4.2.6 Engineering Properties of Soils

Engineering properties of the soils encountered are discussed in this section. Majority of the samples tested were selected from the surface very soft to soft silty soil because this layer is weakest and most compressible.

1) Very Soft to Soft Silty and Clayey Soils Layer

There is clear differences in the engineering properties between soil with organic matter and inorganic soil as shown below :

Table 4.2.5

item	Organic	Inorganic
Moisture content (%)	50 to 197	28 to 57
Liquid limit (%)	59 to 131	26 to 67
Plastic limit (%)	29 to 54	22 to 34
Plasticity index (%)	30 to 77	9 to 35
Specific gravity	2.22 to 2.65	2.67 to 2.72
Wet density (kN/m^3)	11.3 to 16.7	17.4 to 19.6
Soil clasfication	OH and CH	ML and CL
Sand content (%)	0 to 1	0 to 14
Silt content (%)	32 to 69	69 to 80
Clay content (%)	31 to 76	13 to 31
Void ratio	1.18 to 4.81	0.85 to 1.09

Undrained shear strength of silty and clayey soils was determined by the unconfined compression test. The undrained shear strengths for the each type of soil are as follow :

Soil with organic matter	·······	18 and 21.5 kPa
Inorganic soil	·······	11 to 58 kPa

Figures 4.2.7 through 4.2.9 show the consolidation test results for the each type of soil. Compression index varies from 0.447 to 3.48 and from 0.152 to 0.310, for the organic and inorganic soils, respectively. The results show that the organic soil is more compressible than the organic soil.

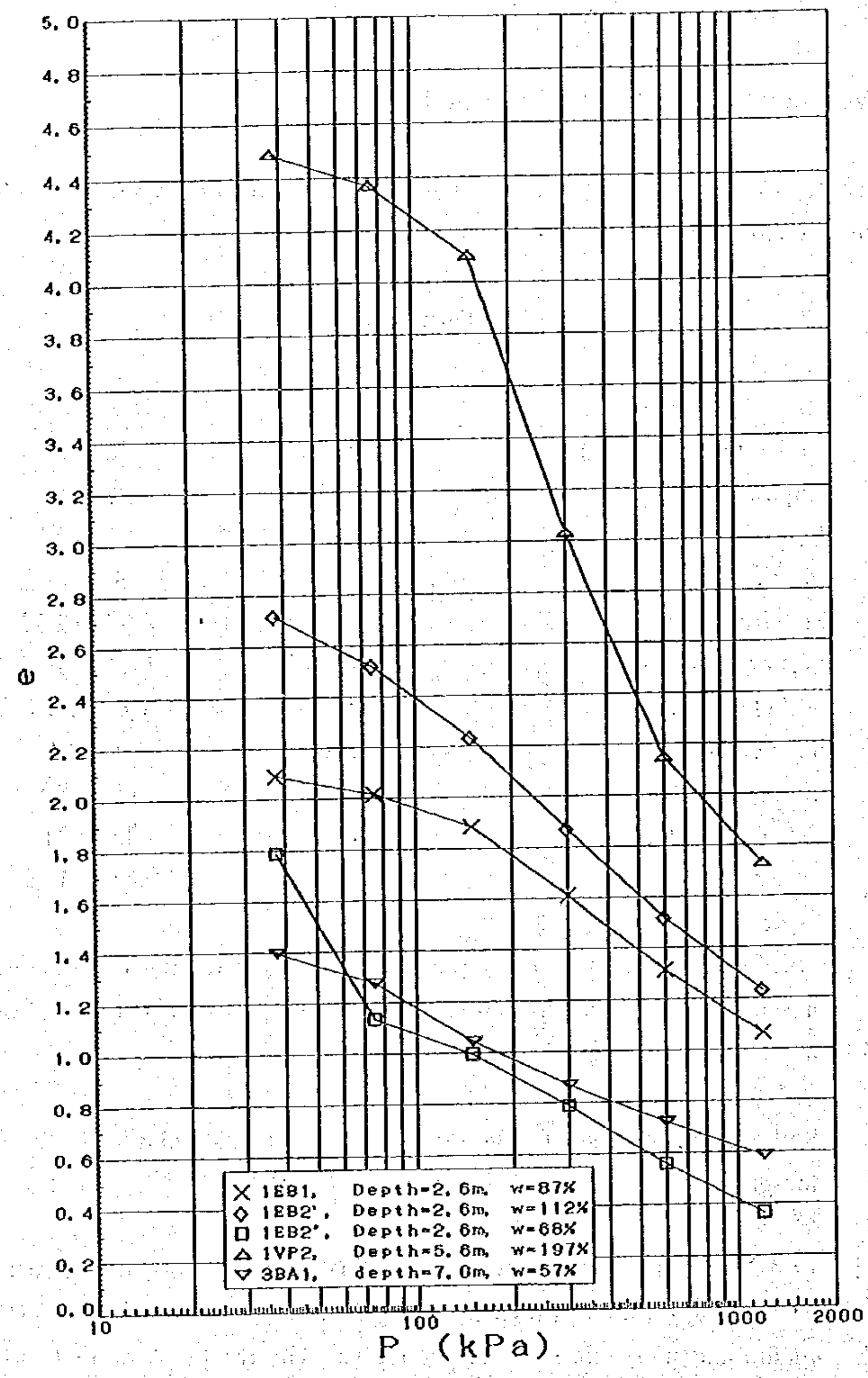


Fig. 4.2.7 e-Log P Curves for Soils with Organic Matter

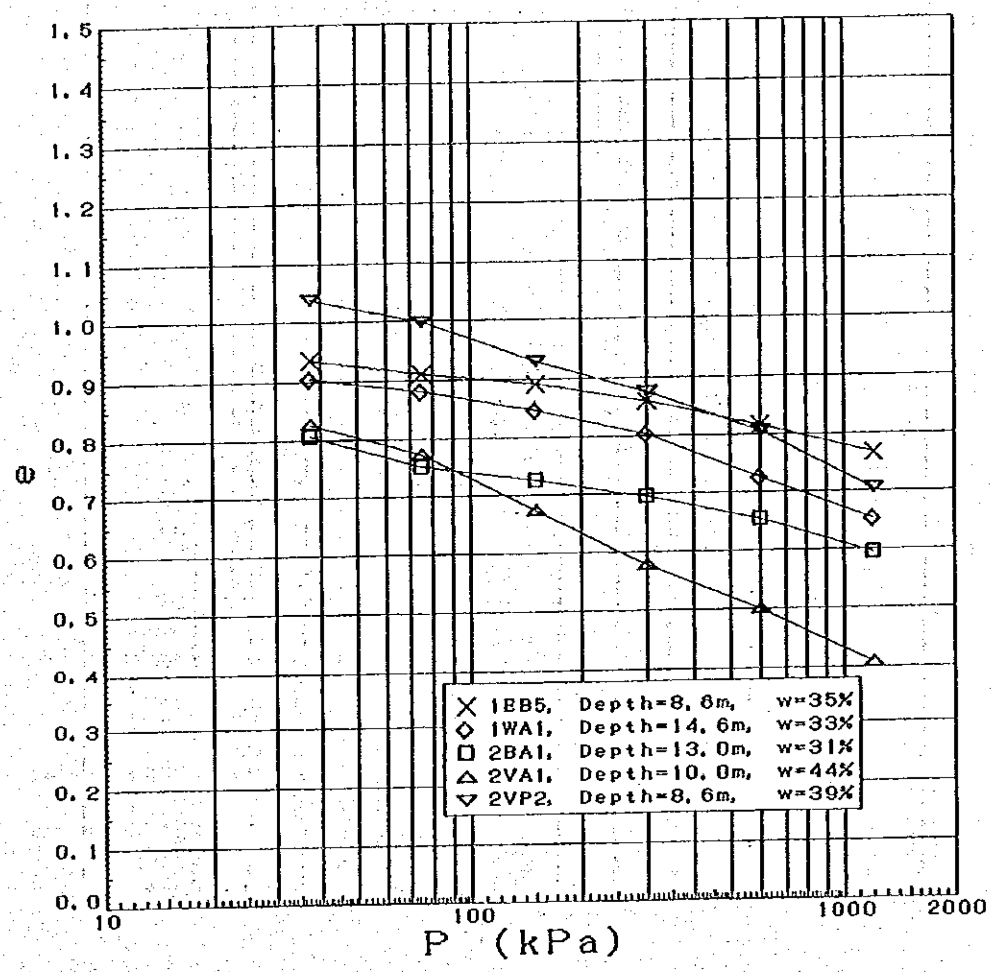


Fig. 4.2.8 e-Log P Curves for Inorganic Soil Obtained from Shallow Depth

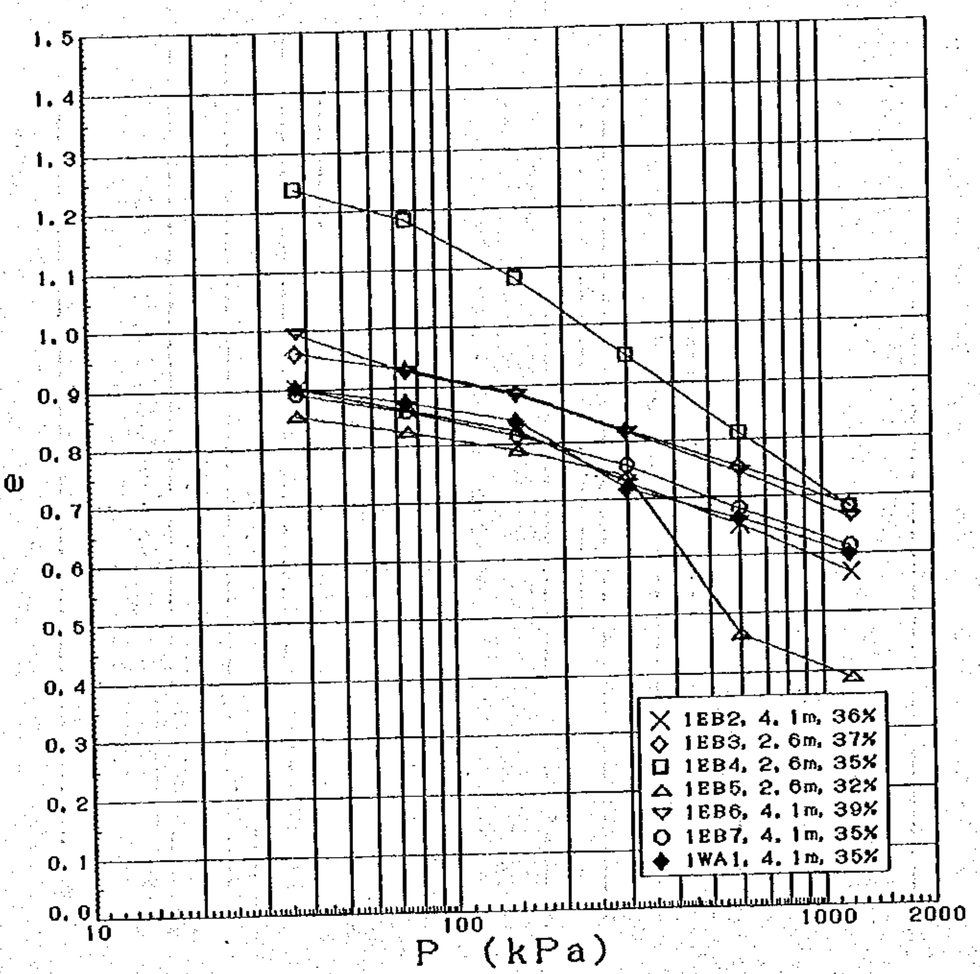


Fig. 4.2.9 e-Log P Curves for Inorganic Soil Obtained from Deep Depth

Table 4.2.6 shows the chemical properties and loss of ignition of the soils with organic matter. The chemical test results show that soils are not aggressive to concrete.

Table 4.2.6 Results of Chemical and Loss of Ignion Tests on Soil with Organic Matter

Borehole No.	Sampling Depth (m)	pH	Cloride (%)	Total Sulphate as SO_3 (%)	Water soluble sulphate as SO_3 (%)	Loss of Ignition (%)
IVA1	3 to 3.45	5.8	0.07	0.18	–	6.23
IA1	3 to 3.45	5.5	0.09	0.16	–	8.28
IEB1	2.55 to 3.0	6.8	–	0.090	0.058	8.66
	4.5 to 4.95	–	0.07	–	–	–
IEB2'	1.5 to 1.95	5.7	0.07	0.17	–	10.3
IVP2	5.4 to 6.0	5.8	–	0.126	0.079	10.82
3BA1	7.0 to 7.45	6.5	–	0.101	0.063	0.075

2) Medium Stiff to Hard Silty and Clayey Soils Layers

Only few tests were carried out on the samples obtained from this layer. Index properties of the medium stiff to hard silty and clayey soils fall within the rages of values shown for the inorganic soil in the very soft to soft soil layer.

3) Sandy Soil Layers

The sandy soil classified to silty fine sand. Content of sand varies from 54 to 88 %. Renges of other index properties are as follow :

Moisture content : 20 to 33 %
Specific gravity : 2.67 to 2.73

4.2.7 Engineering Properties of Bulk Soil Samples

The bulk soil sampling was carried out at 7 locations along the Route 1 to determine engineering properties of possible borrow materials. A total of three samples were taken from the east river bank of the Rupsa River (near BH1BA2) and the same number of the samples were taken from paddy around BH1EB4. One sand sample was also taken from the river bed of the Rupsa River which is 148m away from BH1BA1.

Table 4.2.7 Summary of Material Tests on Bulk Soil Samples

	Rupsa River Bank	Raddy	Rupsa River Bed
Liquid limit (%)	36 to 44	48 to 63	NP
Plastic limit (%)	22 to 26	23 to 24	NP
Plasticity index (%)	14 to 18	24 to 25	NP
Specific gravity	2.71	2.72	2.72
Sand content (%)	2	0	90
Silt content (%)	80	62 and 63	10 (silt and clay)
Clay content (%)	18	37 and 38	
Soil classification	A-6 and A-7-6	A-7-6	A-3
pH	8.2	6.8	—
Clolide content (%)	0.048	0.014	—
CBR * (%)	4 to 11	2 to 4	19
Optimum moisutre content by 2.5kg method (%)	18 to 19	18 to 21	21
Max.Dry density by 2.5kg method (kN/m^3)	16.9	16.3 to 16.7	15.3
Optimum moisture content by 4.5kg methd (%)	15	14 to 16	17
Max.Dry density by 4.5kg method (kN/m^3)	18.2	17.8 to 18.4	16.10

* CBR-value at 95% max. dry density determined by 4.5kg rummer method

Silty soils taken from the paddy and river bank are classified to A-6 and A-7-6 in accordance with AASHTO soil classification system and show low CBR-values. These materials may be able to be used only for the road embankment. The silty and clayly soils with organic matter mentioned in the previous subsection may be encountered beneath these silty materials at most part of land area. These organic soils can not be used as embankment material.

Sand taken from the river bed is classified to A-3 and shows a relatively good CBR-value. This matial can be used for the embankment.

4.2.8 Results of Material Tests on Aggregates

1) Coarse Aggregate

Coarse aggregates, size 20mm and 50mm are subjected to sieving test, chemical tests and Los Angeles abrasion test. Source of these aggregates are brick and hard boulder stone. Test results are tabulated in Tables 4.2.8 through 4.2.10.

Table 4.2.8 Abrassion Values and Chemical Properties 20mm and 50mm Aggregates

	Brick Chip	Stone Chip
Abrassion value (%)	29 and 39	20 and 28
pH	7.2 and 7.8	7.6 and 7.8
Clolide content (%)	0.027 and 0.031	0.014 and 0.017

Table 4.2.9 Grading of 20mm Aggregate

	Passing Persent	
Sieve Size (mm)	Brick Chip (%)	Stone Chip (%)
25	10	100
19	82	67
9.5	14	1
75	6	0
2.36	4	0

Table 4.2.10 Grading of 50mm Aggregate

Sieve Size (mm)	Passing Persent	
	Brick Chip (%)	Stone Chip (%)
63	100	95
50	86	82
25	60	0
12.5	1	0
4.75	1	0

2) Fine Aggregate

Brown medium to coarse sand yieled in Sylhet was subjected to the sieving test. Sylhet is only one source of good natural fine aggregate for civil work in Bangladesh. Sand content and fine modulus are 99% and 2.55, respectively.

3) Alkali-Silika Reaction of Aggregates

The Sylhet sand and five coarse aggregates with different rock type were subjected to the Alkali-Silika Reaction test. Types of rock are purpl granite, pink granite basalt, geneis and mudstone. The test were carried out in accordance with ASTM C-289-94. Relationship with amount of reduction in alkalinity and amount of dissolved silica for the each aggregate shows that potential reactivity of all the tested aggregates are considered to be innocuous.

4.2.9 Settlement and Stability of Embankment

4.2.9.1 Consolidation Settlement

Consolidation settlement of the surface soft ground (silt and clay) was studied for the road embankment.

(1) Magnitude of Settlement

Table 4.2.11 shows the settlements estimated at various points along the project road. The magnitude of settlement varies from about 0.1 to 0.8 m for the road fill height of 2.0 to 6.0 m.

Table 4.2.11 Magnitude of Consolidation Settlement

Location	Settlement (cm)	* Fill Height (m)
STA 0 to STA 2+000	37	3.0
STA 2+000 to Hatia West Bank	37	3.0
Hatia East Bank to STA 3+700	27	2.3
STA 3+700 to STA 5+400	38	3.7
STA 5+400 to STA 6+500	44	4.4
STA 6+500 to Rupsa West Bank	38	3.7
Rupsa East Bank to STA 8+900	38	2.7
STA 8+900 to STA9+900	31	4.0
STA 9+900 to Molonghata	22	4.0
Molonghata to End	19	2.8
West Access Road (Hatia Side)	12	2.6
West Access Road (Rupsa Side)	30	2.6
East Access Road	13	2.0
Hatia Bridge West Approach	66	6.0
Hatia Bridge East Approach	49	5.8
Rupsa Bridge West Approach	79	6.5
Rupsa Bridge East Approach	77	6.5
Molonghata Bridge Approaches	26	4.8

* Fill Height ≒ Design height + Settlement

The following equation is used to estimate consolidation settlement:

$$Sc = \sum_{i=1}^{n} (e_0 - e_1 / 1 + e_0) Hi$$

where Sc = primary consolidation settlement (m)

e_0 = initial void ratio at initial effective overburden pressure

e_1 = final void ratio at final effective overburden pressure

Hi = thickness of silty or clayey soil layer (m)

n = number of layers

Inputting data to the above equation is taken by averaging the data of two adjacent soil borings of each location. Ground analysis model of each location is presented in Figure 1 through 19 in Appendix 4.2.9 A. The wet density of soil is estimated from Fig.4.2.10; and void ratio is estimated from e-logP curves shown in Fig.4.2.11 through 4.2.13 which are established by consolidation tests. To determine the input data, sampling depth, soil classification, moisture content, SPT (Standard Penetration Test) result are taken into acount. Details of the estimation are shown in the tables "Settlement Calculation Sheet" in Appendix 4.2.9 B.

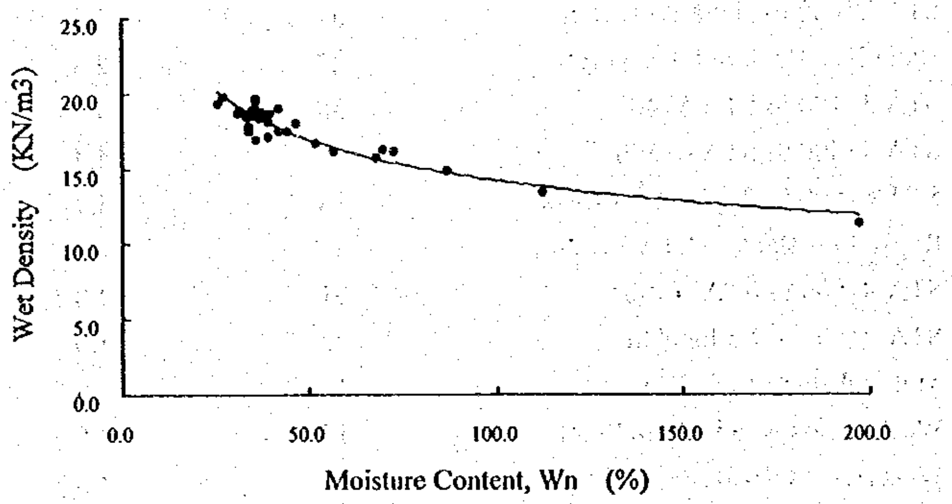


Fig. 4.2.10 Wet Density VS. Moisture Content

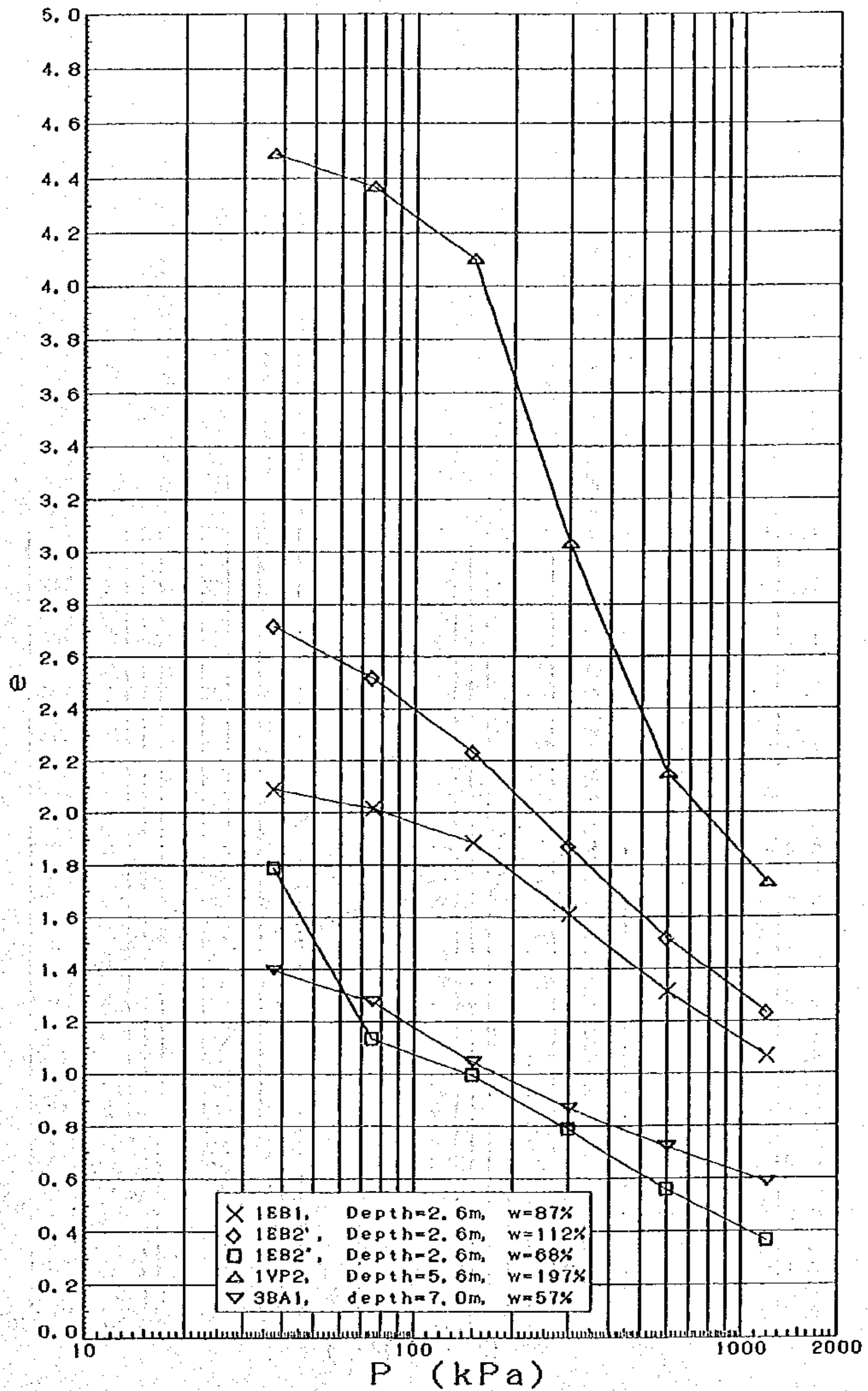


Fig. 4.2.11 e-Log P Curves of Soils with Organic Matter

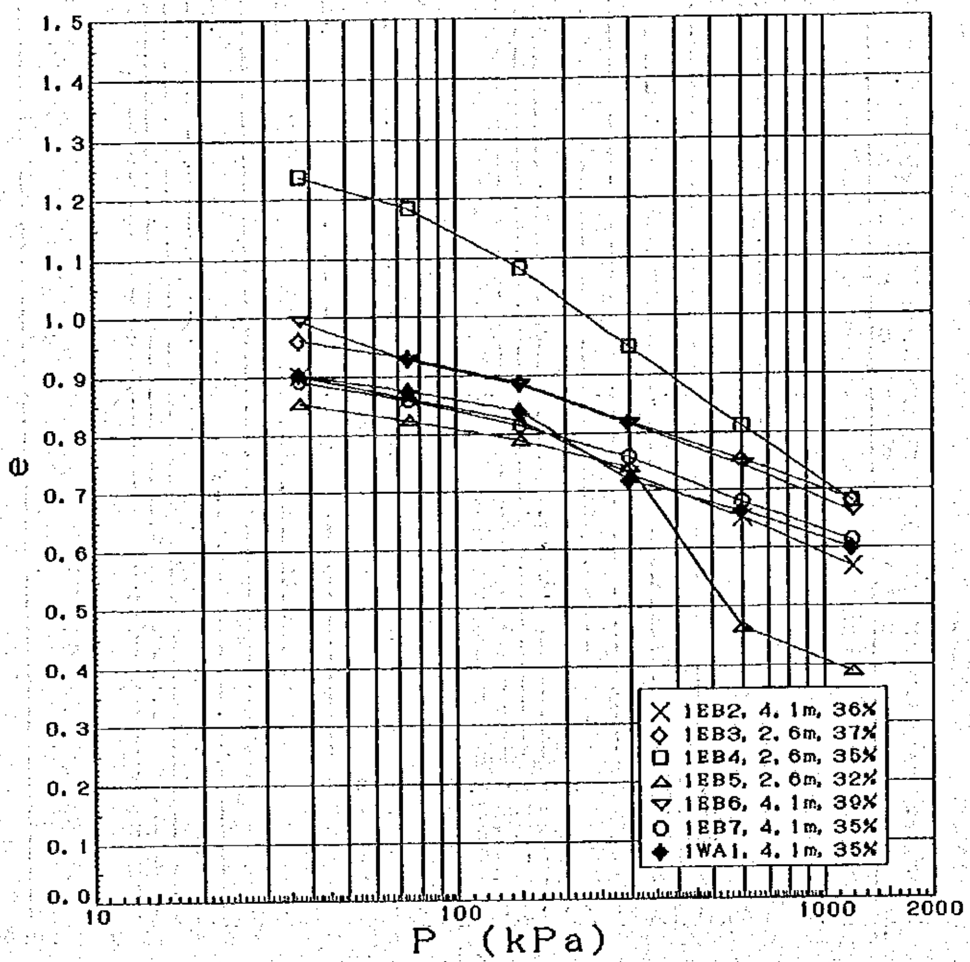


Fig. 4.2.12 e-Log P Curves of Soils without Organic Matter (1/2)

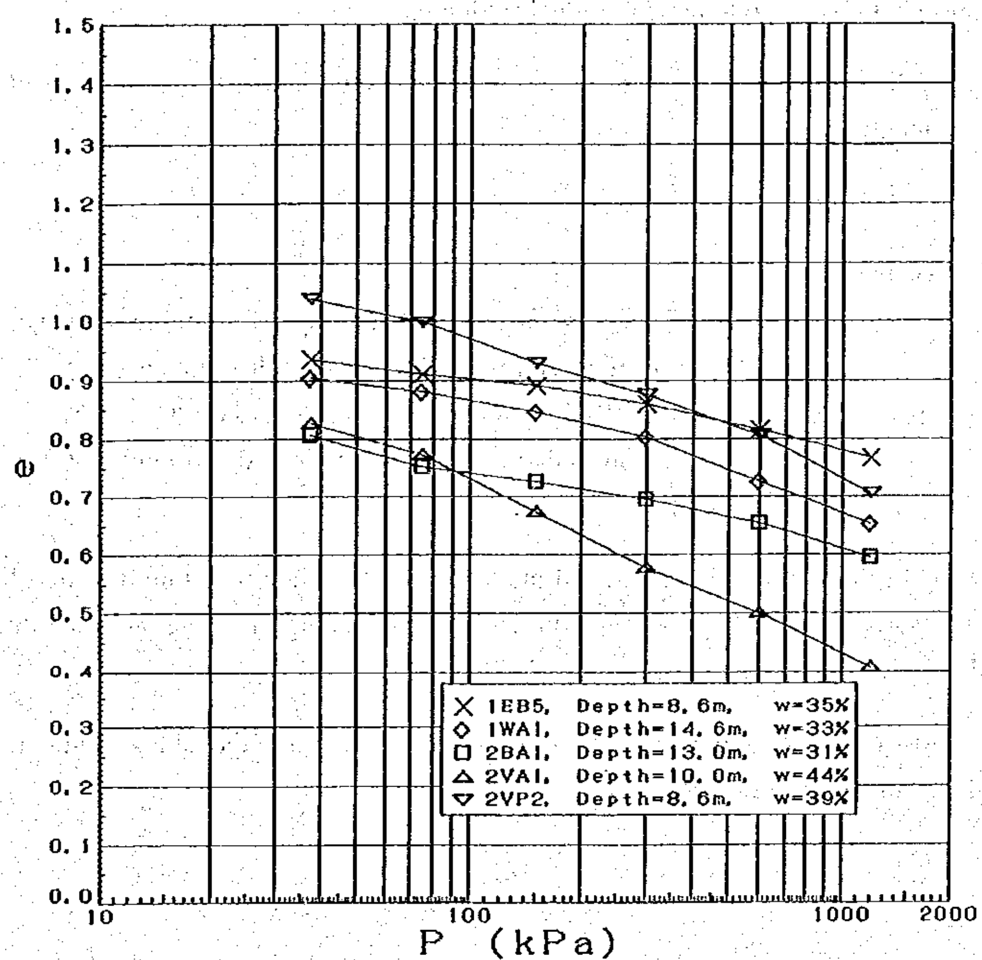


Fig. 4.2.13 e-Log P Curves of Soils without Organic Matter (2/2)

(2) Time for Settlement

Rate of consolidation settlement depends on the permeability of soil and the distance drainage path. Most of the settlements shown in Table 4.2.11 are expected to be developed within 5 years after completion of road fill and the residual settlement at 2 years will be 1 to 22 cm. Large residual settlement is expected at the following location:

- Road section of STA 0+00 and STA 2+000, about 17 cm
- West approach of Hatia Bridge, about 22 cm

In case of the west approach of Hatia Bridge where residual settlement is estimated rather large, maintenance will be necessary in future to correct the differential settlement between the approach fill and the bridge abutment. For the above location, the use of sand mat of about 50 cm in thickness is recommended to facilitate consolidation and so to lessen residual settlement.

The following equation is used to estimate time required for the consolidation settlement;

$$t = d^2 T_v / C_v$$

where t = time (day)

d = half of thickness of consolidation layer for double drainage, or full thickness of consolidation layer for single drainage (cm)

C_v = vertical coefficient of consolidation (cm²/day)

T_v = vertical consolidation time coefficient determined by Terzaghi's formula

The C_v–values shown in the ground models are determined based on the consolidation test results of Fig.4.2.14 thorough 4.2.16. In calculating (T_v), the modified thickness (d') is used to correct the difference of value in layers.

Progress of the settlement at each location is summarized in the tables "Settlement VS. Time," in Appendix 4.2.9 B.

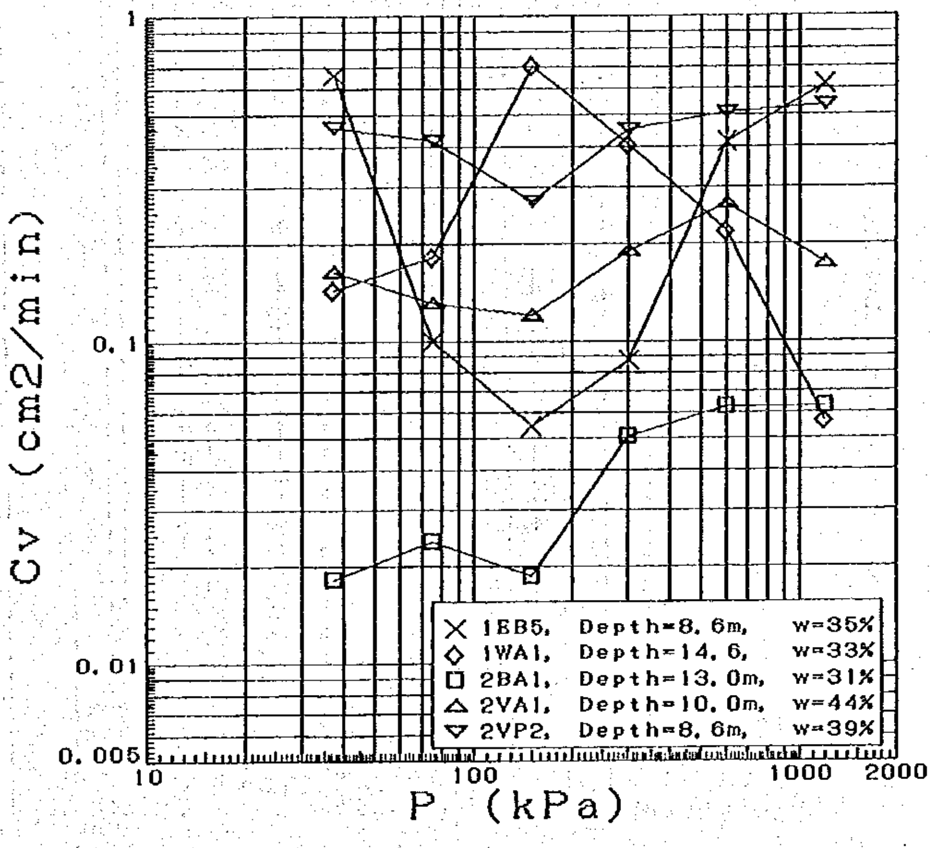


Fig. 4.2.14 log Cv - log P Curves of Soils with Organic Matter

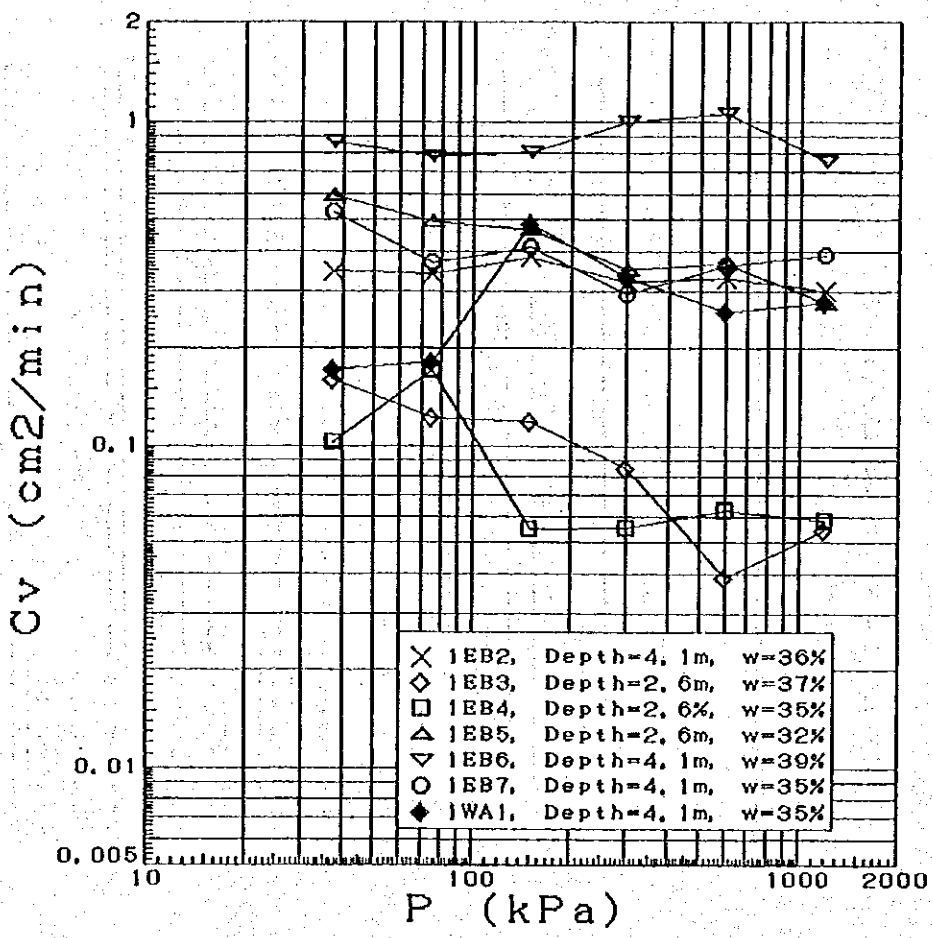


Fig. 4.2.15 log Cv - log P Curves of Soils without Organic Matter (1/2)

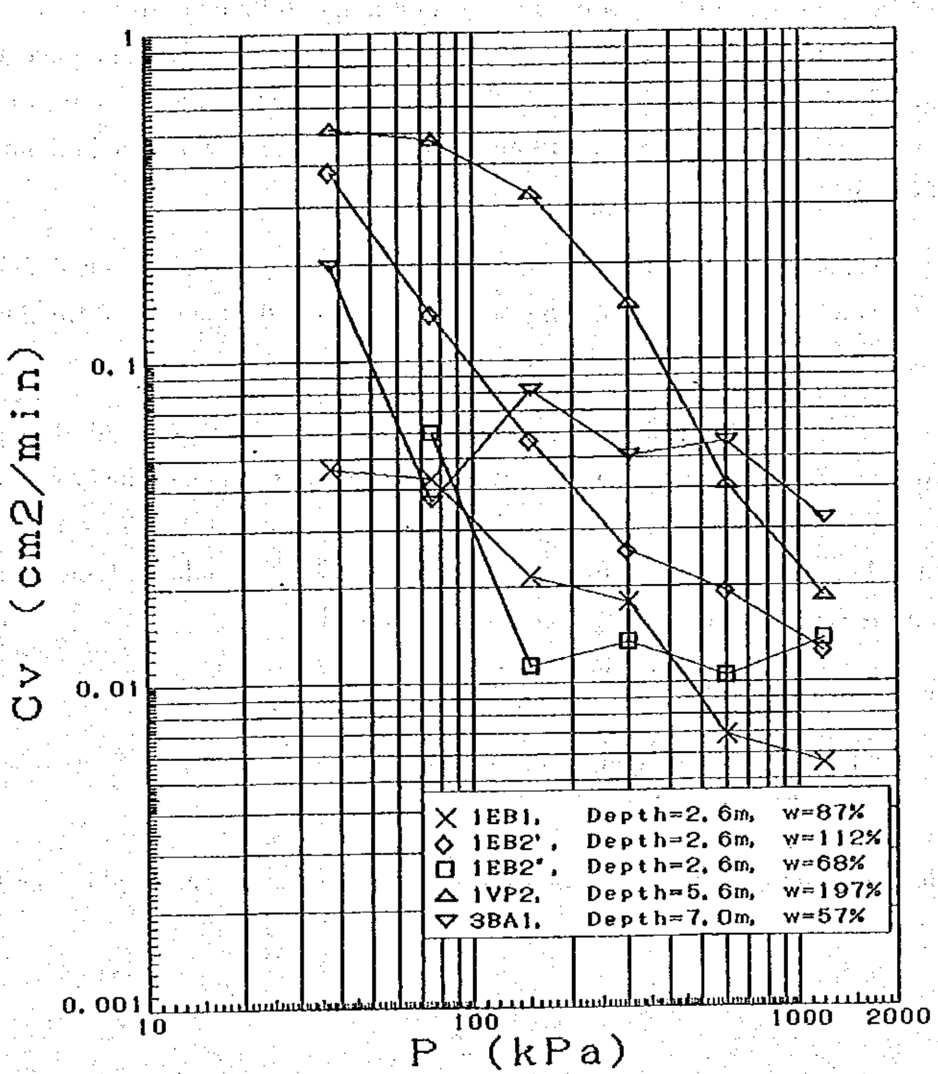


Fig. 4.2.16 log Cv - log P Curves of Soils without Organic Matter (2/2)

4.2.9.2 Stability of Embankment

Slope stability of embankment is analyzed by the simplified Bishop's slip circle method using the program PCSTABLE 5M (version of 1989) which was first developed at Purdue University in 1985.

(1) Stability of Embankment at Normal Road Section

The design height of the normal road section is not to be more than 4.5 m except the approaches to bridge and so that it will be constructed safely within an average filling rate of 5 cm/day. The limit of safe fill height is estimated at about 5 m assuming that untrained shear strength of the soft ground (silt and clay) is 20 kPa and minimum factor of safety is 1.2.

By the analysis in transverse direction, it is revealed that the borrow pit shall be digged not deeper than 2 m and kept away at least 10 m from the toe of road fill slope for the stability of fill.

Ground models for stability analyses are presented in Figures-20 through 31 in Appendix 4.2.9 C. Fig.4.2.17 shows undrained shear strength of the ground estimated from unconfined compressive strength referring not only to the soil investigation of this study but also to other investigations in Khulna area. Undrained shear strength is defined as a half of unconfined compressive strength.

Shear strength of fill is assumed as follows:

Undrained shear strength: $C = 25$ kPa
Internal friction angle: $\phi = 10$ degree

The shear strength of ground improved by consolidation is estimated by the following equation:

$$C = Co + \triangle Pe \cdot m \cdot U / 100$$

Where
- C = undrained shear strength at a certain degree of consolidation (kPa)
- Co = initial undrained shear strength (kPa)
- △Pe = effective stress in ground, assumed by fill load x influence factor-30) (kPa)
- m = rate of strength gain
- U = degree of consolidation (%)

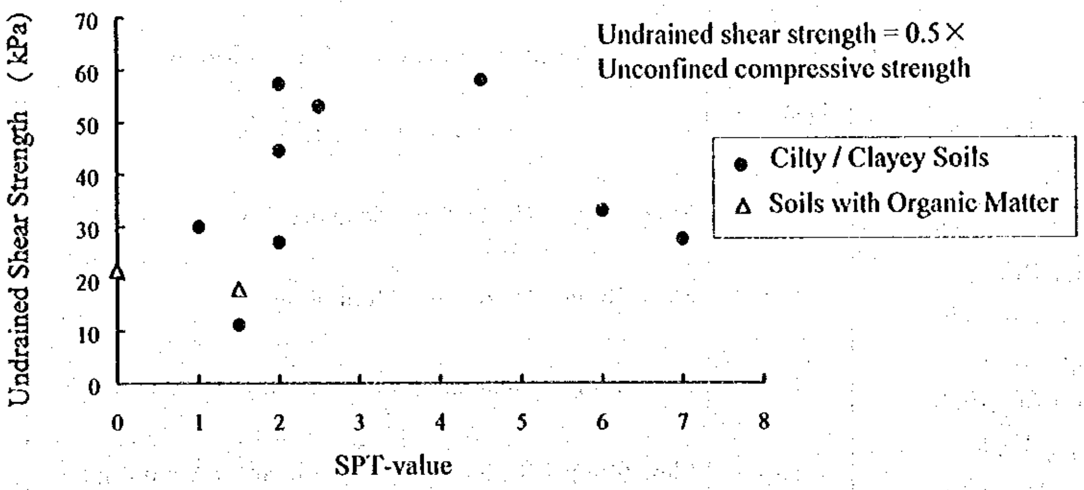


Fig. 4.2.17 SPT-value VS. Undrained Shear Strength

(2) Stability of Embankment at Approach to Bridge

The embankment at approach to bridge shall be constructed by slow filling method with counter berm if required to secure more stability.

Filling speed, curing period and rate of filling at the abutment shall actually be decided by monitoring, because the stability during filling depends on the increase of shear strength of ground. If filling speed is fast and so increase of strength not sufficient, it will result in failure of embankment.

The following monitoring works are recommended:

- For vertical settlement of embankment: install settlement plates on ground surface along road center line in proper intervals.
- For lateral displacement of ground: install displacement pegs across the embankment in proper intervals.
- For movement of abutment: install or mark points on abutment.

Table 4.2.12 summarizes the results of stability analysis together with proposed countermeasures based on which analysis is performed for the critical points. The ground models used for the analysis are presented in Figures-32 through36 in Appendix 4.2.9 C.

Table 4.2.12 Summary of Stability Analyses of Embankment

Location	Factor of Safety	Proposed Countermeasure
Hatia Bridge West Approach	1.28	Slow filling + Geotextile + Sand mat + Monitoring
Hatia Bridge East Approach	1.20	Slow filling + Sand mat + Monitoring
Rupsa Bridge West Approach	1.24	Slow filling + Sand mat + Counter berm* + Monitoring
Rupsa Bridge East Approach	1.25	Slow filling + Sand mat + Counter berm* + Monitoring
Molonghata Bridge Both Approaches	1.39	Sand mat + Monitoring

* Counter berm is required only in longitudinal direction of road.

(a) Hatia Bridge West Approach

Here, the stability of embankment in longitudinal direction toward the river is more critical than in transverse direction. It is recommended that the 6.0 m high embankment be filled by taking 12 months and cured for 11 months before commencing abutment construction as shown in Fig. 4.2.18. Actual filling speed, curing period, timing of commencement of abutment construction and rate of back filling of abutment shall be decided by monitoring.

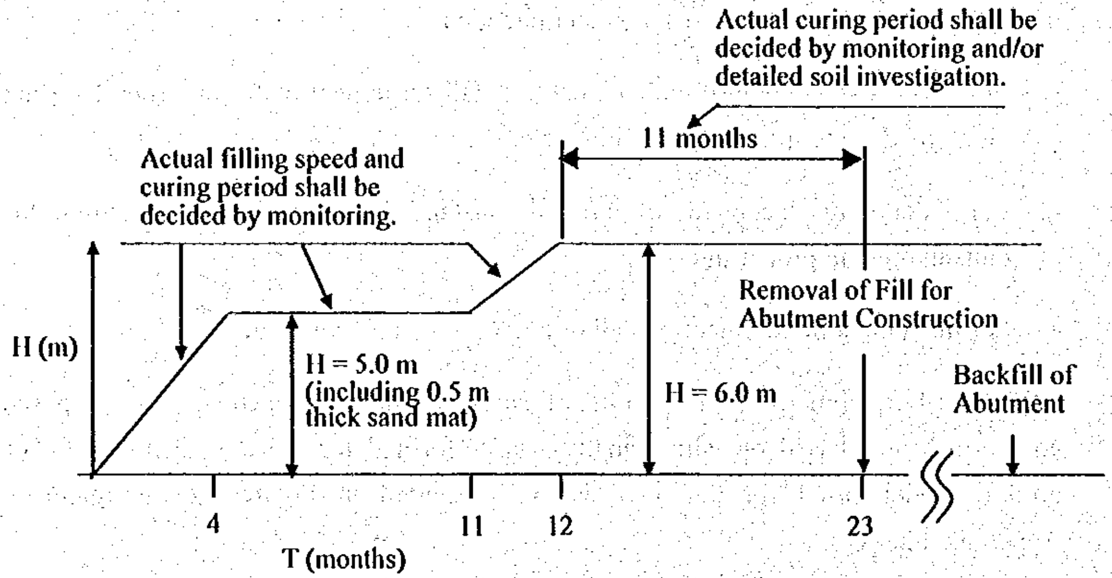


Fig. 4.2.18 Filling Schedule for Hatia Bridge West Approach

Fig. 4.2.19 shows the schematic profile of fill work for both before and after construction of abutment. As shown in the figure, when removing the fill, a minimum thickness of 1.0 m shall be kept for protection of geotextile.

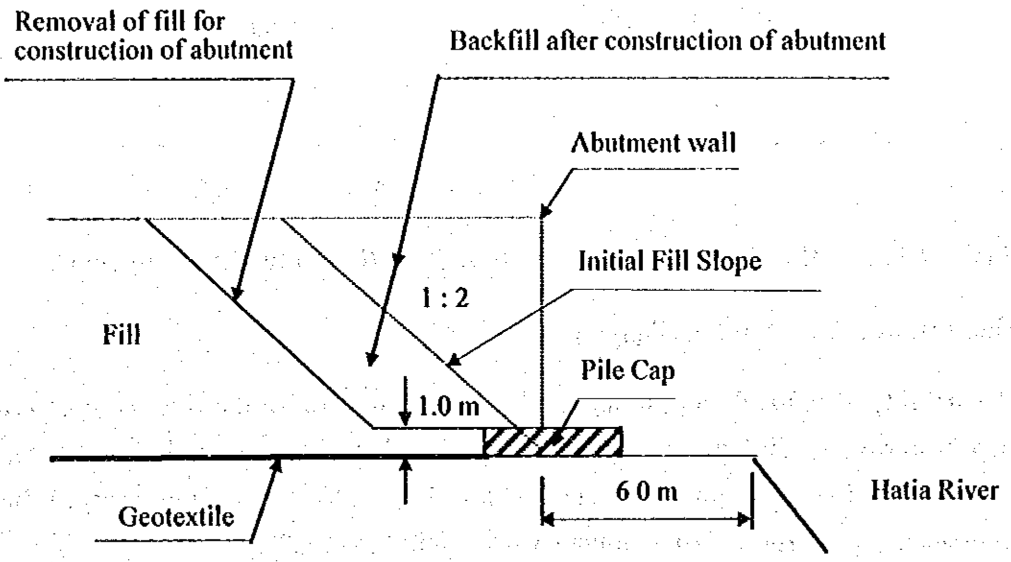


Fig. 4.2.19 Fill in Longitudinal Direction of Hatia Bridge West Approach

(b) Hatia Bridge East Approach

Similar to that of the west approach, the stability of longitudinal direction toward the river is more critical than the transverse. It is recommended that the 5.80 m high embankment be filled by taking 7 months and cured for 5 months before commencing construction of abutment as shown in Fig. 4.2.20.

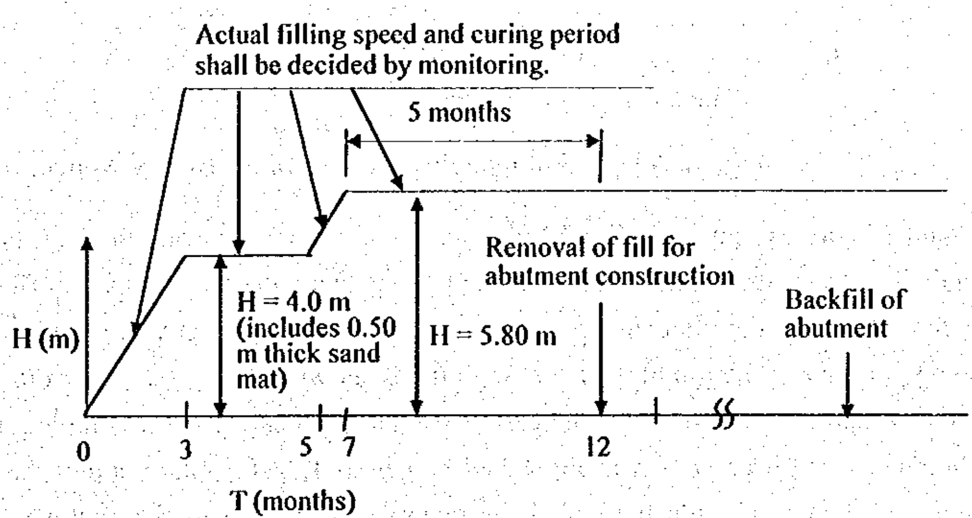


Fig. 4.2.20 Filling Schedule for Hatia Bridge East Approach

Fig. 4.2.21 shows the profile of fill before commencing construction of abutment.

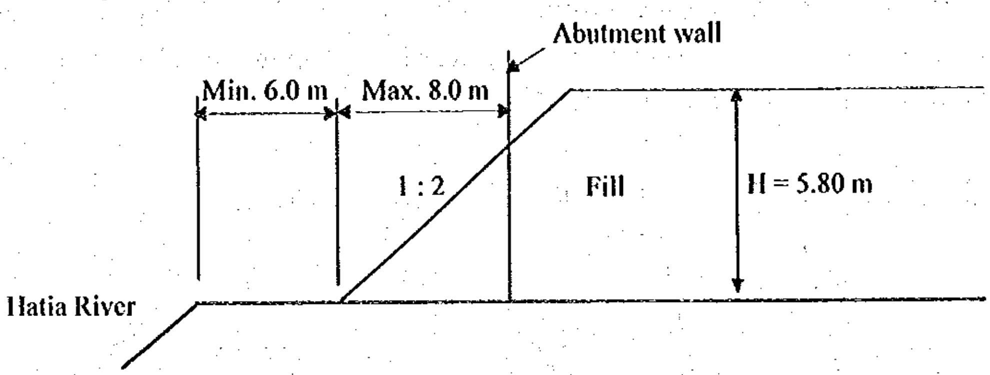


Fig. 4.2.21 Fill in Longitudinal Direction of Hatia Bridge East Approach

(c) Rupsa Bridge West and East Approaches

The stability of embankment in longitudinal direction toward the river is more critical than in transverse direction. It is recommended that the 6.5 m high embankment be filled by taking 6 months and cured for 4 months (one rainy season) before commencing construction of abutment as shown in Fig. 4.2.22.

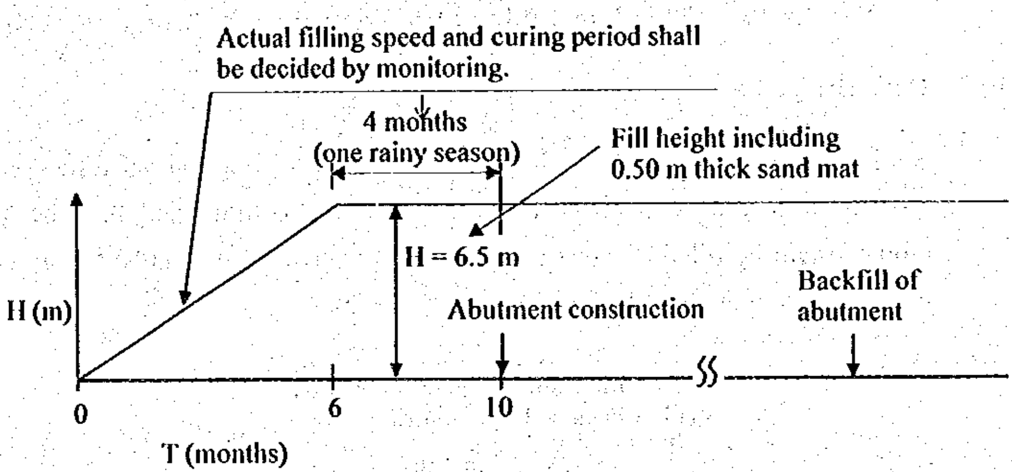


Fig. 4.2.22 Filling Schedule for Rupsa Bridge Approaches

Counter berm is required on the fill in longitudinal direction toward the river but is not in the transverse direction. Fig.4.2.23 and 4.2.24 show the longitudinal profiles of fill before and after commencing construction of abutment respectively. The factor of safety for the completion of the 6.5 m high fill as shown in Fig.4.2.23 comes to 1.24 for the west approach and 1.25 for the east. The factor of safety at the completion of the abutment backfill as shown in Fig.4.2.24 comes to 1.33 for either approach. A 2m high and 4 to 5 m wide berm shall be maintained in front of the abutment for the stability during back filling as shown in the Fig.4.2.24.

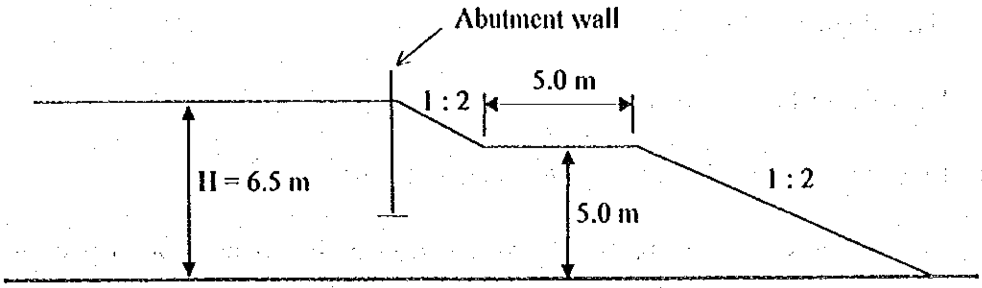


Fig. 4.2.23 Fill in Longitudinal Direction before Construction of Abutment

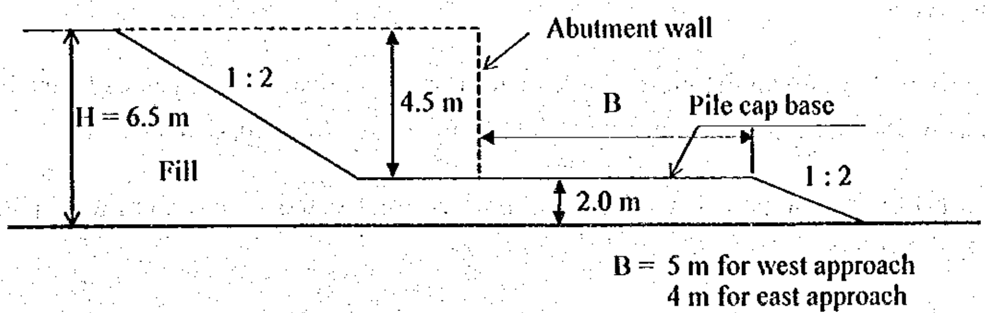


Fig. 4.2.24 Fill in Longitudinal Direction after Commencing Construction of Abutment

(d) Molonghata Bridge Approaches

The stability analysis shows that the 4.8 m high embankment can be filled safely with the average filling rate of 5 cm/day. In such case, the lowest factor of safety comes to 1.39, so that the ground condition here is better than that in the other location. However, by way of precaution, it is recommended to take the counter filling procedure prior to construction of abutment like in the other approaches.

4.3 Hydrological & Meteorological Conditions

4.3.1 Hydrological Conditions

4.3.1.1 River Outline and Hydrological Parameters Investigated

The Rupsa river runs through the South West region of Bangladesh, as a part of Padma (Ganges) river system.

Located to the downstream of Bhairab river, Rupsa river forms a part of the Modhumoti river system that meets the Padma river near Kushita city about 130 km from Khulna. The Atai river joins the Rupsa river about 20km south-west of the confluence point of Bhairab-Majutkhali rivers.

The Rupsa river flows down the eastern side of Khulna urban district, and passes through the Mongla port in Bangladesh and finally flows into Bengal bay. (see Appendix)

The Rupsa bridge and approach road of this project are located in the southwest part of Khulna urban district.

Following hydrological parameters are investigated for design and construction of this project:

- River characteristics
- Water level, Changes in flow velocity, Discharge
- River bank, River bed and countermeasures
- Other relevant issues

For the purpose of collecting data on the above-mentioned items, hydrological survey at proposed bridge site was conducted from July to August 1999.

The survey items of hydrological survey 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.

The analysis as a basis of the above-mentioned data has been described below.

4.3.1.2 River Characteristic

Characteristics of the Rupsa river can be summarized as follows:

1) Water level in Rupsa is greatly influenced by tide in Bay of Bangal. The water level fluctuates periodically not only in dry season but also in flood season. Moreover, back water flow also takes place often.

2) The flood of the Ganges river and the Gorai river which are upstream rivers, do not have any direct influence on Rupsa river. As evidenced in 1998, when Bangladesh witnessed its worst devastating flood, Rupsa river was not much affected. (see Appendix)

3) The drainage basin of the Rupsa river is about 6,000 km^2, excluding the drainage basin of the Ganges river and the Gorai river. As most of the basin is comprised of paddy field, runoff water does not flow into river, and even if few flows, they are aborted by rides, thus protecting to Khulna city from flooding.

Various indicators that describe the river bed stability in the vicinity of Rupsa Bridge site are as listed as follows:

(1) River bed slope (Ib)

Average river bed slope from Bridge point	+1/1000	
Deepest river bed slope from Bridge point	upward	-1/430
	downward	+1/140

(2) Representative particle size (dr)

$\fallingdotseq 0.1$ mm

(3) Average water depth in low water channel (H_L)

$H_L \fallingdotseq 10$ m

(4) Energy gradient (Ie)

$$Ie = \begin{cases} V = 1.0\ m/sec \fallingdotseq \frac{1}{50,000} \\ V = 2.0\ m/sec \fallingdotseq \frac{1}{13,500} \end{cases}$$

(5) Friction velocity (U_*)

$$U_* = (G \cdot H_L \cdot Ie)^{0.5}$$

$$= (980 \times 1000 \times 0.000074)^{0.5}$$

$= 8.51 ^{cm}/_{sec}$

$U_*^2 \doteqdot 72.5 ^{cm^2}/_{sec^2}$

(6) Non-dimension tractive force (T_{*R})

$T_{*R} = U*2/S \times G \times D_R$

$= 72.5/1.65 \times 980 \times 0.01$

$= 4.5$

(7) River width and water depth ratio (B/H_l)

$540/10 = 54$

(8) Water depth and particle size ratio (H_L/D_R)

$1000/0.01 = 10^4$

4.3.1.3 Water Level, Flow Velocity and Discharge

(1) Water Level

In the vicinity of the project site, two water level recording stations are located; Khulna station, about 4 km upstream from proposed bridge and Chalna station, about 20 km downstream. Water level data recorded at both the stations are examined for 30 years period (1968-1998). The highest and lowest water level records of each month and year are shown in Appendix.

The high water and low water level for various recurrence intervals at each station and Bridge site are calculated and presented in Table 4.3.1.

Table 4.3.1 High Water and Low Water Level for Various Recurrence Intervals

Recurrence Interval Year	Khulna		Chalna		Rupsa Bridge	
	H.W.L.	L.W.L.	H.W.L.	L.W.L.	H.W.L.	L.W.L.
100	3.68	-1.06	4.24	-2.25	3.77	-1.26
50	3.58	-0.99	4.10	-2.04	3.67	-1.17
20	3.42	-0.90	3.92	-1.76	3.50	-1.04
10	3.32	-0.83	3.77	-1.56	3.40	-0.95
5	3.20	-0.74	3.61	-1.36	3.27	-0.84

Unit : m (P.W.D)

The annual fluctuations of H.W.L. and L.W.L. at Khulna and Chalna stations are shown in Fig. 4.3.1. The H.W.L showed a remarkable difference between 1970's and after 1985 at both stations. It is due to the influence of construction of polder dike along the Rupsa river on both sides. As for L.W.L, little change occurs at both stations.

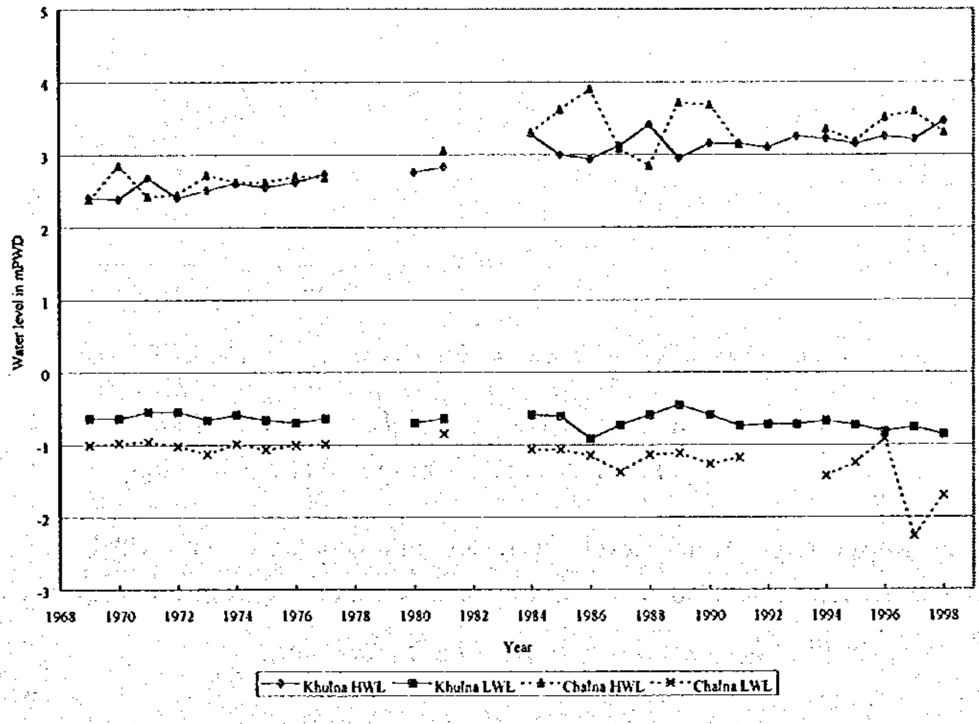


Fig. 4.3.1 Annual H.W.L. & L.W.L. at Khulna & Chalna Stations

The monthly H.W.L and L.W.L at Khulna station are shown in Fig. 4.3.2. This figure shows that there is a continuous increase in H.W.L during all months from 1970 to 1998. L.W.L increased a little over the time. Both H.W.L and L.W.L. are high from July to October and remain low from December to March.

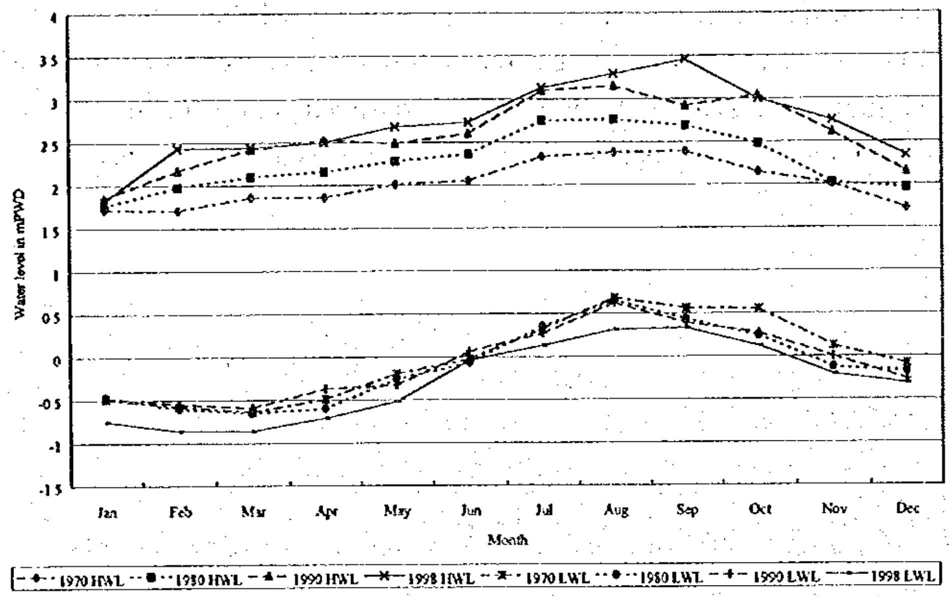


Fig. 4.3.2 Monthly H.W.L. & L.W.L. at Khulna Station
(4 km upstream from proposed bridge location)

In the Rupsa river, water level fluctuates in accordance with tidal flow and subsequently river flow also changes. Fig. 4.3.3 shows changes in water level & river flow over time in a day.

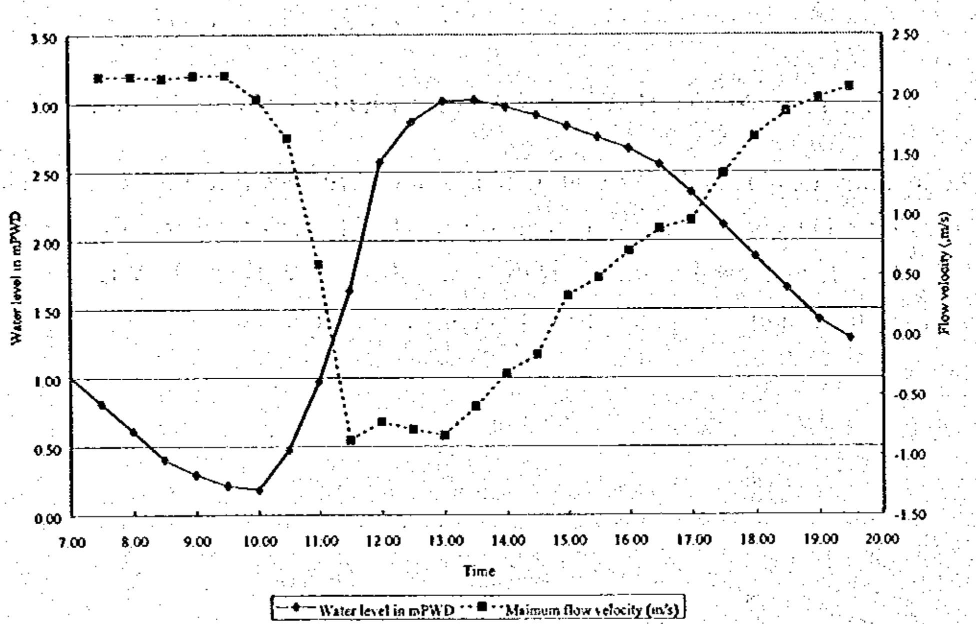


Fig. 4.3.3 Change in Hourly Water Level and Maximum Flow Velocity at Proposed Bridge Site (Date: 29.07.1999)

(2) Flow Velocity

Flow velocity was measured at each river crossing point of route alternatives during 27 and 29 July, 1999.

Characteristics of flow velocity measurement are summarized as follows;

1) The highest flow velocity is observed to the western bank from the center when the water flow goes downstream, and on the contrary, the highest flow velocity is observed to the eastern bank on upstream at the river crossing points of Route 1 and 2. However, at the river crossing point of Route 3, the highest flow velocity is observed at the center and the lowest flow velocity is observed to the eastern bank when the water flow goes downstream, and the highest flow velocity is observed to the eastern bank on upstream.

2) 2.2 m/sec of the maximum flow velocity is recorded during the observation period when the water flow goes downstream together with the average velocity of 1.5 m/sec, and 0.9 m/sec of the maximum on upstream with the average of 0.5m/sec.

3) Maximum discharge of the river of downstream and upstream flows is estimated 5,800 m^3/sec and 2,900 m^3/sec respectively as computed from the maximum velocity.

4.3.1.4 Changes in River Bed Conditions

Following data are obtained to examine historical 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 hydrographic chart measured by BIWTA to secure for ship route (in 1986, 1989, 1992, 1998)
iii) Cross section data of the Rupsa river in 1994-95 measured by BWDB

According to information obtained from local office of BWDB and BIWTA, the river bed of the Rupsa River is getting shallower in general due to 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 level 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.

4.3.2 Meteorological Conditions

4.3.2.1 General

The meteorological parameter and conditions in the Study Area were examined for the Study, and the following data are collected for the meteorological analysis.

- Air Temperature
- Humidity
- Precipitation
- Wind velocity and others

These data were obtained from the Provincial Meteorology Service in Khulna and Meteorological Agency in Dhaka.

The relevant data, analysis procedure and results of the meteorological analysis are summarized as follows.

4.3.2.2 Air Temperature

Temperature data for a period of 11 years (from 1988 to 1998) recorded at Khulna meteorological station is collected for the Study. Mean monthly temperature is summarized in Table 4.3.2.

Table 4.3.2 Air Temperature in Khulna
Period 1988-1998

(Unit : C)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Extreme Max	30.5	33.7	37.7	39.4	40.0	37.2	35.5	35.6	39.1	36.4	34.2	30.4	40.0
Mean Max	29.0	32.3	36.3	37.6	37.3	36.3	35.0	34.6	35.9	34.9	32.8	29.5	
Mean Min	7.6	10.6	14.8	18.6	20.9	22.8	24.2	24.1	23.6	20.5	14.6	10.2	
Extreme Min	6.8	9.0	12.8	15.8	19.4	20.8	22.2	22.3	22.2	18.4	11.9	8.0	6.8

Source: Provincial Meteorology Office - Khulna

4.3.2.3 Precipitation

The monsoon rainy season starts in July and ends in October. This period accounts for 80% of the total annual rainfall.

Table 4.3.3 shows the summary of precipitation data recorded during a period of 30 years from 1969 to 1998 at Khulna station.

The total annual precipitation ranges between a minimum of 475 mm (1971) and a maximum of 2,762 mm(1974). The mean annual rainfall in Khulna is 1,754 mm. The maximum daily precipitation from 1969 to 1998 ranges from 52 mm to 430 mm with an average of 140 mm (Refer to Appendix). The daily precipitation is converted into from 18 mm to 149 mm with an average of 49 mm hourly precipitation, respectively.

Table 4.3.3 Monthly Precipitation in Khulna
Period 1969-1998

(Unit : mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	11.1	34.7	54.9	76.1	183.9	345.2	322.1	321.1	240.2	127.1	31.0	7.1	1754.5
Max	70.0	203.0	220.0	347.0	373.0	783.0	792.0	633.0	843.0	330.0	162.0	65.0	2762.0
Min	0.0	0.0	0.0	0.0	30.0	63.0	48.0	80.0	39.0	17.0	0.0	0.0	475.0

Source : Provincial Meteorology Office – Khulna

Table 4.3.4 also shows the record of the rainy days at Khulna station during the same period of past 30 years. This data is useful for planning the construction schedule.

Table 4.3.4 Monthly Rainy Days & Max Dairy Precipitation in Khulna

Period 1969-1998

(Unit : mm)

	January			February			March			April			May			June		
	Max Rain	0>	10>	Max Rain	0>	10>	Max Rain	0>	10>	Max Rain	0>	10>	Max Rain	0>	10>	Max Rain	0>	10>
Mean		1.2	0.3		2.6	1.1		2.6	1.6		5.5	2.6		9.9	5.5		15.4	8.4
Max	70	4	3	64	10	4	95	10	10	122	12	8	127	19	11	254	27	13
Min	0	0	0	0	0	0	0	0	0	0	0	0	22	2	1	36	3	2

	July			August			September			October			November			December		
	Max Rain	0>	10>	Max Rain	0>	10>	Max Rain	0>	10>	Max Rain	0>	10>	Max Rain	0>	10>	Max Rain	0>	10>
Mean		20.2	9.9		19.9	9.2		14.8	6.9		7.1	3.5		1.8	0.8		0.9	0.1
Max	153	27	19	391	26	15	430	22	14	115	14	8	113	8	4	62	4	2
Min	13	5	2	12	7	2	11	3	2	11	2	1	0	0	0	0	0	0

Source: Provincial Meteorology Office - Khulna (Unit : mm,days)

4.3.2.4 Humidity

Table 4.3.5 shows the data on relative humidity for 11 calendar years, the period from 1988 to 1998, recorded at Khulna station.

The annual mean humidity for this period varies from a minimum of 41.3% to a maximum of 99.8% with an extreme minimum of 9.0%. (Refer to Appendix)

Table 4.3.5 Monthly Humidity in Khulna

Period 1988-1998

(Unit : percent)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Extreme Max	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Mean Max	100.0	100.0	99.8	99.3	99.8	100.0	99.8	99.8	99.8	99.9	99.7	100.0	99.8
Mean Min	26.9	29.7	23.6	27.5	43.2	53.1	57.1	60.8	57.5	45.5	38.0	33.2	41.3
Extreme Min	9.0	22.0	13.0	20.0	27.0	30.0	26.0	51.0	41.0	39.0	31.0	28.0	28.1

Source: Provincial Meteorology Office - Khulna

4.3.2.5 Wind Velocity

Data on monthly maximum wind velocity, measured at 10 meters height at Khulna meteorological station are collected. Table 4.3.6 shows the monthly maximum wind velocity for 11 calendar years period from 1988 to 1998.

A maximum wind velocity of 33.4 m/sec was recorded in September 1997.

The annual mean monthly maximum wind velocity ranges between 6 m/sec to 13 m/sec.

Table 4.3.6 Monthly Maximum Wind Velocity in Khulna
Period 1988-98

(Unit : m/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Max & Min
Mean	6.7	6.2	7.9	12.8	9.3	8.9	8.0	7.7	8.2	5.7	7.1	7.9	
Max	15.9	9.3	13.9	23.1	12.8	18.0	10.3	11.3	33.4	9.3	18.5	18.5	33.4
Min	4.1	4.1	4.6	6.2	6.2	5.1	4.6	5.1	3.1	2.1	2.1	3.1	2.1

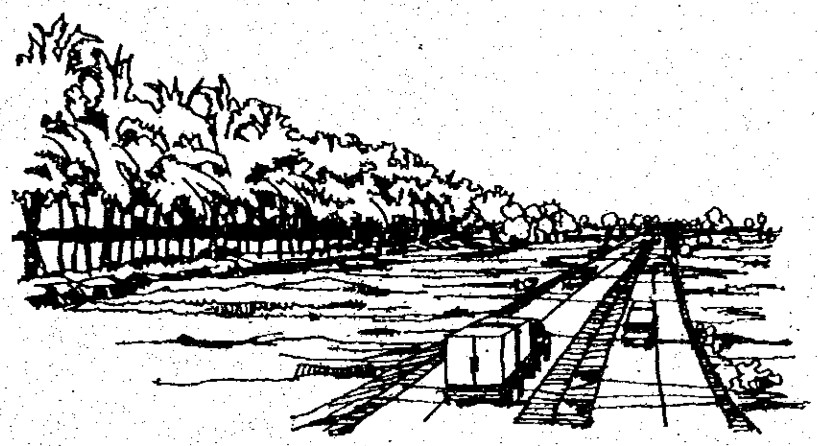
Source : Provincial Meteorology Office - Khulna (Unit : m/s)

The Data of Major Tornadoes that occurred in Bangladesh are as follows.

No	Place	Date	Affected Area (km^2)	Duration of the storm (minutes)	Estimated Highest wind speed (km/hr)
1	Domra	14-4-69	155-168	5-7	644
2	Manikgonji	17-4-73	20.7	8-10	322
3	Faridpur	01-4-77	51.8	2-3	322
4	Manikganj	26-4-89	150.2	Several min	338-419
5	Gazipur	07-5-91	-	〃	290
6	Tangail	13-5-96	120	5-8	320-450

CHAPTER 5

FORMATION OF ALTERNATIVE PLANS



CHAPTER 5 FORMATION OF ALTERNATIVE PLANS

5.1 Route Alternatives

5.1.1 Background

The Study on Construction of the Bridge over the River Rupsa in Khulna (Phase 1) concluded that the Khulna Bypass would be planned on the western side of the Rupsa River, and the Rupsa Bridge would be a undivided 2-lane road bridge.

Since the Khulna Bypass is planned to strengthen the road network of Khulna City and its surroundings as well as to stimulate Mongla Port to induce freight demand, it should bypass congested Rupsa Ferry and other traffic bottlenecks on National Highway No. 7 in the downtown of Khulna as shown in Fig. 5.1.1.

Accordingly, the location of Rupsa Bridge is planned not to be on the existing Rupsa Ferry but to be in 1 - 3 km south of existing ferry crossing point, and furthermore it should be selected at the most stable crossing point from the viewpoint of river morphology as shown in Fig. 5.1.2.

The Khulna Bypass delineated in the Khulna Master Plan revised by KDA starts at Cantonment in Siromony and ends at Khulna-Mongla Road, totaling 27.7 km in length. The northern section of Khulna Bypass is being developed by KDA to connect the Southrn Section of Khulna Bypass (SSKB) at the intersecting point of 150 m (500 ft) apart from the western end of Meteorological office's premise nearby Khulna University on Khulna-Satkhira Road (R760). Therefore, alternative routes for the SSKB are located in the southern part of Khulna city, beginning from Khulna-Satkhira Road and ending at Khulna-Mongla Road.

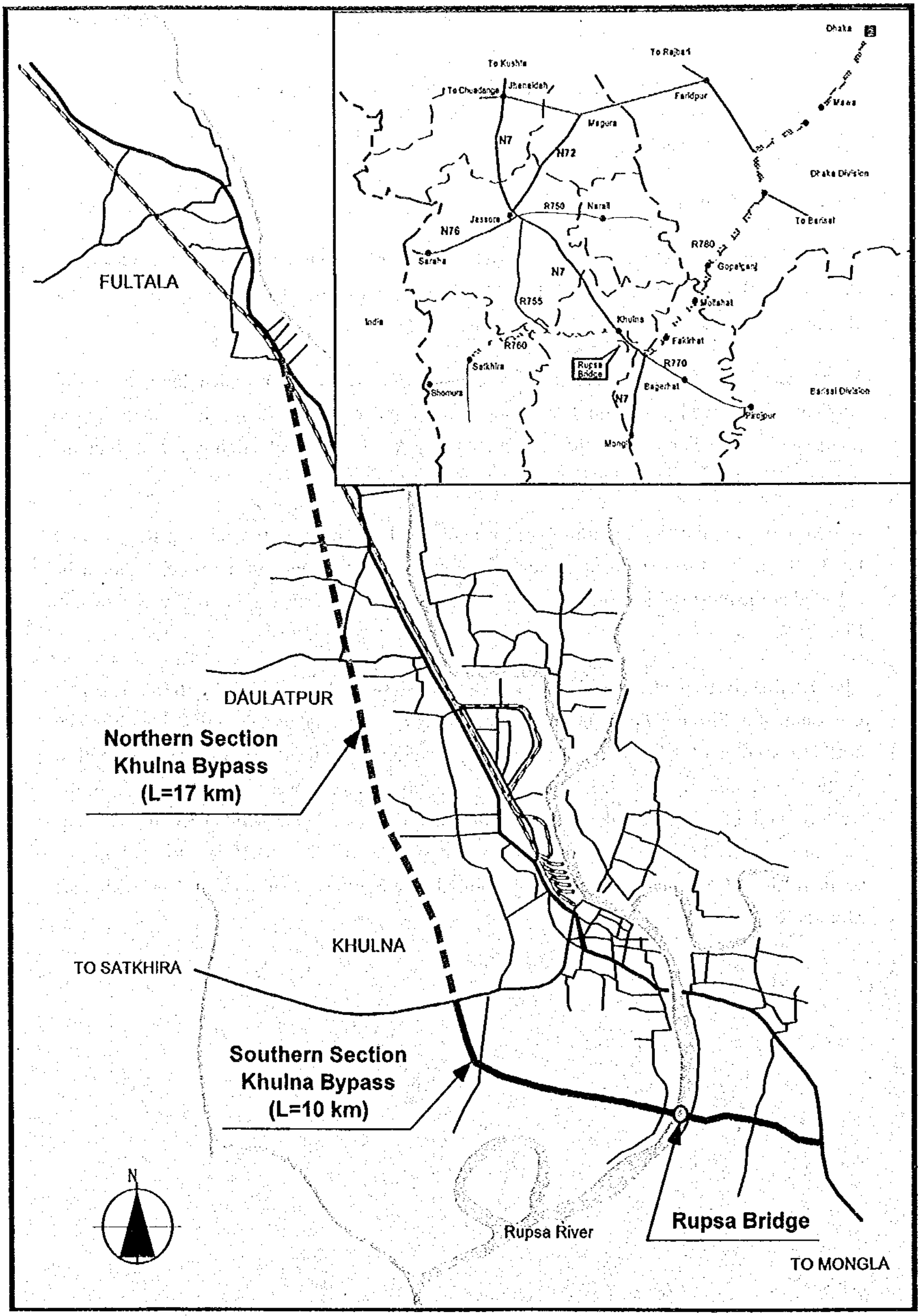


Fig.5.1.1 Location of Study Route and Bridge

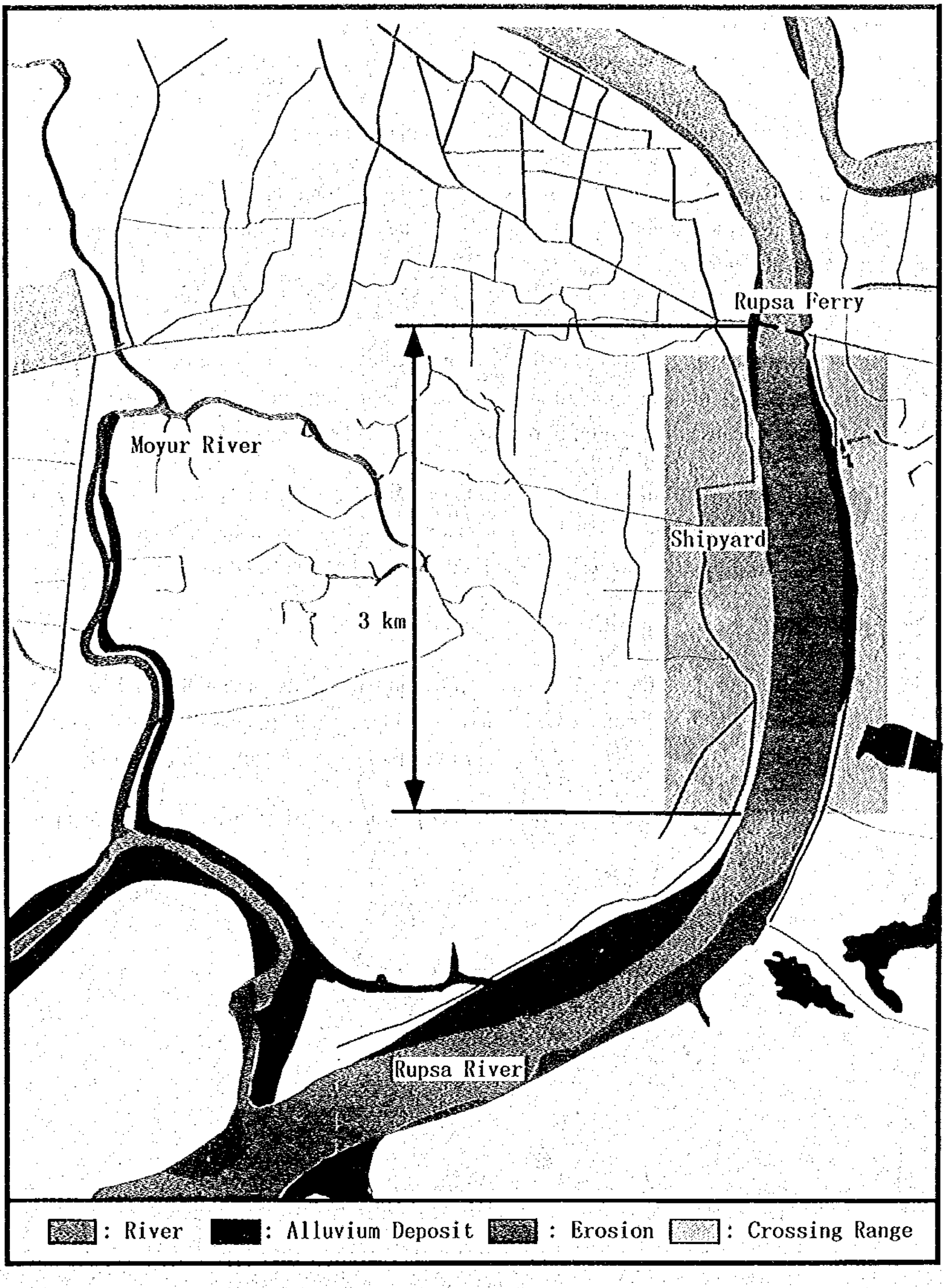


Fig. 5.1.2 River Morphology

5.1.2 Definition of Terms

The term "**Corridor**" is perceived as a concept that it has a wide strip and reveals effects or influences brought by the project road in the study area. The corridor of the SSKB may be fixed in the southern part of Khulna city and 1 - 3 km south of existing ferry crossing point in between Khulna-Satkhira Road and Khulna-Mongla Road.

The term "**Route**" is defined that it has concrete design controls such as type of road, design speed, road width together with number of lanes and location of interchanges/grade separation structures.

A route study will be able to envisage location of road by averting physical constraints such as large-scale factory, public facilities, cemetery, a cluster of homesteads and so forth. However, it still remains ambiguous to identify exact lots and properties affected by the project road because the location of road is neither calculated nor marked up at site.

The term "**Alignment**" is defined so as to have coordinates vertically and horizontally based on outputs of detailed design such as finished grade, curvature, distance from centerline and so forth. Accordingly, affected lots and properties will be identified topographically.

5.1.3 Methodology for Alternative Route Study

Taking into consideration the designated roles and functions of the SSKB based on the corridor study which was conducted in Phase 1 Study, a route study is conducted to set route alternatives for route selection, and it will proceed to the next step of alignment study.

Fig. 5.1.3 shows the methodology of route study, which consists of the five (5) major work items;

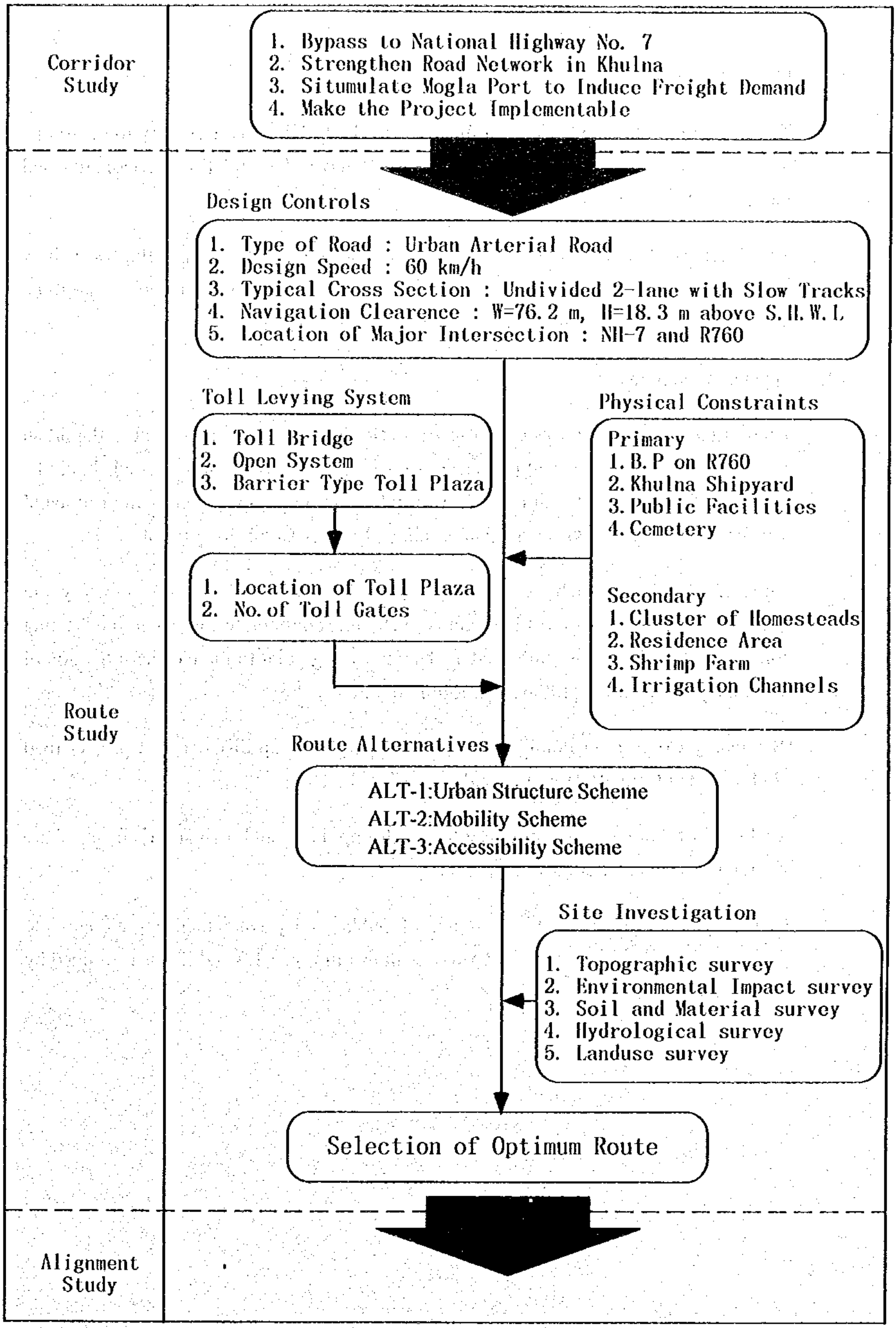


Fig. 5.1.3 Methodology of Route Alternative Study

(1) Design Controls

To realize the designated roles and functions of the SSKB, it is necessary to determine major design controls of which those elements have close relation horizontally and longitudinally to select a route.

The SSKB is planned to connect to local roads which are already existing as well as planned in the study area to collect/distribute traffic. At-grade intersections are to be planned to accommodate traffic demand as shown in Fig. 5.1.4.

(2) Physical Constrains

There usually exist many lots and properties affected by road development in the urban area. Some of those lots and properties are so important that a project road should be controlled to keep distance in order to avert adverse social impacts on them or to avoid considerable compensation costs, that is called "Primary Controlling Point".

Large-scale industry such as Khulna Shipyard, public facilities and cemetery are classified as primary controlling points. On the contrary, established intersecting point on R760 which was confirmed as the connecting point to the Northern Section of Khulna Bypass is also a primary controlling point.

"Secondary Controlling Point" is deemed desirable to keep distance if a project road can be averted from affecting lots and properties.

A cluster of homesteads, residence area, shrimp farm and irrigation channels are regarded as secondary controlling points.

To clarify the land use and importance of public and private facilities along route alternatives, the land use map is prepared as shown in Fig. 5.1.5 and it was examined by site reconnaissance survey.

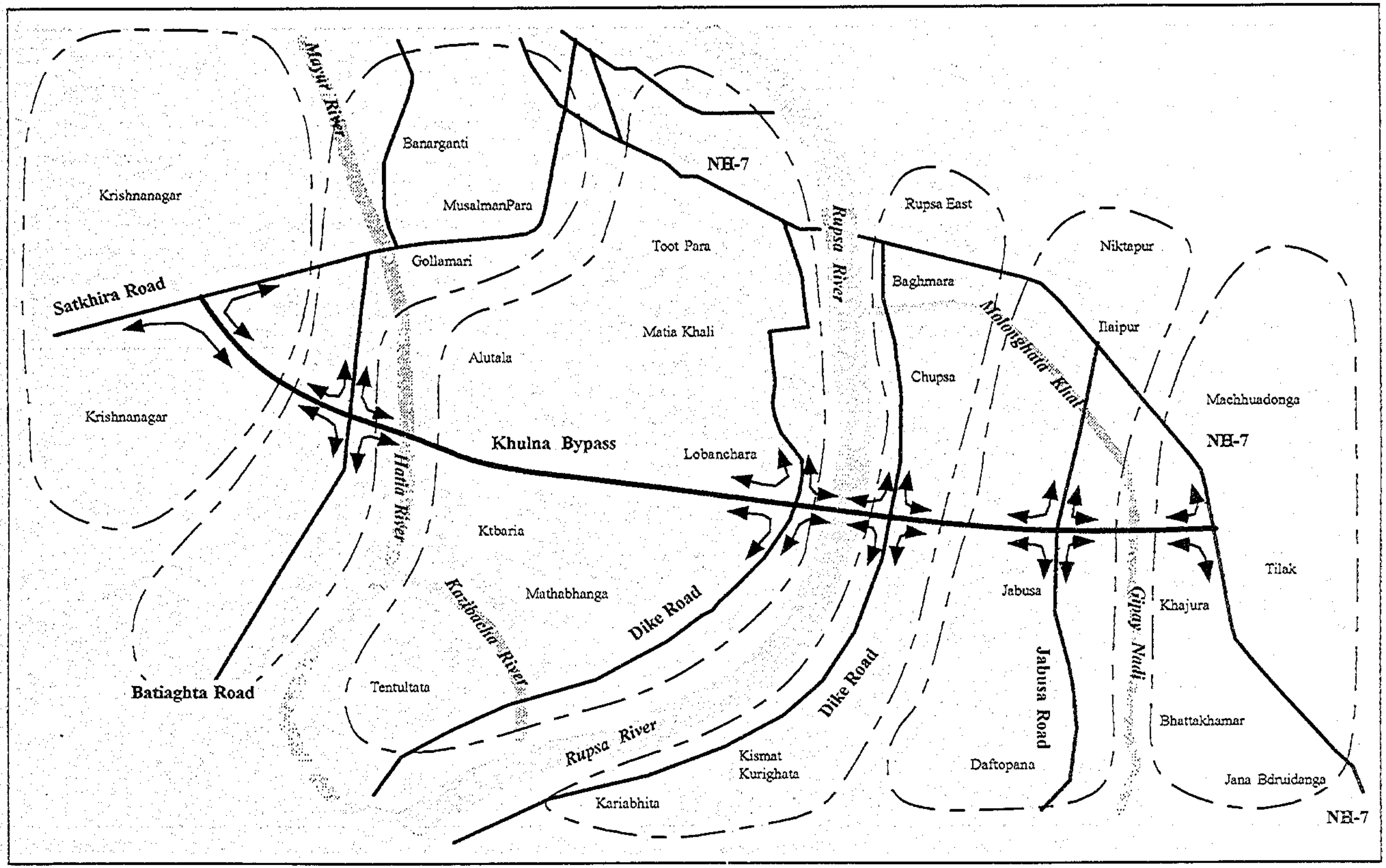


Fig. 5.1.4 Road Network and Planned At-grade Intersections

Fig.5.1.5 Physical Constraints in Study Area

(3) Toll Levying System

Additional design controls and facilities should be taken into account in case of toll road. The closed system may levy a toll from all users allowed to access to and egress from a toll road over the entire stretch, while the open system may levy a toll not from short trip users but from medium and long trip users.

The SSKB is designated to be not a toll road but a toll bridge, and accordingly toll will be levied only from road users who will cross the Rupsa River on the bridge, that is the open system. A barrier-type toll plaza on through traveled way is the most suitable for the Rupsa Toll Bridge due to efficiency of toll levying operator and convenience of users. Fig. 5.1.6 shows the proposed location of toll plaza and the traffic maneuvering in the vicinity of toll plaza. The toll rates will be the same as that of existing Rupsa Ferry, levying tolls from motorized vehicles.

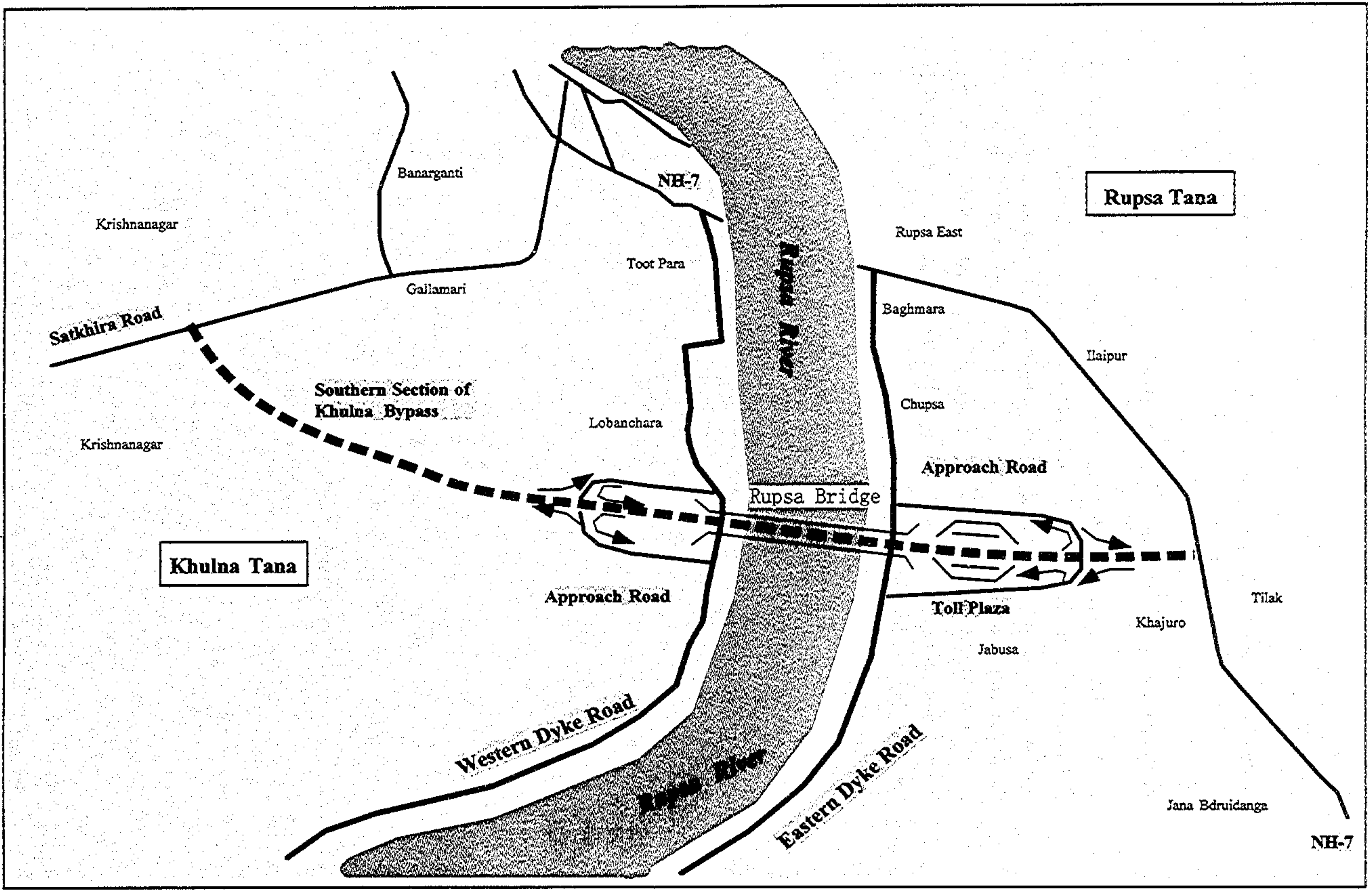


Fig. 5.1.6 Location of Toll Plaza and Service Roads to Connect with Dyke Roads

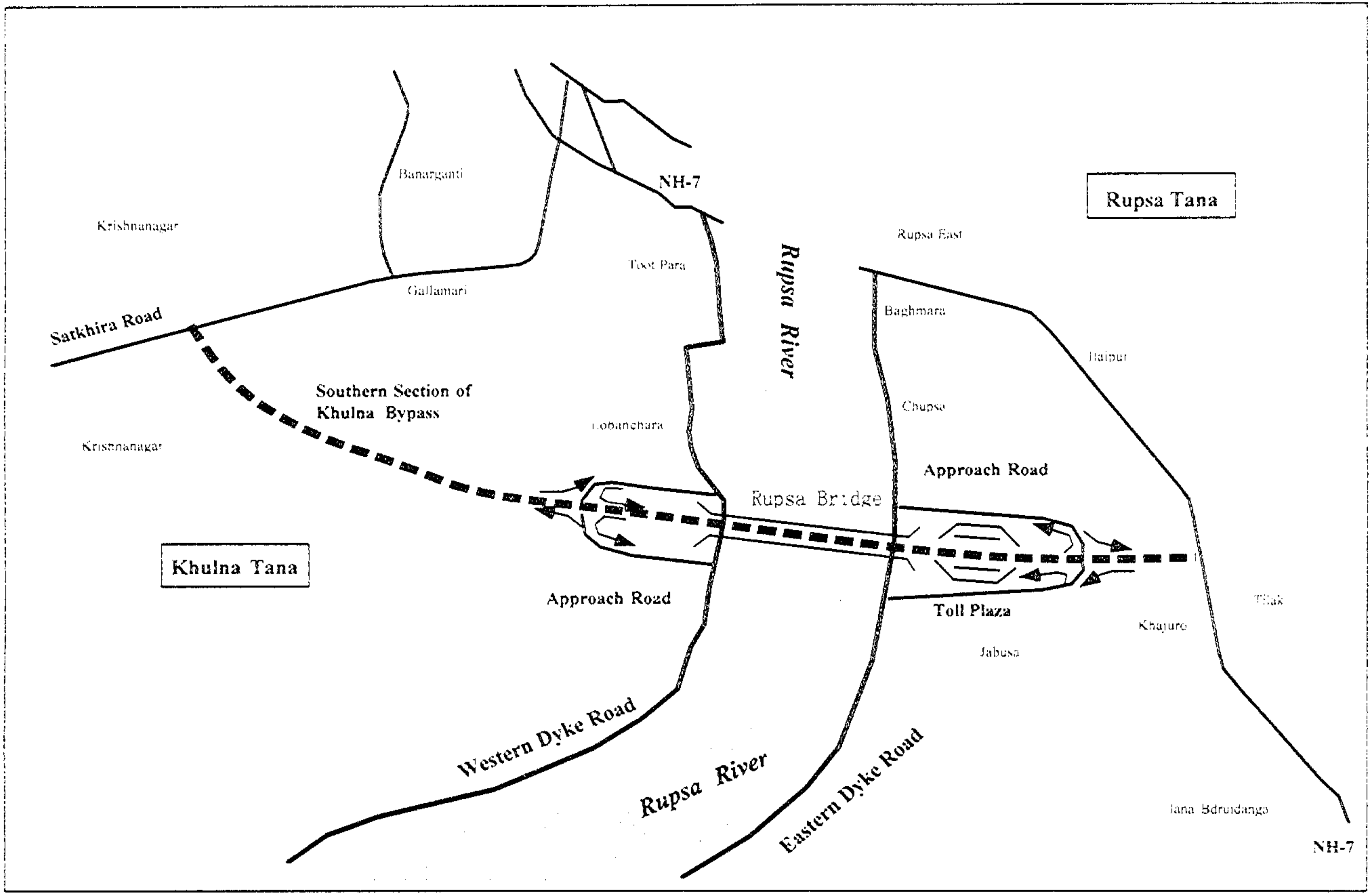


Fig. 5.1.6 Location of Toll Plaza and Service Roads to Connect with Dyke Roads

(4) Route Alternatives

Three alternative routes are contemplated to fulfill expected roles and functions as shown in Fig. 5.1.7.

Alternative-1: Urban Structure Scheme

The Urban Structure Scheme is planned to pass mostly undeveloped area where it is assumed to be the southern boundary of urbanization of Khulna city, thus bringing considerable development impacts to induce future urban structure in south-west direction as well as minimizing adverse social impacts.

Alternative-2: Mobility Scheme

The Mobility Scheme is planned to bypass presently congested roads and intersections in the downtown and it may enable the SSKB to provide good mobility to mainly medium to long trip traffic from the periphery of built-up area in Khulna City, which are not only through traffic of Khulna but also bypass traffic of origin/destination in Khulna. The location of river crossing is planned on the south of Khulna Shipyard.

Alternative-3: Accessibility Scheme

The Accessibility Scheme is planned to pass on the north of Khulna Shipyard where densely inhabited land use is found, and it is only for comparison purpose because the route could not help bringing serious adverse effects to inhabitants. However, it will be able to accommodate mainly short to medium trip traffic generated from and attracted to the built-up area of Khulna or its Central Business District.

(4) Route Alternatives

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Alternative-3: Accessibility Scheme
The Accessibility Scheme is planned to pass on the north of Khulna Shipyard where densely inhabited land use is found, and it is only for comparison purpose because the route could not help bringing serious adverse effects to inhabitants. However, it will be able to accommodate mainly short to medium trip traffic generated from and attracted to the built-up area of Khulna or its Central Business District.

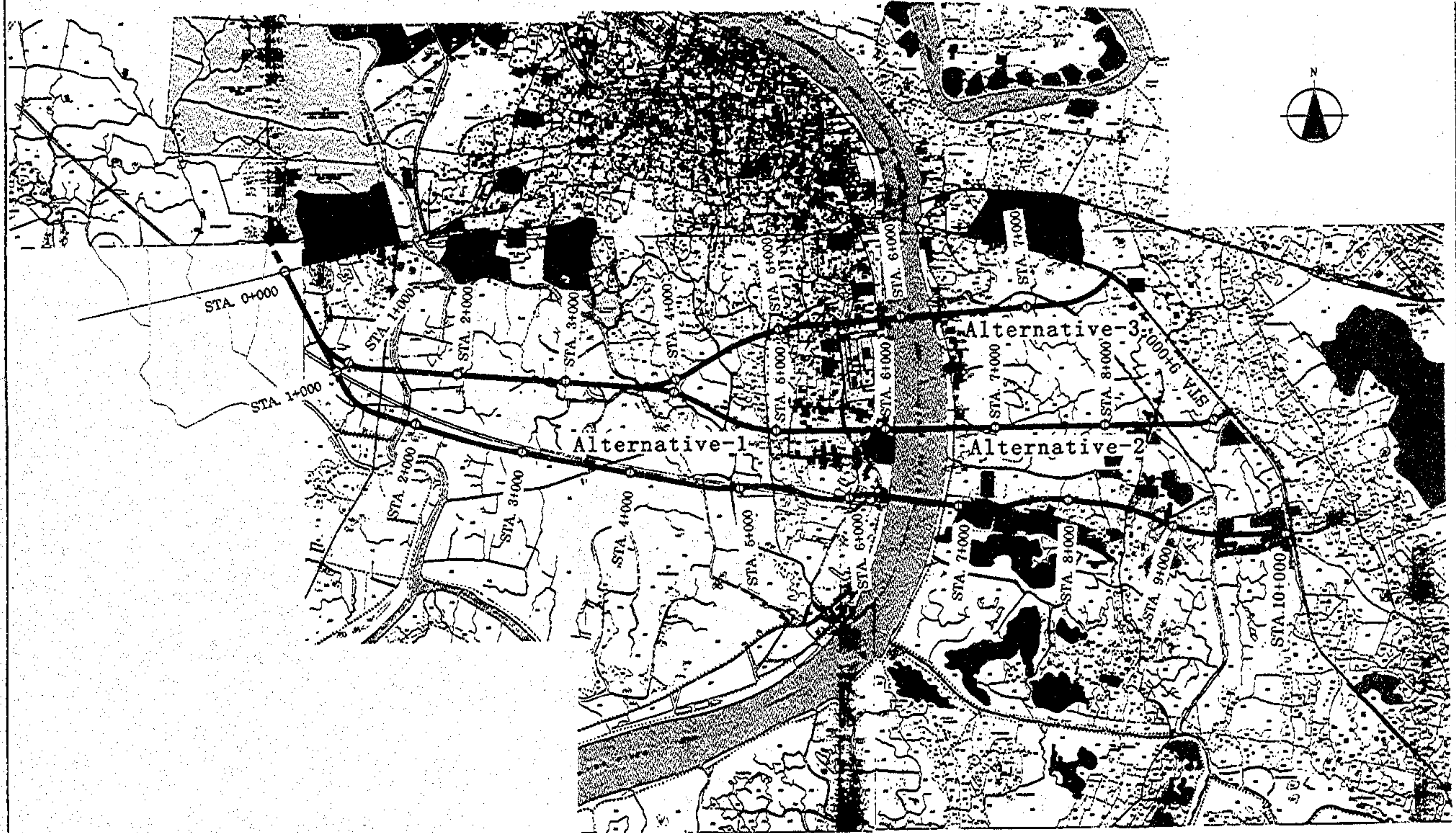

Fig. 5.1.7 Location of Each Route Alternative

(5) Site Investigation/Data Collection

Site investigations, which consist of topographic survey, environmental impact survey, soil and geological survey, hydrological survey, land use survey, traffic survey as well as collecting data concerning river morphology and aerial photos, are carried out to reveal natural and physical conditions of the project area.

These basic data are referred to for technically and financially evaluating each alternative.

5.1.4 Route Description

(1) Alternative-1: Urban Structure Scheme

The river crossing point of this route is located 2.6 km south from Rupsa Ferry, and the total length of the route is 10.043 km.

Accordingly, this route is the farthest from Rupsa Ferry and the longest among alternatives.

The starting point is designated and clearly marked up on Khulna-Sathkira Road (R760) by KDA at 150 m (500ft) toward Satkhira from the western corner of Weather Office under Meteorological Department.

Some houses are found along R760 in the vicinity of intersection, and the route manages to avert these houses and to turn eastward in Krishnanagar area passing through paddy land.

The route is planned to connect with Batiaghta Road (F7606) at Sta.1+614, and to cross the Hatia River of which width is about 60m at Sta. 1+850.

The route is planned to pass through open spaces from Sta. 2+000 to Sta. 5+100 such as agricultural land in Mouza-Dubi, Alutala, and Harin Tana areas.

Although horizontal alignment with some curves are carefully examined to avoid affecting properties along the route, some homesteads will be affected by the route in Matha Bhanga and Laban Chara areas due to selected river crossing point. However, it seems to be possible that the adverse social impacts will be mitigated by practical countermeasures such as removing within their land or relocating in the vicinity.

The route will cross Laban Chara Main Road (Western Dyke Road) by a grade separation structure because the approach bridge of the Rupsa Bridge is planned to become the elevated viaduct so as to secure the navigation clearance of the Rupsa River at Sta.6+560. However, Laban Chara Main Road will have access roads to connect to the SSKB after the approach road becomes at-grade.

The route will run to cross the Rupsa River at open space in between Asha Sea Food Ltd. and Borne Mill, keeping right angle of river crossing.

After crossing the Rupsa River, the route will fly over Char Rupsa Road (Eastern Dyke Road) as the same way of Western Dyke Road, and the route will violate the land of Gemini Sea Food Ltd. to some extent.

The route is planned to pass through open spaces from Sta. 7+500 to Sta. 8+500 such as agricultural land, fishery ponds and shrimp farm along the periphery of residential area in Jabusa. The route is planned to connect with Jabusa Road at Sta.8+515.

The route is planned to pass through scattered inhabited area in between Village Department Project Nursery and Jabusa residence area, minimizing adverse social impacts. The route will run eastward to cross the Molonghata Canal of which width is about 30m at Sta. 9+340, and to pass through open spaces such as agricultural land, fishery ponds and shrimp farm in Jabusha and Telok areas.

The route is planned to connect to Khulna-Mongla Road (NH-7) at existing at-grade intersection in Teelok area where 5m wide Kudir Bat Tala Sarak road exists to lead to Abdul Wadud Memorial Hospital.

The ending point is located 4.8km far from the ferry terminal at Rupsa East.

(2) Alternative-2: Mobility Scheme

The river crossing point of this route is located 2.0 km from Rupsa Ferry on the south of Khulna Shipyard, and the total length is estimated at 9.234 km.

This route is planned to run on the same route as Alternative-1 in the first 1.0 km stretch to pass through open spaces in Krishnanagar area.

The route will turn eastward and connect with Batiaghta Road (F7606) at Sta.1+410, and to cross the Hatia River of which width is about 60 m at Sta. 1+550.

The route is planned to pass through open spaces such as paddy land and coconut farm from Sta. 1+800 to Sta.3+900 in Mouza-Dubi, Alutala and Khola Baria areas.

The route is planned to pass open space in between parallel channel and Harin Tana village with a few disturbances up to Sta. 4+900.

It is so inhabited area in Amitala that the route will affect a cluster of homesteads and it will be necessary to be relocated in groups.

The route will cross Laban Chara Main Road (Western Dyke Road) by a grade separation structure because the elevation of approach road is too high to connect directly even though the dyke road comes inside to some extent. However, Laban Chara Main Road will have access roads to connect to the SSKB after the approach road becomes at-grade.

The route will run to cross the Rupsa River in between Steel Mill and Rice Mill Groups at Sta.6+100.

After crossing the Rupsa River, the route will fly over Char Rupsa Road (Eastern Dyke Road) as the same way of Western Dyke Road.

Although the route is planned to pass through open spaces from Sta.7+000 to Sta. 8+500 such as agricultural land and fishery ponds, some scattered homesteads will be affected by the route due to comparatively high density.

The route will run eastward in open spaces, and to connect with Jabusa Road at Sta.8+600 so as to avert the Bulbul Dairy Farm.

The route will run eastward to cross the Molonghata Canal of which width is about 30m at Sta. 8+565, and to pass through open spaces mainly agricultural land and fishery ponds, and is planned to connect to Khulna-Mongla Road (NH-7) in Amda Bad area where it is approximately 1.0km far from the existing intersection between NH-7 and Jabusa Road.

The ending point is located 3.6 km far from the ferry terminal at Rupsa East.

(3) Alternative-3: Accessibility Scheme

The river crossing point of this route is located 1.0 km from Rupsa Ferry on the north of Khulna Shipyard, and the total length is 7.758 km.

Accordingly, this route is the nearest to Rupsa Ferry and the shortest among alternatives.

This route is planned to run on the same route as Alternative-2 in the first 3.7 km stretch to pass through open spaces in Krishnanagar, Mouza-Dubi, Alutala and Khola Baria area.

The route is planned to divert from Alternative-2 at Sta.3+600 to run eastward in the built-up area of the southern part of Khulna City, and accordingly it runs parallel to Khulna-Satkhira Road to keep 1.5 to 2 km apart.

Therefore, it is expected to provide good accessibility to the built-up area even though considerable adverse social impacts are estimated.

The route is planned to avert primary controls of public facilities such as mosque, primary school and cemetery in Matia Khali area. However, it is inevitable to demolish a densely inhabited area, and it is necessary to relocate affected persons on large scale.

The route continues to pass through residential area to keep distance from Khulna Shipyard, and will run to cross Rupsa Stand Road (Western Dyke Road) by a grade separation structure because the approach bridge of the Rupsa Bridge is planned to become the elevated viaduct so as to secure the navigation clearance of the Rupsa River.

After crossing the Rupsa River, the route will fly over Char Rupsa Road (Eastern Dyke Road) as the same way of Western Dyke Road, and it will pass on the north of Jahanabad Sea Foods Ltd. in the industrial area.

Although the route is planned to pass open spaces such as agricultural land and shrimp farm so as to minimize adverse social impacts, some homesteads will be affected by the route from Sta. 7+200 to Sta. 7+800 due to keeping distance from Molonghata Khal/Canal.

The route is planned to cross the Molonghata Canal of which width is about 30 m at Sta. 7+415, and to connect to Khulna-Mongla Road (NH-7) in Elaipur area where 3 m wide Khorar Bat Tala road exists and connects with the causeway toward the Atherobaki River.

The ending point is located 1.8 km far from the ferry terminal at Rupsa East.

5.2 Bridge Options

5.2.1 Rupsa Main Bridge

(1) Conclusion of Phase 1 Study

The conclusion of the Phase 1 Study on the type and size of the Rupsa main bridge is summarized as follows:

- Concrete bridge was preferred to steel bridge from economic and maintenance reasons.
- The span length of about 100 m up to 200 m was revealed to be the most economical range by comparing the combined super- and substructure costs. From this fact, PC girder type was recommended but cable stayed type was not. As a conclusion, the PC box girder of 100 m class in span length was recommended as the most conventional and therefore economical selection.
- For foundation, RC bored pile was recommended from economical view point and experience in Bangladesh.

(2) Superstructure Options for Phase 2 Study

As regards the superstructure type, the above conclusion of the Phase 1 Study is consistent with the recent experience of construction of major bridges in Bangladesh. In the last decade, Meghna, Meghna-Gumti and Jamuna Bridges were constructed all by the PC box girder of similar span length using balanced cantilever segmental technique. Paksey Bridge is now in process toward construction by following the same suit.

As the Phase 2 Study started by reviewing the Phase 1 Study, a new type of extradosed PC box girder arose as an alternative to the conventional PC box girder for the advantage that the type could make girder depth lower and consequently shorten the approach bridge. The type was developed in France to seek more effective use of PC girder section, but so far its actual practices have been implemented mainly in Japan except a case in Philippine.

In view of such circumstances, in the Phase 2 Study, these two types of PC box girders will be studied in span range of 100 to 200 m as alternatives for the Rupsa main bridge. Also, the possibility of continuous span and rigid frame arrangement will be studied.

(3) Foundation Options for Phase 2 Study

In Bangladesh, RC bored piles have been used for major bridge construction where deep foundation is required, Meghna and Meghna-Gumti Bridges are the example. However, by the recent advancement of driving technique, the construction of large diameter tubular steel piles became practical. Tubular steel piles are light in weight so that advantageous in deep foundation compared to heavy RC bored piles due to self-weight. It may be the reason why Jamuna Bridge adopted tubular steel piles.

In such circumstances, in the Phase 2 Study, the most suitable pile and size for the Rupsa main bridge will be selected by studying these two types.

5.2.2 Approach and Canal Bridges

The conclusion of the Phase 1 Study for the approach bridge that is the standard PC I-section girders of 30 m in span length composite with RC deck slabs, will be reviewed in detail based on the soil boring and topographic data obtained in the Phase 2 Study.

Also, canal bridges will be designed based on these newly obtained site data.