4. RIVER FACILITIES

CHAPTER 4 DESIGN FOR RIVER FACILITIES

4.1 Background

The Phase 2 of the Study on Construction of the Bridge over the River Rupsa in Khulna was conducted following Phase 1 of the Study from February 1998 to March 1999.

As a part of the each Study, hydrological survey was conducted in the Phase 1, and more detailed hydrological survey at proposed bridge site was conducted in the Phase 2 from July to August this year in order to grasp the characteristic of the Rupsa river.

The survey items of hydrological survey in Phase 2 were as follows;

- Bathymetric survey by echosounder
- Flow velocity measurement using directional current meter
- Float measurement to track the transition of current direction

At the same time, the various data including the following major items were collected;

- Water level records at Khulna station from 1968 to 1998 observed by BWDB
- Water depth plan hydrographic chart measured by BIWTA to secure for ship route (in 1986, 1989, 1992, 1998)
- Cross section data of Rupsa river in 1994-95 measured by BWDB

In addition, local interview hearing and field survey were also carried out.

Using the above-mentioned data as a basis, plans of river bank revetment against erosion and protection of piers against scouring was considered.

This technical report for River Facilities Design is based on the working paper that was submitted to RHD in the technical meeting on November 28, 1999.

4.2 Objective

The objective of the technical report is to clarify the type of design for controls of River bank revetment against erosion and protection of piers against scouring applicable to the Study, which was determined in order to conduct detailed design.

4.3 Rupsa river Morphology

4.3.1 River Bank Erosion

Investigation results of Phase-I, revealed that during the course of time the river bank erosion caused the Rupsa river to shift to the east and the south. However, at the proposed site and along bridge route 1-3, no major change is observed between 1973 - 1990. This fact was confirmed through local interview hearing survey.

However, the side of the east bank must be protected because the deepest point is close to this side. Moreover, there is a tendency of erosion spreading to the east bank side, according to the analysis using the topographic map and the satellite image from the 1960s to the present. The causes of the river bank erosion are the wind, the waves generated by winds shipping vessels, apart from river velocity.

Especially, the side of the east bank needs the protection works but there is no necessity for protection works on the side of the west bank except in the range, which is expected to be influenced by the construction of the pier.

4.3.2 Changes in River Bed Conditions

Following data are obtained to examine elapsed change of river cross sections in the vicinity of river crossing points;

i) River cross sections at 33 locations of which the survey was conducted by the Study at 3 river crossing points.
ii) Water depth plan measured by BIWTA to secure for ship route (in 1986, 1989, 1992, and 1998)
iii) BWDB measurements at two river cross sections

According to information obtained from local office of BWDB and BIWTA, the river bed of the Rupsa River is getting shallower in general under such a way of erosion during high flow velocity and sediment during the low repeatedly. There exist many shallows along the river course, and dredging works are required to secure a passage for vessels.

After the completion of Mongla port water depth was measured at 16-17 m, but uninterrupted siltation makes the water depth shallower up to 10-12 m for one decade even though dredging works are done every year.

The deepest and average levels of above-mentioned obtained data are compared to get the following features.

(1) The average elevation of river bed shows a tendency to make it shallower.
(2) The deepest part of river bed remains unchanged from 1986 to 1999.
(3) The depth of the deepest point varies from year to year, depending on the dredging operations.
(4) The deepest point is located to the western bank on Route 3, in the vicinity of the center on Route 2 and to the eastern bank on Route 1. Furthermore, the river bed becomes deeper on the downstream.

The depth of the deepest point on Route 1 may deepen to some extent in the future. The depth is estimated 5m at most taking into considerations the depth of the deepest points of Route 2 and 3. Therefore, the design of piers on Route 1 will require 5m deep allowance against natural degradation of river bed.

4.4 River Training and Bank Protection Works

4.4.1 Selection of the Type of River Training Works for River Bank Erosion

In the Rupsa river, the guide bank, a kind of river training works, whose basic objective is to constrict waterway, is unnecessary for the following reasons;

1) River width and waterway are almost stable, and both sides of the river are nearly parallel almost straight.

2) Length of proposed bridge from abutment to abutment is more than the bank to bank distance of river, and the flow towards the bridge is not oblique.

However, because there is a possibility for, small-scale slope erosion, it is planned to construct revetment as a slope protection measure.

In designing the revetment, it is attached importance to keep existing topography of bank as much as possible, in order to prevent discontinuity of river bank and become easy to connect with upstream and downstream non-constructed bank.

The entire plan is described below.

4.4.1.1 Construction area of revetment

From hydraulic consideration length of protection work for the bridge comes about 140m on either bank.

(See Computation Report for River Facilities Design (1) Revetment length)

Revetment is planned as 50m length each of upstream and downstream from proposed bridge construction point along the bank, and 50m width from the bank because transverse slope of river bed turns flat at about 50m from the bank.

Actual revetment length in the deep water portion is planned as 75m upstream and 75m downstream, so that chances of erosion in the deep water portion which is 40m away from the river bank can be encountered.

4.4.1.2 Revetment alignment

Straight line is recommended as alignment in order to prevent erosion and sedimentation due to a curve of structural line.

Construction area and alignment of revetment are shown in Fig. 4.4.1.

4.4.1.3 Structure of revetment

Considering the ease of construction, economy and durability, C.C.blocks are proposed as revetment material. The sucking-up of fine materials of the river bank will be protected by laying properly selected geotextile filter cloth under C.C.blocks.

From point of view of existing topography and construction method, construction area is divided in following 3 sections and structure of revetment is planned in each section.

1) Road embankment slope

   From crest of embankment to intersection of steep slope and gentle slope.

2) River bank up to L.W.L.

   From intersection of steep slope and gentle slope to intersection of gentle slope and steep slope, which is an around point of contact of L.W.L.

3) Underwater section

From intersection of gentle slope and steep slope to channel bottom (50m from crest of embankment).

The division of cross section is shown in Fig. 4.4.2.

Structure of revetment of each section has been described in the following sections.

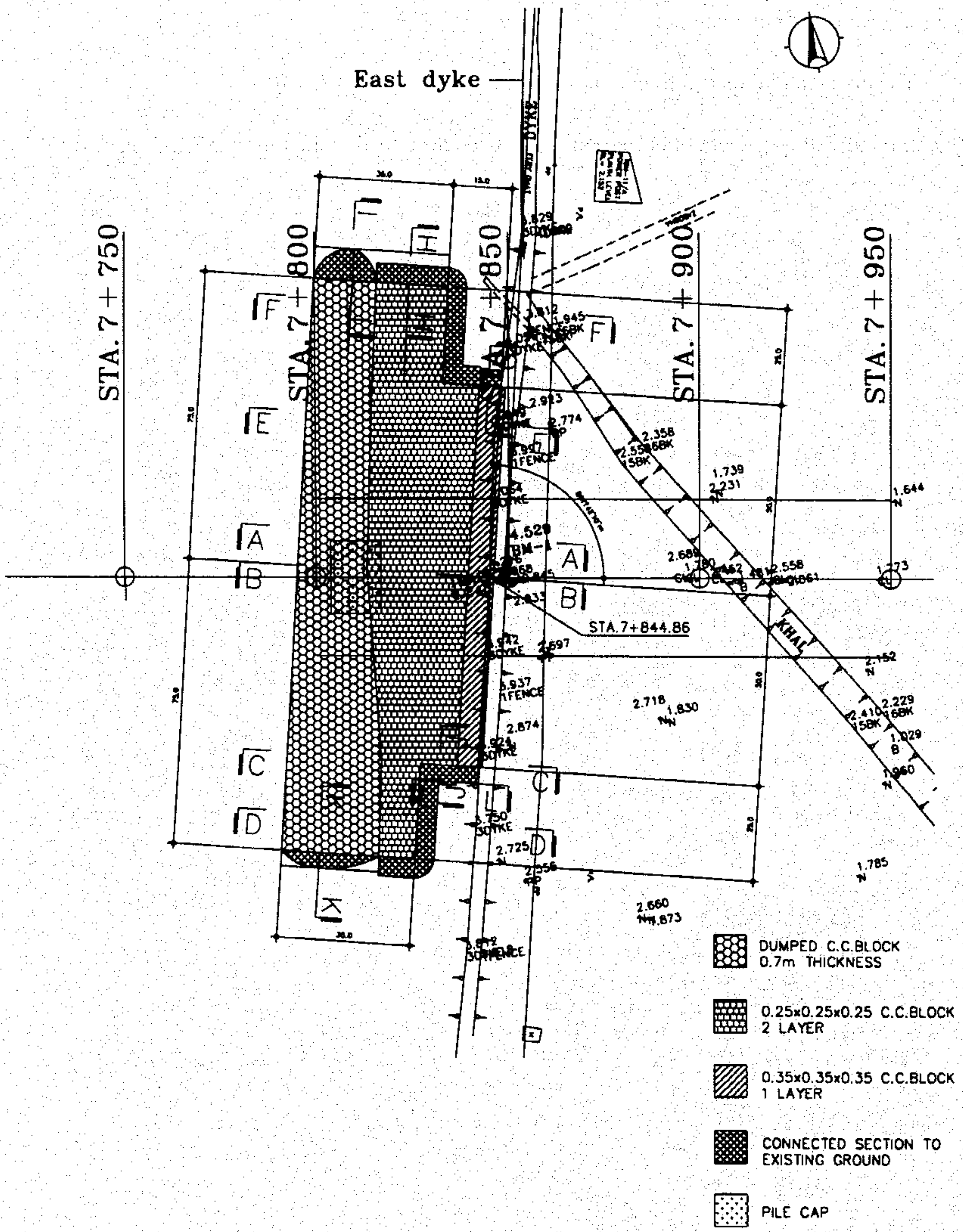


Fig. 4.4.1 Construction Area and Alignment of Revetment

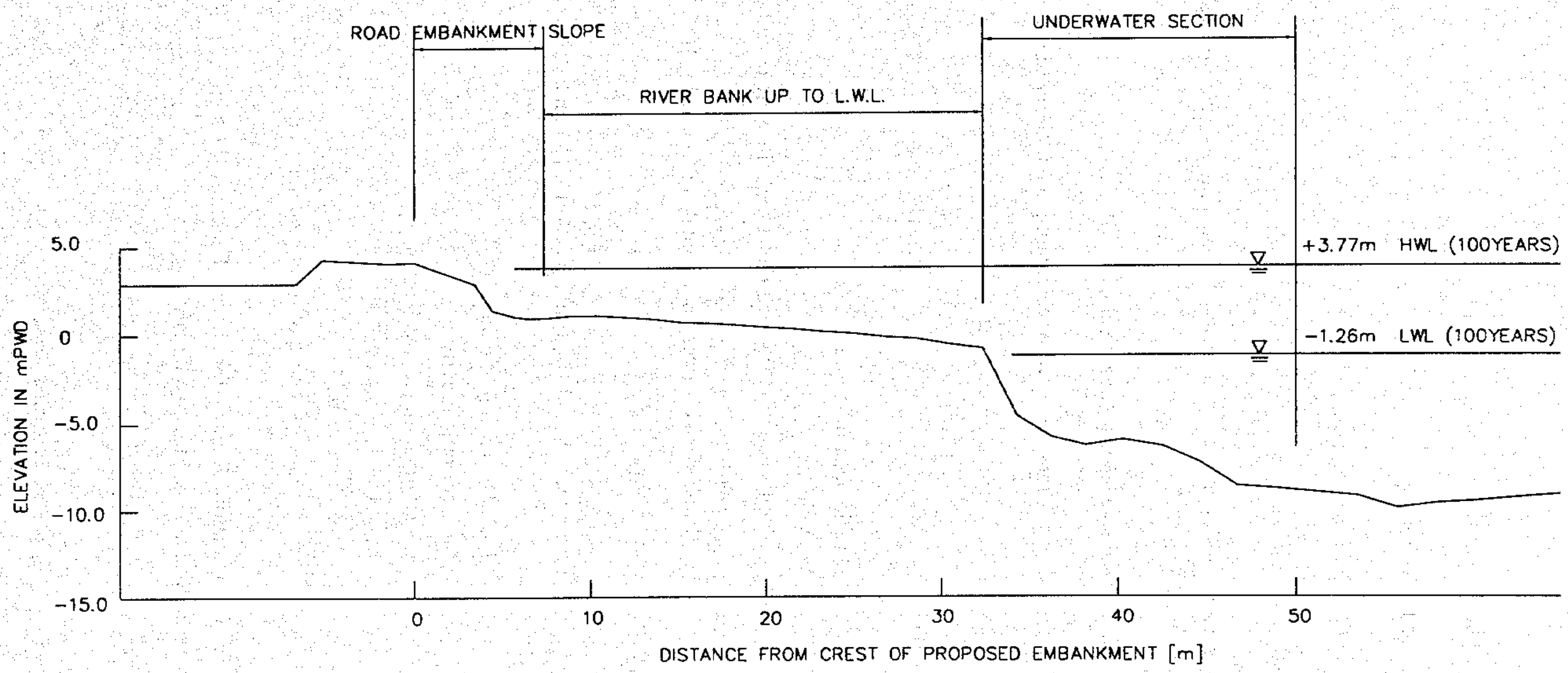


Fig. 4.4.2 The Division of Cross Section

4.4.2 Road embankment slope

4.4.2.1 Form of Protection

C.C.Blocks and Geotextile are hand placed.

4.4.2.2 Rip-Rap material size

The material size of rip-rap has been selected considering its stability against both stream velocity and waves.

1) Revetment material size against stream velocity

The following two equations are used for calculating the material size.

i) Neil

$$D = 0.034V^2$$

where,

D : Diameter of stone

V : Velocity

Note: Neil's equation fits well under the following conditions;
Specific gravity = 2.65,
Bank slopes between horizontal and vertical = 1(V) : 2 (H)

ii) JMBA

$$Dn = 0.7V^2 / (2(Sg-1)g) \times 2 / [\log(6h/D)]^2 \times 1 / [1-(\sin\theta / \sin\phi)^2]^{0.5}$$

where,

Dn : Dimension of cube

Sg : Specific gravity

g : Gravitational acceleration

h : Depth of water

θ : Slope of bank

ϕ : Angle of repose of revetment materials

(See Computation Report for River Facilities Design (2) Revetment Material Size against Stream Velocity)

The result is shown below;

	Velocity [m/s]	Slope of bank	Diameter of material [m]
Neil	2.30	1:2	0.180
	1.68	1:2	0.095
JMBA	2.30	1:2	0.206
	2.30	1:2.5	0.181
	2.30	1:3	0.170
	1.68	1:2	0.109
	1.68	1:2.5	0.096
	1.68	1:3	0.090

Note: 2.30 m/s is maximum velocity of proposed bridge cross section, 1.68 m/s is mean velocity of the cross section, which is calculated by manning equation.
(See Computation Report for River Facilities Design (5) Design Discharge)

2) Revetment material size against waves

The following equation is used for calculating the material size.

・Pilarczyk

$$D = Hs/(Sg-1) \times 1/\beta \times E^{1/2}/\cos\theta$$

where,

D : Cubic dimension
Hs : Significant wave height
Sg : Specific gravity
β : Strength coefficient, 3 for cubes and 2 for randomly dumped cubes
θ : Bank slope angle
E : Wave breaking parameter $=1.25T/Hs^{0.5} \tan\theta$
T : Wave period (sec)

(See Computation Report for River Facilities Design (3) Revetment Material Size against Waves)

The result is shown below;

Slope of bank	Diameter of material [m]
1:2	0.197
1:2.5	0.170
1:3	0.152

Comparing the size of block/stone required against velocity and waves, 250x250x250mm/250mm in diameter is recommended.

Considering possible overtopping due to wave runup and wind setup, 350x350x350mm C.C.blocks are recommended as rip-rap material of this road embankment slop section.

4.4.2.3 Rip-Rap Thickness

350x350x350mm C.C.blocks are laid on one layer.

4.4.2.4 End of revetment of upstream and downstream

C.C.blocks shall be put by minimum 1:5 slope in order to connect with non-constructed bank smoothly.

4.4.2.5 Embankment road

Revetment is constructed along the embankment. However, existing embankment is not straight so that improvement of existing embankment is needed at the same time.

In improvement of existing embankment, it is attached importance to minimize improvement scale and keep existing topography of embankment. This is why major objective is to protect bridge by construction of revetment and not to protect inland. In addition, to keep existing structure of embankment becomes easy to connect with upstream and downstream non-constructed embankment.

From above, recommended design controls of improvement of existing embankment are as follows;

1) Embankment alignment

Straight line is recommended in the same as revetment alignment.

2) Top elevation of embankment

River bed slope of the Rupsa river is almost level, therefore, top elevation of embankment should not be changed and be fixed.

The average top elevation of embankment of the construction area is about 4.2m as shown in Fig. 4.4.3. It exceeds our design H.W.L. 3.77m by 0.4m, which is estimated by frequency analysis as return period 100 year, so that 4.2m is recommended as design embankment top elevation.

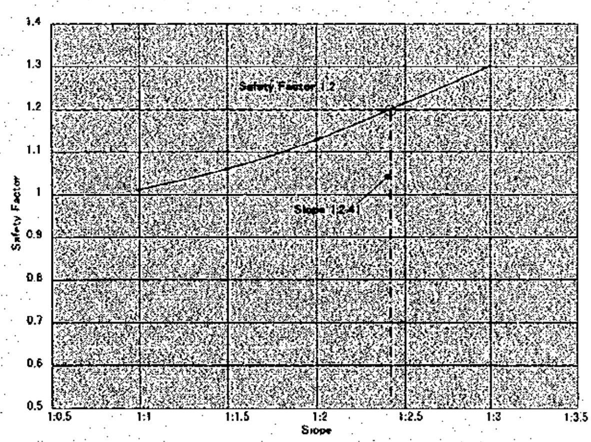
3) Top width of embankment

Existing top width of embankment is 5.2m on the average as shown in Fig. 4.4.4. It is narrower than 25ft(7.6m) of BWDB standard but is sufficiently wider than 12ft(3.7m) of local government standard. Accordingly, minimum 5.2m in width is recommended as design top width of embankment.

4) River side slope of embankment

Natural river side slope of embankment near the construction area is 1:2-2.5 (V : H) as shown in Fig. 4.4.5.

In result of slip surfaces analysis, 1:2.5 slope is safe enough to keep embankment itself after construction of revetment as shown below.



(See Computation Report for River Facilities Design (4) Slip Surface Analysis)

Considering connecting with upstream and downstream, 1:2.5 slope is recommended as design slope of embankment, which is similar to present slope.

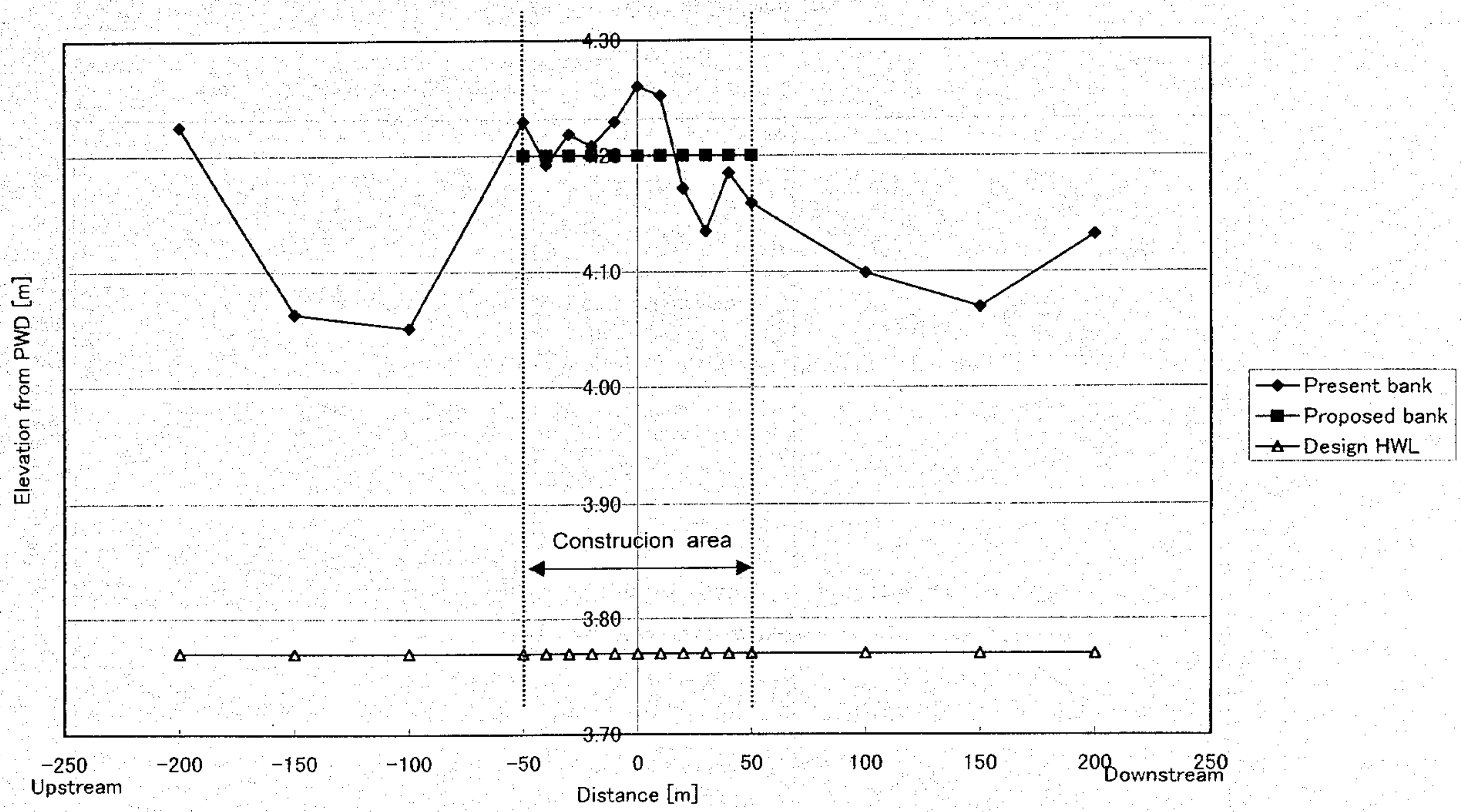


Fig. 4.4.3 Top Elevation of Embankment

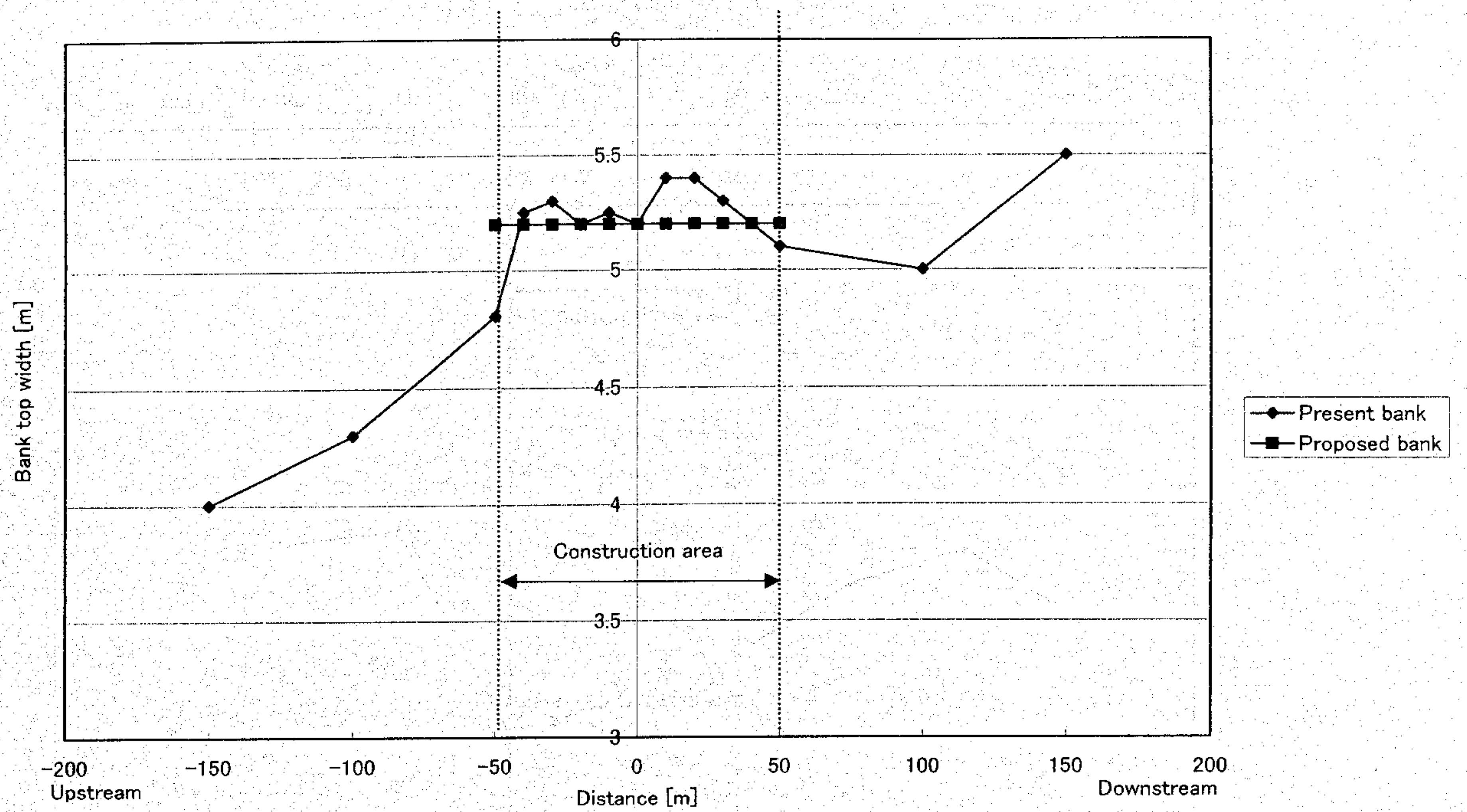


Fig. 4.4.4 Top Width of Embankment

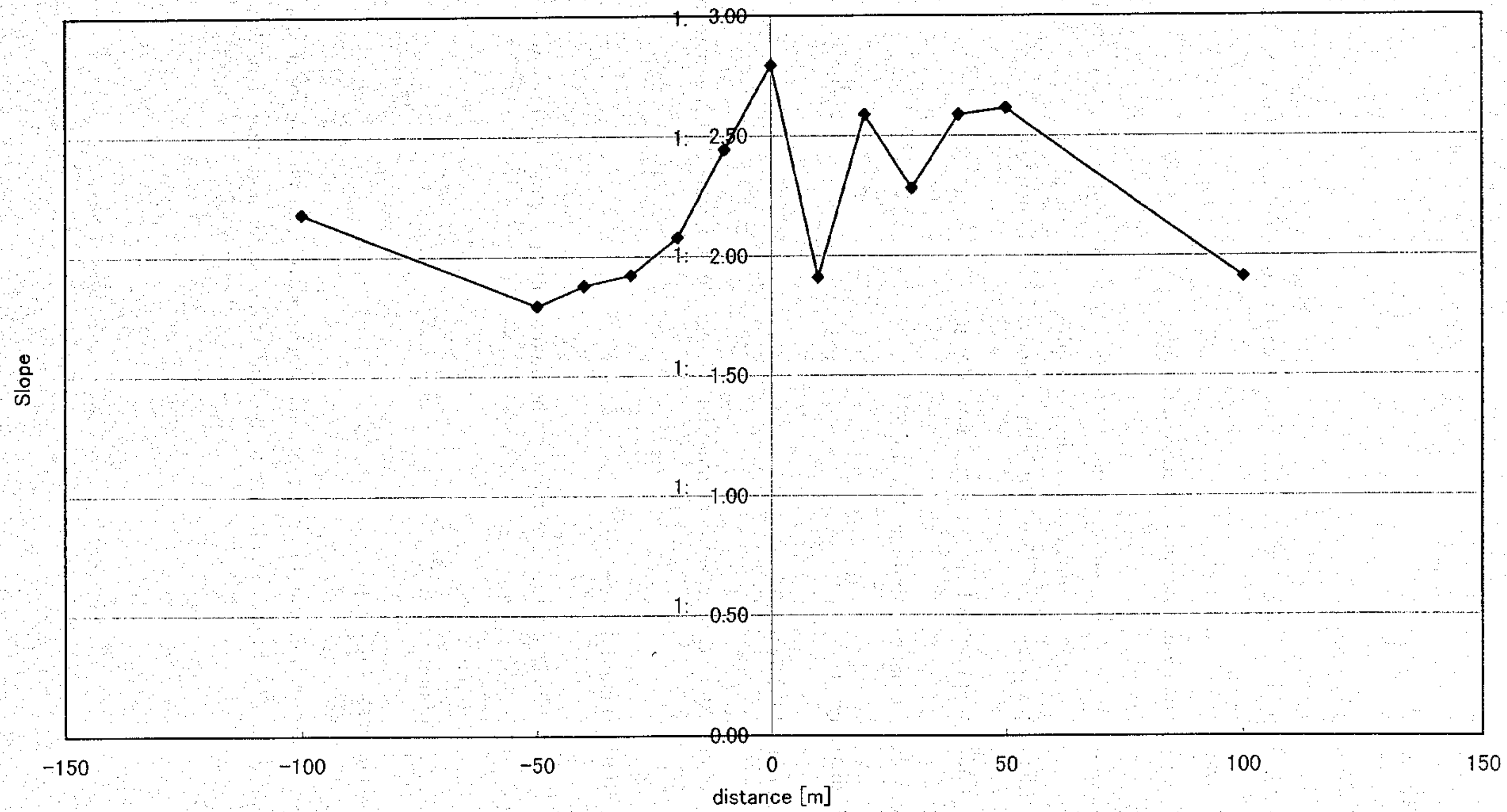


Fig. 4.4.5 Present Slope of Embankment

4.4.3 River bank up to L.W.L.

4.4.3.1 Form of Protection

This section is up to L.W.L., so that C.C.Blocks and Geotextile are able to be hand placed.

4.4.3.2 Rip-rap material size and thickness of rip-rap

This section has a role of launching apron, when underwater section is eroded possibly. In addition, this section is under water during high tide almost all the year round. Therefore, laying two layers of 250x250x250mm blocks is recommended.

4.4.3.3 End of revetment of upstream and downstream

C.C.blocks shall be put by minimum 1:5 slope.

4.4.4 Underwater section

4.4.4.1 Form of Protection

C.C.Blocks are dumped as revetment material. Geotextile is installed using bamboo framework.

4.4.4.2 Rip-rap material size

Mixed sized C.C.blocks are recommended. The mixed portion is described below.

300x300x300mm = 20%
250x250x250mm = 50%
200x200x200mm = 30%

4.4.4.3 Thickness of Rip-rap

Thickness of this section should be 2 times the thickness of road embankment slope section since the C.C.blocks shall have to be laid under water and cannot be hand placed.

4.4.4.4 End of revetment of upstream and downstream

Mixed sized C.C.blocks shall be dumped by minimum 1:2.5 slope. The mixed portion is the same of rip-rap material.

The structural drawing is shown in Fig. 4.4.6.

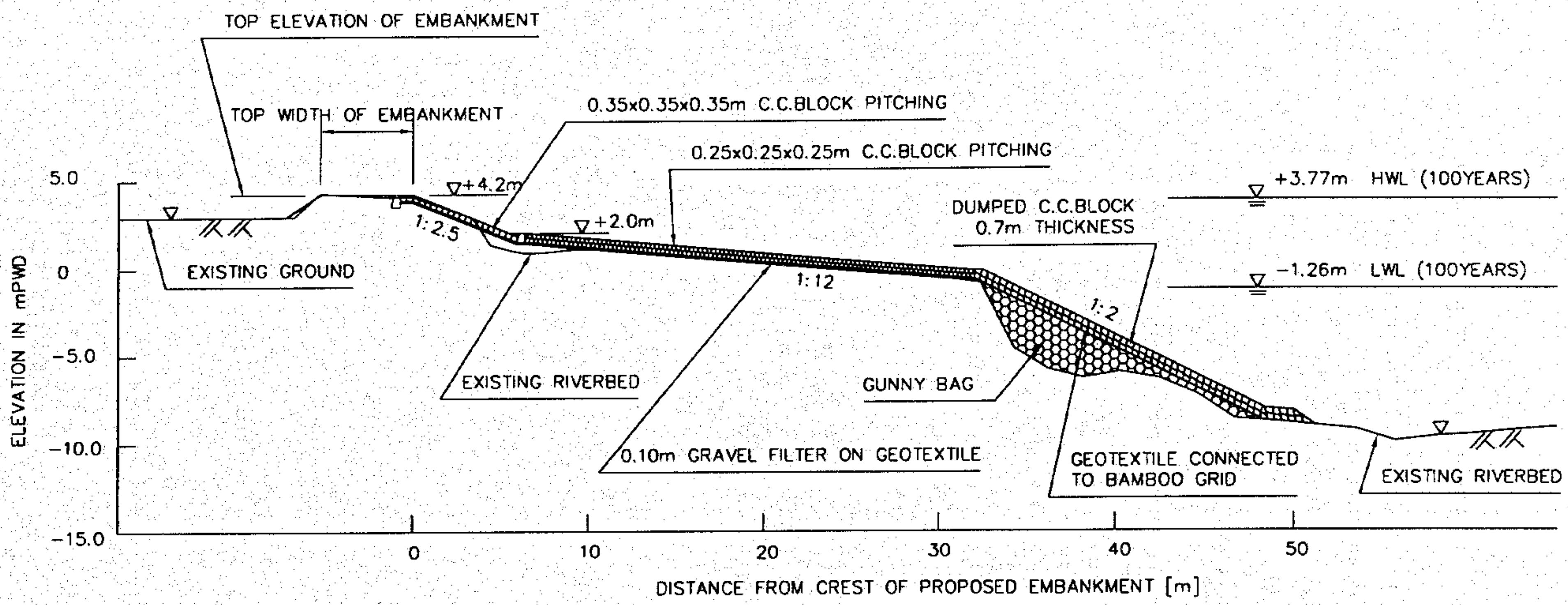


Fig. 4.4.6 Typical Cross Section of Revetment

4.5. Protection of Pier against Scouring

4.5.1 Bridge Pier Scour Depth

Pier scour depth can be determined using the following equations.

ds :The scour depth which was measured as the scour from the river bed
b :Pier width (10 m)
H :Max water depth (13 m)
V :Average velocity (2.0 m/sec)

① Ishihara's method

$$ds = (1.0 \sim 1.5)\, b = 10.0 \sim 15.0 \text{ m}$$

② Laursen's method

From figure $H/b = 13/10 = 1.3$

$ds/b = 1.6$ $\quad$ $ds = 16.0$ m

③ Ogawa's method

$$Fr = V / \sqrt{gH} = 2.0 / \sqrt{9.8 \times 13} = 0.18$$

From figure $ds/H = 0.55$

$$ds = 0.55 \times 13 = 7.2 \text{ m}$$

④ Shen's method

$$ds / H = K\left[Fr^2\left(\frac{b}{H}\right)^3\right]^{1/5} = 1.1\left[0.18^2\left(\frac{10}{13}\right)^3\right]^{1/5} = 0.47$$

$ds/H = 0.47$

$ds = 13 \times 0.47 = 6.1$ m

⑤ Tarapore's method

$$ds = 1.35b = 1.35 \times 10 = 13.5 \text{ m}$$

⑥ Murakami's method

$$ds = 1.45b = 1.45 \times 10 = 14.5 \text{ m}$$

⑦ Andru's method

$$ds/b = 0.8 \times H/b$$

$$ds = 0.8 \times 13 = 10.4 \text{ m}$$

⑧ Larras's method

$$ds = 1.05\,K \cdot b^{0.75}$$
$$= 1.05 \times 1 \times 10^{0.75} = 5.9\ \text{m}$$

⑨ Breusers's method

$$ds = 1.4 \times b = 1.4 \times 10 = 14.0\ \text{m}$$

⑩ Nail's method

$$ds/b = K(H/b)^{0.3}$$
$$= 1.0(13/10)^{0.3} = 1.08$$
$$ds = 10 \times 1.08 = 10.8\ \text{m}$$

⑪ Japan National Railway's method

$$ds/b = 1.6$$
$$ds = 1.6 \times 10 = 16.0\ \text{m}$$

From the above, maximum scour depth becomes about 16.0 m of Japan National Railway's method when the pier width is 10.0 m. Actually, three RC Bored Pile of 2.5 m diameter is constructed so that maximum scour depth becomes 8.0 m (1.6 × (2.5 × 2)=8.0 m). Therefore, 15.0 m from existing river bed should be considered as the maximum degradation of river bed, which is the value that includes 8.0 m of local scour depth by pier and 5.0 m of the natural degradation of river bed.

4.5.2 Protection Works

Protection Works shall be conducted for all piers in the river except the pier of the eastern end in the river, which is situated in the revetment area and shall be protected by revetment.

4.5.2.1 Protection Works for MP2 Pier

MP2 pier is western-most of the piers constructed in the river.

1) Form of Protection

The area around MP2 pier is up to L.W.L., so that C.C.Blocks and Geotextile are able to be hand placed.

2) Rip-rap material size and thickness of rip-rap

This area is under water during high tide almost all the year round. Therefore, laying two layers of 250x250x250mm blocks is recommended.

4.5.2.2 Protection Works for MP3-6 Piers

1) Form of Protection

C.C.Blocks shall be dumped.

2) Size of C.C.Block

Mixed sized C.C.blocks are recommended. The mixed portion is described below.

300x300x300mm = 20%
250x250x250mm = 50%
200x200x200mm = 30%

3) Thickness of C.C.Block

Thickness of protection of piers is recommended as the same thickness, 0.7m, of underwater section of revetment since the C.C.blocks shall have to be dumped.

The structural drawing is shown in Fig. 4.5.1-2.

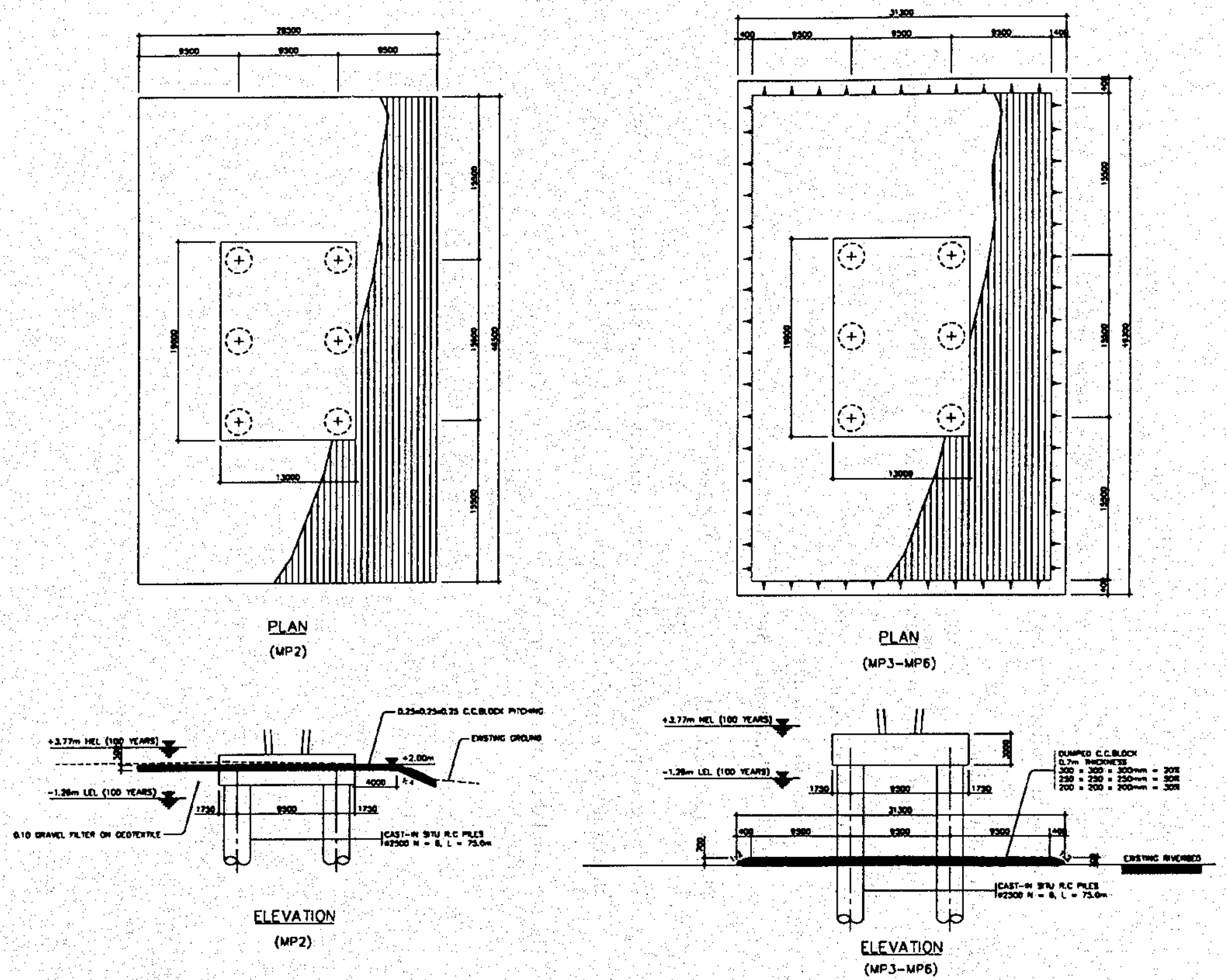


Fig. 4.5.1 Protection of Pier against Scouring

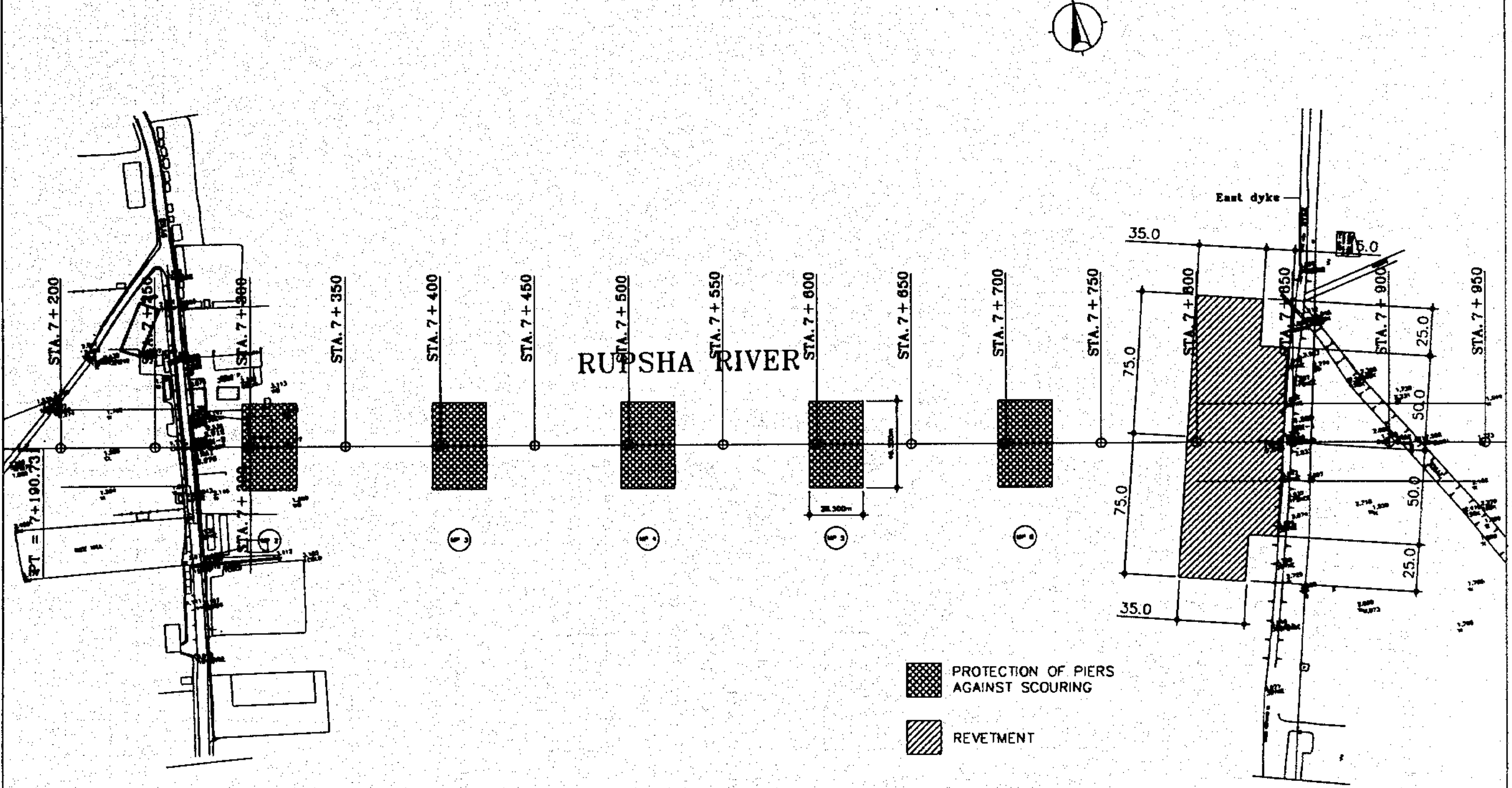


Fig. 4.5.2 Plan of Protection of Piers

4.6 Computation for River Facilities Design

(1) **Revetment length** (Refer to how to deside G.B. length)

after Andreev

Total Upstream Length of G.B./Total Waterway Opening = 0.15

Total Waterway Opening by Lacey's regime equation

$Pw = 4.75 \times Qd^{(1/2)}$

Pw : Required waterway opening (m)

Qd : Dominant discharge (m3/s)

Qd	Pw	Total upstream length [m]
9763.9	469.4	70.4
7169.4	402.2	60.3

Required total length

= Total upstream length × 2

Qd	Total length [m]
9763.9	140.8
8993.2	120.7

(2) **Revetment Material Size against Stream Velocity**

by Neil's equation

$D = 0.034V^2$

D : Diameter of stone (m)

V : Velocity against Stone (m/s)

V	D
2.300	0.180
1.675	0.095

by JMBA's equation

$Dn = 0.7 \times V^2/(2(Sg-1)g) \times 2/(\log(6h/D))^2 \times 1/(1-(\sin\theta/\sin\phi)^2)^{0.5}$

Dn : Dimension of cube (m)

V : Mean velocity in the adjacent channel (m/s)

Sg : Specific gravity

g : Gravitational acceleration (m/s2)

h : Depth of water (m)

θ : Slope of bank (degree)

ϕ : Angle of repose of revetment materials (degree)

V	Sg	g	h/D	θ	(in slope)	ϕ	Dn	D
2.30	2.446	9.81	5	26.57	(1:2)	40	0.167	0.206
2.30	2.446	9.81	5	21.80	(1:2.5)	40	0.147	0.181
2.30	2.446	9.81	5	18.43	(1:3)	40	0.137	0.170

1.68	2.446	9.81	5	26.57	(1:2)	40	0.088	0.109
1.68	2.446	9.81	5	21.80	(1:2.5)	40	0.078	0.096
1.68	2.446	9.81	5	18.43	(1:3)	40	0.073	0.090

(3) **Revetment Material Size against Waves**

The governing factor for determing the rip-rap size against wave action is the wave height and wave period. The wave height and wave period have been determined from the wave forecasting curve (Fig. R1).

Wave forecasting factors are:

gd/u^2 and gF/u^2

g : Acceleration due to gravity

d : Average depth of water in ft.

F : Fetch in feet

u : Wind velocity in ft./sec = 12.8 m/sec = 42.0 ft/sec

* 12.8 m/sec is maximum monthly mean wind velocity (period 1988-1999) in Khulna

gd/u^2

g [ft/sec2]	d [ft]	u [ft/sec]	gd/u^2
32.18	42.64	42.0	0.778

gF/u^2

g [ft/sec2]	F [ft]	u [ft/sec]	gF/u^2
32.18	6560	42.0	119.8

Using curve of Fig. R1

gH/u^2 = 0.036 (a)

Lg/(2 π) × u^2 = 0.060 (b)

H : Wave height in ft.

L : Wave length in ft.

From Eq. (a)

H = 1.97 ft = 0.60 m

From Eq. (b)

L = 20.65 ft

Time for generateing wave :

T^2 = 2 π × L / (g × tanh(2 π × d/L)) = 4.03

T = 2.01 sec

T : Wave period (sec)

E = 1.25 × T/Hs^(1/2) × tan θ

E : Wave breaking parameter

θ : Bank slope angle (degree)

T	Hs	θ	(in slope)	E
2.01	0.60	26.57	(1:2)	1.62
2.01	0.60	21.80	(1:2.5)	1.29
2.01	0.60	18.43	(1:3)	1.08

Using Pilarcyzyk Equation

$D = Hs/(Sg-1) \times 1/\beta \times E^{(1/2)}/\cos\theta$

D : Cubic dimension (m)

Hs : Significant wave height (m)

Sg : Specific gravity

β : Strength coefficient, 3 for cubes and 2 for randomly dumped cubes

Sg	β	θ	(in slope)	E	D
2.446	3	26.57	(1:2)	1.62	0.197
2.446	3	21.80	(1:2.5)	1.29	0.170
2.446	3	18.43	(1:3)	1.08	0.152

(4) **Slip Surface Analysis**

The analysis was conducted by using following equation.

$Fs = R\times \Sigma(C\times l+W'\times\cos\alpha \tan\phi) / (\Sigma(W\times X)+\Sigma(Q\times a))$

$= \Sigma(C\times b+W'\times(\cos\alpha)^2\times\tan\phi)\sec\alpha \;/\; (\Sigma W\sin\alpha+(1/R)\times\Sigma(H\times a))$

Fs : Safety factor

R : Radius of slip circle (m)

C : Cohesion of soil (ton/m2)

ϕ : Angle of friction of soil (degree)

l : Base length of partial solid (m)

b : Width of partial solid (m)

W' : Effective weight of partial solid (ton/m)

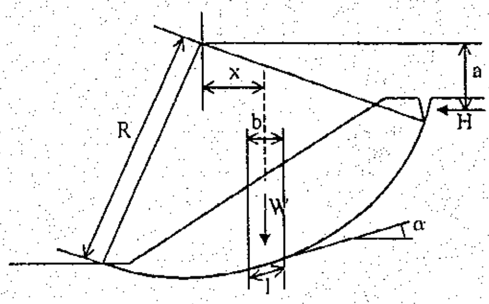
W : Weight of partial solid (ton/m)

α : Inclination of base of partial solid (degree)

X : Horizontal distance between the center of slip circle and the center of gravity of partial solid (m)

H : Horizontal external force

a : Distance between H and the center of slip circle (m)



Slope	γ [tf/m3]	C	ϕ	Fs
1:2	1.765	1.2	0	1.011
1:1.5	1.765	1.2	0	1.06
1:2	1.765	1.2	0	1.128
1:3	1.765	1.2	0	1.302

γ : Unit weight of soil

(5) **Design Discharge**

$Q = A \times V$

Q : Discharge (m3/sec)
A : Area (m2)
V : Velocity (m/sec)

A = 5827.7 in water level 3.77 mPWD
4645.8 in water level 1.00 mPWD

$V = (1/n) \times R^{(2/3)} \times I^{(1/2)}$ by Manning equation

n : Coefficient of roughness
R : Hydraulic radius (m) = A/S
I : Energy gradient
S : Wetted perimeter (m)

S = 580.54 in water level 3.77 mPWD
523.55 in water level 1.00 mPWD

Water Level [mPWD]	A	n	S	R	I	V	Q
3.77	5827.7	0.018	580.54	10.04	4.2E-05	1.68	9763.9
1.00	4645.8	0.018	523.55	8.87	4.2E-05	1.54	7169.4

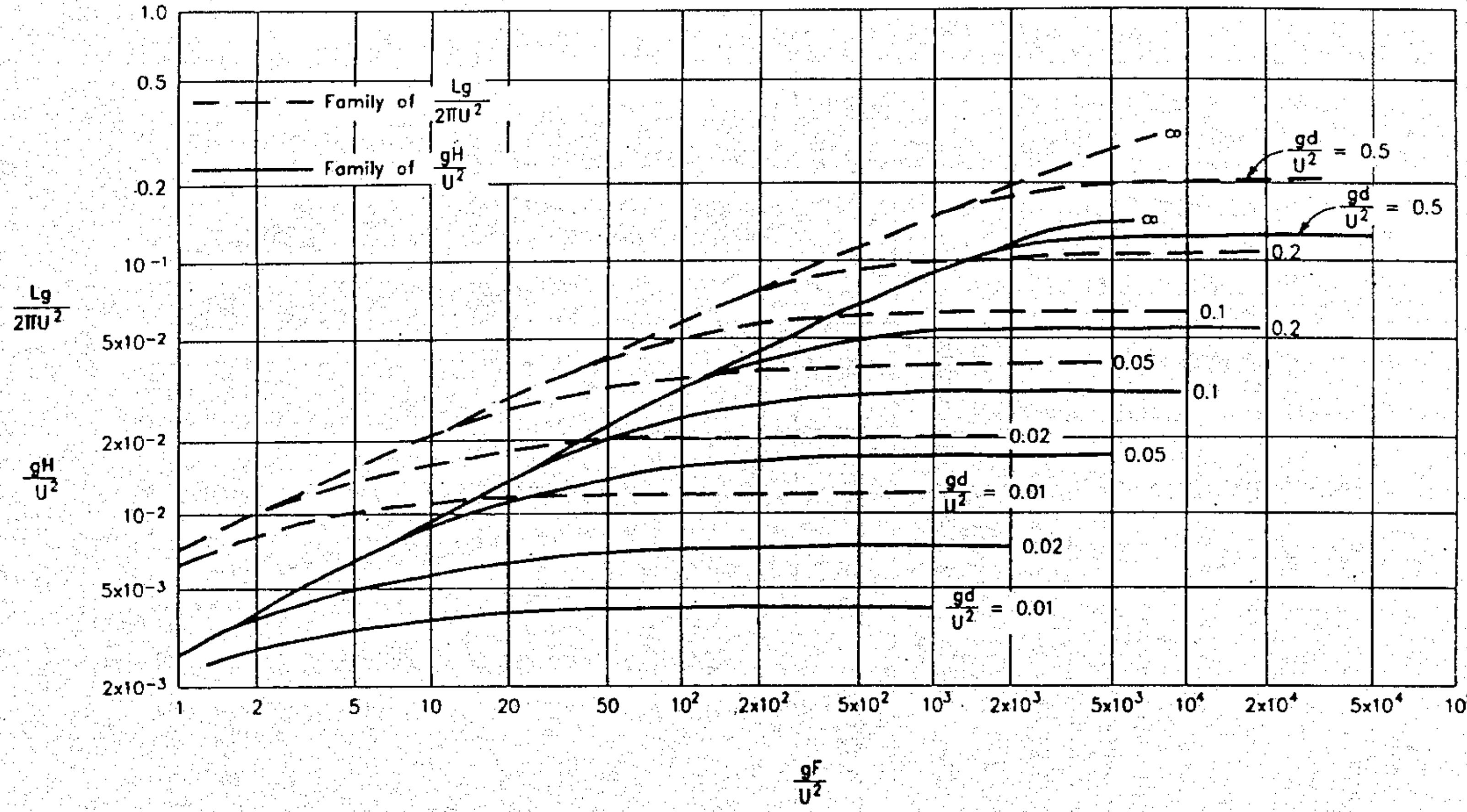


Fig. R1 Growth of Waves in a Limited Depth

Source : United States Army Coastal Engineering Research Center, Technical Report No. 4

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