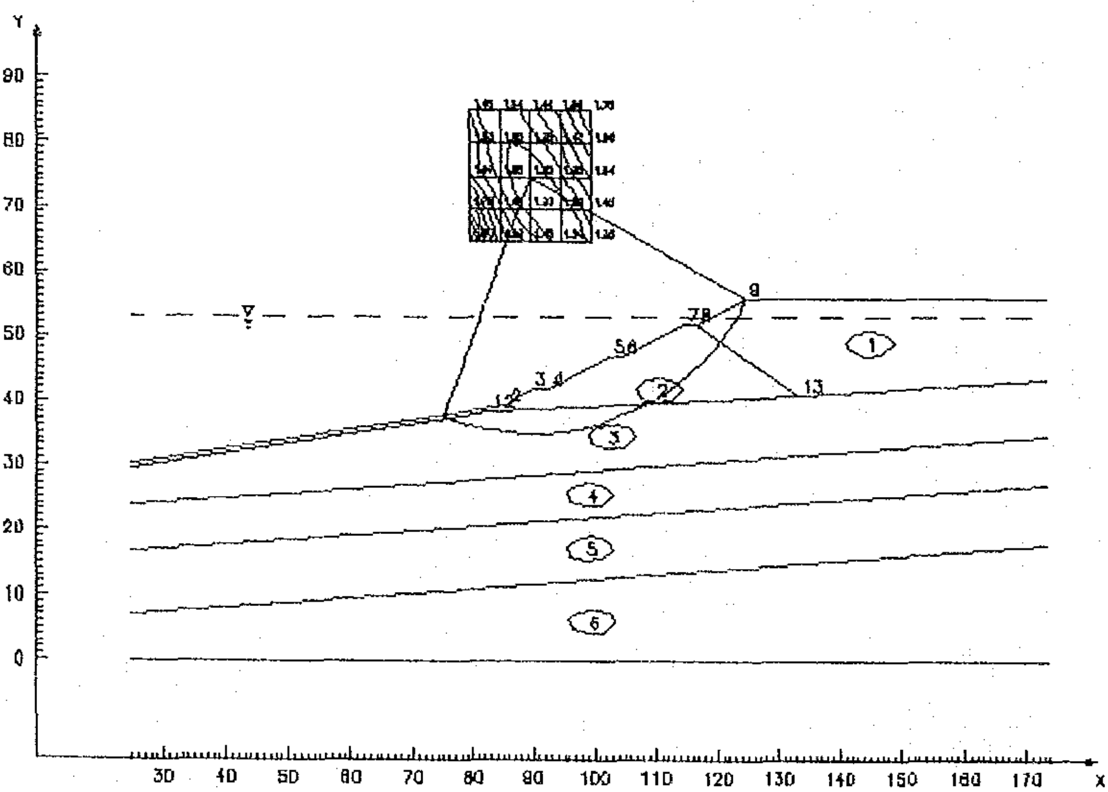


Fig. 7.16 Results of Stability Calculation for Slope Protection (Case − 1)

	X (M)	Y (M)	R (M)	FS	MR (T.M/M)	NS (T.M/M)
1	85.00	60.00	25.00	1.192	1102.76	925.33

* SOIL CONDITION & SEISMIC COEFFICIENT

	GAMMAT (T/M^3)	GAMMAS (T/M^3)	GAMMA (T/M^3)	PHAI	C0 (T/M^2)	K	Y0 (M)	KH	KV
1	1.800	1.900		30.00	0.000	0.000	0.0		
2	2.000	2.100		37.50	0.000	0.000	0.0		
3	1.800	1.900		32.00	0.000	0.000	0.0		
4	1.800	1.900		33.00	0.000	0.000	0.0		
5	1.800	1.900		36.50	0.000	0.000	0.0		
6	1.800	1.900		41.00	0.000	0.000	0.0		

* C = C0 + K (Y0−Y)

Bank protecting works for Maghna river case−2

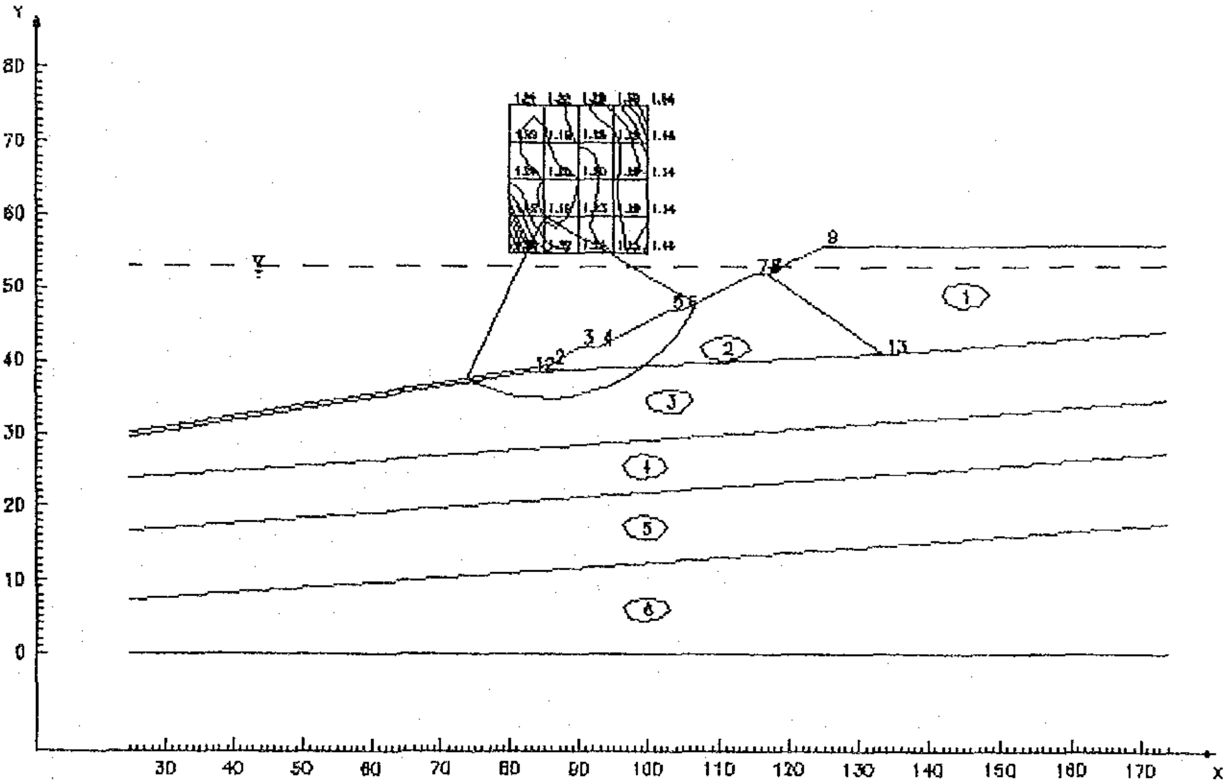


Fig. 7.17 Results of Stability Calculation for Slope Protection (Case − 2)

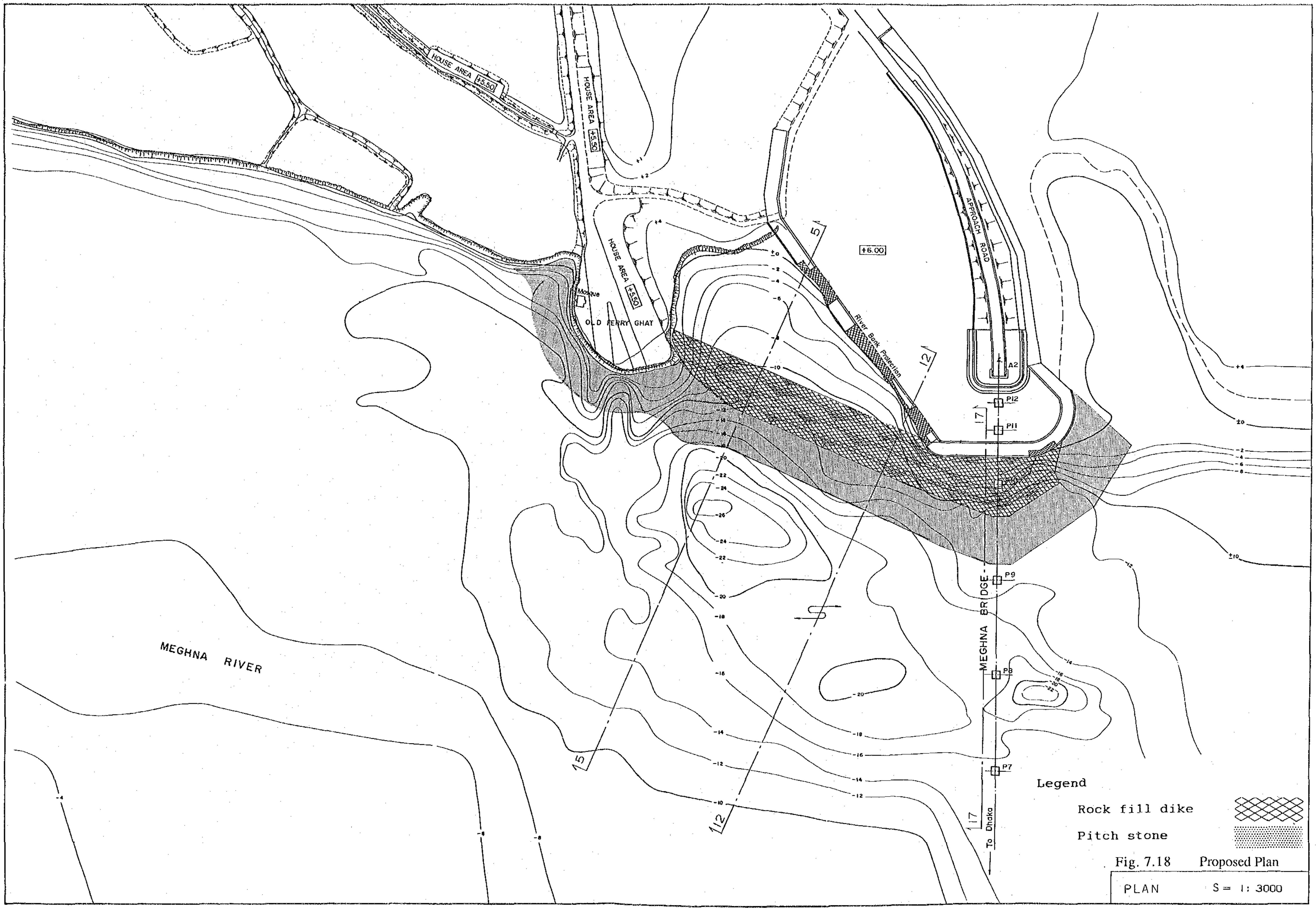
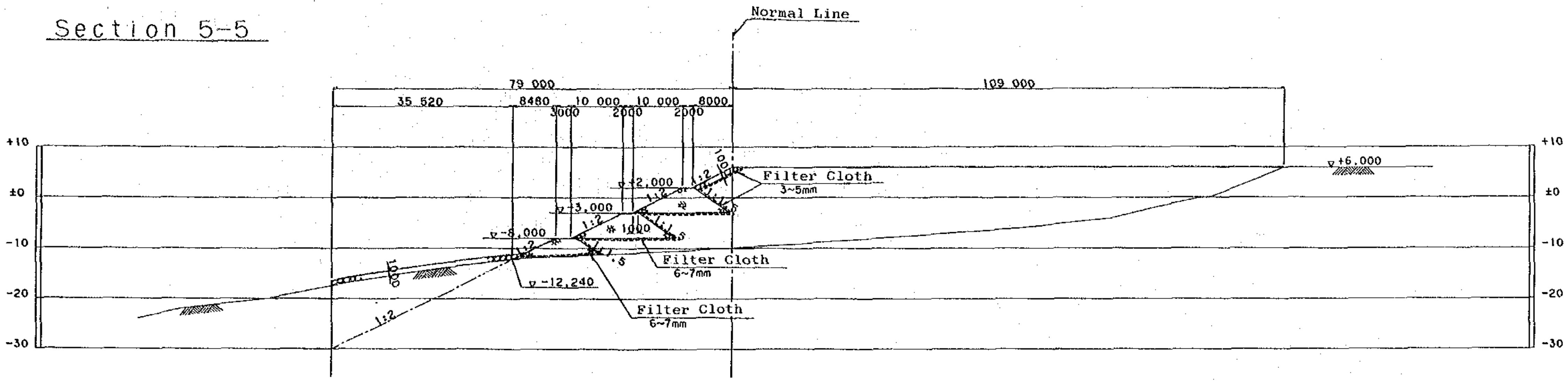


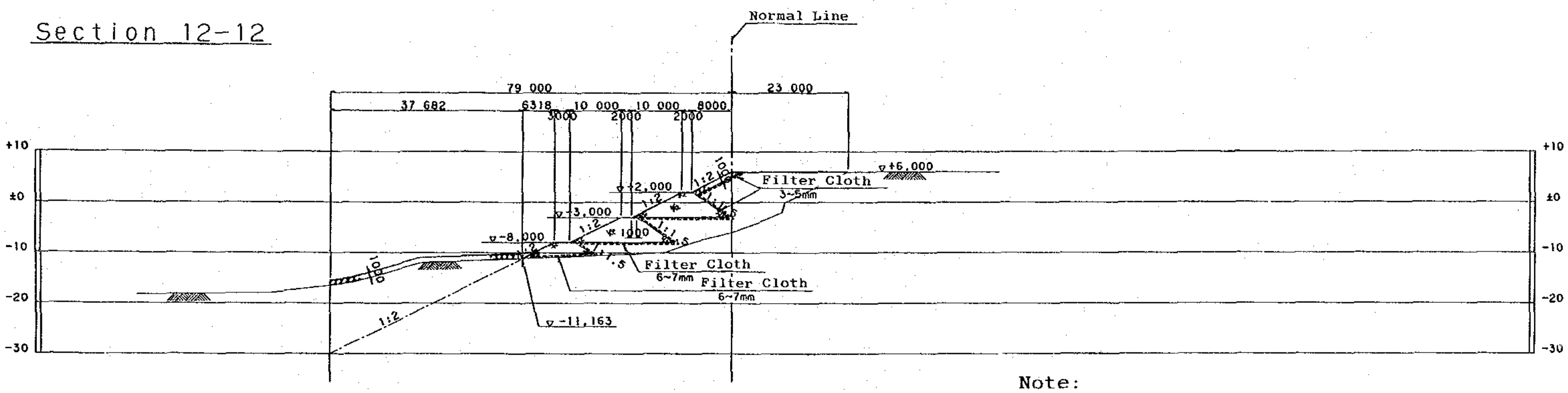
Fig. 7.18 Proposed Plan

PLAN	S = 1: 3000

Section 5-5



Section 12-12



Note:

1) Material of Filter Cloth is made of synthetic resins.

2) Procedure of construction method for Filter Cloth is explained in 7.4 Implementation Plan 7.4.2, 4) c).

3) Diameter Of stone material is min. 30 cm.

Section 17-17

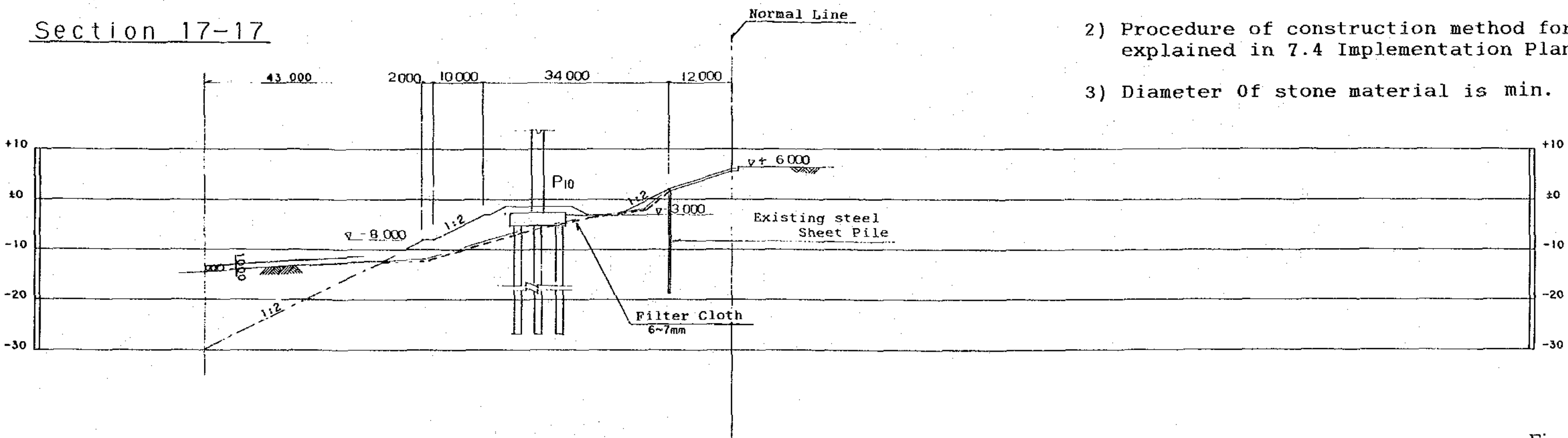


Fig. 7.19 Proposed Cross Section

CROSS SECTION S = 1: 1000

7.4 Implementation Plan:

7.4.1 Method of Construction:

This project proposes to perform short-term protection to the banks of the Comilla Side of the Meghna Bridge opened to traffic in July, 1990 and damaged by the meandering of the Meghna River waterway.

The construction work to be performed can be summarized as follows:

(1) Make maximum use of materials available in Bangladesh, and allow for mid-term and long-term repairs and protection to be made by the Government of Bangladesh.

(2) Complete main works of the project (levee construction) of the underwater portions to be completed before the start of the rainy season.

(3) If a dredger is used to perform any reclamation work in order to reduce the construction time, it will be necessary to assure safe navigation of general river boats plying this section of the river.

(4) To establish a temporary field office to monitor construction, and inspect and accept construction materials since it may become necessary to perform construction works around the clock. The overall construction will be managed from the construction office on the Dhaka side used for the Meghna Bridge construction.

(5) Foreign materials and equipment to be imported will be cleared at Mongla Port for customs inspection.

7.4.2 Matters to be Needed During Construction:

(1) Divers:

Since a large portion of the construction works will be performed underwater, it will be necessary to obtain the services of skilled divers who can perform work with a high degree of accuracy.

The number of divers available in Bangladesh are limited, but the some skilled divers can perform cutting work underwater.

(2) Procurement of Stone:

The stone to be used for this project will be procured in the mountainous area of Sylhet near the Indian border. Since large quantities of stone will be required in a very short time, it is recommended to obtain the cooperation of the Roads and Highways Department.

(3) Import of Equipment and Materials:

The import of proper and adequate quantities of supplies will greatly affect the construction schedule, and it will be necessary to carry out customs clearance promptly.

7.4.3 Construction and Construction Supervision:

(1) Analysis of Construction Plans:

1) Experience of the Meghna Bridge Construction:

An analysis of the Meghna Bridge construction operations has disclosed facts:

- It was planned to land and clear the foreign procured supplies through Chittagong, but due to the overcrowded conditions of the lifting equipment, it was decided to use the facilities at Mongla.

- In spite of being a water transport country, there is a shortage of bottoms including barges, tugboats, lighters, etc., necessary to perform construction underwater that almost all bottoms were brought in from Japan.

- The river bed of the Meghna River has large deposits of fine silt, and the river bed is easily scoured by turbulent flow and it will be effective to place non-corrosive fabric scour preventive sheets on the stone banks.

- The portions of the river bed exposed during dry season are susceptible to damage, and it will be effective to use gabions and mattress-type stone-filled mats.

- The stone sizes that are effective for bank protection are as follows:

Boulders	75 to 300 mm
Botu	50 to 150 mm
Shingles	5 to 50 mm

- The dredger boats to be used for reclaiming land, in view of the earth volumes required for the earthfill, should be similar to the sizes used for the Meghna Bridge project.

2) Examination of the Construction Schedule:

Due to the special nature of this project, it will be necessary to complete the project before the next rainy season when there may high flood waters in the river, and it will be required to protect the left banks of the Meghna Bridge (Comilla side). In addition, the main items of work should be completed by the water levels reach R.L. + 4.00 m in the latter part of June in consideration of the experiences of the Meghna Bridge project and start of the construction and the stone materials procurement.

For this reason, the total construction period could vary somewhat, and is expected to be about 8 months as shown in Fig. 7-21.

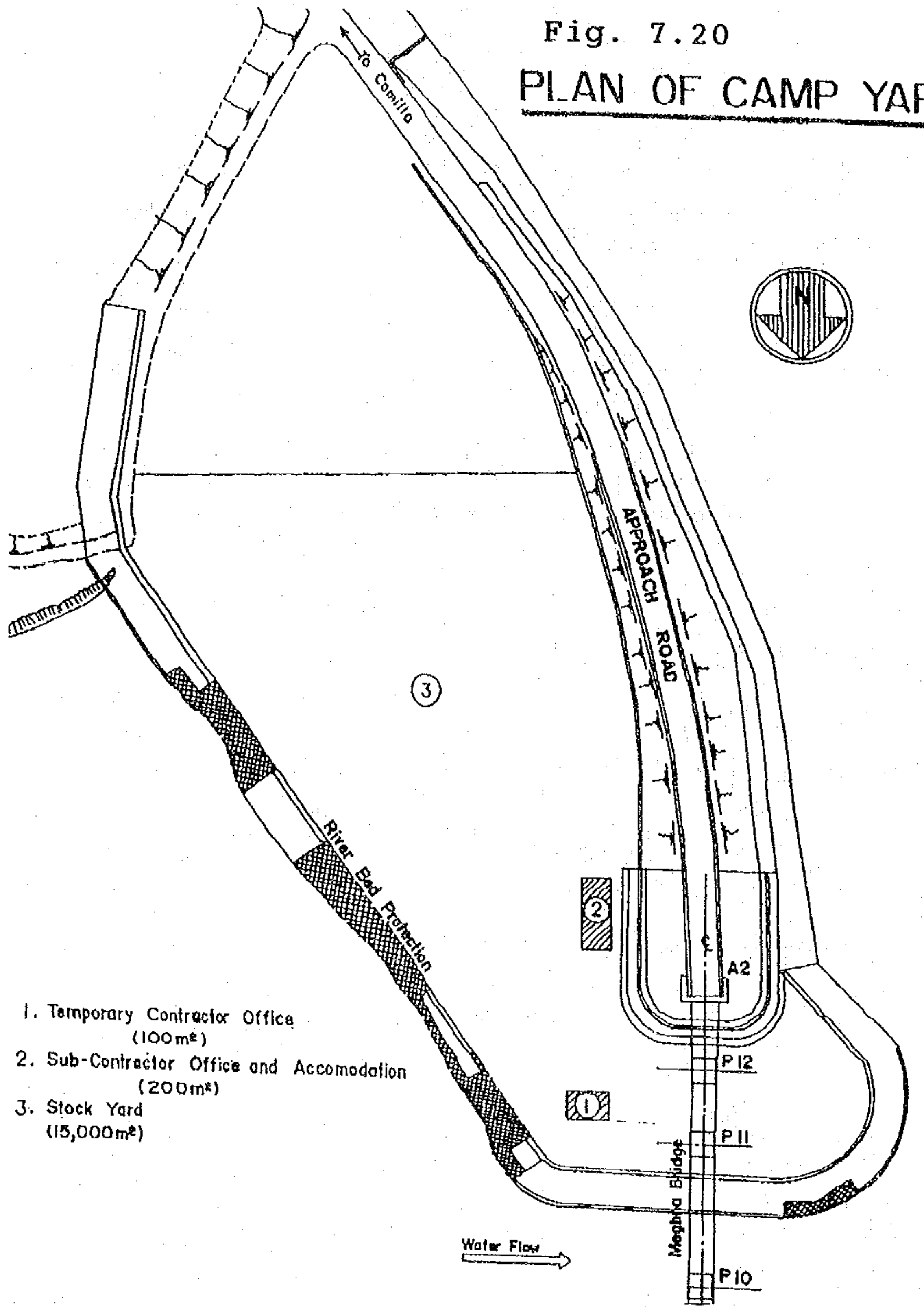
3) Construction Camp Yard:

Basically the office facilities for the Meghna Bridge project on the right bank (Dhaka side) will be used, but due to the day and night round-the-clock construction operations expected, it is planned to construct a simple office and lodging facilities, for construction monitoring, and stone quality inspection, at the upstream left bank (Comilla) side.

A stock yard for fabricating gabions and mattress-type and storing stones with an area of approximately 15,000 m^2 will be provided (see Fig. 7-20, Camp Yard plan.).

Fig. 7.20

PLAN OF CAMP YARD



4) Performance of Temporary and Permanent Works:

A general description of the main items of construction are given as follows:

a) Preparatory Works:

- Survey the project site prior to start of work, and confirm conditions of the river bed.
- Have project site turned-over, and construct necessary facilities.
- Drive guide stakes and install dolphins.

b) Procurement of Supplies:

- Procure local supplies and materials available.
  Especially stones
- Process procurement of import supplies and materials.
- Process import certificates and documents.

c) Protection Work for Loss of Earth and Sand:

Install sheets to prevent loss of earth and sand as follows:

① Confirm for discontinuities and obstructions in the river bed.
② Drive guide stakes with rope to install sheets in designated locations.
③ With barge mounted crane lower rolled sheets in the designated locations in the river bed.
④ Using divers to fix sheet edges by driving stakes.
⑤ Spread sheets along guide ropes using divers.
⑥ Hold down sheets with large stones and then dump stone rapidly over the sheets.
⑦ Repeat items ① to ⑥ over until the operation is completed.

d) Stone Work:

① Pre-survey the location for the stone work, and show the pitching locations using floats and buoys.
② Pitch the stone from the barge or self-propelled barges with machine or by hand.
③ When pitching the stone, confirm the placing operation using divers and measure the depth by sounding method.
④ Vary the size of pitched stone so that the interstices can be filled with smaller stone, and check to see that the density of the layer is increased to form a rigid layer.

e) Pitch Stone Work (Consolidated Stone Layer at Toe):

The stone work is similar Item d) above, but make the face of stone a flat surface and secure a minimum thickness.

f) Gabion Work:

Perform the gabion work in the following manner:

① Compact the slope sufficiently to the required slope.
② Construct an adequate base to reduce the loss of earth and sand from the surface.
③ Install the gabion so that there is no space between the units and is uniform over the bank.

g) Earth Fill Work:

The material for the earth fill should be obtained from the opposite (Dhaka) side in an efficient manner using dredgers for efficient and economic operation. In this case, care should be taken not to obstruct the navigation course of boats plying the river, and it is recommended to install the discharge pipe overhead or in the water.

h) Grading of Dredge Tailings:

Allow water to drain out from the dredge tailings, and compact the fill by walking bulldozers and other construction over the material, and establish the required elevation.

i) Protection of Bridge Supports:

Due to the meandering of the waterways of the Meghna River, it will be necessary to provide protection for Piers P-7 and P-8, and it is recommended to deposit rubble stones at the footings. The work should conform to Item e).

j) Clean Up Work:

After completion of all work, construction equipment imported into Bangladesh should be removed as soon as possible, and the camp yard and stock yard restored to their original condition.

(2) Examination of Construction Equipment:

The construction equipment for the project should generally be as follows:

1) Barge Mounted Crane (50 Tonne Capacity with Clamshell Bucket):

① Stakes should be driven into the river bed to guide or moor the work boats.
② Install the earth and sand protection sheets in their prescribed positions.
③ Install gabions underwater in the prescribed locations.

2) Pile Driving Equipment:

The following equipment will be required to drive the guide piles and dolphins:

- Vibro-hammer 60 KW
- Generating equipment 250 KA

3) Material Hauling Barges (100 Tonne Class):

To haul stones and other materials and equipment from stock yard to project site.

4) Front Wheel Loaders and Dump Trucks:

① To load stones on to barges from the stock yard.
② To move stones within the stock yard.

5) Equipment Required for Dredging:

Dredgers will be used for reclaiming land and to shorten the construction period. The construction can be completed within approximately 4 months. The principal equipment required with the dredgers are as follows:

• Non-navigable Pump Dredger	2,250 PS
Dredged Soil	Fine Sand
Transport Distance	1,000 m
Discharge Pipe Diameter	660 mm
• Anchor Lift Boat	240 PS
• Work Boat	200 PS

6) Tow Boat (400 PS Class):

For towing crane mounted barges, dredge boats, and material barges.

7) Air Compressors and Diving Gear:

Equipment required for diving operations.

8) Equipment for Temporary Work:

Lighting equipment and generators (100 KW).

(3) Construction Management:

This project is not difficult technically, but has a limited time schedule. For this reason construction management (materials, equipment, labor management) together with underwater work will require close control. The construction contractor and consultant should have local staff with a minimum number of Japanese staff. There will be stone masons required around the clock together with additional staff.

7.4.4 Procurement of Materials and Equipment:

Procurement of construction materials and equipment will be from the market of the donor country Japan and the recipient country (Bangladesh).

(1) Materials to be Procured from Japan

- Earth and sand washout preention sheet.
- Construction equipment.
- Temporary steel materials

(2) Materials to be Procured from Bangladesh:

- Stone.
- Construction equipment, temporary steel materials (partial).

(3) Procurement Routes:

- The materials and equipment to be imported by the construction contractor will be landed at Mongra Port, and thence hauled by domestic barges 300 km up the river to the camp yard at Meghna Bridge on the Dhaka side. They will be retransported to the Comilla side as required.
- Stones will be transported by local constructors by boat or trucks.

7.4.5 Implementation Schedule:

After the Exchange of Notes for this project has been concluded, the preparation of the detailed design and tender documents will take about 2 months. Subsequently the construction period will require about 8 months.

The provisional programme for execution of the works is indicated in Fig. 7.21.

7.4.6 Obligations of the Government of Bangladesh:

The Government of Bangladesh will be obligated to provide the following items:

(1) Furnishing of Existing Facilities:

Of the facilities constructed for the Meghna Bridge project, make available a part of the Supervisor's Office, Laboratory, and Local Administrative Personnel Lodging Facilities. Also make available the existing reclaimed land on the Comilla side.

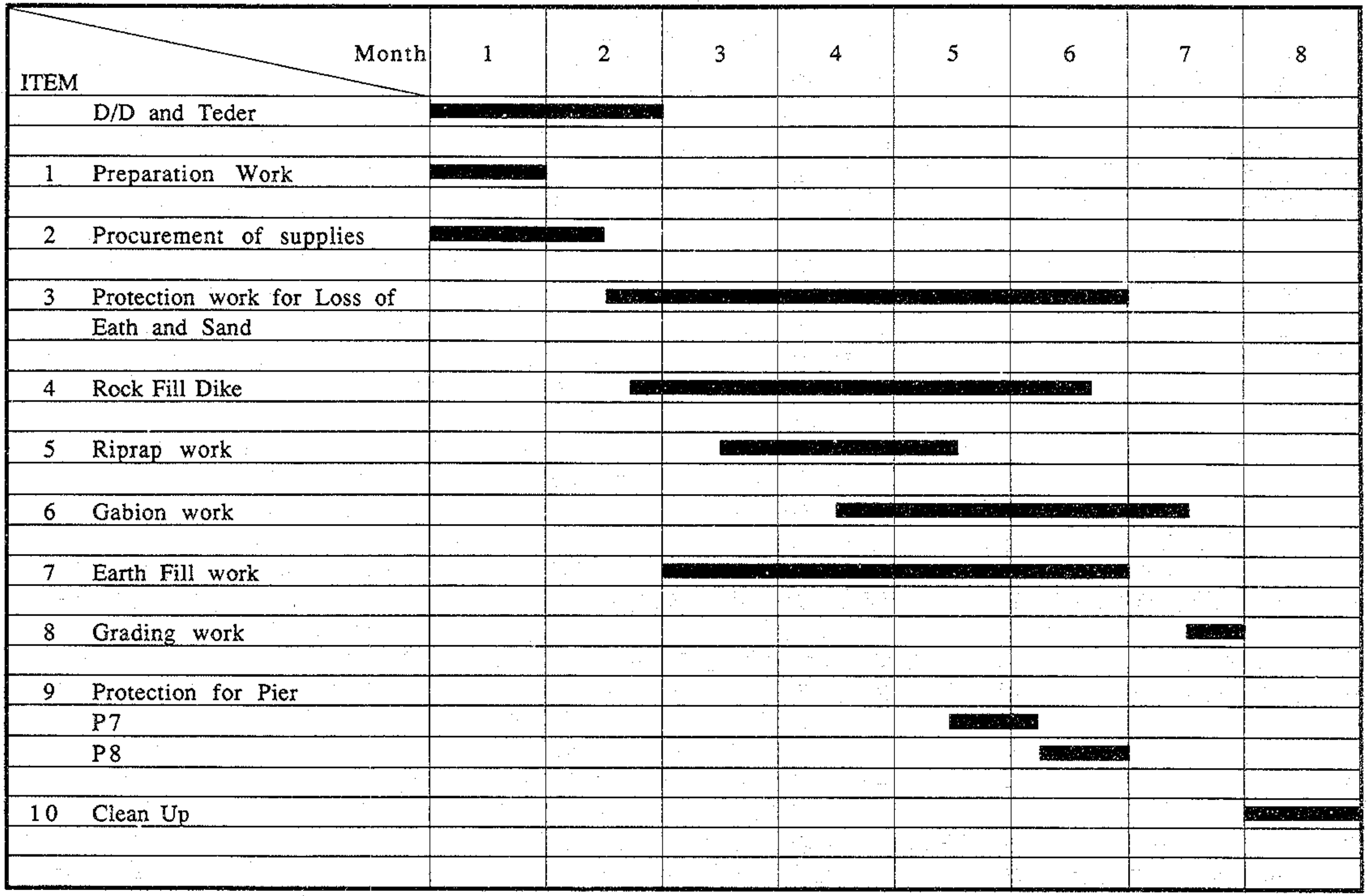
2) Issue of Import Permits and Payment of Import Duties:

As the actual construction period is short, it will be imperative for the early issue of import permit certificates and prompt payment of the import duties.

3) *Construction Cost borne by Bangladesh*

There is no share to be borne by the Government of Bangladesh.

Fig. 7.2.1 Imprementation Schedule



CHAPTER 8 RECOMMENDATIONS ON MONITORING AND MAINTENANCE WORKS OF BANK PROTECTION

CHAPTER 8 RECOMMENDATION ON MONITORING AND MAINTENANCE WORKS OF BANK PROTECTION

8.1 General

Failure of bank protection and embankments is quite a common occurrence on many rivers and may lead to serious damage to land and inhabitants in the region. One of the main reasons of their failure is erosion; the movement of particles composing the river bank or embankment by current or waves. In order to minimize the damage caused by erosion, proper monitoring and maintenance works are essential. These activities, if appropriately carried out, will enable detection and control of abnormal phenomena by providing timely countermeasures in order to maintain the safety of the embankments.

In Bangladesh, monitoring and maintenance of river structures is of vital importance. This aspect must be emphasized because most of national land is deemed as flood prone areas which could be subject to huge potential damage. In particular, bank erosion, which is causing recession of shoreline and deteriorating the safety of river structures, should be continuously monitored.

Although the present features of the Meghna River were clarified in Chapter 5, many factors such as the future alignment of the river course and characteristics of scouring and siltation are still uncertain. It should be noted that the proposed bank protection in this study is a short-term countermeasure in the limited area to secure safety of the existing revetment and abutment at Comilla side. It is not a mid-term or long-term countermeasure derived from flood control aspects based on overall basin-wide study of the Meghna River. In order to establish a definite plan aimed at the mid-term and long-term stabilization of the river channel, it is essentially required to carry out further extended studies on hydrology/hydraulics, flood inundation, fluctuation of river cross sections and river bed, scouring/siltation characteristics, sand bar movement and river course shifting, sediment transportation and river bed material characteristics, etc.

In addition, since the numerical simulation by two-dimensional flow model conducted in this study was based on only three years' hydrological data, verification by discharge measurements during flood and survey on river bed fluctuation are indispensable to create an appropriate model representing the present features of the Meghna River.

On the other hand, the Government of Bangladesh is requested to establish an institutional organization for monitoring and maintenance works of the bank protection after its completion and to take immediate countermeasures as required. The maintenance works at the Harding Bridge is a successful example.

The Harding Bridge, catering solely for railways (around 1,800 m long), was constructed in 1915 by a British engineer, Sir R.R.Gales. At the abutments and connected training dike of this bridge, pitched stone was utilized for revetments to protect the slope of the dike against scouring. About 1 million m^3 of earth and 0.6 million m^3 of pitched stone were used for construction of the training dike. Further, approximately 80,000 m^3 has been stored at the site for repair and maintenance works.

After completion, since serious scouring occurred in front of the dike and around the piers, pitched stone was placed on the scoured portion. To monitor the surface of the stone protection, bathymetric survey by echo-sounder has been carried out in the river channel and surrounding piers. Repair work, by placing stone, was carried out performed as soon as the souring depth exceeded the dangerous level. A maintenance strategy was established to prevent extraordinary scouring which endangers the stability of the abutment and dike. The channel bed adjacent to the bridge has been stabilized by this method. The maintenance cost for the survey works and placement of the pitched stone is estimated at around 1 million Taka/year.

8.2 Required Monitoring and Maintenance Works of Bank Protection after Completion

8.2.1 Monitoring of Bank Protection at Comilla Side

After completion of the proposed works, periodical monitoring of stone protection is recommended, as stated Chapter 7, to predict extraordinary scouring and slope failure. Because most of the proposed stone protection will be submerged throughout the year, sounding of the surface of the stone by echo-sounder will be necessary to obtain profiles of the embankment. Along the stone protection, the sections to be surveyed should be determined and then set immediately after construction. The interval between the sections should be approximately 30 m. The results of monitoring works should be compiled on drawings in the form of cross sections with the records of water level and date for chronological comparison.

The monitoring works are tentatively recommended to be conducted as follows:

- 1st : Just after the completion
- 2nd : October to November 1993 (post-flood season)

- 3rd : April to May 1993 (post-dry season)
- onward : As for 2nd and 3rd

8.2.2 Monitoring of River Conditions

In order to monitor the fluctuation of the river bed near the Meghna Bridge, river cross-section survey must be carried out periodically. Four survey results are now available ; April 1989, January 1990, January 1992, and June 1992. These series of cross sections as well as future ones should be reviewed regularly.

In order assess the effect of floods against scouring, siltation, and sediment transport, the cross section survey, using same control points which have been established through the survey in June 1992, should be performed just after the wet season (October to November) yearly. To enable quick comparison of each cross section, draughting should be done on the same scale as specified. Further, in connection with the cross-section survey, the river section at the Bridge site should be measured to confirm safety of piers against local scouring.

It is advisable that monitoring and maintenance works of the proposed short-term bank protection be conducted by the involvement of experienced engineers from the Bangladesh University of Engineering and Technology (BUET), as has been done during the Basic Design Study.

8.2.3 Recommendation on Maintenance Works

As the suggestion made for the measure to protect the river fauns were for the short-term protective structures, the maintenance works to be performed after the completion of the construction works will be important.

It is been noticed that the maintenance works performed at the Harding Bridge has been successful example for their project.

After the project has been completed, the maintenance works to be applied by the Bangladesh authorities should follow the methods used at the Harding Bridge and include the following:

① Store a spare stock of 10 % (4,000 m^3/rr) of the stone used in the project of 40,000 m^3.

② After accumulating a stock of 3 years, start repair work of the damaged stone work. The estimated cost for this work is expected to be approximately 12,320,000 takea/year.

8.3 The Justification and Practical Effects

This project is for the important facility of the Meghna Bridge which is located on the Dhaka-Chittagong Highway. This roadway has the largest amount of road traffic of all the existing roads in Bangladesh, and is the most important of the roadways which will affect the socio-economic aspects of daily life, and is maintained with the highest priority. With this point in mind, and with the impending spread of the river bank erosion and the necessity to protect the river banks and bridge facilities, the project is well justified. The implementation of this project is expected to provide the following benefits:

- prevent further erosion of the river banks at the bridge site.
- the stone river protection will require preventive maintenance work which will lead on to establishment of methods to prevent erosion of similar projects.
- the use of locally produced materials will contribute to the local economy.

APPENDICES

APPENDICES

Appendix 1 Members of the Japanese Basic Design Team ---------------------------- App - 1

Appendix 2 List of Persons Met -- App - 2

Appendix 3 Minutes of Discussions, June 17, 1992---------------------------------- App - 4

Appendix 4 Minutes of Discussions, September, 1992------------------------------ App - 8

Appendix 5 Reference-- App-12

APPENDIX 1 MEMBER OF THE JAPANESE BASIC DESIGN TEAM

Team Leader

Name	Mr. Masayuki WATANABE
Present Post	Institute for International Cooperation Japan International Cooperation Agency JICA

Project Coordinator

Name	Mr. Toshiyuki IWAMA
Present Post	Second Basic Design Study Division Grant Aid Study & Design Department

Technical Experts

Name	Assignment
Mr Takeshi NAKAYAMA	Chief, Overall Design Manager/ Bridge Engineer
Mr. Yoshihiro MOTOKI	River Engineer
Mr. Katsufumi MATSUZAWA	Geodetic Engineer

APPENDIX 2 LIST OF PERSONS MET

Japanese Side

Japanese Embassy in Bangladesh

Mr Tetsurou Itou	Minister
Mr Takeshi Ota	First Secretary
Mr. Akashi Ito	Second Secretary

JICA Office in Bangladesh

Mr. Takeshi Imazu	Resident Representative
Mr. Takeshi Naruse	Deputy Resident Representative

Bangladesh Side

Ministry of Planning

Dr. K.M. Febiduddin	Member of Planning Commission
Mr. Amir Ali Khan Majlash	Joint Chief

Ministry of Communication (MOC)

Mr. Moonzur UL Earim	Secretary
Mr. A. Rakib	Joint Secretary
Mr. Azizur Rarman	Assistants Secretary
Mr. A. Quadir	Staff

Roads and Highways Department (RHD)

Mr. Ataur Rahman	Chief Engineer
Mr. Nural Azamkhan	Project Director of Meguna-Gumti Bridge Construction Project
Mr. Abdul Halim Miah	Project Manager of Meghna-Gumti Construction Project
Mr. Sohrabuddih Meah	Sub-Divisional Engineer

Bangladesh Technical College

Mr. K Horshed Alam	Chief Professor
Mr. Ainum Nishat	Professor
Mr. Abdul Hannan	Professor
Mr. Muhammad Ali	Assistants Professor
Mr. Abdul Mafin	Assistants Professor
Mr. Monowas Hassui	Assistants Professor

MINUTES OF DISCUSSIONS
BASIC DESIGN STUDY ON THE PROJECT FOR PROTECTING REVETMENT ON THE BANK OF MEGHNA RIVER IN THE PEOPLE'S REPUBLIC OF BANGLADESH

In response to a request from the Government of the People's Republic of Bangladesh, the Government of Japan decided to conduct a Basic Design Study on the Project for the protecting revetment on the bank of the Meghna river in the People's Republic of Bangladesh (hereinafter referred to as "the Project") and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to the People's Republic of Bangladesh a study team, which was headed by Mr. Masayuki WATANABE, Special Advisor for Civil Engineering Development, Institute for International Cooperation, JICA, and is scheduled to stay in the country from June 14 to July 2, 1992.

The team held discussions with the officials concerned of the Government of Bangladesh and conducted a field survey in the study area.

In the course of discussions and field survey, both parties have confirmed the main items described on the attached sheets. The team will proceed to further works and prepare the Basic Design Study Report.

17, June, 1992

Mr. Masayuki WATANABE
Leader
Basic Design Study Team
JICA

Mr. Md. Ataur Rahman
Chief Engineer
Roads and Highways Department
Roads and Road Transport Division
Ministry of Communications

ATTACHMENT

1. Objective

   The objective of the Project is to take emergency safety measures to protect Meghna Bridge at the Comilla side.

2. Project sites

   Along the river bank on the Comilla side in the upstream and downstream reaches of the Meghna Bridge.

3. Responsible organization, executing organization

   Responsible organization for the Project is Economic Relations Division, Ministry of Finance, Government of Bangladesh.

   Executing organization for the Project is Roads and Highways Department, Roads and Road Transport Division, Ministry of Communications, Government of Bangladesh.

4. Items agreed by both sides

   After discussion with the Basic Design Study Team, the following items were finally agreed by both sides.

   1) This is an urgent rehabilitation project.

   2) The improvements shall cover the indicated area as shown in Annex-1.

   3) The type of improvements shall be determined considering the complexity and nature of the problem in addition to the availability of materials and equipment and suitability of maintenance works that would be done by the Bangladesh side.

5. Japan's Grant Aid System

   1) The People's Republic of Bangladesh has understood the system of Japanese Grant Aid explained by the team.

   2) The Government of Bangladesh will take necessary measures, described in Annex-2 for smooth implementation of the Project, on condition that the Grant Aid Assistance by the Government of Japan is extended to the Project.

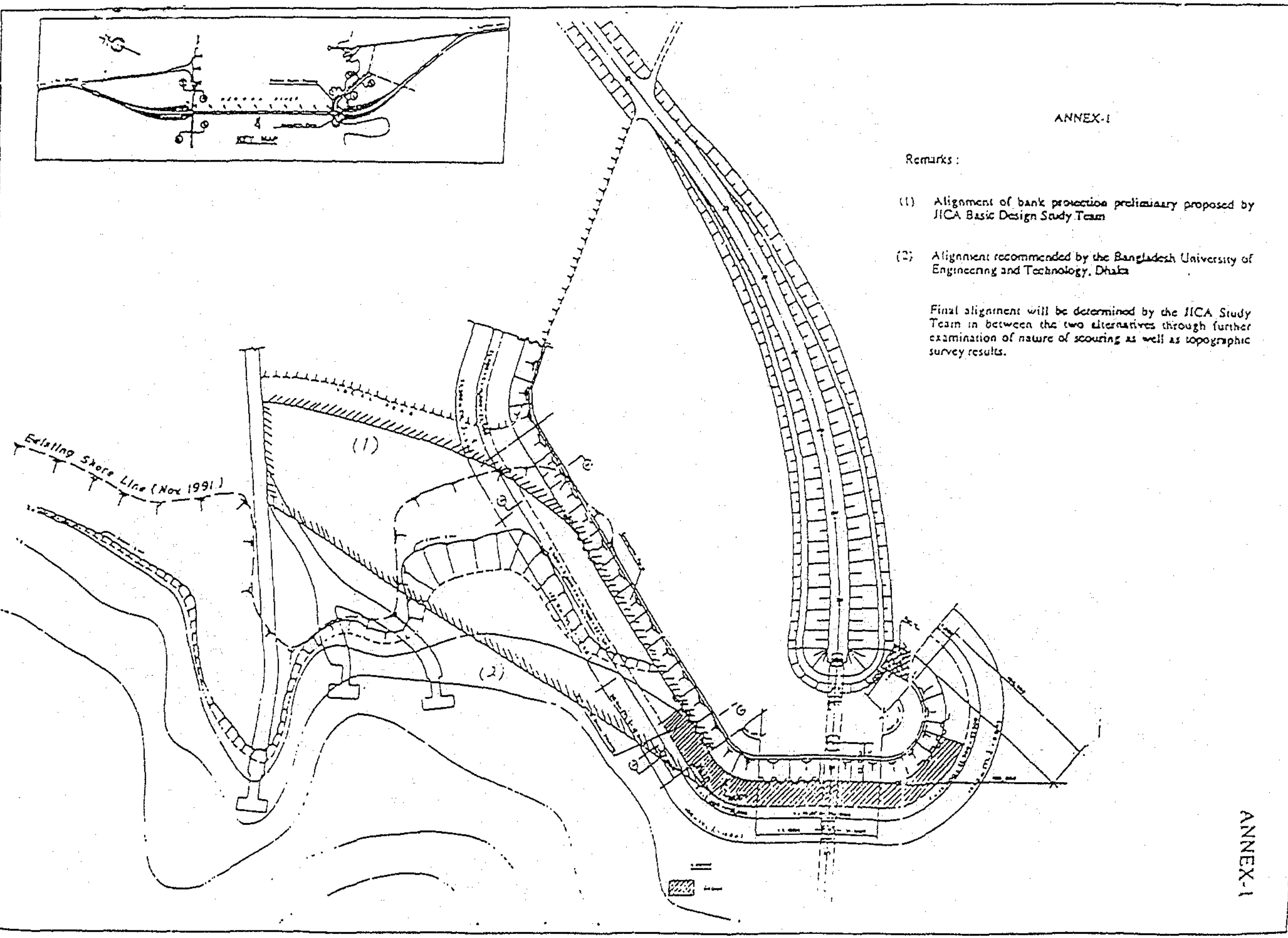
6. Schedule of the Study

   1) The study team will proceed to further studies in People's Republic of Bangladesh until July 2, 1992.

   2) JICA will prepare the interim report in English which covers the draft final design of the revetment work, and dispatch a mission in order to explain its contents around September 1992.

   3) JICA will complete the final report and send it to the Government of Bangladesh by November, 1992.

ANNEX-1



ANNEX-1

Remarks :

(1) Alignment of bank protection preliminary proposed by JICA Basic Design Study Team

(2) Alignment recommended by the Bangladesh University of Engineering and Technology, Dhaka

Final alignment will be determined by the JICA Study Team in between the two alternatives through further examination of nature of scouring as well as topographic survey results.

ANNEX - 2

Following necessary measures should be taken by the Government of Bangladesh in case Japan's Grant Aid is executed.

1) To secure the site for the Project.

2) To clear and level the site prior to commencement of construction, if necessary.

3) To bear commissions to the Japanese foreign exchange bank for the banking services based upon the Banking Agreement.

4) To ensure necessary taxes and to take necessary measures for customs clearance of the materials and equipment brought for the Project at the port of disembarkation.

5) To exempt Japanese nationals engaged in the Project from customs duties, internal taxes and other fiscal levies which may be imposed in Bangladesh with respect to the supply of the products and the services under the verified contracts.

6) To accord Japanese nationals whose services may be required in connection with the supply of the products and the services under the verified contracts such facilities as may be necessary for their entry into Bangladesh and stay therein for the performance of their work.

7) To maintain and use properly and effectively the facilities constructed and equipment purchased under the Grant.

8) To bear all the expenses other than those to be borne by the Grant.

MINUTES OF DISCUSSIONS
BASIC DESIGN STUDY ON THE PROJECT FOR PROTECTING REVETMENT ON THE BANK OF MEGHNA RIVER THE PEOPLE'S REPUBLIC OF BANGLADESH

In September 1992, the Japan International Cooperation Agency (JICA) dispatched a Basic Design Study team on the Project for Protecting Revetment on the Bank of Meghna River (hereinafter referred to as "the Project") in the People's Republic of Bangladesh, and through discussions, field survey, and technical examination of the results in Japan, has prepared the interim report of the study.

In order to explain and to consult the Bangladesh side on the components of the interim report, JICA sent to Bangladesh a study team, which is headed by Mr. Masayuki WATANABE, Special Advisor for Civil Engineering Development, Institute for International Cooperation, JICA, and is scheduled to stay in the country from September 3 to 21, 1992.

In the course of discussions, both parties have confirmed the main items described on the attached sheets.

October 7, 1992.

Mr. Takeshi Imazu
Resident Representative
JICA Bangladesh office.

Dr. A. M. M. Shawkat Ali
Additional Secretary
Economic Relations Division
Ministry of Finance

ATTACHMENT

1. Components for Interim Report

The Government of Bangladesh has agreed and accepted the components of the Interim Report proposed by the team. Minor amendments suggested by the Government of Bangladesh will be incorporated.

2. Japan's Grant Aid System

(1) The Government of Bangladesh has understood the system of Japanese Grant Aid explained by the team.

(2) The Government of Bangladesh will take the necessary measures, described in ANNEX 1, for smooth implementation of the project on condition that the Grant Aid assistant by the Government of Japan is extended to the Project.

3. Further Schedule

The team will make the Final Report in accordance with the confirmed items, and send it to the Government of Bangladesh by the end of November 1992.

4. Administrative Proceedings for Project Implementation.

(1) The Bangladesh side will prepare the Project Concept Paper as soon as possible for early project approval within the Government of Bangladesh.

(2) Considering the emergency nature of the Project and aiming at earlier commencement of the construction works, the Government of Bangladesh will examine possible arrangement to expedite the implementation.

Overall implementation schedule by the individual two contracting methods (direct and competitive contracting) is comparatively illustrated in the figure attached for reference (ANNEX 2).

The Government of Bangladesh will inform the result of examination on the contracting method to the Government of Japan at the earliest opportunity.

5. Riprap Work

In order to ensure smooth flowlines along the embankment, both parties agreed that the tip of the former ferry ghat be removed and riprap be extended to the upper base of the former ferry ghat.

ANNEX 1

Following necessary measures should be taken by the Government of Bangladesh in case Japan's Grant Aid is executed.

1) To secure the site for the Project.

2) To clear and level the site prior to commencement of construction,if necessary.

3) To bear commissions to the Japanese foreign exchange bank of the banking services based upon the Banking Agreement.

4) To ensure necessary taxes and to take necessary measures for customs clearance of the materials and equipment brought for the Project at the port of disembarkation.

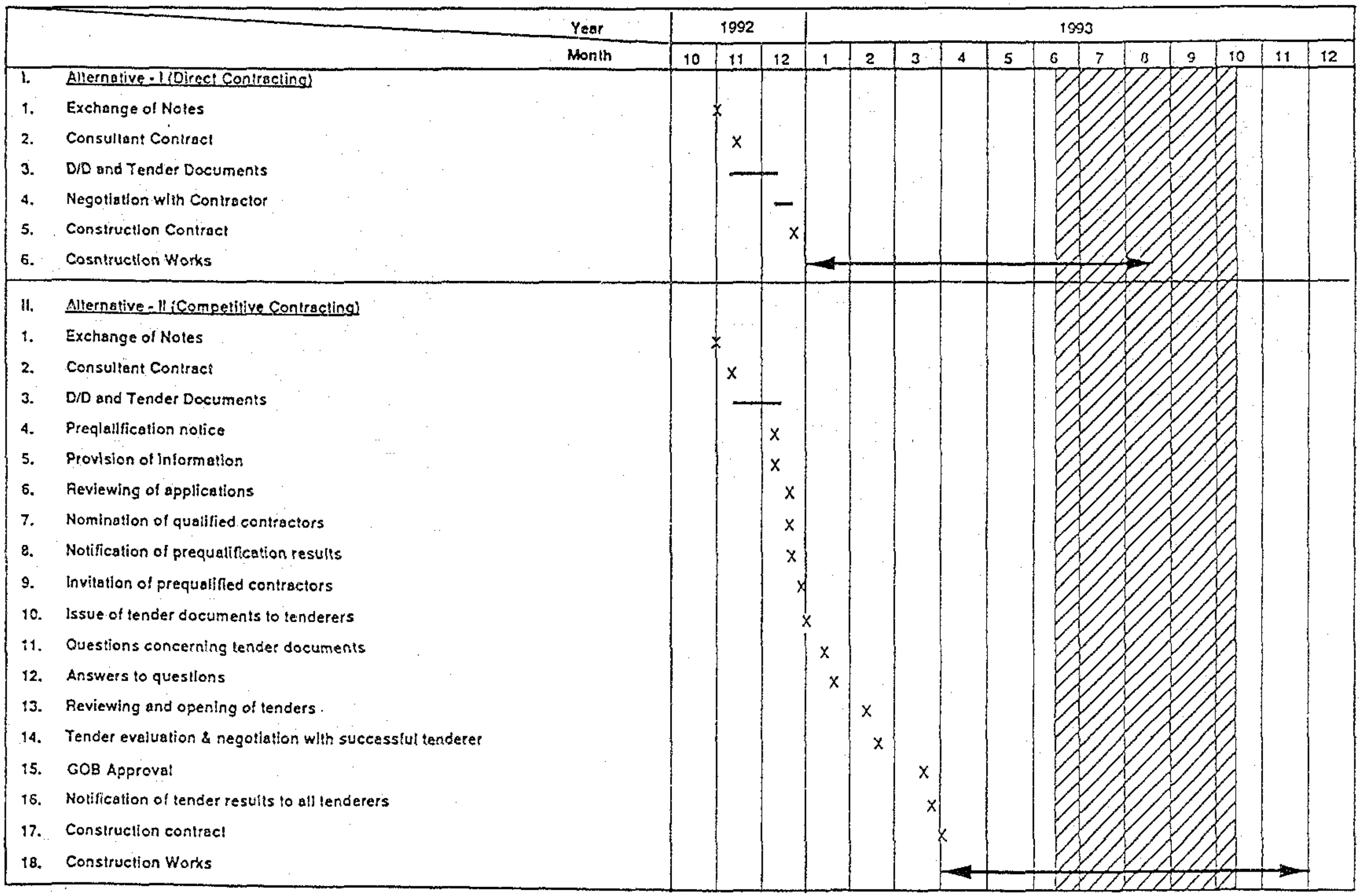
5) To exempt Japanese nationals engaged in the Project from customs duties,internal taxes and other fiscal levies which may be imposed in Bangladesh with respect to the supply of the products and the srevices under the verified contracts.
However, the cost of duties,internal taxes and other fiscal levies to be imposed under the Bangladesh Regulations shall be borne by the relevant Ministry/Agency concerned with the project for which necessary budget provision shall be made by them.

6) To accord Japanese nationals whose services may be required in connection with the supply of the products and the srevices under the verified contracts such facilities as may be necessary for their entry into Bangladesh and stay therein for the performance of their work.

7) To maintain and use properly and effectively the facilities constructed and equipment purchased under the Grant.

8) To bear all the expenses other than those to be borne by the Grant.

ANNEX.2 C..parison of Implementation Schedule



Legend : [hatched] Flood season with water level above R.L. +4.00 m at the Project site

Notes :

1. The implementation schedule for both alternatives above is prepared on condition that the Grant-Aid Assistance by the Government of Japan is extended to this Project and E/N is completed by the end of October 1992.
2. The commencement of construction works by the competitive contracting will be delayed for around three (3) months than by the direct contracting as shown above.
3. In Alternative - I, most of construction works underwater would be completed by the start of flood season, while in the case of Alternative - II, major construction works might be performed during flood season which may become difficult to be completed on schedule.
4. The schedule of Alternative - II is prepared referring to the experiences in the Meghna-Gumti Bridge Construction Project. Taking into account the difference in complexity of the construction works between the Meghna-Gumti Bridge Construction Project and this Project, it might be possible to shorten the contracting arrangement period by around one (1) month in Alternative - II, that means two (2) months difference between the alternatives.

REFERENCE

1. PRELIMINARY REPORT ON JAMUNA BRIDGE CONSTRUCTION PROJECT, JICA, March 1973 (in Japanese)

2. FEASIBILITY STUDY ON MEGHNA, MEGHNA-GUMTI BRIDGES CONSTRUCTION PROJECT, FINAL REPORT AND APPENDICES, Japan International Cooperation Agency, March 1985

3. FLOODS IN BANGLADESH, RECURRENT DISASTER AND PEOPLE'S SURVIVAL, Universites Research Center, Dhaka, August 1987

4. STUDY REPORT ON SCOURING OF RIVER BANK NEAR MEGHNA BRIDGE, Pacific Consultant International, August 1989 (in Japanese)

5. SECOND FLOOD DAMAGE RESTORATION PROJECT, CONSULTANCY SERVICES FOR PROTECTION OF MEGINA RIVER RAILWAY BRIDGE AT BHAIRAB BAZAR, DRAFT FINAL REPORT (Vol. I & II), Development Design Consultants Limited, December 1989

6. WORKING PAPER FOR THE STUDY OF EROSION PHENOMENON AT UPSTREAM OF MEGHNA BRIDGE SITE, PCI & NK, November 1991 and January 1992

7. STUDY REPORT ON RIVER BED FLUCTUATION AT UPSTREAM OF MEGHNA BRIDGE, Pacific Consultant International and Nippon Koei Co., Ltd., January 1992 (in Japanese)

8. MEGHNA RIVER BANK PROTECTION SHORT TERM STUDY, FINAL REPORT, Haskoning Royal Dutch Consulting, February 1992

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