No.

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
JAMUNA MULTIPURPOSE BRIDGE AUTHORITY (JMBA)

The Feasibility Study of
Padma Bridge in
The People's Republic of BANGLADESH

FINAL REPORT

Volume 4

TOPOGRAPHIC SURVEY AND GEOTECHNICAL INVESTIGATION

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NIPPON KOEI CO., LTD.
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STRUCTURE OF FINAL REPORT

The Feasibility Study of Padma Bridge

Final Report

(Vol. 4 Topographic Survey and Geotechnical Investigation)

Table of Contents

List of Table

Appendix 3

Appendix 4

List of Figure

Appendix 3

Appendix 4

Appendix-3 Topographic and Bathymetric Surveys

Chapter 1 Topographic and Bathymetric Surveys for Site-1 Paturia-Goalundo and Site-3 Mawa-Janjira

1.1 GENERAL

The Study Area for the Topographic Survey was selected at two alternative areas based on the result of screening of alternatives.

A3 These study areas cover the area proposed for new bridge construction on the Padma River and associated regions as shown in the following Figure1.1.1.

Topographic survey and bathymetric survey were carried out along two followings planed area,

- Paturia – Goalundo and
- Mawa – Janjira, respectively.

The locations are shown in Figure1.1.2 and Figure1.1.3.

The objective of the Survey for this stage is to help the selection of final proposed area with further studies.

This Survey has two majors' activities, one is Field Topographic Survey Works of the approach road and another one is Bathymetric Survey of the river of the proposed area.

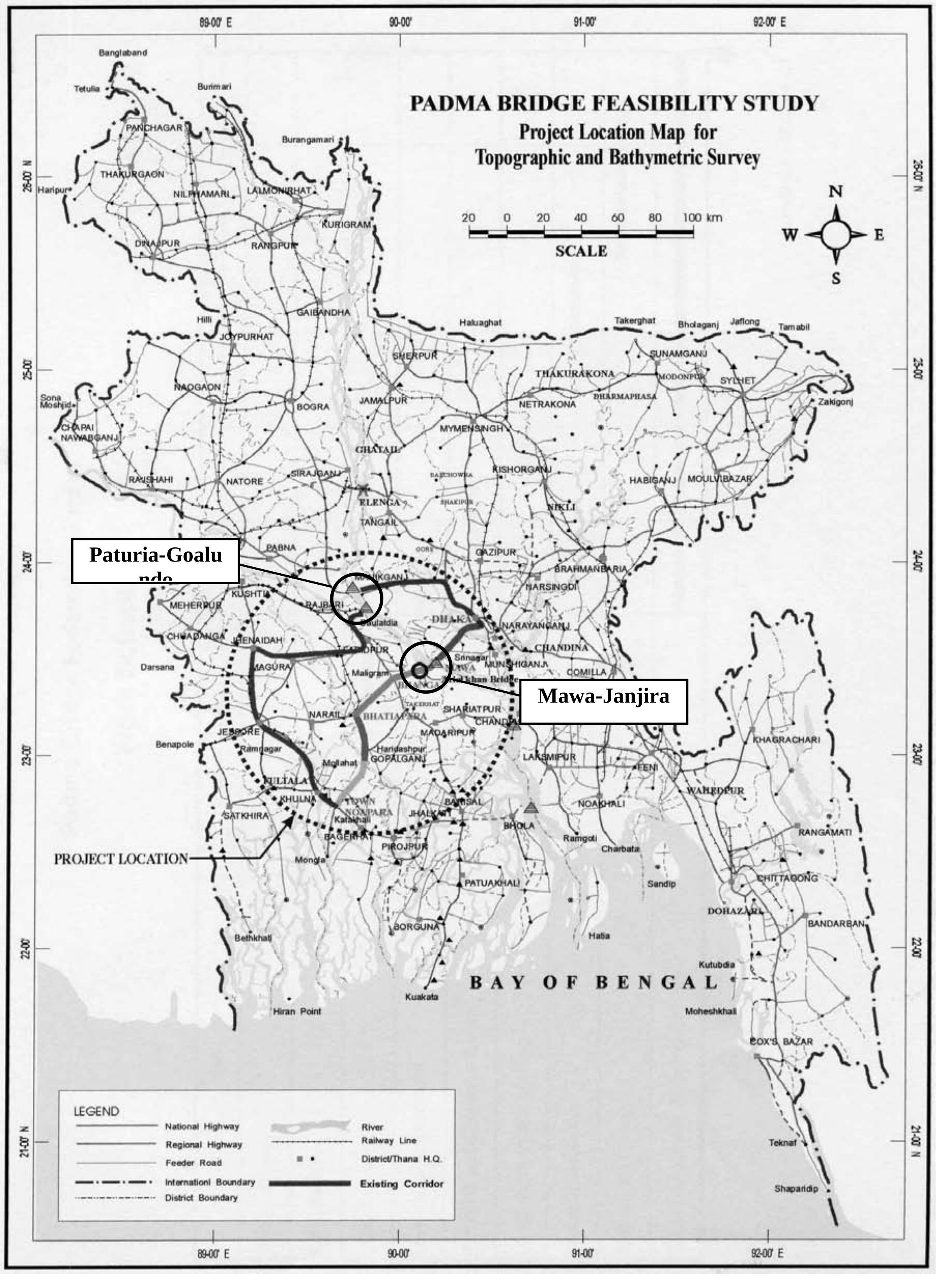


Figure 1.1.1 Study Area

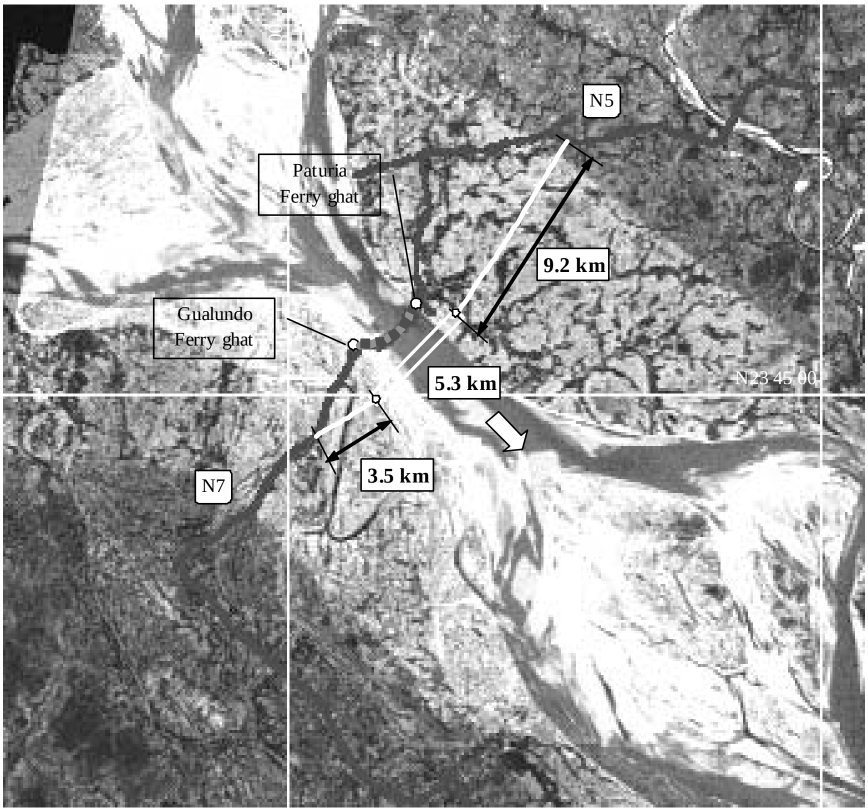


Figure 1.1.2 Topographic Survey Area (Paturia-Goalundo)

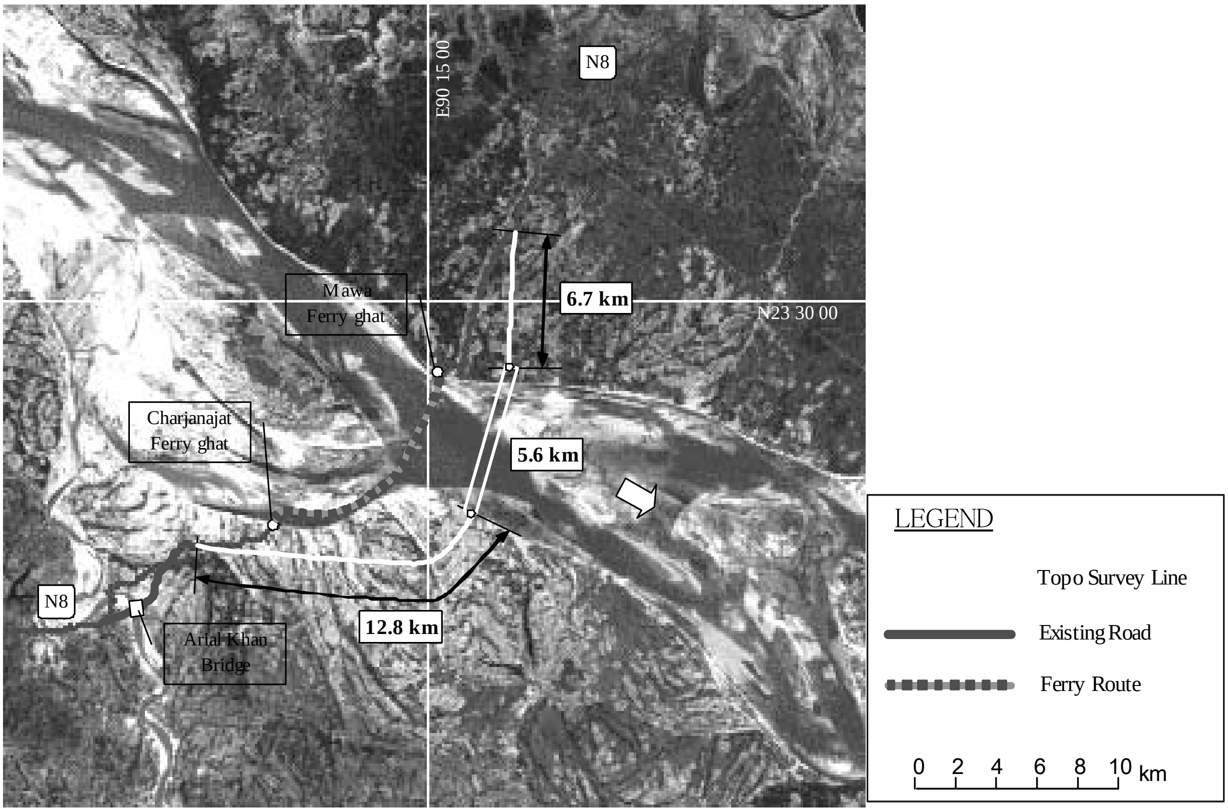


Figure 1.1.3 Topographic Survey Area (Mawa-Janjira)

1.2 OVERVIEW OF STUDY AREA

1.2.1 Topography

The alignment passes through the mature delta of the Ganges flood plain. The Padma receives flood water from the Ganges and the Jamuna. The area does not receive extensive silt deposits any more, nor is it subjected to much diluvion. (Geography of Bangladesh, Haroun Er Rashid, 1991). Land types are Medium High Land and Medium Low Land (The Geography of the Soils of Bangladesh, Hugh Brammer,1996). The topography of the active flood plain of the Ganges River and its adjoining meander flood plain comprises a low ridge and basin relief crossed by channels and creeks. Local difference in elevation are generally less than 1m. The flood plains are studded with swamps. The areas are inundated upto a depth of about 2m every year. Houses, markets, roads etc are constructed on built up lands. The annual inundation occurs due to rise in Ganges water; which starts rising in May and usually reaches peak by late-August / early September.

1.2.2 Location of Site

The proposed Paturia- Daulatdia area takes off near 76th km of N5 Highway (Dhaka Aricha Highway), near Mahadebpur Market, Mahadebpur union, Shibaloy P.S. of Manikganj district: Then it passes through Ulail and Sharisha bari village of Ulail union, and Darikandi village of Aroa Union of Shibaloy P.S. of Manikganj district. Then it crosses the Padma River and reaches Uttar Daulatdia village, Daulatdia union, Goalondo P.S. of Rajbari district. Then it crosses Nazim Uddin Fakir Para, Daulatdia union, Goalondo P.S. of Rajbari district. Finally it meets the N7 Highway (Faridpur- Daulatdia Highway) at about 4 km from Daulatdia.

The proposed Mawa- Janjira area takes off from Dhaka-Mawa Highway (N8 Highway) from a place about 30 km from Dhaka at Bejgaon village, Patabhog union, Sreenogar P.S. of Dist. Munshiganj. Then it passes through Kazir Pagla village, Medini Mandol union; Mochua village, Haldia Union and Wari village, Kumerbhog union of Louhajong P.S of Dist Munshiganj. Then the alignment crosses the Padma River and reaches Majhikandi village, Naoduba union, Janjira P.S. of Shariatpur district. Then it crosses Latif Fakir's village, Dhali Kandi and Majid Dhali's Kandi villages of Naoduba union, Janjira P.S. of Shariatpur district. Then it meets the under construction N8 Highway at Sikderkandi village, Matbor Char union, Shibchar P.S. of Madaripur District.

1.3 METHODOLOGY

1.3.1 Scope of Works

The scope of works covers the following activities in each study area (Paturia-Goalundo and Mawa-Janjira).

- Installation of Concrete Control Points
- Installation of Bench Mark
- Longitudinal Profile Leveling and Centerline Survey
- Topographic Survey
- Bathymetric Survey for the Padma River Section

1.3.2 Coordinates System and Datum Level

The local coordinates system was adopted and was related to the coordinates system of the relative civil construction project and existing road.

The datum level also was related to the hydrological data, which is used to analyze the high water level for the bridges of this project.

The horizontal and vertical control data in the vicinity of the proposed bridge crossing was collected from Survey of Bangladesh (SOB).

The survey charts have been prepared on Bangladesh Traverse Marcator (BTM) Projection. The parameter used for conversion of WGS-84 data into BTM coordinates are as follows;

Ellipsoid	:	Everest Modified
Projection	:	Transverse Mercator
Latitude Origin	:	0^{o} 00’ 00”.0
Central Meridian	:	90^{o} 00’ 00”.0
Scale factor	:	0.99960
False Easting	:	500,000.00m
False Northing	:	-2,000,000.00m
Semi-major axis	:	6,377,298.52400
Semi-minor axis	:	6,356,097.52000
Inverse Flattening 1/F	:	300.80170000
Rotation X	:	0
Rotation Y	:	0
Rotation Z	:	0
Translation X	:	-288.000m
Translation Y	:	-735.000m
Translation Z	:	-255.000m

1.3.3 Establishment of Control Points

Prior to the beginning of the survey, 9 (nine) Concrete Control Points were erected along the planned line. The conditions of control point location were; to be useful for control survey and topographic survey work; remain up to construction stage and easy to find, etc. The pillar was buried 0.6m in the ground below and the remaining 0.1m was above ground and flag of signboard was stood near by for identification (refer to 4 (5)).

Each control point was accompanied by a clear and intelligible monograph comprising a brief description of the location, sketch with distance from near landmarks, numeric photograph and 3 dimension coordinates data (refer to 4 (1)) .

The control point (GPS Reference Station) was established by using Differential Global Positioning System (DGPS). The coordinates of these points were determined by GPS observations.

The horizontal control was established by traverse with reference to grid coordinates established earlier by GPS observation. The close circuit was done by traverse network for the entire area. The traversing was done by Total station.

The accuracy of linear closure was less than 1/8,000.

1.3.4 Establishment of Bench mark

4 nos. of existing National Bench Mark (BM) at prominent places were used for control survey and leveling. Each BM point was accompanied by a clear and intelligible monograph comprising a brief description of the location, sketch with distance from near landmarks, numeric photograph and 3 (three) dimension coordinates data (refer to 4 (1)).

1.3.5 Connection and Longitudinal Profile Leveling

The vertical control was carried out with reference to existing National Bench Mark available near by the area and closing the same Bench Mark. While conducting the leveling line, the horizontal control points were connected so that, they can be treated as BM vertical control points. The height was taken with reference to Public Works Department Datum (PWD Datum).

The longitudinal section was taken along the proposed line with an interval of 50m apart and at every changing point. The spot height was taken each side by using Total Station.

The observation error between forward and backward or the closure error in connecting to known point was less than $15\sqrt{s}$ mm, s being the observation distance in km.

1.3.6 Topographic Survey

Topographic Survey was carried out for a strip of 100m wide along the proposed line. Topographic Survey was carried out with reference to traverse station established earlier. All details were picked up such as Landmarks, structures and topographic features such as houses, buildings, bridges, culverts, electricity poles, telephone poles, land use boundaries, water courses, road shoulders edges, pavement edge, rails, ponds, rivers, embankments, depressions and spot heights etc.

1.3.7 Bathymetric Survey

For position fixing, Differential Global Positioning System (DGPS) was used, the data was received from satellites in World Geodetic System- 84 (WGS-84) and transmitted differential corrections from the Reference Station. The position fixing on the cross-section line was done by the mobile GPS set on board the Survey boat and radio link that receives positional data from the satellites and corrections from Reference Station. The WGS-84 data receive at the mobile GPS set onboard and at the Reference Station ashore were converted (on line) into Bangladesh Traverse Market (BTM) co-ordinates by using hydro software.

The positions and depths on the cross section were obtained simultaneously GPS Receiver and Echo Sounder fitted on board the survey boat (refer to 4 (5)).

The positional and the sounding data collected in were backed up in floppy, which shall subsequently be brought to the office for processing purpose.

The soundings were taken for proposed line on the each line an interval of 50m apart and measurement of depths/soundings on the line by using MS-26 Echo Sounder. The depths/soundings shown on the charts are reduced to PWD level in the area. Therefore, in order to know the actual depth at any spot of the chart the following calculation was done.

Actual depth at any spot of the chart = Water Level (from the gauge) + Reduced depth

The level of tide was also recorded with an appropriate time intervals and used for the correction for the depth reading.

1.4 RESULT OF TOPOGRAPHIC AND BATHYMETRIC SURVEYS

The quantities of activities which have been done in each study area are shown in the following table.

Table 1.4.1 Quantities of Activities for Each Study Area

Paturia – Goalundo

	Control Point (pts)	Longitudinal Profile Leveling (km)	Topographic Survey (ha)	Bathymetric Survey (km)
Left Bank Side	2	9.2	20	
Right Bank Side	2	3.5	20	
In the River				5.3
Total	4	12.7	40	5.3

Mawa – Janjira

	Control Point (pts)	Longitudinal Profile Leveling (km)	Topographic Survey (ha)	Bathymetric Survey (km)
Left Bank Side	2	6.7	67	
Right Bank Side	3	12.8	128	
In the River				5.6
Total	5	19.5	195	5.6

All topographic survey data were properly processed by using SDR Mapping & Design; and Bathymetric Survey Data was processed by Hydro Pac software output by Auto CAD 2002 format. The survey drawings were made to scale H 1:1000 & V 1:200.

Survey results of the following along with photos and detailed information were compiled into Technical Report, which had been submitted to JMBA separately in November 2003.

1) Description of Control Points / Bench Marks
2) Table of Result for Traverse
3) Table of Result for Leveling
4) Table of Result for Bathymetric
5) Photograph
6) Drawings

Table 1.4.2 Description of Location of Control Points

Sl.	Location	Position	Identification of Control Point	Remarks
Paturia – Goalundo				
1	Vill: Mohadebpur Market Union: Mohadebpur P.S.: Shibaloy Dist: Manikganj	Starting point for Paturia side on the Dhaka – N5 National Highway	JPG1	The proposed bridge approach starts on the left side from 76th km of Dhaka-Aricha National Highway (N5) at Mohadebpur Market
2	Vill: Darikandi Union: Aroa P.S.: Shibaloy Dist.: Manikganj	Land point on Paturia side	JPG2	
3	Vill: Uttar Daulatdia P.S.: Goalundo Dist.: Rajbari	Land point on Daulatdia (Goalundo) side	JPG3	Near the house of Mr. Aker Shaikh
4	Vill: Ghunapara Daulatdia Municipality P.S.: Goalundo Dist: Rajbari	Meeting point at Daulatdia side with N7 highway	JPG4	On the left side of N7 highway about 4 km from Daulatdia
Mawa - Janjira				
1	Near Srinagar Bridge Vill: Pashim Bejgaon Union: Patabhog P.S.: Srinagar Dist: Munshiganj	Starting point for Mawa side on Dhaka-Mawa road (National Highway N8)	JMC1	The proposed bridge approach road starts on the left side from approximately 30th km of Dhaka-Mawa Highway (National Highway N8) at Vill: Bejgaon Union: Patabhog P.S.: Srinagar Dist: Munshiganj
2	Vill: Wari Union: Kumarbogh P.S.: Louhajong Dist: Munshiganj	Land point on left bank	JMC2	
3	Vill: Majhikandi Union: Purba Naoduba P.S.: Jajira Dist: Shariatpur	Land point on right bank	JMC3	
4	Vill: Dhalikandi Union: Naoduba P.S.: Janjira Dist: Shariatpur	Land point on curve	JMC4	
5	Vill: Sikderkandi Union: Matbor Char P.S.: Shibchar Dist: Madaripur	Meeting point of Janjira side with National Highway N8	JMC5	Meet with the under construction National Highway N8, before the under construction Arail Khan Bridge

Note: Vill = Village, P.S. = Police Station, Dist = District

Table 1.4.3 Particulars of BMs

Sl..	A3 Location	Identification	RL in mPwD
Paturia – Goalundo			
1	Vill: Goalkhali P.S.: Shibalay Dist: Manikganj	JICA BM No. 6186	10.544 mPwD
2	VIP Rest House P.S.: Goalundo Dist: Rajbari	JICA BM No. 6185	11.133 mPwD
Mawa - Janjira			
1	Vill: Kumarbhog P.S.: Louhajong Dist: Munshiganj	F.M BM No. 1714	7.495 mPwD
2	Char Janajat Ferry Ghat P.S.: Shibchar Dist: Madaripur	F.M BM No. 228	8.091 mPwD
3	Omar Bepari Primary School P.S.: Shibchar Dist: Madaripur	SoB BM No. 1009	7.323 mPwD
4	Vill: Sanyasir Char P.S.: Shibchar Dist: Madaripur	FM BM No. 230	7.690 mPwD

Table 1.4.4 Three Dimensional Positions of Control Points

Sl..	Point ID	Longitude	Latitude	Level in mPwD
Paturia – Goalundo				
1	JPG-1	488400.028	637415.098	10.389 mPwD
2	JPG-2	482845.990	630082.756	9.282 mPwD
3	JPG-3	479021.604	626174.480	9.388 mPwD
4	JPG-4	476098.129	624463.027	11.374 mPwD
Mawa – Janjira				
5	JMC-1	529732.160	601726.677	8.567 mPwD
6	JMC-2	528919.027	595252.260	6.867 mPwD
7	JMC-3	527941.371	589674.817	7.101 mPwD
8	JMC-4	526094.093	587390.689	7.142 mPwD
9	JMC-5	516641.825	587837.246	5.860 mPwD

Table 1.4.5 Summary for Height of Control Point

Study Area	Control Point	Height (m PWD)
Paturia - Goalundo		
Paturia	JPG1	10.389
Paturia	JPG2	9.282
Goalundo	JPG3	9.398
Goalundo	JPG4	11.375
Mawa - Janjira		
Mawa	JMC1	8.570
Mawa	JMC2	6.867
Janjira	JMC3	7.100
Janjira	JMC4	7.140
Janjira	JMC5	5.871

Chapter 2 Topographic Survey for Selected Mawa-Janjira Site

2.1 GENERAL

The Study Area for the Topographic Survey was selected at Mawa – Janjira area based on the result of screening of alternatives.

The study area covers the area for new bridge construction on the Padma River and associated regions as shown in the following Figure 2.1.1.

Topographic survey and bathymetric survey were carried out along the following location as shown in Figure 2.1.2.

The objective of the Survey for this stage is to help the preliminary design of bridges, approche road, and river facilities.

This Survey has two majors’ activities, one is Field Topographic Survey Works for the along the alignment, riverbank and another one is Bathymetric Survey of the river of the proposed area.

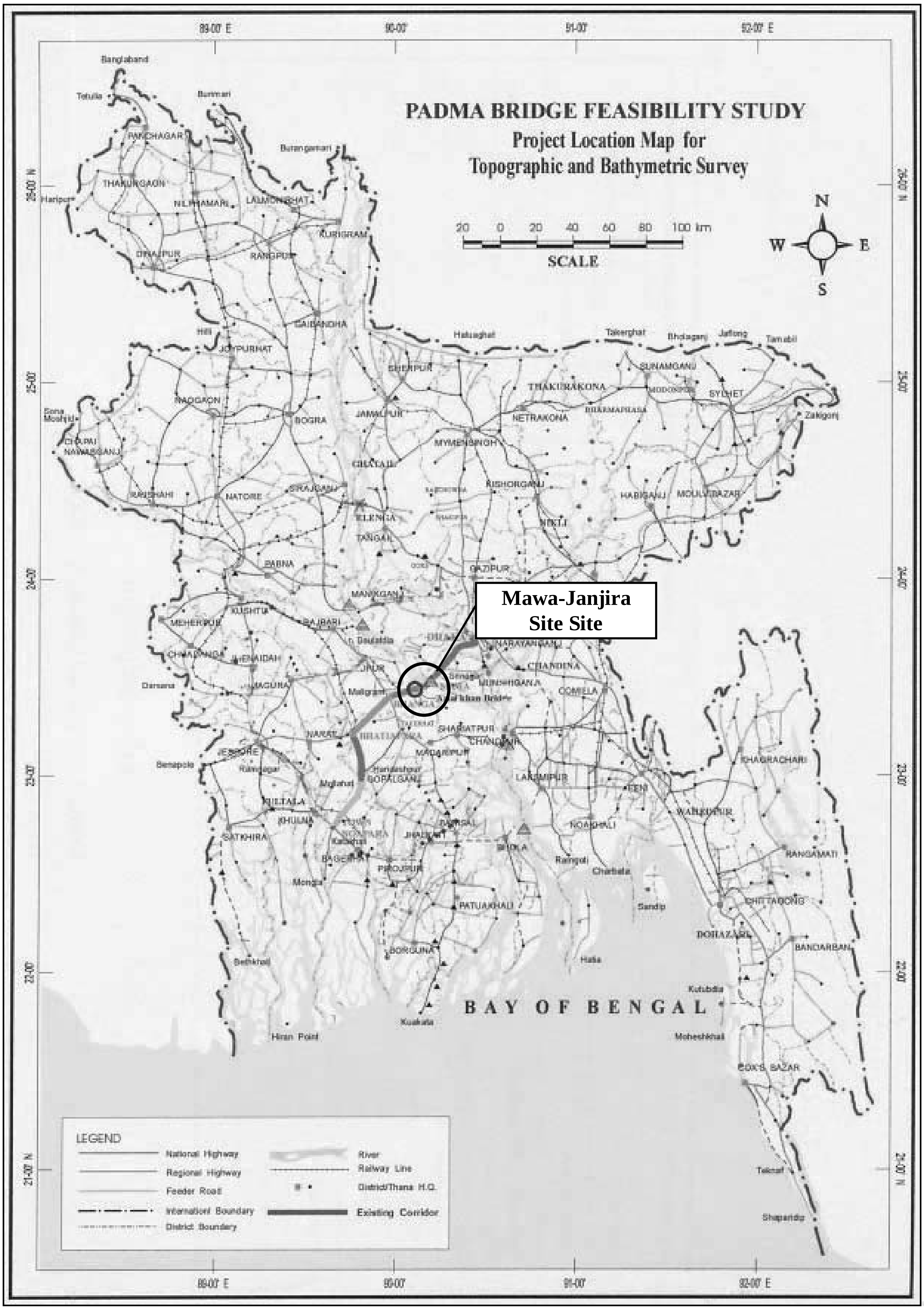


Figure 2.1.1 Location Map of Study Area

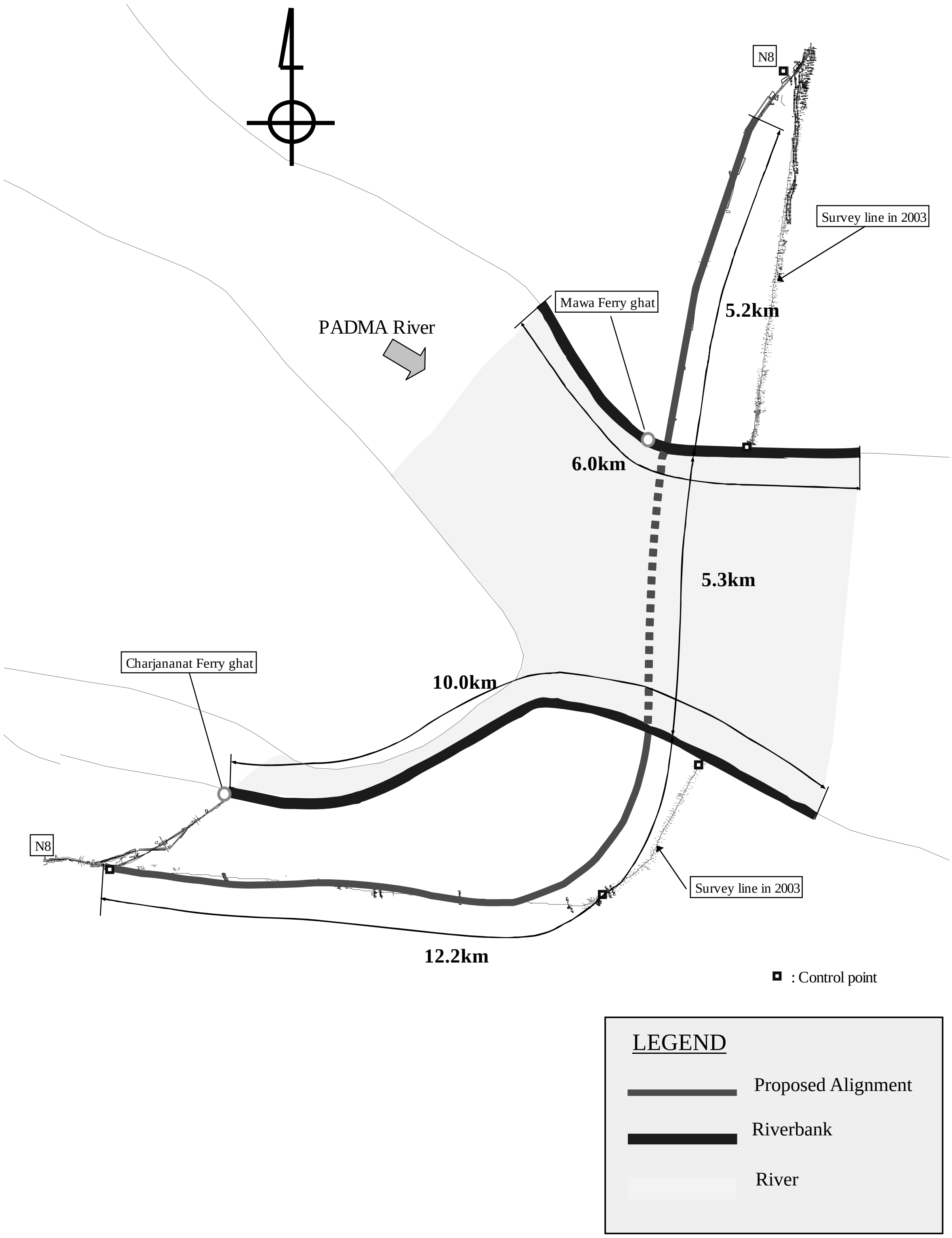


Figure 2.1.2 Topographic Survey Area

2.2 OVERVIEW OF STUDY AREA

2.2.1 Topography

The alignment follows the existing road at Mawa site and at Janjira site it passes through the villages and cropped land. The proposed alignment of approach road at Janjira site finally meets the existing road at about 12km away from the bridge point meeting the riverbank at Jnajira site. The area except the existing roads on both side of the river are flood plain and every year it is inundated by the water of the Padma river. The survey area comprises medium high, medium low and low land. At Janjira area, the proposed alignment is crossed by existing waterways and some villages. Land elevation is between 4.0m to 7.5m (PWD). Houses, markets, roads, etc. are constructed in the survey area.

2.2.2 Climate

Bangladesh is a tropical monsoon climate and the climate of the project area is characterized by high temperature, heavy rainfall and excessive humidity. Mean monthly temperature ranges between 18 deg. Centigrade in January and 30 deg.Centigrade in April-May. The average maximum and minimum summer temperature are 34 deg. Centigrade and 21 deg. Centigrade respectively. Mean annual rainfall varies from 1500mm to 2000mm in the Gange basin. The maximum rainfall occurs from mid-May to August..

2.2.3 Vegetation

Rice is the main agricultural product of the region. Some wheat, pulses etc are also grown. Floating aquatic plants covers large areas of flooded land in the monsoon season and persist in some beels and stagnant waterways during the dry season. Water hyacinth and many other aquatic plants including nitrogen fixing water fern and many species of algae occur in the inundated flood plain during the monsoon.

2.2.4 Location of Site

The survey work starts from near Stringar bridge 5.2km away from the riverbank at Mawa site and starting from the bridge point on the right bank of the river in village Majikandi of Janjira Upazilla, Soriotpur district at Janjira site and finally it meats the existing road at village Pachchor, Shibchar Upazilla of Mandaripur district. This survey area covers the area of finally selected aite for construction of Bridge over the Padma river and its approach roads on both sides of the river as shown in the Figure 2.1.2.

2.3 METHODOLOGY

2.3.1 Scope of Works

The survey work comprises the checking of the controlled points installed in the 1st phase of the work, identification and demarcation of centerline in the field longitudinal profile survey, cross section measurement, bathymetric survey, topographic features survey, etc. by GPS and Total Station. The scope of works under the project covers the followings activities in the area of the proposed Padma Bridge:

The scope of works covers the followings activities in the study area.

- Check Survey of Installed Control Points
- Centerline Setting
- Connection and Longitudinal Profile Leveling

- Cross Section Survey
- Topographic Survey
- Bathymetric Survey for the Padma River Section

2.3.2 Coordinates System and Datum Level

The local coordinates system was adopted and was related to the coordinates system of the relative civil construction project and existing road.

The datum level also was related to the hydrological data, which is used to analyze the high water level for the bridges of this project.

The horizontal and vertical control data in the vicinity of the proposed bridge crossing was collected from Survey of Bangladesh (SOB).

(a) Horizontal Control:

The Local Grid coordinate system was adopted for Both Topographic and Hydrographical surveys. The Charts were prepared on Bangladesh Travers Marcator (BTM). The parameter used for conversion of WGS-84 data into BTM coordinates are as follows:

Ellipsoid	:	Everest Modified Bangladesh
Projection	:	Transverse Mercator
Latitude Origin	:	0° 00’ 00”.0
Central Meridian	:	90° 00’ 00”.0
Scale factor	:	0.99960
False Easting	:	500,000.00m
False Northing	:	-2,000,000.00m
Semi-major axis	:	6,377,298.52400
Semi-minor axis	:	6,356,097.52000
Inverse Flattening 1/F	:	300.80170000
Rotation X	:	0
Rotation Y	:	0
Rotation Z	:	0
Translation X	:	-288.000m
Translation Y	:	-735.000m
Translation Z	:	-255.000m

Horizontal control reference to JMC1 established earlier in the project area has been used as primary control point for survey of this project area.

(b) Vertical control (Datum level)

All elevation references are in meter and reduced to local PWD Datum. Control points JMC1 and JMC5 were used for left bank (Mawa side) & right bank (Janjira side) respectively as vertical reference (Annex-1).

For Hydrographic survey a TIDE Table in PWD datum was prepared with respect to JMC1 (Annex-3).

2.3.3 Check Survey of Installed Control Points

The five (5) concrete control points were established in Mawa-Janjira area last year. However, the one of the concrete control points which was established in riverbank of Janjira (JIMC3, ref. Table 4.1 Technical Report on Topographic Survey Oct. 2003) was disappeared due to riverbank erosion.

Prior to the beginning of the survey works, all four (4) remaining concrete control points were confirmed by traverse survey the followings method;

A Traverse survey was carried out to establish control network system for survey of the whole project area. Two separate closed traverses were run at each bank using Electric Total Station. To obtain the Azimuth & connecting the both traverse (river crossing) RTK GPS was used. Bordwitch method was used for traverse corrections (Annex-2).

The accuracy of linear closure was less than 1/8,000.

These Traverse points, later on, were used as Temporary Control Points for carrying out all survey activities. Also these Traverse Points were connected to PWD datum level by double run level fly.

Each control point was accompanied by a clear and intelligible monograph comprising a brief description of the location, sketch with distance from near landmarks, numeric photograph and 3 dimension coordinates data.

2.3.4 Centerline Setting

The centerline of the proposed alignment has been set on ground by Total station at 50 m intervals along the route and demarcated in the field by inserting pegs. Coordinates of each point have been determined from the nearest Temporary Control Points.

2.3.5 Connection and Longitudinal Profile Leveling

The level survey was carried out along the centerline of the proposed alignment and ground elevation was measured at every 50 m interval & at every changing points.

The height was taken with reference to Public Works Department Datum (PWD Datum).

The observation error between forward and backward or the closure error in connecting to known point was less than $15\sqrt{s}$ mm, s being the observation distance in km.

2.3.6 Cross section Survey

The cross-sectional survey conducted at 50 m interval perpendicular to the alignment extending upto 100 m on both sides of the centerline.

Cross sections of the riverbanks on both sides parallel to the river crossing line have been measured at 200 m interval along the bank line and 250 m meter towards the landside from the bank line. The survey of a block of 4000m x 1500m at the right bank in addition to 200 m riverbank sections has been carried out.

Long sections of the existing canals crossing the proposed alignment on both sides of the proposed alignment have been measured.

2.3.7 Topographic Survey

The topographic survey was carried out generally for a strip of 100m wide along the proposed alignment and for for a strip of 250m wide along the riverbank.

The topographic survey was carried out with reference to traverse station established earlier.

All details were picked up such as landmarks, structures and topographic features such as houses, buildings, bridges, culverts, electricity poles, telephone poles, land use boundaries, water courses, road shoulders edges, pavement edge, rails, ponds, rivers, embankments, depressions and spot heights etc.

2.3.8 Bathymetric Survey

To obtain river bed level, the hydrographic survey has been carried out using DGPS and Echosounder. Hydrographic survey software PDS1000 used for online data collection and navigation. The position and its depth have been recorded simultaneously by GPS receiver and Echosounder fitted on survey boat.

The calibration of equipment (Bar Check) was carried out before starting of Hydro survey everyday. The TIDE table has been prepared from the gauge reading at every one-hour time interval (Annex-3).

Survey boat ran parallel to the river crossing line at 100 m interval. The survey covers 2000 m down to proposed alignment and 4000 m up at upstream. Also at Branch River cross line follows the same direction and intervals.

2.3.9 Equipment used for surveys

Digital survey was carried out for both Topographic and Hydrographic survey works. The equipment used for this project for survey works are as follows:

- Topographic survey equipment
  - GPS Total Station RTK Trimble 5700 with TSI Controller (data Logger)
  - Electronic Total Station
    Model : Sokkia Power Set 2010
    Model : Sokkia Set 3CII
    Model : Sokkia Set 2CII
    Auto Level
    GPS Magellan Tracker
    Walkie-talkie Motorola GP328
- Hydrographic survey equipment
  - GPS Trimble 4000RS (DGPS)
  - Radio link (Pacific Crest)
  - Echosounder Odom Echotrak MIKE-II
- Survey & Processing Software
  - Land survey software
    SDR Mapping & Design
    Eaglepoint, Microsurvey
  - Geodetic software
    Trimble office geometric
  - Hydographic survey software
    PDS1000
    AutoCAD suite

2.4 RESULT OF TOPOGRAPHIC SURVEY

The quantities of major activities which have been done in study area are shown in the following table.

Table 2.4.1 The Quantities of Activities for Study Area

Mawa – Janjira

	Check Survey of Installed Control Point (pts)	Longitudinal Profile Leveling (km)	Topographic Survey (ha)		Bathymetric Survey (km)
			Alignment	Riverbank	
Left Bank Side	2	5.2	117	150	
Right Bank Side	2	12.2	157	250	
In the River					71
Waterways		6 nos			
Total	4	17.4	274	400	71

All topographic data was processed by Eagle Point software, mapping and design have done by AutoCAD. Bathymetric Survey Data Processed by PDS-1000 and output given by AutoCAD software.

The Survey Drawing Scale:

Topographic Map	:	Scale 1:10,000	
Plan and Longitudinal Profile	:	Scale H = 1:4000	V = 1:400
Cross Section	:	Scale H = 1:2000	V = 1:2000
Cross Section for Riverbank and river	:	Scale H = 1:30000	V = 1:3000

The annex of the topographic survey is shown as follows;

Annex-1) Description of Control Points / Bench Marks
Annex-2) Result for Traverse Survey
Annex-3) TIDE Table in PWD
Annex-4) Photograph

Annex-1) Description of Control Points / Bench Marks

Description of Location of Control Points

Sl.	Location	Position	Identification of Control Point	Remarks
Mawa - Janjira				
1	Near Srinagar Bridge Vill: Pashim Bejgaon Union: Patabhog P.S.: Srinagar Dist: Munshiganj	Starting point for Mawa side on Dhaka-Mawa road (National Highway N8)	JMC1	The proposed bridge approach road starts on the left side from approximately 30th km of Dhaka-Mawa Highway (National Highway N8) at Vill: Bejgaon Union: Patabhog P.S.: Srinagar Dist: Munshiganj
2	Vill: Wari Union: Kumarbogh P.S.: Louhajong Dist: Munshiganj	Land point on left bank	JMC2	
3	Vill: Majhikandi Union: Purba Naoduba P.S.: Jajira Dist: Shariatpur	Land point on right bank	JMC3	Disappeared due to erosion
4	Vill: Dhalikandi Union: Naoduba P.S.: Janjira Dist: Shariatpur	Land point on curve	JMC4	
5	Vill: Sikderkandi Union: Matbor Char P.S.: Shibchar Dist: Madaripur	Meeting point of Janjira side with National Highway N8	JMC5	Meet with the under construction National Highway N8, before the under construction Arail Khan Bridge

Note: Vill = Village, P.S. = Police Station, Dist = District

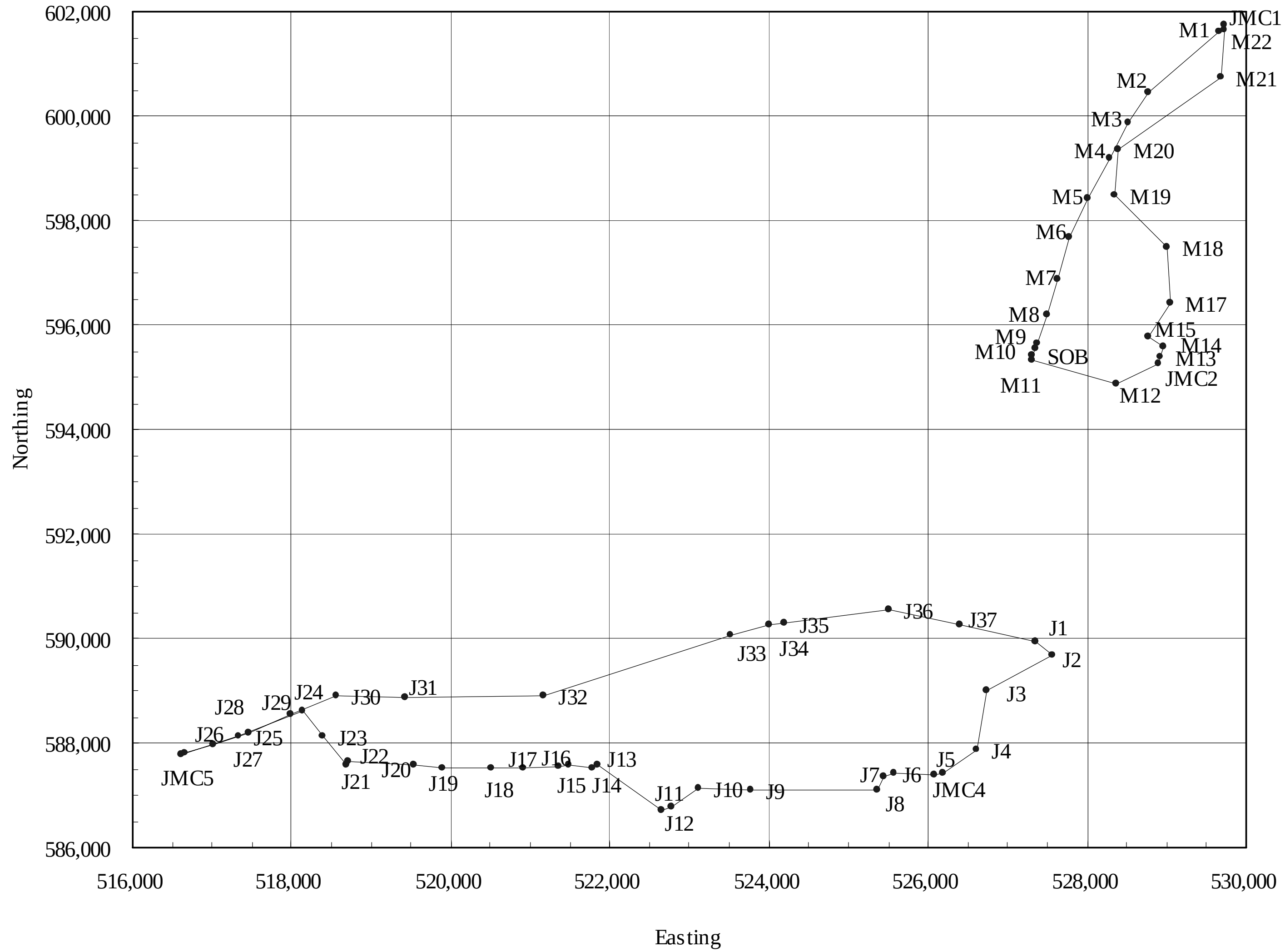
Particulars of BMs

Sl..	Location	Identification	Elevation in mPwD
Mawa - Janjira			
1	Vill: Kumarbhog P.S.: Louhajong Dist: Munshiganj	F.M BM No. 1714	7.495 mPwD
2	Char Janajat Ferry Ghat P.S.: Shibchar Dist: Madaripur	F.M BM No. 228	8.091 mPwD
3	Omar Bepari Primary School P.S.: Shibchar Dist: Madaripur	SoB BM No. 1009	7.323 mPwD
4	Vill: Sanyasir Char P.S.: Shibchar Dist: Madaripur	FM BM No. 230	7.690 mPwD

Three Dimensional Positions of Control Points

Sl..	Point ID	Longitude	Latitude	Elevation in mPwD
Mawa – Janjira				
5	JMC-1	529,732.160	601,726.677	8.567 mPwD
6	JMC-2	528,898.836	595,252.884	6.867 mPwD
7	JMC-3	Disappeared due to riverbank erosion		
8	JMC-4	526,082.488	587,374.056	7.142 mPwD
9	JMC-5	516,623.543	587,758.285	5.860 mPwD

Annex-2) Result for Traverse Survey



Traverse Survey Networks

Working Coordinate for Mawa Site (without Scale Factor)

ST No.	Observed Angle (ddd:mm:ss)			Observed Angle (Decimal)	Corrected Angle	WCB	Horiz. Length	Delta E (Sin)	Delta N (Cos)	Corrected Delta E	Corrected Delta N	Stn. Easting	Stn. Northing
JMC1												529732.160	601726.677
M1	188	57	36.30	188.96008333	188.96014549	208.75991197	126.821	-61.019	-111.177	-61.018	-111.177	529671.142	601615.500
M2	165	41	46.70	165.69630556	165.69636771	217.72005746	1455.346	-890.386	-1151.192	-890.378	-1151.195	528780.763	600464.305
M3	175	9	41.75	175.16159722	175.16165938	203.41642516	651.820	-259.040	-598.137	-259.037	-598.138	528521.727	599866.167
M4	181	4	0.00	181.06666667	181.06672882	198.57808454	714.231	-227.552	-677.013	-227.548	-677.014	528294.179	599189.153
M5	177	52	34.90	177.87636111	177.87642326	199.64481336	819.871	-275.631	-772.150	-275.627	-772.152	528018.552	598417.002
M6	174	9	54.00	174.16500000	174.16506215	197.52123662	778.670	-234.426	-742.544	-234.422	-742.545	527784.130	597674.456
M7	178	43	32.50	178.72569444	178.72575660	191.68629878	822.578	-166.616	-805.527	-166.611	-805.529	527617.519	596868.928
M8	181	58	18.10	181.97169444	181.97175660	190.41205537	701.312	-126.745	-689.764	-126.742	-689.765	527490.777	596179.162
M9	177	14	2.38	177.23399444	177.23405660	192.38381197	543.932	-116.651	-531.276	-116.648	-531.277	527374.129	595647.885
M10	188	36	2.13	188.60059167	188.60065382	189.61786857	110.350	-18.437	-108.799	-18.436	-108.799	527355.693	595539.086
SOB	168	44	12.30	168.73675000	168.73681215	198.21852239	130.244	-40.720	-123.715	-40.719	-123.715	527314.974	595415.371
M11	106	40	2.38	106.66732778	106.66738993	186.95533454	89.317	-10.816	-88.660	-10.815	-88.660	527304.158	595326.711
M12	119	1	51.10	119.03086111	119.03092326	113.62272447	1173.507	1075.172	-470.239	1075.178	-470.241	528379.336	594856.470
JMC2	136	0	10.38	136.00288333	136.00294549	52.65364773	653.469	519.497	396.415	519.500	396.414	528898.836	595252.884
M13	185	19	7.75	185.31881944	185.31888160	8.65659322	144.719	21.782	143.070	21.783	143.070	528920.619	595395.954
M14	120	30	20.80	120.50577778	120.50583993	13.97547482	195.528	47.221	189.740	47.222	189.740	528967.841	595585.694
M15	248	43	1.60	248.71711111	248.71717326	314.48131475	277.448	-197.953	194.401	-197.952	194.401	528769.889	595780.094
M17	155	34	2.63	155.56739722	155.56745938	23.19848801	679.193	267.546	624.277	267.550	624.276	529037.439	596404.370
M18	147	54	20.70	147.90575000	147.90581215	358.76594739	1065.118	-22.939	1064.871	-22.933	1064.869	529014.506	597469.239
M19	216	27	37.30	216.46036111	216.46042326	326.67175954	1213.758	-666.881	1014.139	-666.874	1014.137	528347.631	598483.376
M20	219	44	12.80	219.73688889	219.73695104	3.13218280	863.117	47.160	861.828	47.165	861.826	528394.796	599345.202
M21	138	40	18.90	138.67191667	138.67197882	42.86913384	1896.983	1290.567	1390.317	1290.577	1390.313	529685.374	600735.516
M22	192	45	51.60	192.76433333	192.76439549	1.54111266	903.304	24.294	902.977	24.298	902.976	529709.672	601638.491
JMC1	14	27	15.63	14.45434167	14.45440382	14.30550815	91.008	22.487	88.186	22.488	88.186	529732.160	601726.677
Sum =	3947	771	534.63	3959.99850833	3960.00000000		16101.644	-0.086	0.030	0.000	0.000		

Sum of Obs. Angle= **3959.99850833**
Theo. Sum Angle = **3960.00000000**
Misclosure = **0.00149167**
Angular Correction = **0.00006215**

Positional Misclosure= $\sqrt{\delta E^2 + \delta N^2}$
= 0.091 m

Adjustment to Delta Easting and Northing By Bowditch
Fractional Linear Error = 1 in 177121

Working Coordinate for Janjira Site (without Scale Factor)

ST No.	Observed Angle (ddd:mm:ss)			Observed Angle (Decimal)	Corrected Angle	WCB	Horiz. Length	Delta E (Sin)	Delta N (Cos)	Corrected Delta E	Corrected Delta N	Stn. Easting	Stn. Northing
J1												527352.776	589941.090
						288.11883483	992.952	-943.715	308.797	-943.715	308.768		
J37	179	45	20.80	179.75577778	179.75613746							526409.061	590249.858
						287.87497229	947.205	-901.482	290.736	-901.482	290.708		
J36	150	51	8.13	150.85225833	150.85261802							525507.579	590540.566
						258.72759031	1327.049	-1301.449	-259.403	-1301.449	-259.442		
J35	184	19	43.00	184.32861111	184.32897080							524206.130	590281.124
						263.05656111	198.737	-197.279	-24.025	-197.280	-24.031		
J34	165	43	59.60	165.73322222	165.73358191							524008.850	590257.093
						248.79014302	532.756	-496.668	-192.743	-496.668	-192.759		
J33	174	47	31.30	174.79202778	174.79238746							523512.182	590064.334
						243.58253049	2621.534	-2347.784	-1166.342	-2347.784	-1166.419		
J32	205	37	29.10	205.62475000	205.62510969							521164.398	588897.916
						269.20764017	1723.375	-1723.210	-23.832	-1723.211	-23.883		
J31	181	44	1.73	181.73381389	181.73417358							519441.187	588874.033
						270.94181375	885.244	-885.124	14.551	-885.125	14.525		
J30	148	37	13.10	148.62030556	148.62066524							518556.062	588888.558
						239.56247899	656.566	-566.079	-332.615	-566.080	-332.634		
J29	177	23	51.10	177.39752778	177.39788746							517989.982	588555.924
						236.96036645	640.327	-536.782	-349.118	-536.782	-349.137		
J28	184	5	17.83	184.08828611	184.08864580							517453.200	588206.787
						241.04901225	491.098	-429.727	-237.722	-429.728	-237.736		
J27	185	27	42.60	185.46183333	185.46219302							517023.473	587969.051
						246.51120527	403.693	-370.242	-160.900	-370.242	-160.912		
J26	144	15	44.20	144.26227778	144.26263746							516653.230	587808.139
						210.77384274	58.022	-29.687	-49.852	-29.687	-49.854		
JMC5	31	56	57.88	31.94941111	31.94977080							516623.543	587758.285
						62.72361353	799.912	710.967	366.586	710.966	366.563		
J25	175	14	29.00	175.24138889	175.24174858							517334.510	588124.848
						57.96536211	942.837	799.269	500.111	799.269	500.083		
J24	275	40	59.80	275.68327778	275.68363746							518133.778	588624.932
						153.64899957	562.554	249.700	-504.100	249.700	-504.116		
J23	178	7	17.25	178.12145833	178.12181802							518383.478	588120.815
						151.77081759	627.845	296.970	-553.171	296.970	-553.189		
J22	57	52	5.00	57.86805556	57.86841524							518680.449	587567.626
						29.63923284	79.852	39.490	69.404	39.490	69.402		
J21	245	7	38.17	245.12726944	245.12762913							518719.938	587637.028
						94.76686197	829.952	827.081	-68.970	827.081	-68.994		
J20	183	51	4.50	183.85125000	183.85160969							519547.019	587568.033
						98.61847165	343.923	340.039	-51.538	340.039	-51.548		
J19	172	23	21.00	172.38916667	172.38952635							519887.058	587516.485
						91.00799801	624.578	624.481	-10.988	624.481	-11.006		
J18	177	20	21.60	177.33933333	177.33969302							520511.539	587505.479
						88.34769103	392.706	392.543	11.323	392.543	11.312		
J17	177	39	8.38	177.65232778	177.65268746							520904.082	587516.791
						86.00037849	446.260	445.173	31.127	445.173	31.114		
J16	171	54	10.00	171.90277778	171.90313746							521349.255	587547.905
						77.90351596	147.626	144.348	30.936	144.348	30.932		
J15	202	18	5.67	202.30157500	202.30193469							521493.603	587578.837
						100.20545064	291.810	287.193	-51.702	287.193	-51.711		
J14	139	28	5.42	139.46817222	139.46853191							521780.796	587527.126
						59.67398255	75.803	65.431	38.274	65.431	38.272		
J13	256	45	43.60	256.76211111	256.76247080							521846.227	587565.398
						136.43645335	1162.048	800.835	-842.032	800.835	-842.066		
J12	108	59	0.13	108.98336944	108.98372913							522647.062	586723.332
						65.42018248	147.390	134.034	61.308	134.034	61.304		
J11	159	5	34.88	159.09302222	159.09338191							522781.096	586784.636
						44.51356439	473.871	332.221	337.910	332.220	337.896		
J10	227	56	0.00	227.93333333	227.93369302							523113.316	587122.532
						92.44725741	668.627	668.017	-28.550	668.017	-28.570		
J9	177	6	38.00	177.11055556	177.11091524							523781.333	587093.963
						89.55817265	1586.828	1586.781	12.236	1586.780	12.190		
J8	110	1	52.00	110.03111111	110.03147080							525368.113	587106.153
						19.58964345	248.647	83.367	234.255	83.367	234.248		
J7	214	32	49.80	214.54716667	214.54752635							525451.480	587340.400
						54.13716980	144.098	116.780	84.419	116.780	84.415		
J6	221	29	53.70	221.49825000	221.49860969							525568.260	587424.815
						95.63577949	516.726	514.228	-50.745	514.228	-50.760		
JMC4	153	53	9.63	153.88600833	153.88636802							526082.488	587374.056
						69.52214751	110.858	103.853	38.783	103.853	38.780		
J5	152	50	13.10	152.83697222	152.83733191							526186.341	587412.836
						42.35947942	619.552	417.442	457.807	417.442	457.789		
J4	144	12	14.00	144.20388889	144.20424858							526603.782	587870.624
						6.56372799	1149.061	131.347	1141.529	131.347	1141.496		
J3	224	44	45.60	224.74600000	224.74635969							526735.129	589012.120
						51.31008768	1063.318	829.963	664.686	829.962	664.655		
J2	89	55	1.00	89.91694444	89.91730413							527565.091	589676.775
						321.22739181	339.036	-212.315	264.325	-212.315	264.315		
J1	146	53	27.90	146.89108333	146.89144302							527352.776	589941.090
Sum =	6638	1302	1029.50	6659.98597222	6660.00000000		25874.275	0.009	0.755	0.000	0.000		

Sum of Obs. Angle= **6659.98597222**
Theo. Sum Angle = **6660.00000000**
Misclosure = **0.01402778**
Angular Correction = **0.00035969**

Positional Misclosure= $\sqrt{\delta E^2 + \delta N^2}$
= 0.755 m

Adjustment to Delta Easting and Northing By Bowditch
Fractional Linear Error = 1 in 34288

Annex-3) TIDE Table in PWD

Water level of Padma River

Unit of W.level : m PWD

10/7/04

Time	T: Gauge	W.Level
9:00	1.130	5.298
10:00	1.120	5.288
11:00	1.100	5.268
12:00	1.100	5.268
13:00	1.020	5.188
14:00	1.080	5.248
15:00	1.200	5.368
16:00	1.250	5.418
17:00	1.260	5.428
18:00	1.270	5.438
19:00	1.280	5.448

11/7/04

Time	T: Gauge	W.Level
9:00	1.340	5.508
10:00	1.330	5.498
11:00	1.320	5.488
12:00	1.320	5.488
13:00	1.330	5.498
14:00	1.350	5.518
15:00	1.380	5.548
16:00	1.400	5.568
17:00	1.410	5.578
18:00	1.460	5.628
19:00	1.460	5.628

12/7/04

Time	T: Gauge	W.Level
9:00	1.590	5.758
10:00	1.580	5.748
11:00	1.560	5.728
12:00	1.560	5.728
13:00	1.570	5.738
14:00	1.580	5.748
15:00	1.540	5.708
16:00	1.660	5.828
17:00	1.680	5.848
18:00	1.680	5.848
19:00	1.690	5.858

13/7/04

Time	T: Gauge	W.Level
9:00	1.790	5.958
10:00	1.790	5.958
11:00	1.780	5.948
12:00	1.780	5.948
13:00	1.790	5.958
14:00	1.800	5.968
15:00	1.780	5.948
16:00	1.800	5.968
17:00	1.800	5.968
18:00	1.820	5.988
19:00	1.820	5.988

14/7/04

Time	T: Gauge	W.Level
9:00	1.960	6.128
10:00	1.970	6.138
11:00	1.960	6.128
12:00	1.960	6.128
13:00	1.980	6.148
14:00	1.980	6.148
15:00	1.950	6.118
16:00	1.940	6.108
17:00	1.950	6.118
18:00	1.960	6.128
19:00	1.960	6.128

15/7/04

Time	T: Gauge	W.Level
9:00	2.100	6.268
10:00	2.120	6.288
11:00	2.120	6.288
12:00	2.120	6.288
13:00	2.130	6.298
14:00	2.130	6.298
15:00	2.100	6.268
16:00	2.100	6.268
17:00	2.100	6.268
18:00	2.100	6.268
19:00	2.110	6.278

21/7/04

Time	T: Gauge	W.Level
9:00	2.400	6.568
10:00	2.420	6.588
11:00	2.420	6.588
12:00	2.440	6.608
13:00	2.450	6.618
14:00	1.170	6.618
15:00	1.160	6.608
16:00	1.160	6.608
17:00	1.160	6.608
18:00	1.140	6.588
19:00	1.120	6.568

22/7/04

Time	T: Gauge	W.Level
9:00	1.17	6.618
10:00	1.17	6.618
11:00	1.21	6.658
12:00	1.23	6.678
13:00	1.23	6.678
14:00	1.23	6.678
15:00	1.22	6.668
16:00	1.22	6.668
17:00	1.22	6.668
18:00	1.22	6.668
19:00	1.21	6.658

23/7/04

Time	T: Gauge	W.Level
9:00	1.23	6.678
10:00	1.23	6.678
11:00	1.27	6.718
12:00	1.30	6.748
13:00	1.24	6.688
14:00	1.24	6.688
15:00	1.30	6.748
16:00	1.30	6.748
17:00	1.28	6.728
18:00	1.28	6.728
19:00	1.28	6.728

24/7/04

Time	T: Gauge	W.Level
9:00	1.28	6.73
10:00	1.30	6.75
11:00	1.32	6.77
12:00	1.32	6.77
13:00	1.32	6.77
14:00	1.35	6.80
15:00	1.36	6.81
16:00	1.35	6.80
17:00	1.36	6.81
18:00	1.36	6.81
19:00	1.35	6.80

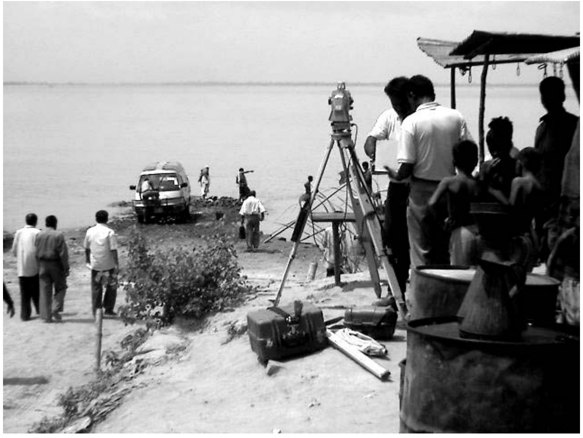
25/7/04

Time	T: Gauge	W.Level
9:00	1.32	6.768
10:00	1.31	6.758
11:00	1.30	6.748
12:00	1.30	6.748
13:00	1.32	6.768
14:00	1.32	6.768
15:00	1.34	6.788
16:00	1.34	6.788
17:00	1.33	6.778
18:00	1.34	6.788
19:00	1.30	6.748

26/7/04

Time	T: Gauge	W.Level
9:00	1.29	6.738
10:00	1.29	6.738
11:00	1.28	6.728
12:00	1.27	6.718
13:00	1.27	6.718
14:00	1.28	6.728
15:00	1.29	6.738
16:00	1.27	6.718
17:00	1.28	6.728
18:00	1.29	6.738
19:00	1.30	6.748

Annex-4) Photograph



1. Traverse Survey at Mawa Site

2. Check Survey of Installed Control Point by GPS

3. Topographic Survey along the existing road at Mawa

4. Topographic Survey along the Riverbank at Janjira

5. Topographic Survey along theproposed alignment at Janjira

6. Preparation for Bathmetric Survey at Mawa

Appendix-4 Geotechnical Investigation

Chapter 1 Geotechnical Investigations for Surveys for Site-1 Paturia - Goalundo and Site-3 Mawa - Janjira

1.1 GENERAL

The geotechnical studies and investigations for the feasibility study of Padma Bridge were carried out for the following purposes:

1) Investigation for bridges

To provide the design engineers with information on the engineering properties of the natural soils, which will permit the determination of the foundation type and foundation structure.

2) Investigation for approach roads

To provide the design engineers with information on the foundation of minor bridges over channels and embankment for approach roads.

The geotechnical investigation consists of core drilling, Standard Penetration Test, Pressuremeter Test, laboratory tests for soil and laboratory tests for groundwater for bridges and approach roads at Mawa Janjira and Paturia Goalundo sites.

1.2 GEOLOGY

A comprehensive classification of Bangladesh physiography can be described in the following 23 geomorphic units as shown in Figure 1.2.1.

Floodplain Areas

1. Old Himalayan Piedmont Plain
2. Teesta Floodplain
3. Karatoya-Bangali Floodplain
4. Lower Atrai Floodplain
5. Lower Purnabhaba Floodplain
6. Young Brahmaputra Floodplain
7. Old Brahmaputra Floodplain
8. Ganges River Floodplain
9. Ganges Tidal Floodplain
10. Gopalganj-Khulna Beels
11. Arial Beel
12. Middle Meghna Floodplain
13. Lower Meghna River Floodplain
14. Young Meghna Estuarine Floodplain
15. Old Meghna Estuarine Floodplain
16. Surma-Kusiyara Floodplain

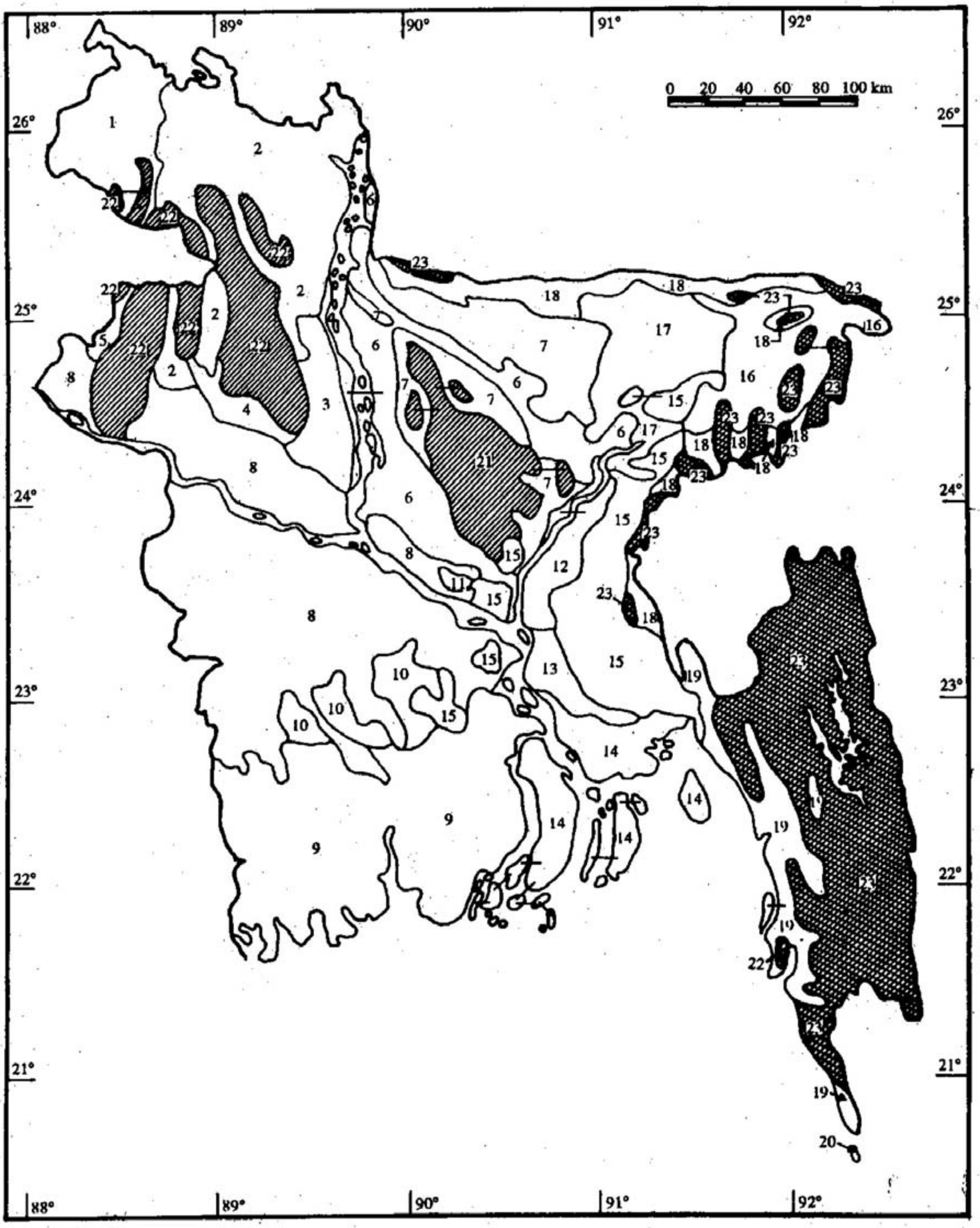


Figure 1.2.1 Bangladesh physiography

17. Sylhet Basin
18. Northern and Eastern Piedmont Plains
19. Chittagong Coastal Plain
20. St Martin's Island

Terrace Areas

21. Madhupur Tract
22. Barind Tract

Hill Areas

23. Northern and Eastern Hills

In broad terms, there are three main geological formations in Bangladesh:

- **Tertiary sediments** in the northern and eastern hills;
- the **Madhupur Clay** of the Madhupur and Barind Tracts in the center and west; and
- **recent alluvial plain** underlying the floodplain and estuarine areas which occupy the remainder of the country.

Tertiary sediments in the northern and eastern hills, which occupy about 12 percent of Bangladesh, are underlain mainly by unconsolidated or little-consolidated beds of sandstones, siltstones and shales, together with minor beds of limestone and conglomerates. They have been uplifted and folded into a series of pitching anticlines and synclines. These are aligned approximately NNW to SSE in the Chittagong Hill Tracts and Chittagong regions and the south of Sylhet region, swinging round to almost east-west in the north of Sylhet and Mymensingh regions.

The Madhupur and Barind Tracts, which together occupy about 8 percent of the country, are underlain by the Madhupur Clay. The Madhupur Clay was earlier called the 'older alluvium' and was regarded as Pleistocene in age. The 1964 Geological Map of Pakistan gave the formation the name Madhupur Clay, and suggested that it might correlate with the Dupi Tila formation, regarded as of Mio-Pliocene age. In some places, the Madhupur Clay has been considerably altered by weathering and changed into red-mottled clay which forms the substratum of the overlying soils. Where it is less altered, it comprises gray, heavy clay with prominent slickensides, and usually with a few small, hard, ironstone (or iron-coated manganese) concretions scattered throughout.

Recent alluvial plain underlying unconsolidated floodplain sediments occupy about 80 percent of Bangladesh. The vast alluvial plain has emerged from the sedimentation process of the three mighty rivers, the Ganges, the Brahmaputra-Jamuna and the Meghna and their innumerable tributaries. No places in the flood plain can be seen to be of 30 feet above mean sea level and average slope is less than 5" to a mile.

Padma Bridge Project area is situated in the above Ganges flood plain, which is one of recent alluvial plains. The Ganges in Bangladesh is known as the Padma and occupies one of the largest area of land formation. The flood plain is characterized by the new char formation. The Ganges flood plain can be identified as active, moribund and meander flood plain on the basis of river activity. The active area include the newly built chars where soil formation is yet to develop. The Ganges flood plain especially the active flood plain is flooded in the month of June and flood water recedes in the month of September. The area is erosion prone with population displacement and other social problem is generated in the area due to severity of the hazard. Some parts of the greater Kushtia, Jessore and northern part of Khulna district is called as moribund area. The rivers are no longer active in the area and therefore no deposition occurs. The water level is also as high as the Padma and large scale siltation in the past has resulted the rising up of the bed. The levee formation by the distributaries has buried the irregular surfaces. The surface water erosion is feeding the ridges (Brammer, 1964).

The Padma flood plain is renamed by some as deltaic flood plain. With the extension of delta, the branching of the Padma has moved downward. The whole meander flood plain of the Padma can again be considered as old and new. The highest discharge of the river is 72,300m3/sec (1988). The active flood plain is sandy or silty and has no evidence of soil formation. The meander flood plain is composed of several deposits. The high ridges are sandy or silty and basins are clayey silt. The recently deposited alluvium of the Padma is obviously calcareous and annually recharged with nutrients. The flood plain is flooded during the monsoon season. Perched water table is seen in the basin. In the moribund region the soils become saturated due to capillary movement of water and with withdrawal of water surface salt cover is seen. The Padma flood plain is sometime mixed with Brahmaputra alluvium on the margin. The changing nature of the course on the Padma channel has left some imprint on the surface as well.

1.3 OUTLINE OF GEOTECHNICAL INVESTIGATION

The geotechnical investigation consists of core drilling, Standard Penetration Test, Lateral Loading Test, undisturbed soil sampling, groundwater sampling, laboratory tests for soil and laboratory tests for groundwater at both Mawa Janjira site and Paturia Goalundo site.

The quantity and standard of each test item are described in Table 1.3.1.

At Mawa Janjira site, four boreholes were conducted. A 40m deep borehole (JMBH1) and a 120m deep borehole (JMBH2) were drilled on the left bank. On the right bank, a 40m deep borehole (JMBH4) and a 120m deep borehole (JMBH3) were drilled. At Paturia Goalundo site, four boreholes were also conducted. A 40m deep borehole (PDBH1) and a 103m deep borehole (PDBH2) were drilled on the left bank. On the right bank, a 57m deep borehole (PDBH4) and a 120m deep borehole (PDBH3) were drilled. The locations of the boreholes are shown in Figures 1.3.1 and 1.3.2.

The Standard Penetration Test and Split-Barrel Sampling of soils (ASTM D 1586) were carried out at an interval of one meter and disturbed sampling was conducted for laboratory tests.

The Lateral Loading Test was conducted in four boreholes, comprising three depths at JMBH2, five depths at JMBH3, four depths at PDBH2 and four depths at PDBH3.

For cohesive soils, undisturbed samples were taken for laboratory tests using a thin wall sampling tube.

Sampling of groundwater was taken after 24 hours from the drilled boreholes for investigating the groundwater quality.

Laboratory test for soil consists of natural water content, specific gravity, unit weight, atterberg limit, grain size analysis, triaxial compression test, consolidation test, mica content, pH, total sulfate content, soluble sulfate content and total chloride content.

On the other hand, laboratory test for groundwater consists of pH, sulfate content and chloride content.

Table 1.3.1 Test Items and Quantities of Geotechnical Investigation

Test Item	Unit	Quantities								Standard
		Mawa-Janjira				Paturia-Goalundo				
		JMBH1	JMBH2	JMBH3	JMBH4	PDBH1	PDBH2	PDBH3	PDBH4	
(1) In-situ Test										
Core Drilling	m	40.0	120.0	120.0	40.0	40.0	103.0	120.0	57.0	
Standard Penetration Test	test	40	120	120	40	40	103	120	57	ASTM D 1586
Lateral Loading Test	test	0	3	5	0	0	4	4	0	ASTM D 4719
Undisturbed Soil Sample	sample	1	2	1	1	1	2	2	2	ASTM D 1587
Groundwater Sample	sample	1	1	1	1	1	1	1	1	
(2) Laboratory Test for Soil										
Natural Water Content	sample	7	18	16	6	7	14	16	8	ASTM D 2216
Specific Gravity of Soil	sample	7	18	17	7	7	16	18	10	ASTM D 854
Unit Weight	sample	0	0	0	0	0	0	0	0	ASTM D 2937
Atterberg Limit	sample	2	3	2	2	2	2	3	3	ASTM D 4318
Grain Size Analysis	sample	7	18	17	7	7	16	18	10	ASTM D 422
Triaxial Compression (UU)	sample	1	2	1	1	1	2	2	2	ASTM D 2850
Consolidation	sample	1	2	1	1	1	1	2	2	ASTM D 2435
Mica Content	sample	1	1	1	1	1	1	1	1	ASTM C 295
pH	sample	1	1	1	1	1	1	1	1	ASTM D 4972
Total Sulfate Content	sample	1	1	1	1	1	1	1	1	BS 1377
Soluble Sulfate Content	sample	1	1	1	1	1	1	1	1	BS 1377
Total Chloride Content	sample	1	1	1	1	1	1	1	1	BS 1377
(3) Laboratory Test for Groundwater										
pH	sample	1	1	1	1	1	1	1	1	Electrometric Method
Sulfate Content	sample	1	1	1	1	1	1	1	1	Turbidimetric Method
Chloride Content	sample	1	1	1	1	1	1	1	1	Argentometric Method

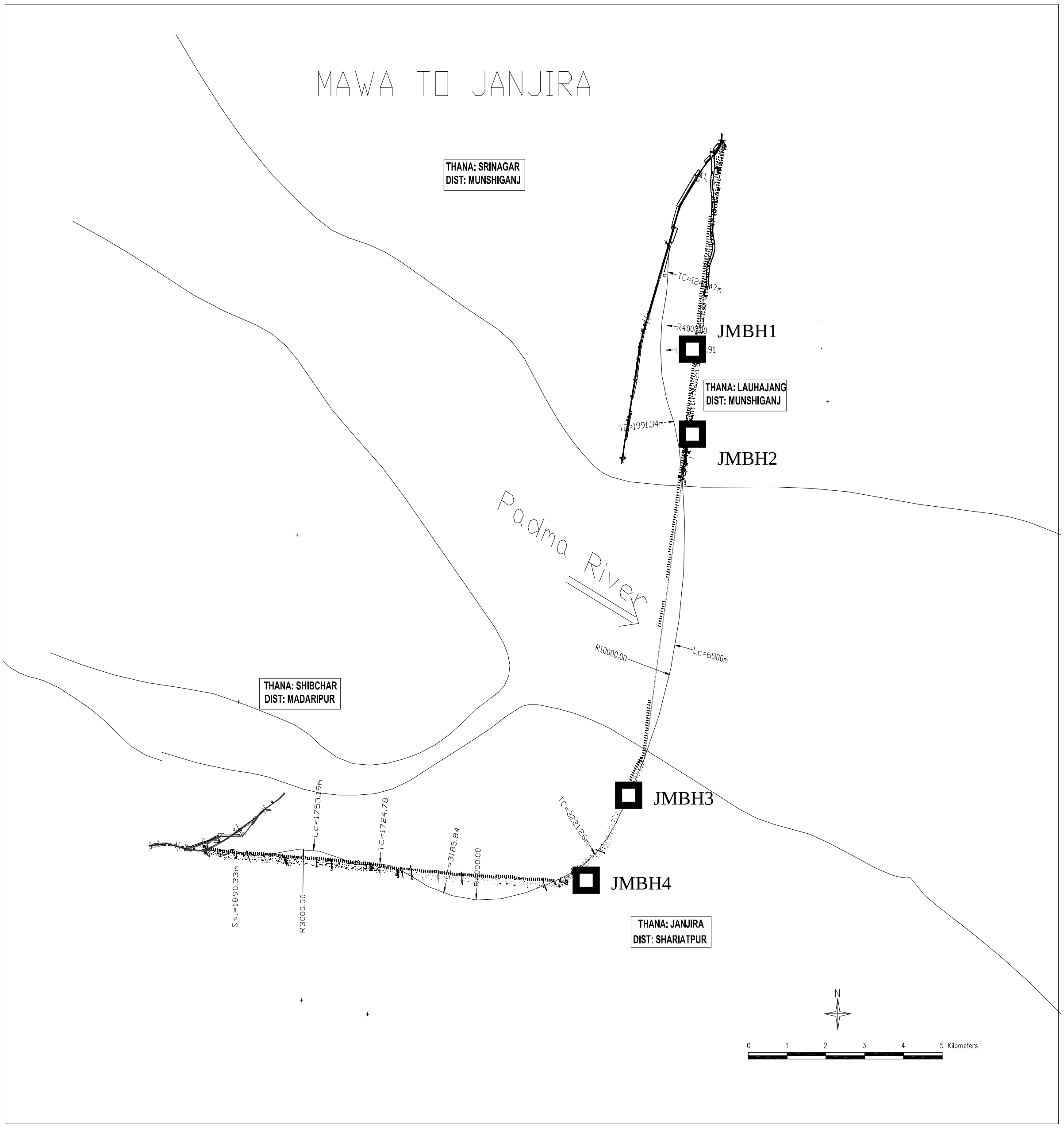


Figure 1.3.1 Location Map of Boreholes (Mawa – Janjira site)

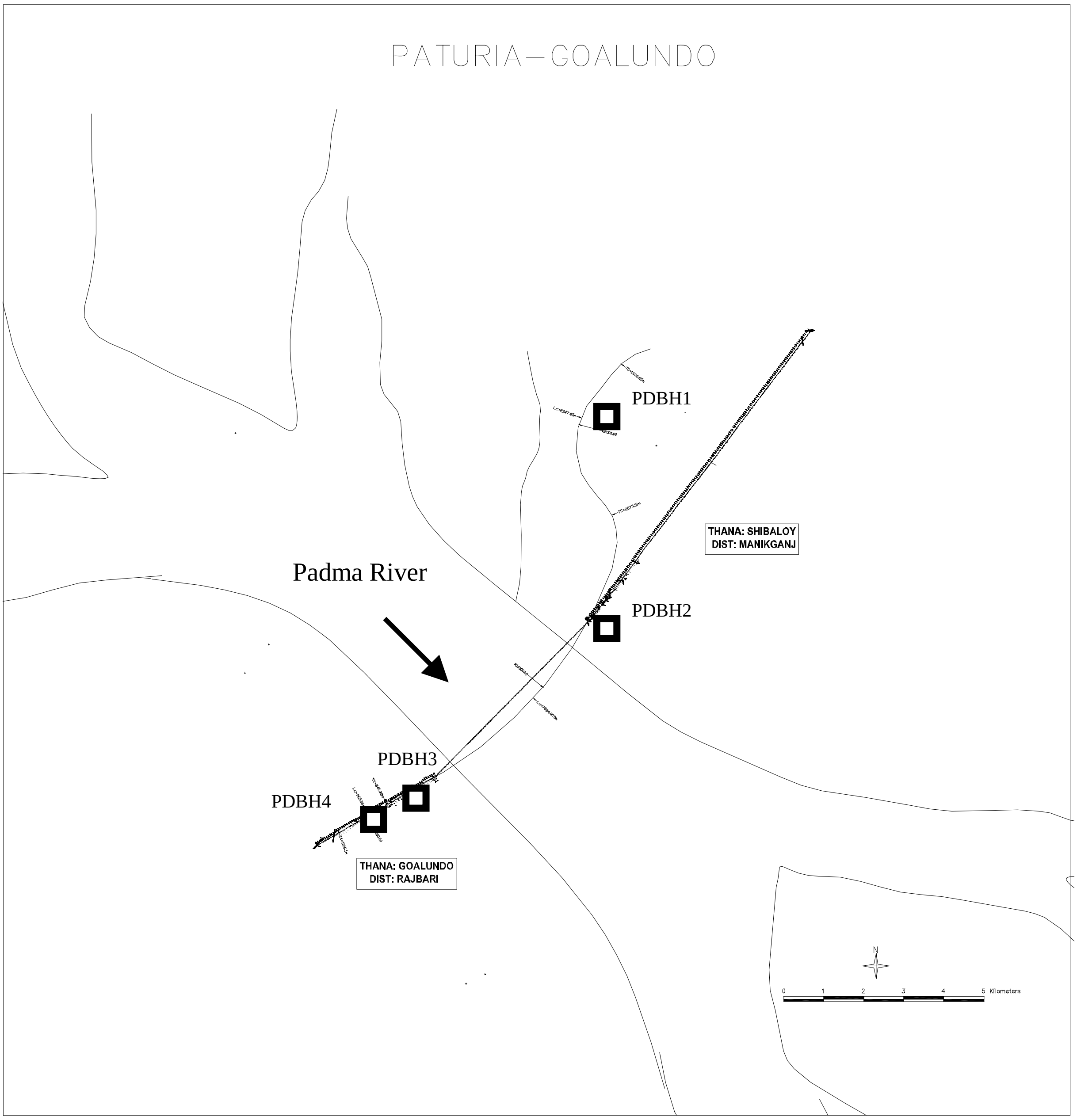


Figure 1.3.2 Location Map of Boreholes (Paturia – Goalundo site)

1.4 GROUND CONDITIONS

1.4.1 Geological Profile

The following chronological and stratigraphical classification was used for drawing the geological profiles of Mawa Janjira site and Paturia Goalundo site. Based on the results of grain size analysis, the following classification is proposed:

Stratum	Criteria
Unit-1a	Clay + Silt ≥ 50%
Unit-1b	20% ≤ Clay + Silt < 50%
Unit-2	Clay + Silt < 20% and Medium Sand < 10%
Unit-3	Clay + Silt < 20% and Medium Sand ≥ 10%

Gradation curves of each stratum are shown in Figure 1.4.1. From these gradation curves, each stratum can be characterized as follows:

Stratum	Description
Unit-1a	CLAY or SILT with fine sand
Unit-1b	very silty fine SAND
Unit-2	silty fine SAND
Unit-3	slightly silty fine and medium SAND

As the gradation curve of Unit-2 is steep and the uniformity coefficient is very small, the soil of Unit-2 is evaluated to be poorly graded. Therefore, the soil of Unit-2 is estimated to be looser than that of Unit-1b and Unit-3. Geological profiles of Mawa Janjira site and Paturia Goalundo site are shown in Figures 1.4.2 and 1.4.3 respectively. These geological profiles are drawn up, based on the results of grain size analysis and visual observation of the disturbed split spoon samples obtained from the Standard Penetration Tests.

Based on the result of drilling JMBH1 and JMBH2 on the left bank at Mawa Janjira site, Unit-1a was found in the upper part up to El. -10.293m ~ -15.397m, CLAY or SILT with fine sand. In the lower part below Unit-1a, Unit-1b was found, very silty fine SAND. At the borehole site of JMBH2, Unit-2 lies between Unit-1a and Unit-1b from El. -10.293m to El. -19.293m, silty fine SAND.

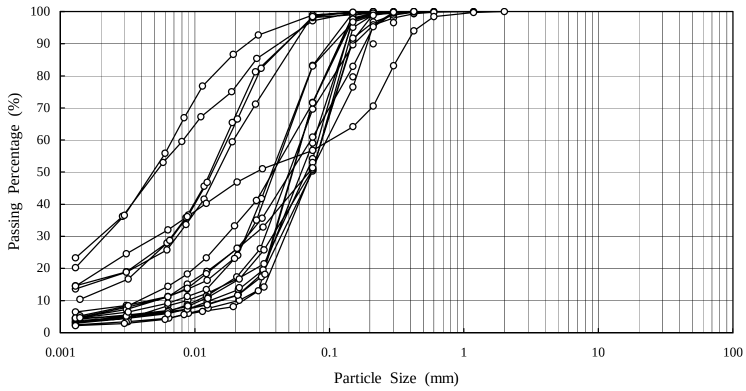
On the right bank at Mawa Janjira site, at the borehole site of JMBH3, Unit-1b was found from the ground surface through 120m in depth, very silty fine SAND. On the other hand, at the borehole site of JMBH4, Unit-1a was found in the upper part up to El. -6.496m, CLAY or SILT with fine sand. In the lower part, Unit-2 was found, silty fine SAND.

Based on the result of drilling PDBH1 and PDBH2 on the left bank at Paturia Goalundo site, Unit-1a was found in the upper part up to El. -0.595m ~ -0.847m, CLAY or SILT with fine sand. In the lower part below Unit-1a, Unit-2 was found, silty fine SAND.

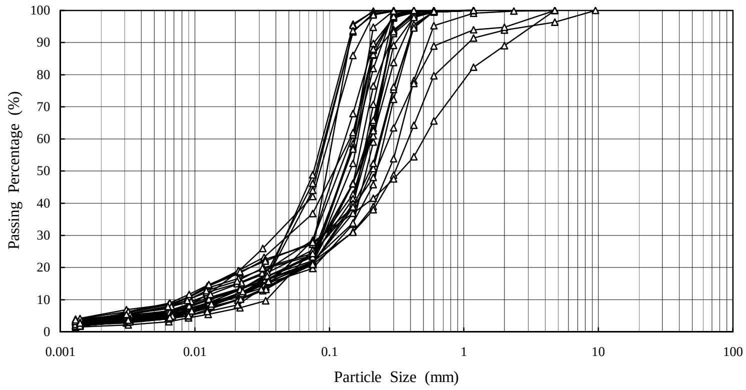
On the right bank, based on the result of drilling PDBH3 and PDBH4, Unit-1a was found in the upper part up to El. -7.199m ~ -15.752m, CLAY or SILT with fine sand. In the middle part, Unit-2 was found, silty fine SAND. In the lower part, Unit-3 was found below El. -62.752m, slightly silty fine and medium SAND.

There is a remarkable difference of geological profile between Mawa Janjira site and Paturia Goalundo site, that is, Unit-1b predominates at Mawa Janjira site while Unit-2 predominates at Paturia Goalundo site.

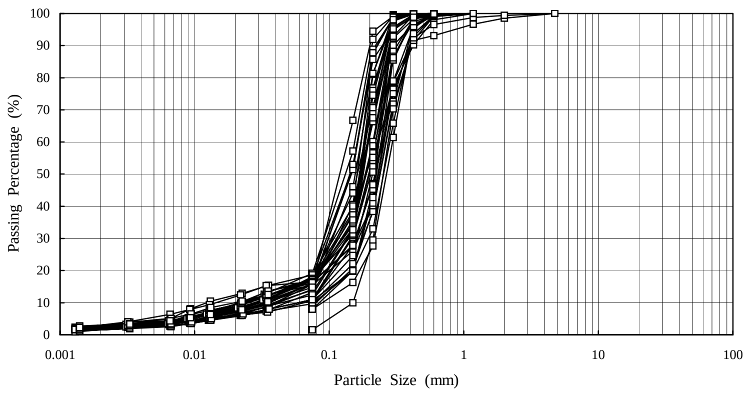
(Unit – 1a)



(Unit – 1b)



(Unit – 2)



(Unit – 3)

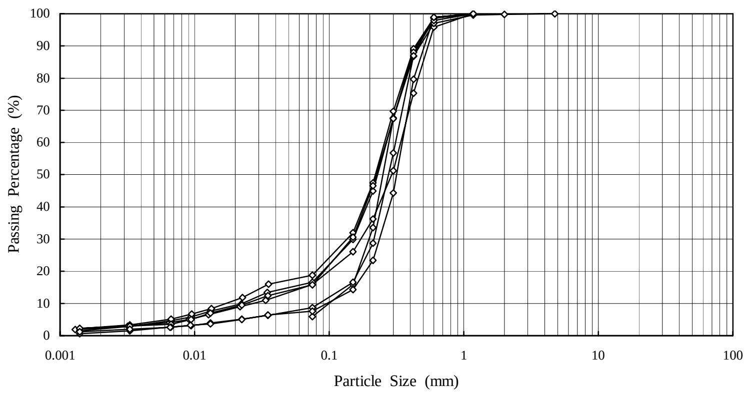


Figure 1.4.1 Gradation Curves of Each Stratum

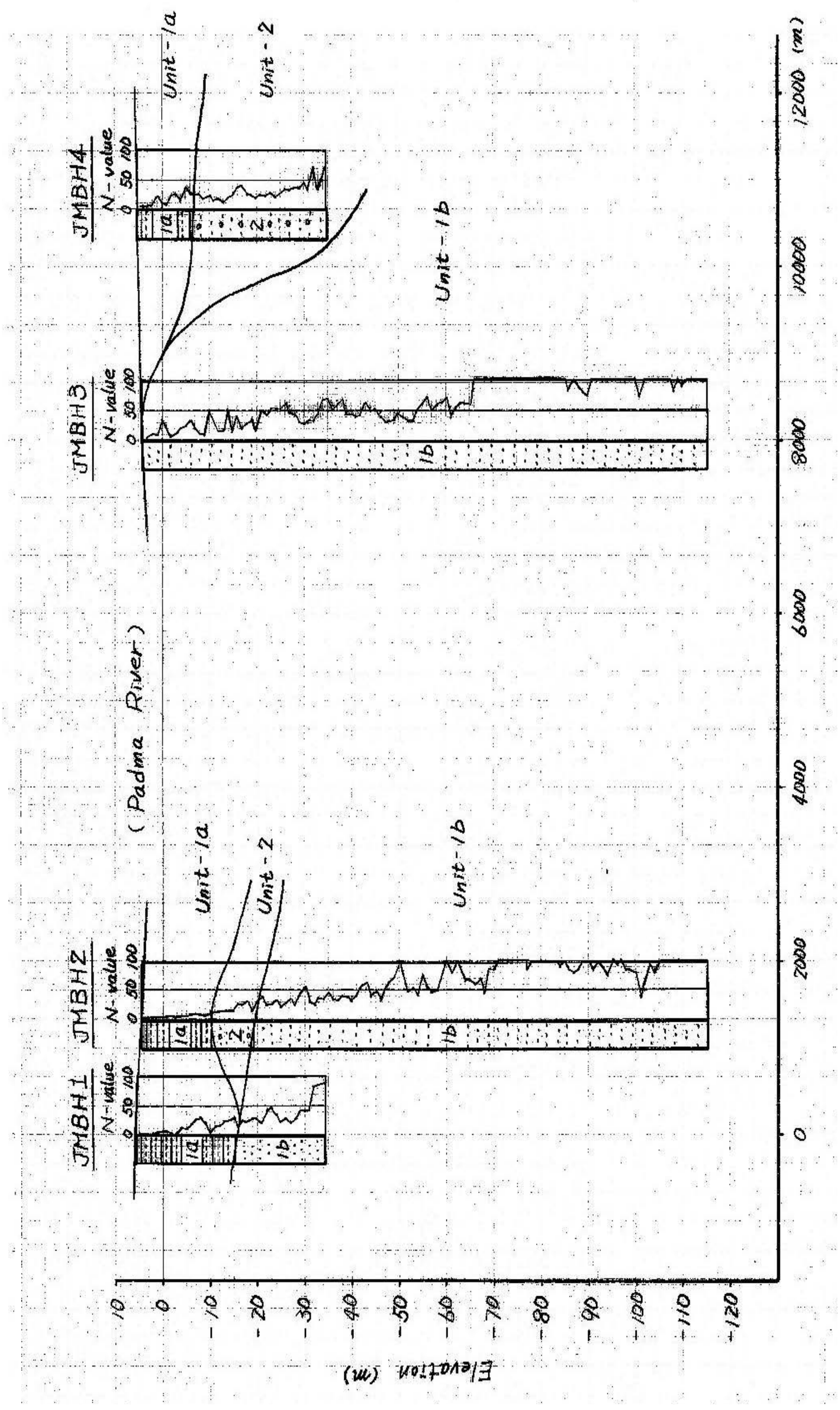


Figure 1.4.2 Geological Profile (Mawa Janjira site)

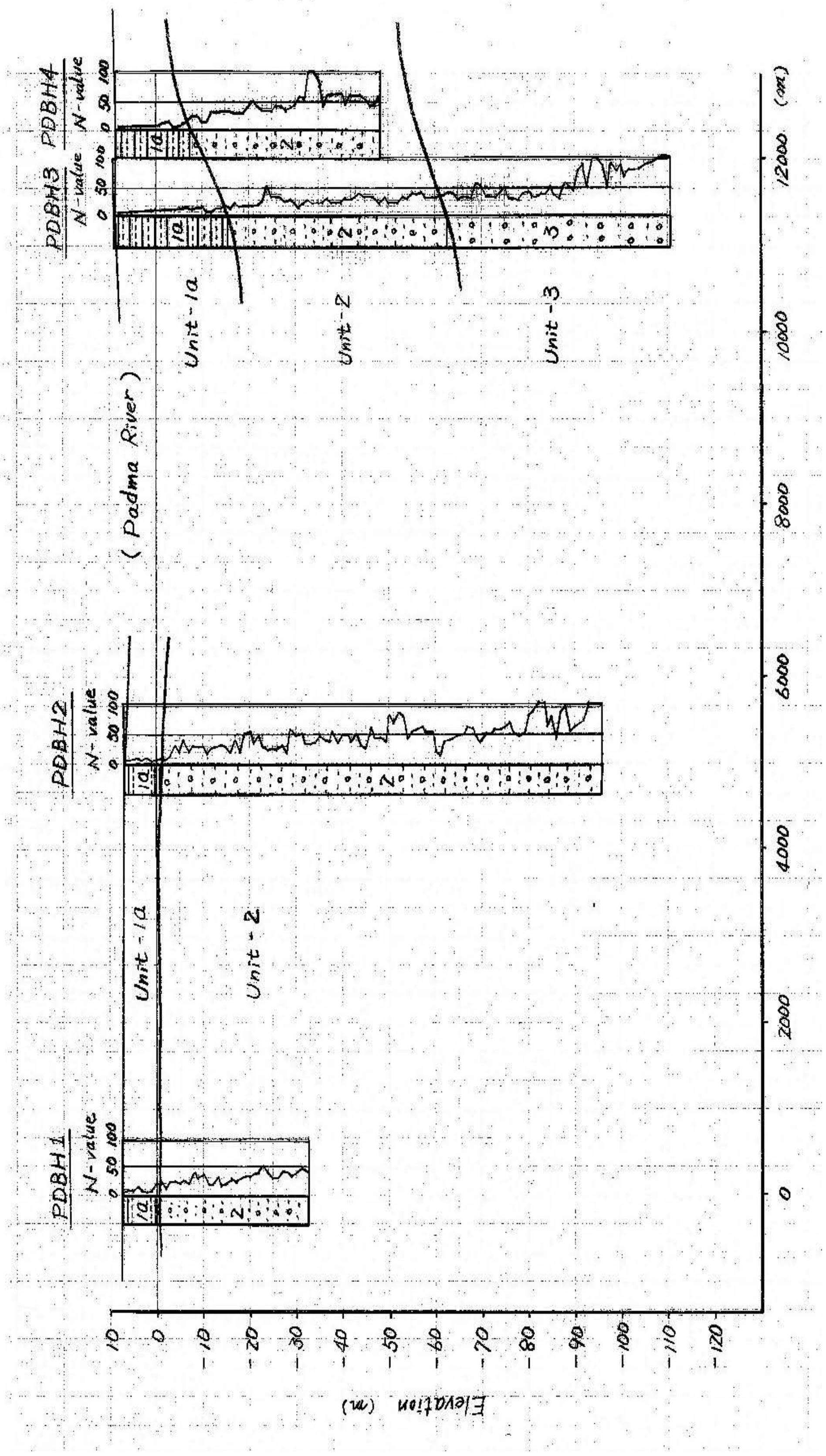


Figure 1.4.3 Geological Profile (Paturia Goalundo site)

1.4.2 N-value

The Standard Penetration Test was carried out at an interval of one meter for the full depth of each borehole. The measured N-values have a problem because blow energy has kinds of losses on the way to the bed in the very deep position where the measurements are obtained imperfectly.

A number of study results have been provided by Terzaghi - Peck (1948), Ikeda (1959), Thornburn (1963), Uto (1974) and others on the correction of such measured N-values.

In this study, considering that the highest is the loss of blow energy caused on the way of its transmission to the bottom of a bore, the loss-error of the measured N-value was corrected by the formula of Uto (1974). That is the way the corrected N-values were evaluated for the comparison between Mawa Janjira site and Paturia Goalundo site, and the proposal of design value.

The following formula (Uto, 1974) was applied for N-value correction:

$$N = N' \qquad (L < 20m)$$
$$N = (1.06 - 0.003 \times L) \times N' \qquad (L \geq 20m)$$

where,

N: corrected N-value
N': measured N-value
L: length of drill rods (m)

The distributions of corrected N-value at Mawa Janjira site and Paturia Goalundo site are shown in Figures 1.4.4 and 1.4.5 respectively. Further, lower design line and average design line of corrected N-value distribution are proposed for design of bridge substructure at both sites. At Mawa Janjira site, there is no marked difference between left bank and right bank. On the other hand, at Paturia Goalundo site, there is some difference between left bank and right bank below El. -40m. In a word, N-value on the left bank is larger than that on the right bank below El. -40m.

The comparison of corrected N-value between Mawa Janjira site and Paturia Goalundo site is shown in Figure 1.4.6. It is clear that there is a remarkable difference between Mawa Janjira site and Paturia Goalundo site below El. -40m. In short, N-value at Mawa Janjira site is much larger than that at Paturia Goalundo site below El. -40m. However, there is not clear difference up to El. -40m.

Reduction in overburden pressure at the scoured bed level will induce a reduction in the density of the soil, and hence the N-values at depths below scour level. The following equations are applied to obtain the scour reduced N-values:

$$N' = N \times B_1$$
$$B_1 = 0.75 \times \sqrt{\frac{Z + 0.8 \times \sqrt{s \times z} + z \times z}{s + z}}$$

where,

B_1: scour reduction factor
N': N-value at depth after scour
N: corrected N-value at depth before scour
s: scour depth (m)
z: depth below GL after scour (m)

The depths of scour near bridge piers and guide bund are summarized below:

Site	Maximum scour near bridge piers and guide bund
Mawa Janjira	El. -43.0 m
Paturia Goalundo	El. -39.3 m

The distributions of N-value after scour at Mawa Janjira site and Paturia Goalundo site are shown in Figures 1.4.7 and 1.4.8 respectively. Further, the comparison of N-value after scour between Mawa Janjira site and Paturia Goalundo site is shown in Figure 1.4.9. It is clear that N-value after scour at Mawa Janjira site is much larger than that at Paturia Goalundo site.

Histograms of N-value for Unit-1a, Unit-1b, Unit-2 and Unit-3 are shown in Figures 1.4.10 to 1.4.13 respectively. Based on these histograms, the mean value of Mawa Janjira site and Paturia Goalundo site, which was calculated from the data of N-value excluding more than 100, was adopted as the typical N-value of each stratum. The adopted mean values are as follows:

Stratum	Mean N-value
Unit-1a	10.7
Unit-1b	49.1
Unit-2	38.7
Unit-3	57.6

The mean N-value of Unit-2 is lower than that of Unit-1b and Unit-3, because the soil of Unit-2 is poorly graded and is estimated to be looser than that of Unit-1b and Unit-3.

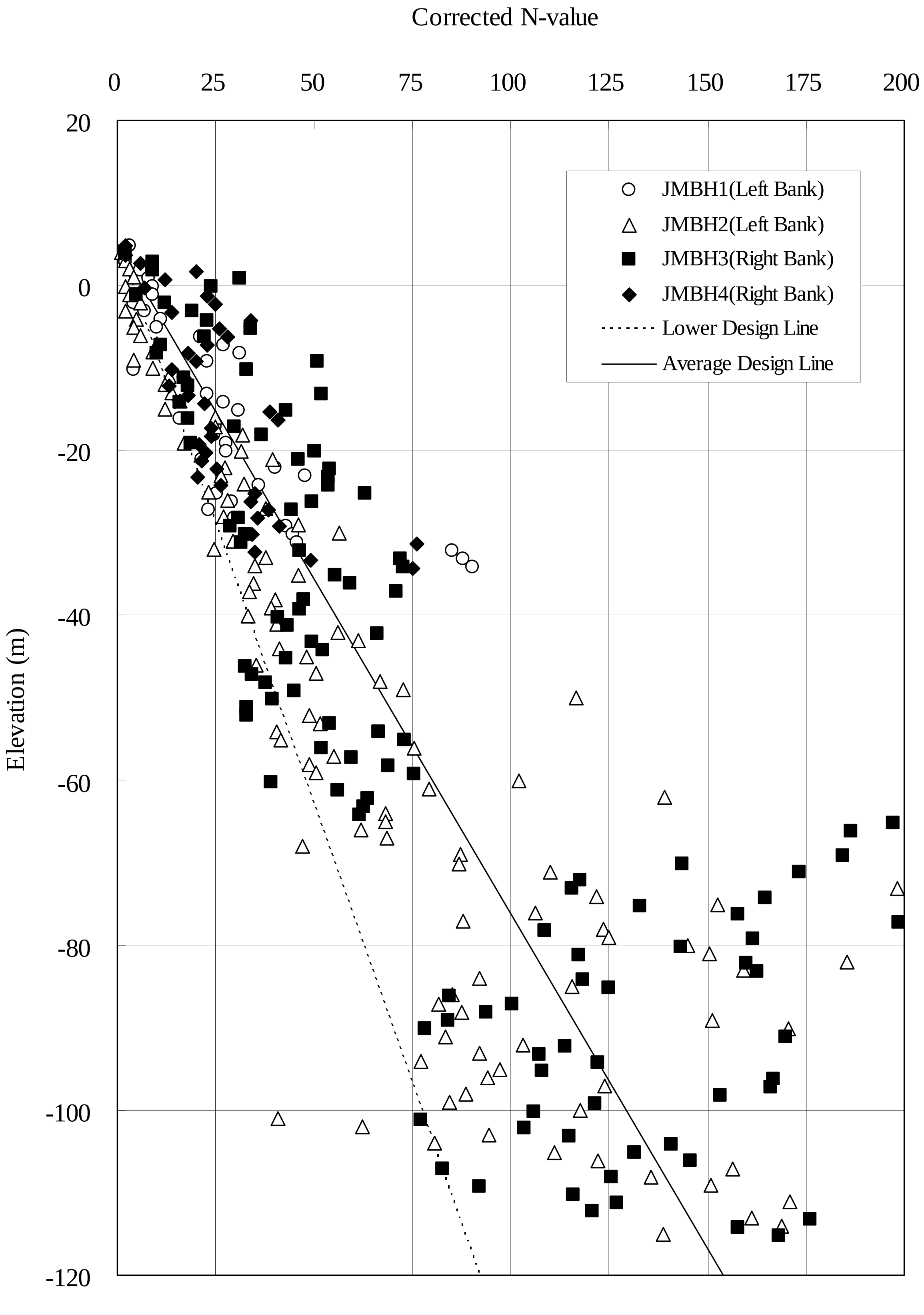


Figure 1.4.4 Distribution of Corrected N-value (Mawa-Janjira site)

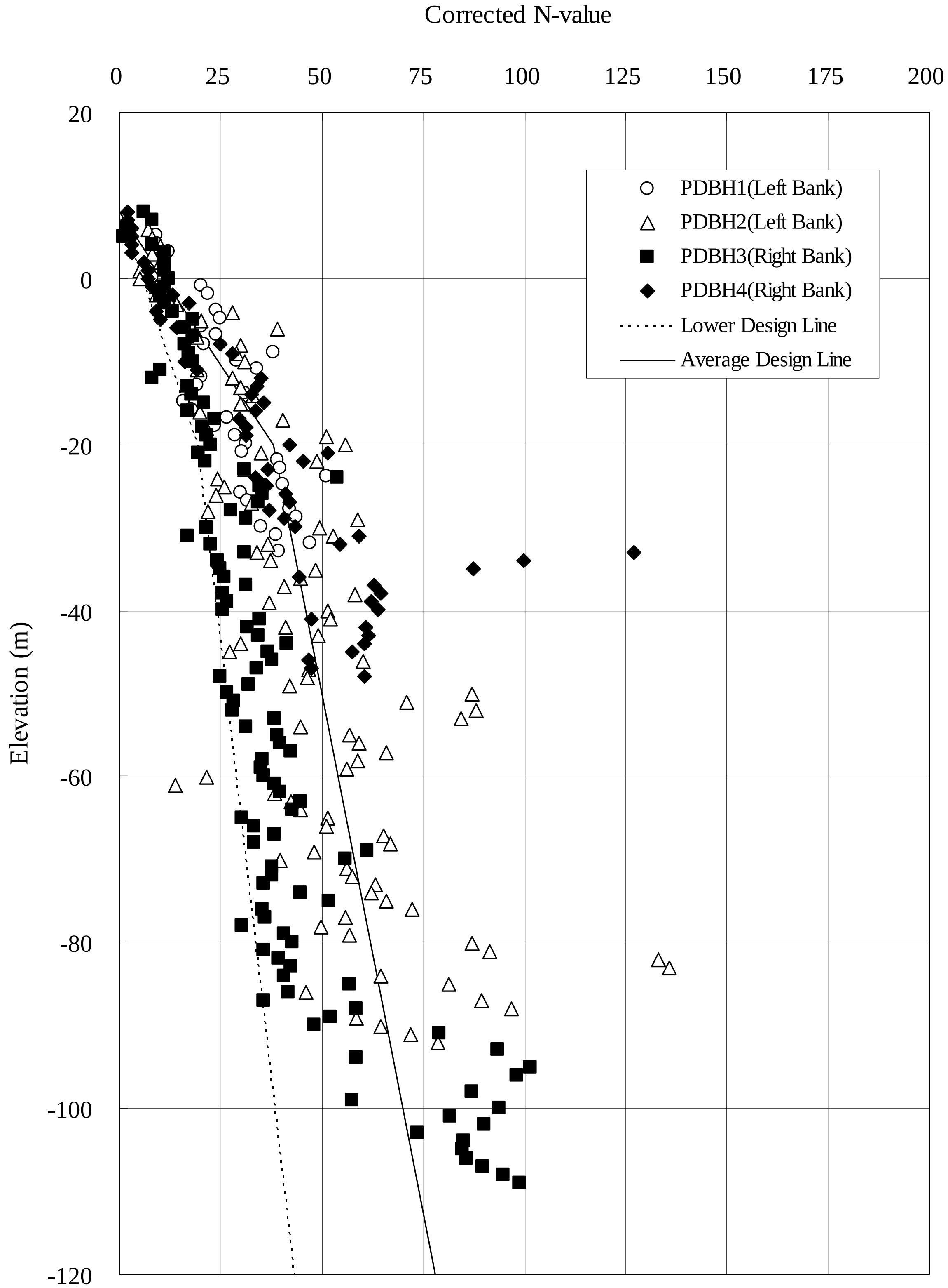


Figure 1.4.5 Distribution of Corrected N-value (Paturia-Goalundo site)

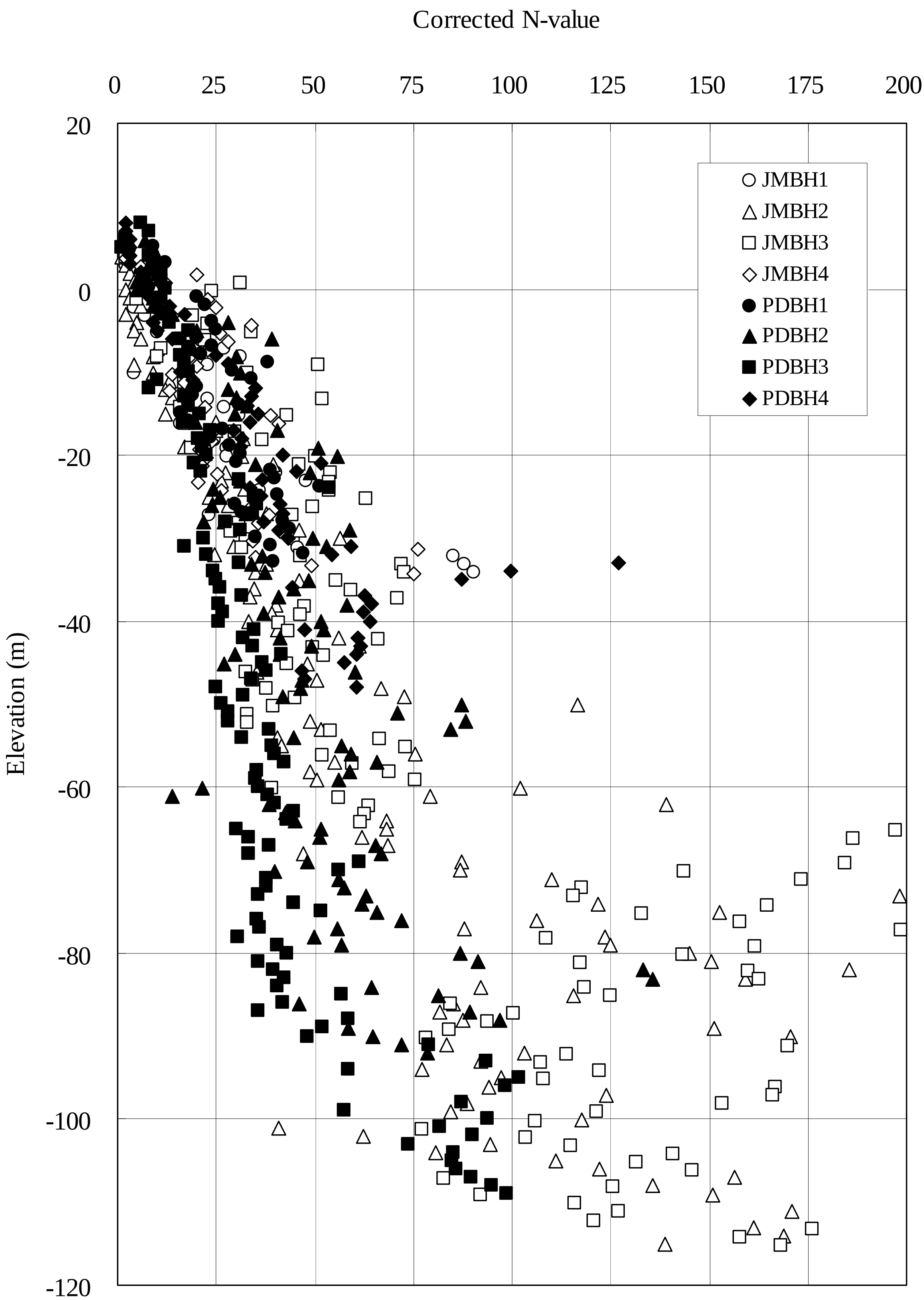


Figure 1.4.6 Comparison of Corrected N-value between Mawa-Janjira and Paturia - Goalundo sites

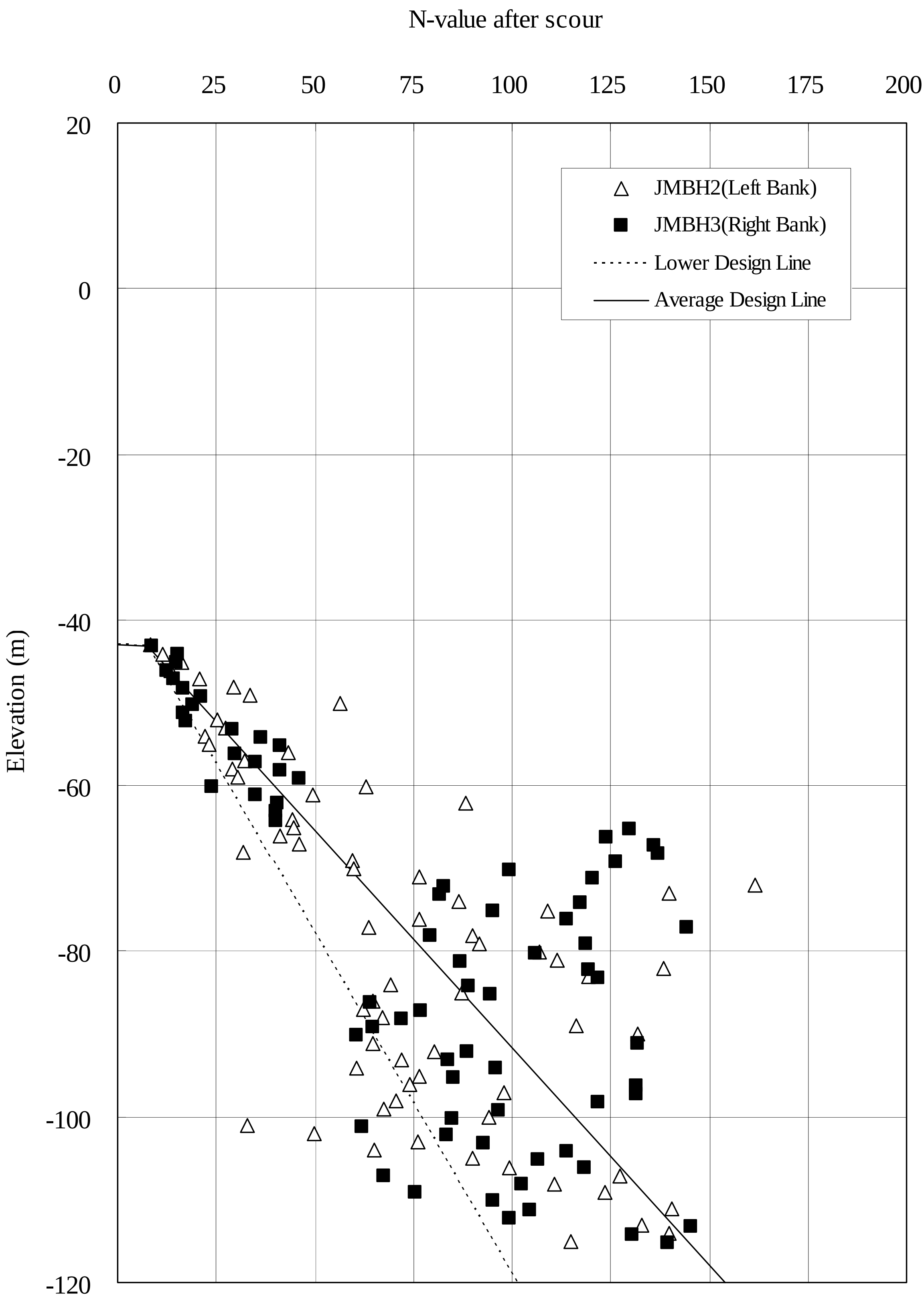


Figure 1.4.7 Distribution of N-value after Scour (Mawa-Janjira site, River Scour to -43.0m)

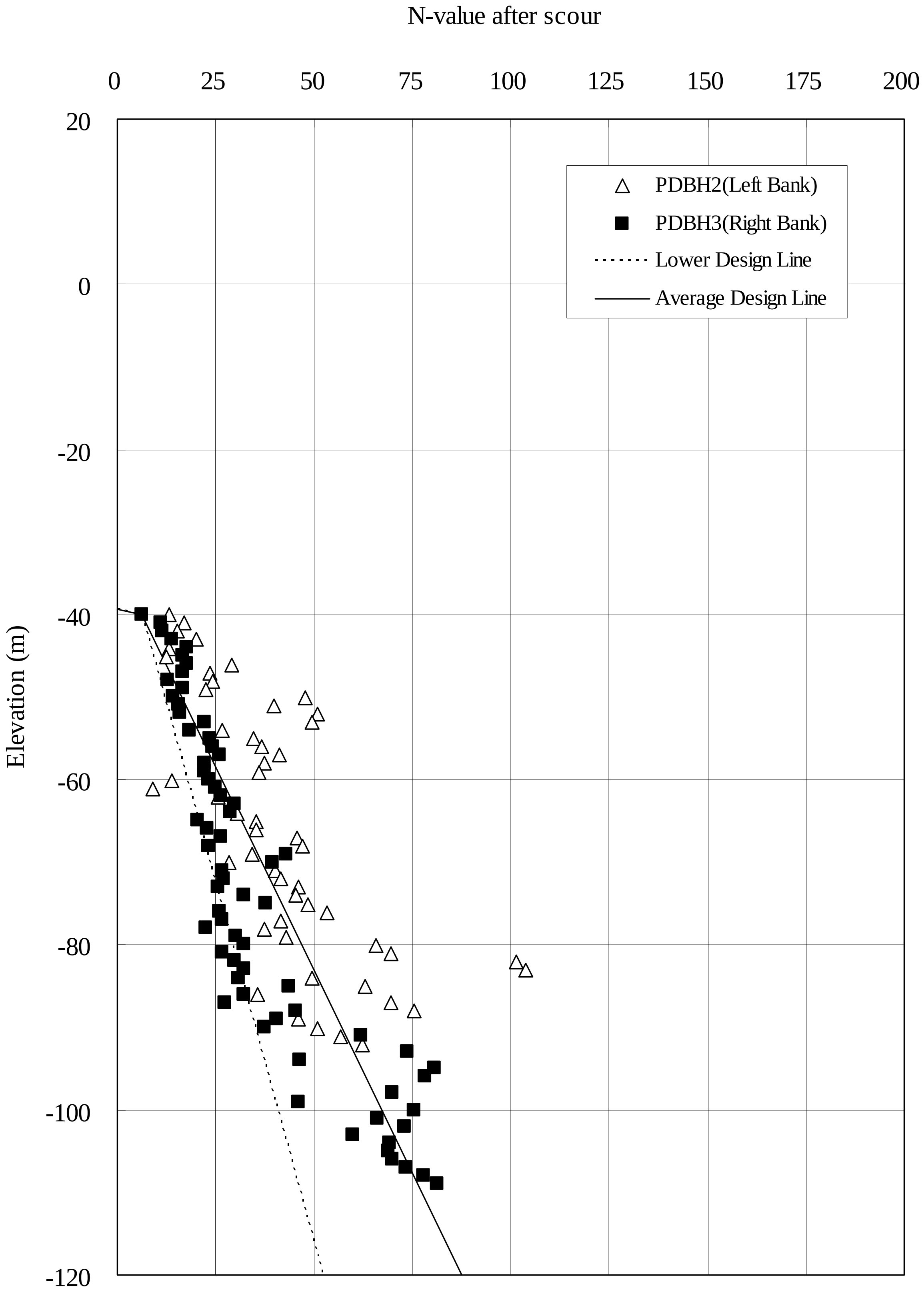


Figure 1.4.8 Distribution of N-value after Scour (Paturia-Goalundo site, River Scour to -39.3m)

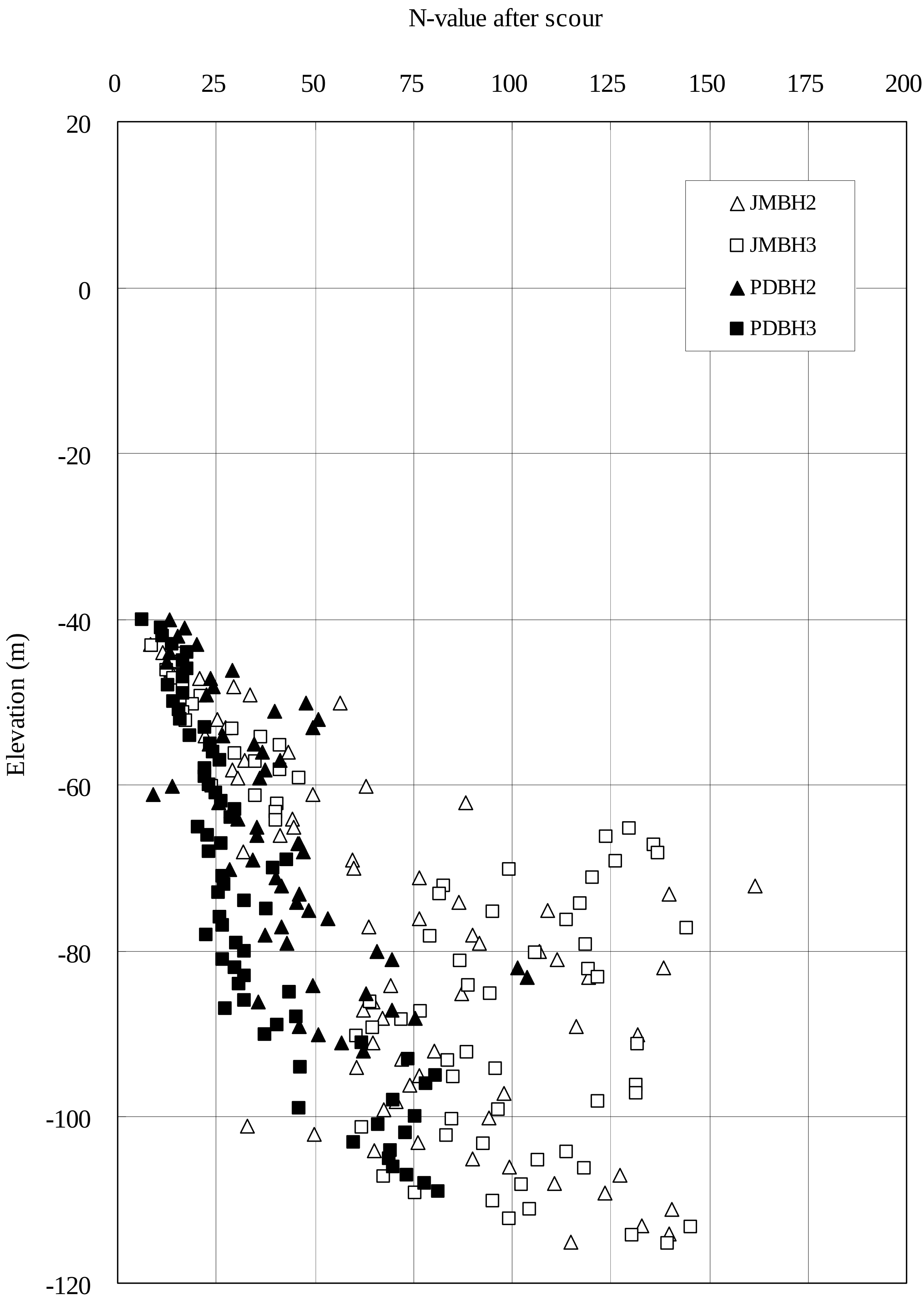
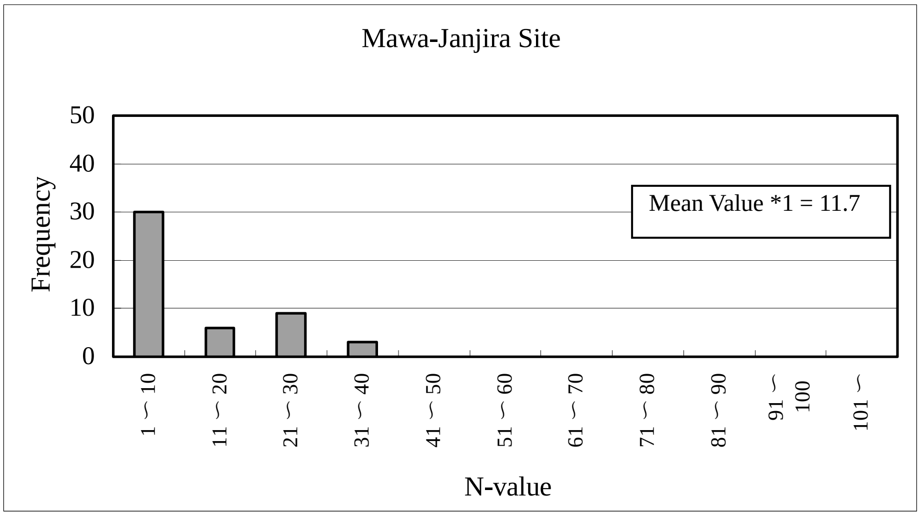
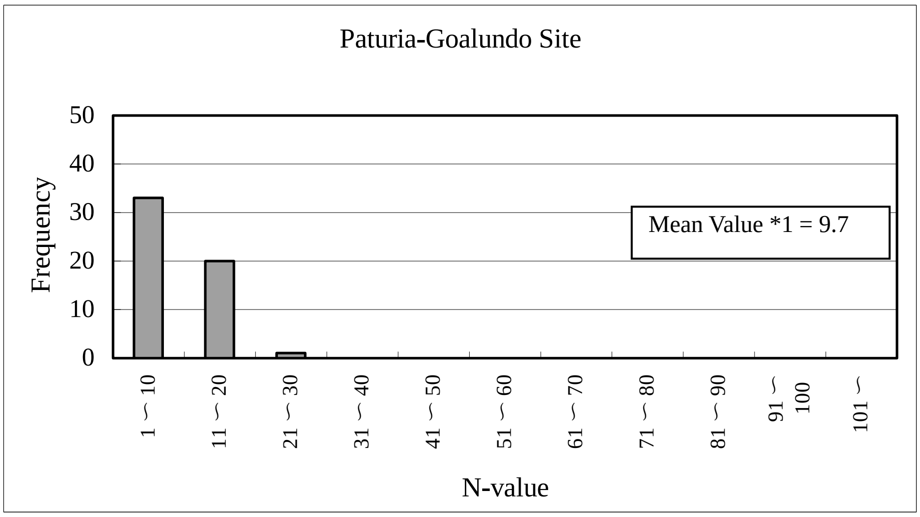
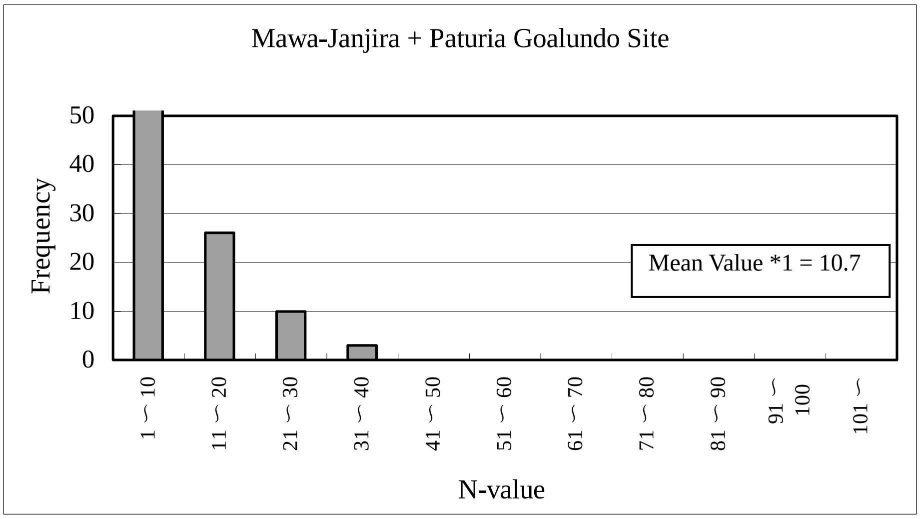


Figure 1.4.9 Comparison of N-value after Scour between Mawa-Janjira site and Paturia-Goalundo site

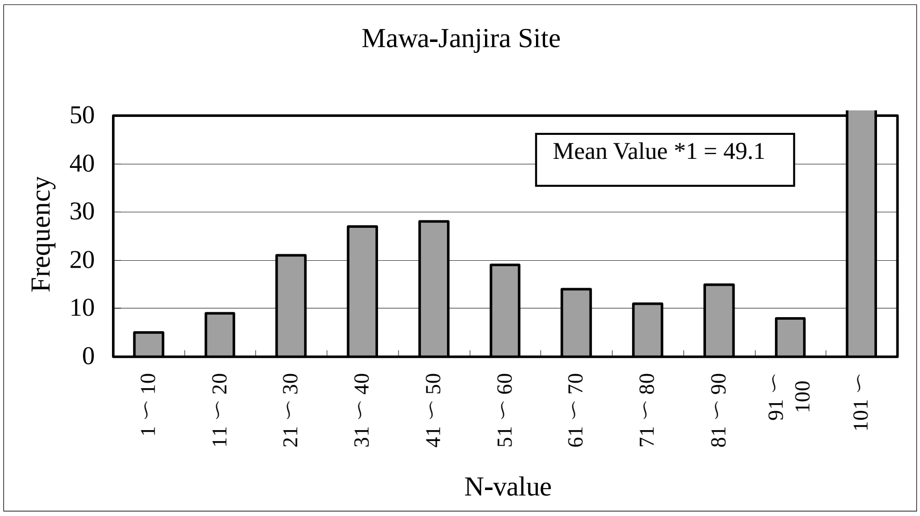


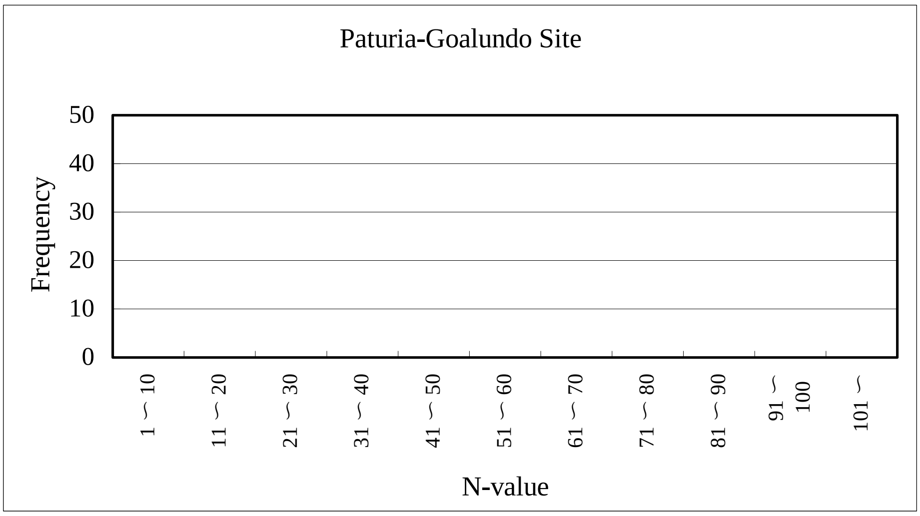


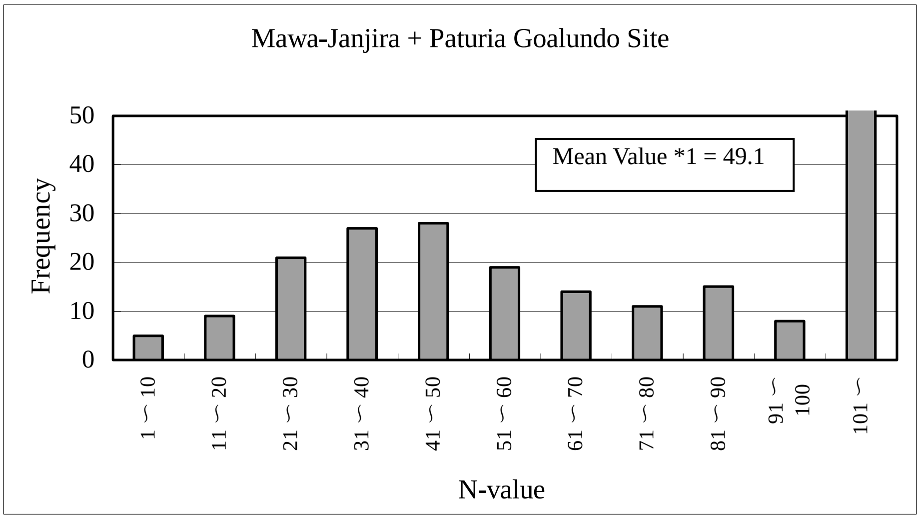


*1: Mean Value is calculated from the data of N-value excluding more than 100

Figure 1.4.10 Histogram of N-value for Unit-1a

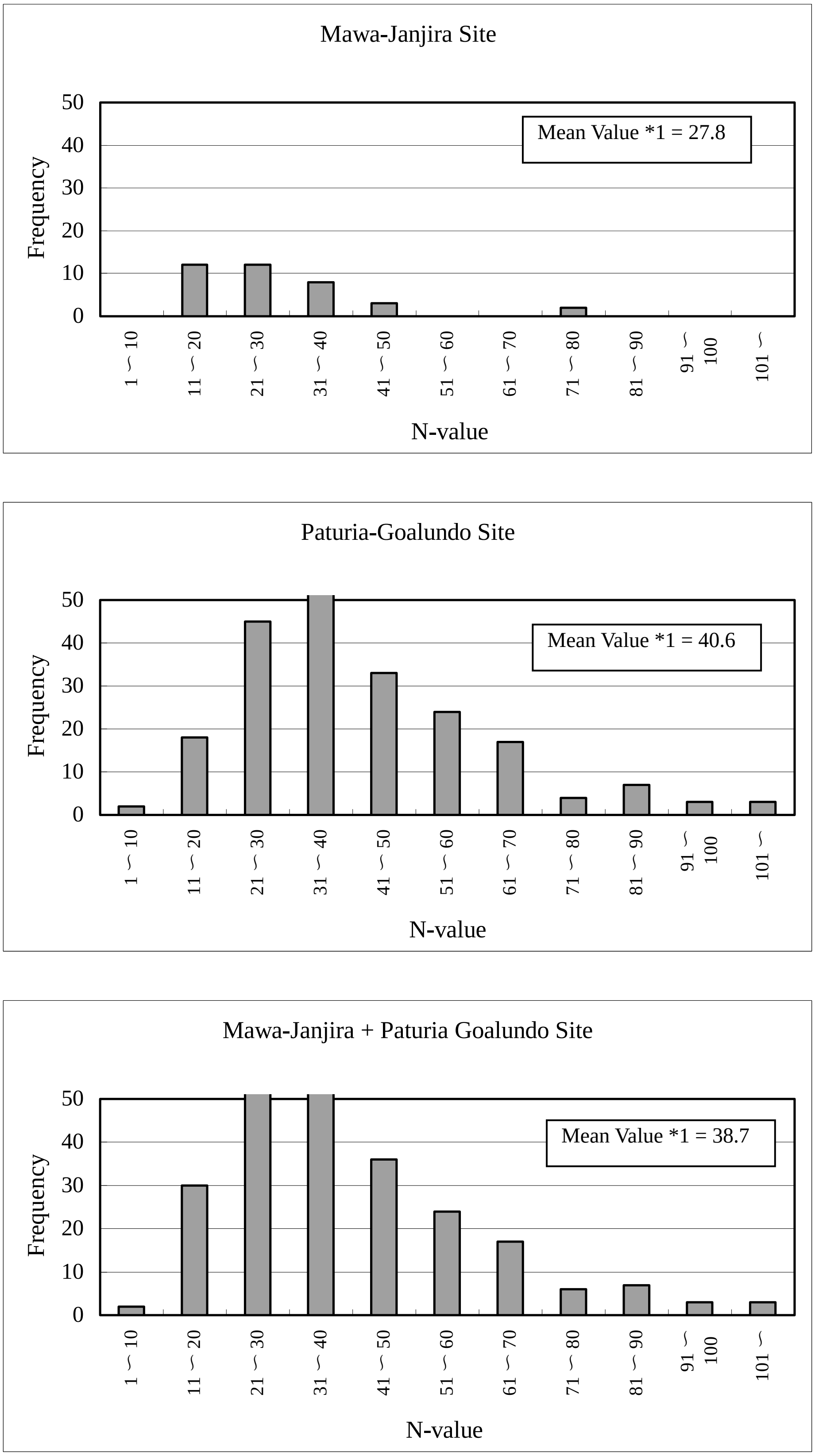






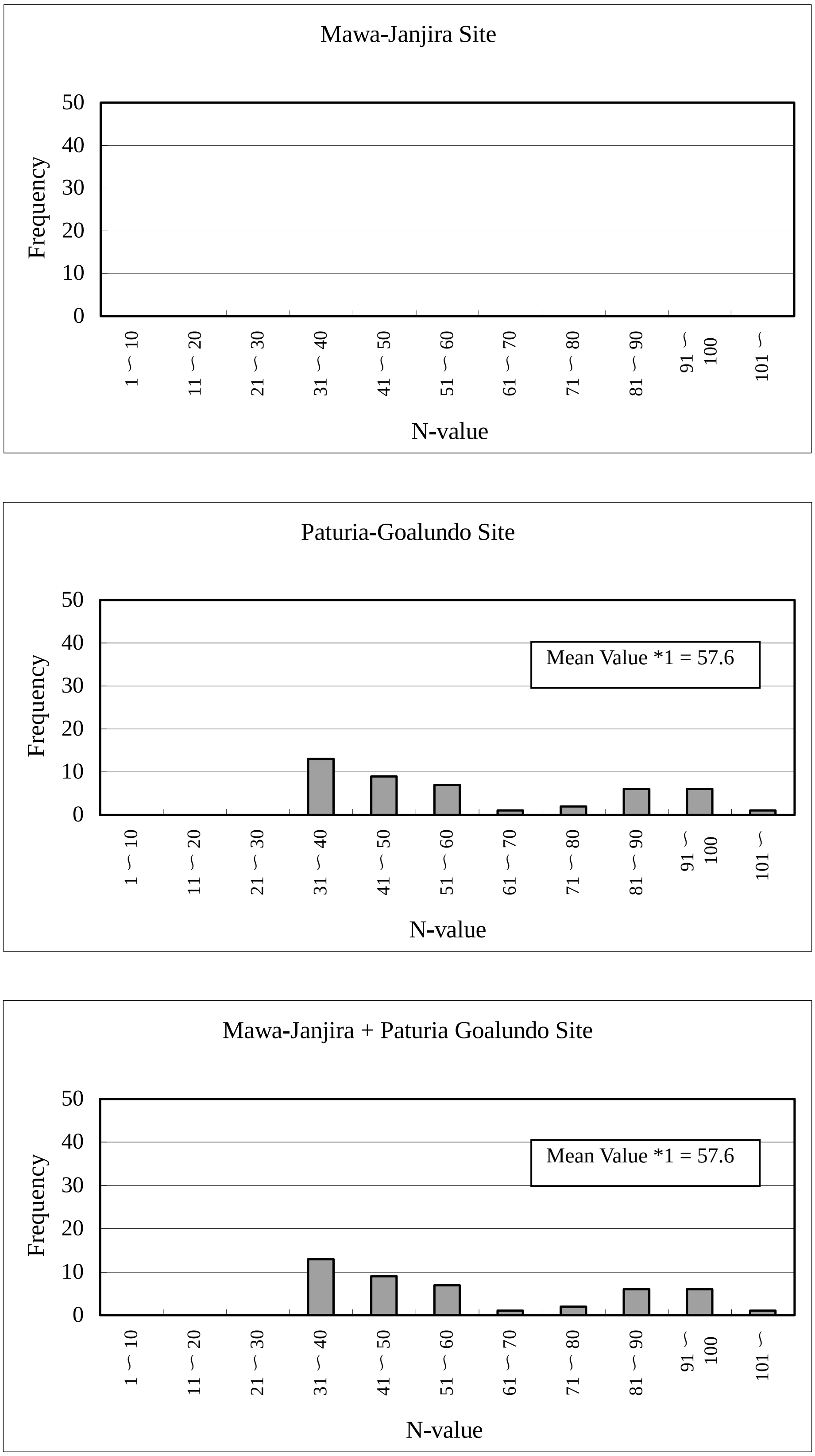
*1: Mean Value is calculated from the data of N-value excluding more than 100

Figure 1.4.11 Histogram of N-value for Unit-1b



*1: Mean Value is calculated from the data of N-value excluding more than 100

Figure 1.4.12 Histogram of N-value for Unit-2



*1: Mean Value is calculated from the data of N-value excluding more than 100

Figure 1.4.13 Histogram of N-value for Unit-3

1.5 RESULTS OF LATERAL LOADING TEST

To determine the lateral reaction of soil, there are several methods as follows:

1) empirical calculation from N-value,
2) measurement by loading on bore wall with rubber tube,
3) measurement by plate loadtest, and
4) measurement with test pile.

For the rubber tube method 2), the DOKEN (Public Works Research Institute under the government of Japan) system, the lateral loading test system and the pressio-meter system are generally used in Japan. In this study, the lateral loading test was adopted.

The results of lateral loading test are summarized in Table 1.5.1. Based on the above test results, the correlation between corrected N-value and modulus of elasticity (Em) obtained from lateral loading test is shown in Figure 1.5.1. There is a definite tendency that Em is getting increase gradually with increase of N-value. From the above tendency, the formula of N – Em relation, Em = 4.52 N, was obtained for the design of substructure.

Table 1.5.1 Measured Results of Lateral Loading Test

Site	Borehole No.	Depth (m)	Strata Unit	Corrected N-value	Coefficient of soil reaction Km (MPa/cm)	Mean radius of K value calculation r_m (cm)	Modulus of elasticity *1 Em (kgf/cm^2)	E-value estimated from N-value *2 Eo (kgf/cm^2)
Mawa-Janjira	JMBH2	31	1b	28.1	2.92	3.83	145	197
		41	1b	34.7	1.96	4.63	118	243
		51	1b	35.4	1.94	4.42	111	248
	JMBH3	21	1b	18.0	1.10	4.27	61	126
		31	1b	44.4	1.70	4.14	92	311
		41	1b	59.1	1.85	4.57	110	414
		51	1b	32.7	3.91	4.12	209	229
		61	1b	51.8	3.10	3.89	157	363
Paturia-Goalundo	PDBH2	31	2	24.2	5.10	3.84	255	169
		41	2	37.5	2.98	3.97	154	263
		51	2	29.9	1.30	4.06	69	209
		61	2	44.7	9.10	3.79	449	313
	PDBH3	31	2	21.3	2.40	4.11	128	149
		41	2	22.5	4.05	4.05	213	158
		51	2	31.7	3.20	3.90	162	222
		61	2	28.0	4.65	3.98	241	196

*1: $Em = (1+\nu) \times Km \times rm$

*2: $Eo = 7 \times N$

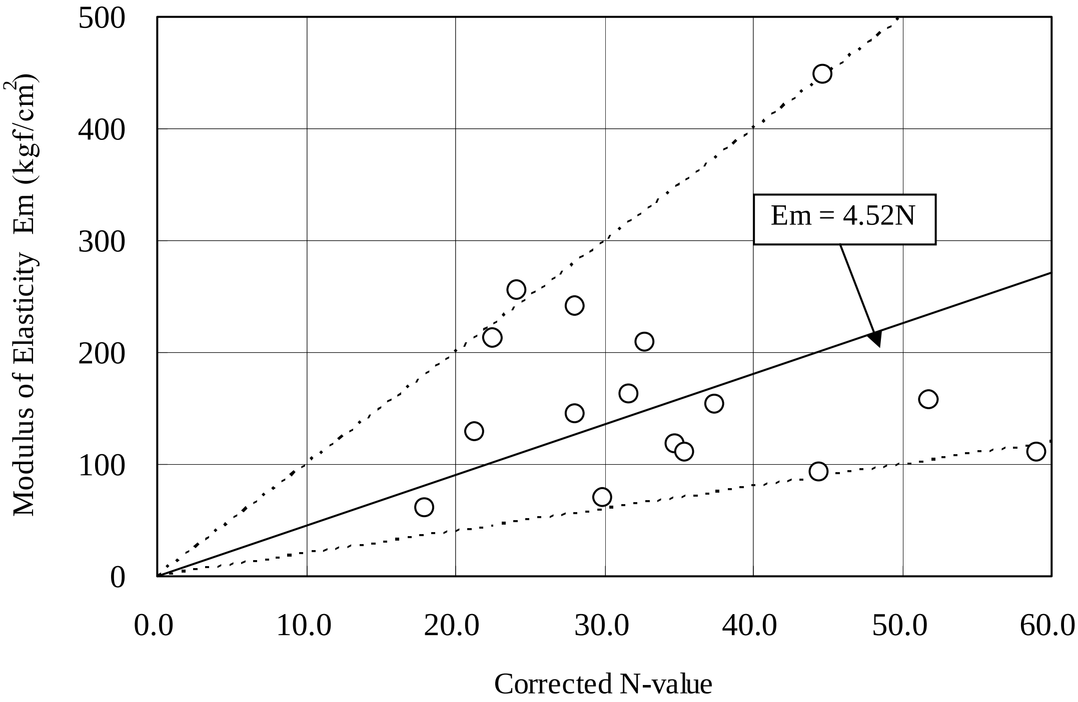


Figure 1.5.1 Correlation between N-value and Modulus of elasticity

1.6 RESULTS OF LABORATORY TEST

1.6.1 Chemical Properties of Soil Samples

Chemical property tests consisting of mica content, pH, total chloride content, soluble sulfate content and total sulfate content were carried out employing the SPT samples.

The results of chemical property tests are summarized in Table 1.6.1.

Mica content ranges from 3.5 to 66.6 % much widely. However, the data of JMBH1, JMBH4 and PDBH1 are judged to be too much large according to the visual observation and the previous investigation. Therefore, mica content is evaluated to range from 3.5 to 17.2 %. In Jamuna Bridge Project, it is reported that some flow sliding occurred during excavation works for guide bund foundation of which soil contains some mica. Judging from these failure accidents, also in Padma Bridge Project, enough attention needs to be paid to excavation works for guide bund construction.

The value of pH ranges from 6.9 to 8.4 and the soil is nearly neutral.

Total chloride content, soluble sulfate content and total sulfate content range from 0.0238 to 0.0341 %, from 0.0120 to 0.0170 % and from 0.1114 to 0.1749 % respectively.

Table 1.6.1 Chemical Properties of Soil Samples

Site	Borehole No.	Sample Depth (m)	Mica Content (%)	pH	Total Chloride Content (%)	Soluble Sulfate Content (%)	Total Sulfate Content (%)
Mawa-Janjira	JMBH1	32.55 - 33.00		8.4	0.0255	0.0152	0.1577
		13.55 - 14.00	62.0				
	JMBH2	49.55 - 50.00		7.2	0.0307	0.0140	0.1402
		58.55 - 59.00	17.2				
	JMBH3	58.55 - 59.00		6.9	0.0272	0.0135	0.1325
		46.55 - 47.00	3.5				
	JMBH4	6.55 - 7.00		8.1	0.0293	0.0170	0.1749
		27.55 - 28.00	64.7				
Paturia-Goalundo	PDBH1	16.00 - 16.45		7.8	0.0273	0.0147	0.1523
		20.00 - 20.45	66.6				
	PDBH2	70.00 - 70.45		8.1	0.0256	0.0120	0.1216
		78.00 - 78.45	14.4				
	PDBH3	57.00 - 57.45		8.2	0.0238	0.0125	0.1114
		70.00 - 70.45	15.3				
	PDBH4	34.55 - 35.00		8.1	0.0341	0.0154	0.1645
		39.55 - 40.00	4.3				

1.6.2 Chemical Properties of Groundwater

Chemical property test results of groundwater are summarized in Table 1.6.2. Chemical property of groundwater consists of pH, chloride content and sulfate content.

The value of pH ranges from 7.0 to 8.9 and the groundwater is nearly neutral. Chloride content and sulfate content range from 11.0 to 275.0 mg/L and from 1.0 to 125.0 mg/L respectively.

1.6.3 Laboratory Test Results of Undisturbed Samples

Laboratory tests consisting of natural water content, specific gravity, grain size analysis, atterberg limit, triaxial compression test and consolidation were carried out employing undisturbed samples.

The laboratory test results of undisturbed samples are summarized in Table 1.6.3.

The shear strength of cohesion and internal friction angle is 30.0 kN/m^2 and 15.8 degree at Mawa Janjira site. On the other hand, the shear strength of cohesion and internal friction angle is 26.0 kN/m^2 and 14.6 degree at Paturia Goalundo site.

Compression index (Cc) ranges from 0.081 to 0.642 and is characteristic of silt soil.

Table 1.6.2 Chemical Properties of Groundwater

Site	Borehole No.	pH	Chloride Content (mg/L)	Sulfate Content (mg/L)
Mawa-Janjira	JMBH1	7.06	275.00	2.00
	JMBH2	7.00	18.00	2.00
	JMBH3	7.80	17.00	12.00
	JMBH4	7.60	11.00	1.00
Paturia-Goalundo	PDBH1	7.50	38.00	23.00
	PDBH2	7.60	106.00	55.00
	PDBH3	8.90	125.00	125.00
	PDBH4	7.40	123.00	70.00

Table 1.6.3 Summary of Laboratory Test Results of Undisturbed Samples

Borehole	No.		JMBH1	JMBH2	JMBH2	JMBH3	JMBH4	PDBH1	PDBH2	PDBH2	PDBH3	PDBH3	PDBH4	PDBH4
Depth		(m)	2.10 ~ 2.55	1.55 ~ 2.00	4.05 ~ 4.50	0.60 ~ 1.10	0.70 ~ 1.20	1.30 ~ 1.75	1.50 ~ 1.95	6.55 ~ 7.00	1.50 ~ 1.95	4.00 ~ 4.45	3.10 ~ 3.55	6.10 ~ 6.55
Natural Water Content	Wn	(%)	36.3	47.5	38.8			31.6						
Specific Gravity	Gs		2.69	2.74	2.74	2.75	2.75	2.79	2.72	2.55	2.72	2.72	2.80	2.78
Gradation	Gravel	(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sand	(%)	8.0	3.0	46.4	4.5	5.3	3.0	10.0	7.6	32.0	2.0	0.6	5.3
	Silt	(%)	68.0	64.5	51.9	87.0	86.0	75.0	84.0	68.0	63.0	82.0	91.0	85.0
	Clay	(%)	24.0	32.5	1.7	9.0	9.0	22.0	6.0	24.0	5.0	16.0	8.0	10.0
Consistency	LL	(%)	53.0	50.0	Non-Plastic	Non-Plastic	Non-Plastic	42.8	Non-Plastic	106.3	Non-Plastic	44.0	41.5	Non-Plastic
	PL	(%)	29.5	27.3	Non-Plastic	Non-Plastic	Non-Plastic	25.9	Non-Plastic	52.0	Non-Plastic	27.0	26.0	Non-Plastic
	PI	(%)	23.5	22.7	Non-Plastic	Non-Plastic	Non-Plastic	16.9	Non-Plastic	54.3	Non-Plastic	17.0	15.5	Non-Plastic
Triaxial Compression Test	Cohesion	(kN/m^2)	(		30.0		)	(			26.0			)
	Internal Friction Angle	(degree)	(		15.8		)	(			14.6			)
Consolidation	eo		1.27	0.86	0.99	1.07	1.05	0.93		1.69	0.80	0.99	0.98	0.95
	Cc		0.290	0.270	0.098	0.182	0.208	0.270		0.642	0.081	0.246	0.298	0.188

1.7 DESIGN VALUES

Design values of each stratum (Unit-1a, Unit-1b, Unit-2 and Unit-3) consist of saturated density, submerged density, strength parameters and modulus of elasticity. Strength parameters and modulus of elasticity were estimated from N-value using the below formulas.

1) $Cu = N$ for Unit-1a
   $Cu = 0$ for Unit-1b, 2 and 3
2) $\phi = 0$ for Unit-1a
   $\phi = 15 + \sqrt{15N}$ for Unit-1b, 2 and 3
3) $Em = 4.52 \times N$

The estimated parameters are summarized in Table 1.7.1.

Based on the above estimated parameters, the design values of ϕ are proposed by reducing the estimated values a little in consideration of the effect of mica content to the shear strength of sand. Saturated density and submerged density were also estimated referring to the N-value. As a result of the above modifications, the proposed design values are summarized in Table 1.7.2.

Table 1.7.1 Estimated Parameters from N-value

Stratum			Unit - 1a	Unit - 1b	Unit - 2	Unit - 3
N-value			11	49	39	58
Saturated Density	γt (tf/m^3)		-	-	-	-
Submerged Density	γsub (tf/m^3)		-	-	-	-
Strength Parameter						
Cohesion	C (tf/m^2)	*1	11.0	0	0	0
Internal Friction Angle	ϕ (degree)	*2	0	42	39	44
Modulus of Elasticity	Em (kgf/cm^2)	*3	50	221	176	262

*1: Cu = N for Unit - 1a and Cu = 0 for Unit - 1b, 2 and 3

*2: f = 0 for Unit - 1a and f = 15 + $\sqrt{15N}$ for Unit - 1b, 2 and 3

*3: Em = 4.52N

Table 1.7.2 Proposed Design Values

Stratum		Unit - 1a	Unit - 1b	Unit - 2	Unit - 3
N-value		11	49	39	58
Saturated Density	γt (tf/m^3)	1.80	1.95	1.90	2.00
Submerged Density	γsub (tf/m^3)	0.80	0.95	0.90	1.00
Strength Parameter					
Cohesion	C (tf/m^2)	11.0	0	0	0
Internal Friction Angle	ϕ (degree)	0	38	35	40
Modulus of Elasticity	Em (kgf/cm^2)	50	220	170	260

1.8 LIQUEFACTION POTENTIAL ANALYSIS

Liquefaction potential has been evaluated using the Seed method (ref. Seed and Idriss, 1971) and the Iwasaki method (ref. Iwasaki and Tatsuoka, 1978). The method consists of evaluating the cyclic stress ratio (L) in an element of soil resulting from an earthquake acceleration and comparing it with the cyclic resistance ratio (R). The liquefaction resistance (F_L) is defined as $F_L = R / L$. If F_L is less than 1.0, liquefaction may occur.

The liquefaction resistance (F_L) is conventionally determined from the following equations:

$F_L = R / L$

$R = R_1 + R_2 + R_3$

$L = 0.65 \times \alpha_{max} \times \gamma d \times \sigma v / \sigma v'$

$R_1 = 0.0882 \times \sqrt{\dfrac{N}{\sigma v' + 0.7}}$

R_2 =	0.19	(0.02mm $\leq D_{50} \leq$ 0.05mm)
	0.225 x $\log_{10}(0.35 / D_{50})$	(0.05mm < $D_{50} \leq$ 0.6mm)
	-0.05	(0.6mm < $D_{50} \leq$ 2.0mm)
R3 =	0.0	(0% $\leq$ FC $\leq$ 40%)
	0.004 x FC – 0.16	(40% < FC $\leq$ 100%)
	$\gamma d = 1.0 - 0.015x$	

where,

F_L:	liquefaction resistance
R:	cyclic resistance ratio
L:	cyclic stress ratio
α_{max}:	maximum horizontal acceleration coefficient
γd:	stress reduction coefficient
σv:	total vertical stress (tf/m^2)
$\sigma v'$:	effective vertical stress (tf/m^2)
N:	N-value
D_{50}:	diameter at which 50% of the soil is finer (mm)
FC:	fine particle content (%)
x:	depth (m)

The estimated maximum horizontal accelerations for the bridge design have been assessed at 0.125g at Mawa Janjira site and 0.15g at Paturia Goalundo site in pre-feasibility study of Padma Bridge, 2000. Therefore, the above maximum horizontal accelerations were adopted for the liquefaction potential analysis in this study.

The liquefaction potential analysis was carried out on four borehole sections of JMBH2, JMBH3, PDBH2 and PDBH3 in two cases of before scour and after scour.

The results of liquefaction potential analysis are shown in Tables 1.8.1 to 1.8.8. As a result of analysis, the following conclusions have been obtained:

1) At Mawa Janjira site of JMBH2 and JMBH3, there is no potential for liquefaction both in cases of before scour and after scour.
2) At Paturia Goalundo site of PDBH2 and PDBH3, there is some potential for liquefaction in some depths both in cases of before scour and after scour. As a result of the above analysis, some countermeasures against liquefaction are judged to be needed for guide bund and bridge substructure at Paturia Goalundo site.

Table 1.8.1 Liquefaction Potential Analysis (JMBH2)

Borehole No.: JMBH2
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth (m)	Stratum	γ (tf/m^3)	γ' (tf/m^3)	σv (tf/m^2)	σv' (tf/m^2)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio R1	R2	R3	R	Stress Reduction Coefficient γd	CyclicStressRatio L	FL=R/L	Liquefaction Potential
0.000																
0.775	1a	1.80	0.80	1.395	0.620	1	0.07	53	0.077	0.157	0.052	0.286	0.988	0.181	1.583	Not possible
1.775	1a	1.80	0.80	3.195	1.420	2	0.07	53	0.086	0.157	0.052	0.295	0.973	0.178	1.657	Not possible
2.775	1a	1.80	0.80	4.995	2.220	3	0.07	53	0.089	0.157	0.052	0.299	0.958	0.175	1.705	Not possible
3.775	1a	1.80	0.80	6.795	3.020	4	0.07	53	0.091	0.157	0.052	0.301	0.943	0.172	1.744	Not possible
4.775	1a	1.80	0.80	8.595	3.820	2	0.07	53	0.059	0.157	0.052	0.268	0.928	0.170	1.579	Not possible
5.775	1a	1.80	0.80	10.395	4.620	3	0.07	53	0.066	0.157	0.052	0.276	0.913	0.167	1.650	Not possible
6.775	1a	1.80	0.80	12.195	5.420	6	0.07	53	0.087	0.157	0.052	0.297	0.898	0.164	1.806	Not possible
7.775	1a	1.80	0.80	13.995	6.220	2	0.07	53	0.047	0.157	0.052	0.257	0.883	0.161	1.589	Not possible
8.775	1a	1.80	0.80	15.795	7.020	5	0.07	51	0.071	0.157	0.044	0.272	0.868	0.159	1.715	Not possible
9.775	1a	1.80	0.80	17.595	7.820	4	0.07	51	0.060	0.157	0.044	0.262	0.853	0.156	1.677	Not possible
10.775	1a	1.80	0.80	19.395	8.620	6	0.07	51	0.071	0.157	0.044	0.272	0.838	0.153	1.775	Not possible
11.775	1a	1.80	0.80	21.195	9.420	10	0.07	51	0.088	0.157	0.044	0.289	0.823	0.151	1.920	Not possible
12.775	1a	1.80	0.80	22.995	10.220	9	0.07	51	0.080	0.157	0.044	0.281	0.808	0.148	1.904	Not possible
13.775	1a	1.80	0.80	24.795	11.020	4	0.07	51	0.052	0.157	0.044	0.253	0.793	0.145	1.743	Not possible
14.775	1a	1.80	0.80	26.595	11.820	9	0.07	51	0.075	0.157	0.044	0.276	0.778	0.142	1.940	Not possible
15.000	1a	1.80	0.80	27.000	12.000											
	2	1.90	0.90													
15.775	2	1.90	0.90	28.473	12.698	13	0.19	17	0.087	0.060	0.000	0.147	0.763	0.139	1.054	Not possible
16.775	2	1.90	0.90	30.373	13.598	12	0.19	17	0.081	0.060	0.000	0.140	0.748	0.136	1.034	Not possible
17.775	2	1.90	0.90	32.273	14.498	14	0.19	17	0.085	0.060	0.000	0.144	0.733	0.133	1.088	Not possible
18.775	2	1.90	0.90	34.173	15.398	16	0.19	17	0.088	0.060	0.000	0.148	0.718	0.130	1.140	Not possible
19.775	2	1.90	0.90	36.073	16.298	12	0.19	17	0.074	0.060	0.000	0.134	0.703	0.126	1.058	Not possible

Table 1.8.2 Liquefaction Potential Analysis (JMBH3)

Borehole No.:	JMBH3
Maximum horizontal acceleration coefficient:	0.125g
Groundwater Level:	Ground surface

Depth (m)	Stratum	γ (tf/m^3)	γ' (tf/m^3)	σv (tf/m^2)	σv' (tf/m^2)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio				Stress Reduction Coefficient	CyclicStressRatio	FL=R/L	Liquefaction Potential
									R1	R2	R3	R	γd	L		
0.000																
0.775	1b	1.95	0.95	1.511	0.736	2	0.075	49	0.104	0.151	0.036	0.291	0.988	0.165	1.763	Not possible
1.775	1b	1.95	0.95	3.461	1.686	9	0.075	49	0.171	0.151	0.036	0.358	0.973	0.162	2.204	Not possible
2.775	1b	1.95	0.95	5.411	2.636	9	0.075	49	0.145	0.151	0.036	0.331	0.958	0.160	2.073	Not possible
3.775	1b	1.95	0.95	7.361	3.586	31	0.075	49	0.237	0.151	0.036	0.424	0.943	0.157	2.693	Not possible
4.775	1b	1.95	0.95	9.311	4.536	24	0.075	49	0.189	0.151	0.036	0.375	0.928	0.155	2.424	Not possible
5.775	1b	1.95	0.95	11.261	5.486	5	0.075	49	0.079	0.151	0.036	0.266	0.913	0.152	1.745	Not possible
6.775	1b	1.95	0.95	13.211	6.436	12	0.075	49	0.114	0.151	0.036	0.301	0.898	0.150	2.008	Not possible
7.775	1b	1.95	0.95	15.161	7.386	19	0.075	49	0.135	0.151	0.036	0.322	0.883	0.147	2.184	Not possible
8.775	1b	1.95	0.95	17.111	8.336	23	0.14	22	0.141	0.090	0.000	0.230	0.868	0.145	1.590	Not possible
9.775	1b	1.95	0.95	19.061	9.286	34	0.14	22	0.163	0.090	0.000	0.252	0.853	0.142	1.773	Not possible
10.775	1b	1.95	0.95	21.011	10.236	22	0.14	22	0.125	0.090	0.000	0.215	0.838	0.140	1.535	Not possible
11.775	1b	1.95	0.95	22.961	11.186	11	0.14	22	0.085	0.090	0.000	0.174	0.823	0.137	1.270	Not possible
12.775	1b	1.95	0.95	24.911	12.136	10	0.14	22	0.078	0.090	0.000	0.167	0.808	0.135	1.242	Not possible
13.775	1b	1.95	0.95	26.861	13.086	51	0.14	22	0.170	0.090	0.000	0.259	0.793	0.132	1.959	Not possible
14.775	1b	1.95	0.95	28.811	14.036	33	0.14	22	0.132	0.090	0.000	0.222	0.778	0.130	1.706	Not possible
15.775	1b	1.95	0.95	30.761	14.986	17	0.14	22	0.092	0.090	0.000	0.181	0.763	0.127	1.424	Not possible
16.775	1b	1.95	0.95	32.711	15.936	18	0.14	22	0.092	0.090	0.000	0.181	0.748	0.125	1.452	Not possible
17.775	1b	1.95	0.95	34.661	16.886	52	0.14	22	0.152	0.090	0.000	0.241	0.733	0.122	1.972	Not possible
18.775	1b	1.95	0.95	36.611	17.836	16	0.14	22	0.082	0.090	0.000	0.171	0.718	0.120	1.431	Not possible
19.775	1b	1.95	0.95	38.561	18.786	43	0.14	22	0.131	0.090	0.000	0.221	0.703	0.117	1.880	Not possible

Table 1.8.3 Liquefaction Potential Analysis (PDBH2)

Borehole No.: PDBH2
Maximum horizontal acceleration coefficient: 0.15g
Groundwater Level: Ground surface

Depth (m)	Stratum	γ (tf/m³)	γ' (tf/m³)	σv (tf/m²)	σv' (tf/m²)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio R1	R2	R3	R	Stress Reduction Coefficient γd	CyclicStressRatio L	FL=R/L	Liquefaction Potential
0.000																
1.225	1a	1.80	0.80	2.205	0.980	7	0.052	72	0.180	0.186	0.128	0.494	0.982	0.215	2.296	Not possible
2.225	1a	1.80	0.80	4.005	1.780	8	0.052	72	0.158	0.186	0.128	0.473	0.967	0.212	2.229	Not possible
3.225	1a	1.80	0.80	5.805	2.580	10	0.052	72	0.154	0.186	0.128	0.468	0.952	0.209	2.243	Not possible
4.225	1a	1.80	0.80	7.605	3.380	8	0.052	72	0.124	0.186	0.128	0.438	0.937	0.205	2.131	Not possible
5.225	1a	1.80	0.80	9.405	4.180	10	0.052	72	0.126	0.186	0.128	0.441	0.922	0.202	2.179	Not possible
6.225	1a	1.80	0.80	11.205	4.980	5	0.052	72	0.083	0.186	0.128	0.397	0.907	0.199	1.996	Not possible
7.225	1a	1.80	0.80	13.005	5.780	5	0.052	72	0.077	0.186	0.128	0.392	0.892	0.196	2.003	Not possible
8.000	1a	1.80	0.80	14.400	6.400											
	2	1.90	0.90													
8.225	2	1.90	0.90	14.828	6.603	9	0.2	10	0.098	0.055	0.000	0.153	0.877	0.192	0.795	Possible
9.225	2	1.90	0.90	16.728	7.503	9	0.2	10	0.092	0.055	0.000	0.147	0.862	0.187	0.785	Possible
10.225	2	1.90	0.90	18.628	8.403	14	0.2	10	0.109	0.055	0.000	0.164	0.847	0.183	0.897	Possible
11.225	2	1.90	0.90	20.528	9.303	28	0.2	10	0.148	0.055	0.000	0.202	0.832	0.179	1.130	Not possible
12.225	2	1.90	0.90	22.428	10.203	20	0.2	10	0.119	0.055	0.000	0.174	0.817	0.175	0.995	Possible
13.225	2	1.90	0.90	24.328	11.103	39	0.2	10	0.160	0.055	0.000	0.215	0.802	0.171	1.255	Not possible
14.225	2	1.90	0.90	26.228	12.003	19	0.2	10	0.108	0.055	0.000	0.163	0.787	0.168	0.970	Possible
15.225	2	1.90	0.90	28.128	12.903	30	0.2	10	0.131	0.055	0.000	0.186	0.772	0.164	1.132	Not possible
16.225	2	1.90	0.90	30.028	13.803	29	0.2	10	0.125	0.055	0.000	0.179	0.757	0.160	1.118	Not possible
17.225	2	1.90	0.90	31.928	14.703	31	0.2	10	0.125	0.055	0.000	0.180	0.742	0.157	1.145	Not possible
18.225	2	1.90	0.90	33.828	15.603	19	0.2	10	0.095	0.055	0.000	0.150	0.727	0.154	0.976	Possible
19.225	2	1.90	0.90	35.728	16.503	28	0.2	10	0.113	0.055	0.000	0.167	0.712	0.150	1.113	Not possible
20.225	2	1.90	0.90	37.628	17.403	30	0.2	10	0.114	0.055	0.000	0.168	0.697	0.147	1.146	Not possible

Table 1.8.4 Liquefaction Potential Analysis (PDBH3)

Borehole No.: PDBH3
Maximum horizontal acceleration coefficient: 0.15g
Groundwater Level: Ground surface

Depth	Stratum	γ	γ'	σv	σv'	N-value	D50	FC	Cyclic Resistance Ratio				Stress Reduction Coefficient	CyclicStressRatio	FL=R/L	Liquefaction
(m)		(tf/m^3)	(tf/m^3)	(tf/m^2)	(tf/m^2)		(mm)	(%)	R1	R2	R3	R	γd	L		Potential
0.000																
1.225	1a	1.80	0.80	2.205	0.980	6	0.015	98	0.167	0.190	0.232	0.589	0.982	0.215	2.734	Not possible
2.225	1a	1.80	0.80	4.005	1.780	8	0.015	98	0.158	0.190	0.232	0.580	0.967	0.212	2.737	Not possible
3.225	1a	1.80	0.80	5.805	2.580	2	0.015	98	0.069	0.190	0.232	0.491	0.952	0.209	2.351	Not possible
4.225	1a	1.80	0.80	7.605	3.380	1	0.015	98	0.044	0.190	0.232	0.466	0.937	0.205	2.266	Not possible
5.225	1a	1.80	0.80	9.405	4.180	8	0.015	98	0.113	0.190	0.232	0.535	0.922	0.202	2.646	Not possible
6.225	1a	1.80	0.80	11.205	4.980	11	0.015	98	0.123	0.190	0.232	0.545	0.907	0.199	2.739	Not possible
7.225	1a	1.80	0.80	13.005	5.780	11	0.015	98	0.115	0.190	0.232	0.537	0.892	0.196	2.745	Not possible
8.225	1a	1.80	0.80	14.805	6.580	11	0.015	98	0.108	0.190	0.232	0.530	0.877	0.192	2.758	Not possible
9.225	1a	1.80	0.80	16.605	7.380	12	0.015	98	0.107	0.190	0.232	0.529	0.862	0.189	2.801	Not possible
10.225	1a	1.80	0.80	18.405	8.180	11	0.015	98	0.098	0.190	0.232	0.520	0.847	0.186	2.801	Not possible
11.225	1a	1.80	0.80	20.205	8.980	10	0.039	72	0.090	0.190	0.128	0.408	0.832	0.182	2.234	Not possible
12.225	1a	1.80	0.80	22.005	9.780	11	0.039	72	0.090	0.190	0.128	0.408	0.817	0.179	2.279	Not possible
13.225	1a	1.80	0.80	23.805	10.580	13	0.039	72	0.095	0.190	0.128	0.413	0.802	0.176	2.347	Not possible
14.225	1a	1.80	0.80	25.605	11.380	18	0.039	72	0.108	0.190	0.128	0.426	0.787	0.173	2.467	Not possible
15.225	1a	1.80	0.80	27.405	12.180	16	0.039	72	0.098	0.190	0.128	0.416	0.772	0.169	2.459	Not possible
16.225	1a	1.80	0.80	29.205	12.980	18	0.039	72	0.101	0.190	0.128	0.419	0.757	0.166	2.525	Not possible
17.225	1a	1.80	0.80	31.005	13.780	16	0.039	72	0.093	0.190	0.128	0.411	0.742	0.163	2.524	Not possible
18.225	1a	1.80	0.80	32.805	14.580	17	0.039	72	0.093	0.190	0.128	0.411	0.727	0.159	2.579	Not possible
19.225	1a	1.80	0.80	34.605	15.380	18	0.039	72	0.093	0.190	0.128	0.411	0.712	0.156	2.635	Not possible
20.225	1a	1.80	0.80	36.405	16.180	10	0.039	72	0.068	0.190	0.128	0.386	0.697	0.153	2.525	Not possible

Table 1.8.5 Liquefaction Potential Analysis after Scour (JMBH2)

Borehole No.: JMBH2
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth (m)	Stratum	γ (tf/m^3)	γ' (tf/m^3)	σv (tf/m^2)	$\sigma v'$ (tf/m^2)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio				Stress Reduction Coefficient	CyclicStressRatio	FL=R/L	Liquefaction Potential
									R1	R2	R3	R	γd	L		
0.000																
0.068	1b	1.95	0.95	0.133	0.065	8.2	0.12	29	0.289	0.105	0.000	0.393	0.999	0.167	2.361	Not possible
1.068	1b	1.95	0.95	2.083	1.015	11.5	0.12	29	0.228	0.105	0.000	0.333	0.984	0.164	2.029	Not possible
2.068	1b	1.95	0.95	4.033	1.965	16.4	0.12	29	0.219	0.105	0.000	0.323	0.969	0.162	2.001	Not possible
3.068	1b	1.95	0.95	5.983	2.915	13.5	0.12	29	0.170	0.105	0.000	0.275	0.954	0.159	1.729	Not possible
4.068	1b	1.95	0.95	7.933	3.865	20.9	0.12	29	0.189	0.105	0.000	0.293	0.939	0.157	1.873	Not possible
5.068	1b	1.95	0.95	9.883	4.815	29.3	0.12	29	0.203	0.105	0.000	0.308	0.924	0.154	1.998	Not possible
6.068	1b	1.95	0.95	11.833	5.765	33.7	0.12	29	0.201	0.105	0.000	0.306	0.909	0.152	2.018	Not possible
7.068	1b	1.95	0.95	13.783	6.715	56.4	0.12	29	0.243	0.105	0.000	0.348	0.894	0.149	2.333	Not possible
9.068	1b	1.95	0.95	17.683	8.615	25.4	0.12	29	0.146	0.105	0.000	0.250	0.864	0.144	1.737	Not possible
10.068	1b	1.95	0.95	19.633	9.565	27.5	0.12	29	0.144	0.105	0.000	0.249	0.849	0.142	1.758	Not possible
11.068	1b	1.95	0.95	21.583	10.515	22.3	0.12	29	0.124	0.105	0.000	0.229	0.834	0.139	1.646	Not possible
12.068	1b	1.95	0.95	23.533	11.465	23.3	0.12	29	0.122	0.105	0.000	0.227	0.819	0.137	1.660	Not possible
13.068	1b	1.95	0.95	25.483	12.415	43.3	0.12	29	0.160	0.105	0.000	0.265	0.804	0.134	1.975	Not possible
14.068	1b	1.95	0.95	27.433	13.365	32.3	0.12	29	0.134	0.105	0.000	0.238	0.789	0.132	1.811	Not possible
15.068	1b	1.95	0.95	29.383	14.315	29.1	0.12	29	0.123	0.105	0.000	0.227	0.774	0.129	1.762	Not possible
16.068	1b	1.95	0.95	31.333	15.265	30.5	0.12	29	0.122	0.105	0.000	0.227	0.759	0.127	1.789	Not possible
17.068	1b	1.95	0.95	33.283	16.215	62.9	0.12	29	0.170	0.105	0.000	0.275	0.744	0.124	2.214	Not possible
18.068	1b	1.95	0.95	35.233	17.165	49.6	0.12	29	0.147	0.105	0.000	0.252	0.729	0.122	2.069	Not possible
19.068	1b	1.95	0.95	37.183	18.115	88.2	0.12	29	0.191	0.105	0.000	0.296	0.714	0.119	2.482	Not possible

Table 1.8.6 Liquefaction Potential Analysis after Scour (JMBH3)

Borehole No.: JMBH3
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth (m)	Stratum	γ (tf/m^3)	γ' (tf/m^3)	σv (tf/m^2)	σv' (tf/m^2)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio R1	R2	R3	R	Stress Reduction Coefficient γd	CyclicStressRatio L	FL=R/L	Liquefaction Potential
0.000																
0.187	1b	1.95	0.95	0.365	0.178	8.6	0.23	22	0.276	0.041	0.000	0.317	0.997	0.166	1.907	Not possible
1.187	1b	1.95	0.95	2.315	1.128	15.1	0.23	22	0.254	0.041	0.000	0.295	0.982	0.164	1.798	Not possible
2.187	1b	1.95	0.95	4.265	2.078	14.8	0.23	22	0.204	0.041	0.000	0.245	0.967	0.161	1.516	Not possible
3.187	1b	1.95	0.95	6.215	3.028	12.6	0.23	22	0.162	0.041	0.000	0.203	0.952	0.159	1.279	Not possible
4.187	1b	1.95	0.95	8.165	3.978	14.3	0.23	22	0.154	0.041	0.000	0.195	0.937	0.156	1.249	Not possible
5.187	1b	1.95	0.95	10.115	4.928	16.8	0.23	22	0.152	0.041	0.000	0.193	0.922	0.154	1.258	Not possible
6.187	1b	1.95	0.95	12.065	5.878	20.9	0.23	22	0.157	0.041	0.000	0.198	0.907	0.151	1.310	Not possible
7.187	1b	1.95	0.95	14.015	6.828	19.2	0.23	22	0.141	0.041	0.000	0.182	0.892	0.149	1.222	Not possible
8.187	1b	1.95	0.95	15.965	7.778	16.7	0.23	22	0.124	0.041	0.000	0.165	0.877	0.146	1.127	Not possible
9.187	1b	1.95	0.95	17.915	8.728	17.2	0.23	22	0.119	0.041	0.000	0.160	0.862	0.144	1.114	Not possible
10.187	1b	1.95	0.95	19.865	9.678	29	0.23	22	0.147	0.041	0.000	0.188	0.847	0.141	1.334	Not possible
11.187	1b	1.95	0.95	21.815	10.628	36.5	0.23	22	0.158	0.041	0.000	0.199	0.832	0.139	1.436	Not possible
12.187	1b	1.95	0.95	23.765	11.578	41.2	0.23	22	0.162	0.041	0.000	0.203	0.817	0.136	1.487	Not possible
13.187	1b	1.95	0.95	25.715	12.528	29.8	0.23	22	0.132	0.041	0.000	0.173	0.802	0.134	1.296	Not possible
14.187	1b	1.95	0.95	27.665	13.478	34.9	0.23	22	0.138	0.041	0.000	0.179	0.787	0.131	1.367	Not possible
15.187	1b	1.95	0.95	29.615	14.428	41.2	0.23	22	0.146	0.041	0.000	0.187	0.772	0.129	1.449	Not possible
16.187	1b	1.95	0.95	31.565	15.378	45.9	0.23	22	0.149	0.041	0.000	0.190	0.757	0.126	1.505	Not possible
17.187	1b	1.95	0.95	33.515	16.328	24	0.23	22	0.105	0.041	0.000	0.146	0.742	0.124	1.177	Not possible
18.187	1b	1.95	0.95	35.465	17.278	35.1	0.23	22	0.123	0.041	0.000	0.164	0.727	0.121	1.354	Not possible
19.187	1b	1.95	0.95	37.415	18.228	40.4	0.23	22	0.129	0.041	0.000	0.170	0.712	0.119	1.430	Not possible

Table 1.8.7 Liquefaction Potential Analysis after Scour (PDBH2)

Borehole No.: PDBH2
Maximum horizontal acceleration coefficient: 0.15g
Groundwater Level: Ground surface

Depth (m)	Stratum	γ (tf/m^3)	γ' (tf/m^3)	σv (tf/m^2)	σv' (tf/m^2)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio R1	R2	R3	R	Stress Reduction Coefficient γd	CyclicStressRatio L	FL=R/L	Liquefaction Potential
0.000																
0.772	2	1.90	0.90	1.467	0.695	13.3	0.16	16	0.272	0.076	0.000	0.349	0.988	0.203	1.715	Not possible
1.772	2	1.90	0.90	3.367	1.595	17.1	0.16	16	0.241	0.076	0.000	0.317	0.973	0.200	1.583	Not possible
2.772	2	1.90	0.90	5.267	2.495	15.3	0.16	16	0.193	0.076	0.000	0.270	0.958	0.197	1.366	Not possible
3.772	2	1.90	0.90	7.167	3.395	20	0.16	16	0.195	0.076	0.000	0.271	0.943	0.194	1.398	Not possible
4.772	2	1.90	0.90	9.067	4.295	13	0.16	16	0.142	0.076	0.000	0.219	0.928	0.191	1.145	Not possible
5.772	2	1.90	0.90	10.967	5.195	12.5	0.16	16	0.128	0.076	0.000	0.205	0.913	0.188	1.090	Not possible
6.772	2	1.90	0.90	12.867	6.095	29.1	0.16	16	0.183	0.076	0.000	0.259	0.898	0.185	1.401	Not possible
7.772	2	1.90	0.90	14.767	6.995	23.4	0.16	16	0.154	0.076	0.000	0.230	0.883	0.182	1.266	Not possible
8.772	2	1.90	0.90	16.667	7.895	24.1	0.27	8	0.148	0.025	0.000	0.173	0.868	0.179	0.968	Possible
9.772	2	1.90	0.90	18.567	8.795	22.4	0.27	8	0.135	0.025	0.000	0.161	0.853	0.176	0.916	Possible
10.772	2	1.90	0.90	20.467	9.695	47.8	0.27	8	0.189	0.025	0.000	0.214	0.838	0.173	1.243	Not possible
11.772	2	1.90	0.90	22.367	10.595	39.8	0.27	8	0.166	0.025	0.000	0.191	0.823	0.169	1.126	Not possible
12.772	2	1.90	0.90	24.267	11.495	50.7	0.27	8	0.180	0.025	0.000	0.205	0.808	0.166	1.233	Not possible
13.772	2	1.90	0.90	26.167	12.395	49.5	0.27	8	0.171	0.025	0.000	0.197	0.793	0.163	1.205	Not possible
14.772	2	1.90	0.90	28.067	13.295	26.7	0.25	11	0.122	0.033	0.000	0.155	0.778	0.160	0.966	Possible
15.772	2	1.90	0.90	29.967	14.195	34.5	0.25	11	0.134	0.033	0.000	0.167	0.763	0.157	1.063	Not possible
16.772	2	1.90	0.90	31.867	15.095	36.5	0.25	11	0.134	0.033	0.000	0.167	0.748	0.154	1.084	Not possible
17.772	2	1.90	0.90	33.767	15.995	41.3	0.25	11	0.139	0.033	0.000	0.172	0.733	0.151	1.137	Not possible
18.772	2	1.90	0.90	35.667	16.895	37.3	0.25	11	0.128	0.033	0.000	0.161	0.718	0.148	1.091	Not possible
19.772	2	1.90	0.90	37.567	17.795	36	0.25	11	0.123	0.033	0.000	0.156	0.703	0.145	1.077	Not possible

Table 1.8.8 Liquefaction Potential Analysis after Scour (PDBH3)

Borehole No.: PDBH3
Maximum horizontal acceleration coefficient: 0.15g
Groundwater Level: Ground surface

Depth (m)	Stratum	γ (tf/m³)	γ' (tf/m³)	σv (tf/m²)	σv' (tf/m²)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio R1	R2	R3	R	Stress Reduction Coefficient γd	CyclicStressRatio L	FL=R/L	Liquefaction Potential
0.000																
0.677	2	1.90	0.90	1.286	0.609	6.3	0.22	11	0.193	0.045	0.000	0.239	0.990	0.204	1.172	Not possible
1.677	2	1.90	0.90	3.186	1.509	11	0.22	11	0.197	0.045	0.000	0.242	0.975	0.201	1.207	Not possible
2.677	2	1.90	0.90	5.086	2.409	11.5	0.22	11	0.170	0.045	0.000	0.215	0.960	0.198	1.088	Not possible
3.677	2	1.90	0.90	6.986	3.309	13.7	0.22	11	0.163	0.045	0.000	0.208	0.945	0.194	1.072	Not possible
4.677	2	1.90	0.90	8.886	4.209	17.7	0.22	11	0.167	0.045	0.000	0.213	0.930	0.191	1.112	Not possible
5.677	2	1.90	0.90	10.786	5.109	16.6	0.22	11	0.149	0.045	0.000	0.194	0.915	0.188	1.033	Not possible
6.677	2	1.90	0.90	12.686	6.009	17.8	0.22	11	0.144	0.045	0.000	0.189	0.900	0.185	1.021	Not possible
7.677	2	1.90	0.90	14.586	6.909	16.7	0.22	11	0.131	0.045	0.000	0.176	0.885	0.182	0.967	Possible
8.677	2	1.90	0.90	16.486	7.809	12.7	0.22	11	0.108	0.045	0.000	0.153	0.870	0.179	0.855	Possible
9.677	2	1.90	0.90	18.386	8.709	16.8	0.22	11	0.118	0.045	0.000	0.163	0.855	0.176	0.928	Possible
10.677	2	1.90	0.90	20.286	9.609	14.3	0.22	8	0.104	0.045	0.000	0.149	0.840	0.173	0.863	Possible
11.677	2	1.90	0.90	22.186	10.509	15.6	0.22	8	0.104	0.045	0.000	0.149	0.825	0.170	0.880	Possible
12.677	2	1.90	0.90	24.086	11.409	15.9	0.22	8	0.101	0.045	0.000	0.146	0.810	0.167	0.878	Possible
13.677	2	1.90	0.90	25.986	12.309	22.2	0.22	8	0.115	0.045	0.000	0.161	0.795	0.164	0.982	Possible
14.677	2	1.90	0.90	27.886	13.209	18.5	0.22	8	0.102	0.045	0.000	0.147	0.780	0.161	0.916	Possible
15.677	2	1.90	0.90	29.786	14.109	23.4	0.22	8	0.111	0.045	0.000	0.156	0.765	0.157	0.992	Possible
16.677	2	1.90	0.90	31.686	15.009	24.2	0.22	8	0.109	0.045	0.000	0.155	0.750	0.154	1.003	Not possible
17.677	2	1.90	0.90	33.586	15.909	26.1	0.22	8	0.111	0.045	0.000	0.156	0.735	0.151	1.031	Not possible
18.677	2	1.90	0.90	35.486	16.809	22.1	0.22	8	0.099	0.045	0.000	0.144	0.720	0.148	0.975	Possible
19.677	2	1.90	0.90	37.386	17.709	22.3	0.22	8	0.097	0.045	0.000	0.142	0.705	0.145	0.982	Possible

1.9 CONCLUSIONS AND RECOMMENDATIONS

As a result of geotechnical investigation, the following are concluded and recommended for the design of bridge substructure.

- The classification of four strata consisting of Unit-1a, 1b, 2 and 3 was recommended for drawing the geological profiles of Mawa Janjira site and Paturia Goalundo site.
- As the gradation curve of Unit-2 is steep and the uniformity coefficient is very small, the soil of Unit-2 is evaluated to be poorly graded and estimated to be looser than that of Unit-1b and Unit-3.
- There is a remarkable difference of geological profile between Mawa Janjira site and Paturia Goalundo site, that is, Unit-1b predominates at Mawa Janjira site while Unit-2 predominates at Paturia Goalundo site.
- N-value at Mawa Janjira site is much larger than that at Paturia Goalundo site below El. -40m.
- N-value after scour at Mawa Janjira site is much larger than that at Paturia Goalundo site.
- The mean N-value of Unit-2 is lower than that of Unit-1b and Unit-3, because the soil of Unit-2 is poorly graded and is estimated to be looser than that of Unit-1b and Unit-3.
- There is a definite tendency that Em is getting increase gradually with increase of N-value. From the above tendency, the formula of N – Em relation, Em = 4.52 N, was obtained for the design of substructure.
- Mica content ranges from 3.5 to 66.6 % much widely. However, the data of JMBH1, JMBH4 and PDBH1 are judged to be too much large according to the visual observation and the previous investigation. Therefore, mica content is evaluated to range from 3.5 to 17.2 %. In Jamuna Bridge Project, it is reported that some flow sliding occurred during excavation works for guide bund foundation of which soil contains some mica. Judging from these failure accidents, also in Padma Bridge Project, enough attention needs to be paid to excavation works for guide bund construction.
- The proposed design values are summarized below.

Stratum		Unit - 1a	Unit - 1b	Unit - 2	Unit - 3
N-value		11	49	39	58
Saturated Density	γt (tf/m^3)	1.80	1.95	1.90	2.00
Submerged Density	γsub (tf/m^3)	0.80	0.95	0.90	1.00
Strength Parameter					
Cohesion	C (tf/m^2)	11.0	0	0	0
Internal Friction Angle	ϕ (degree)	0	38	35	40
Modulus of Elasticity	Em (kgf/cm^2)	50	220	170	260

- The above design values of ϕ are proposed by reducing the estimated values a little in consideration of the effect of mica content to the shear strength of sand. In the next step, therefore, it is recommended that the relationship between mica content and shear strength of sand shall be investigated in detail by means of laboratory test.
- At Mawa Janjira site of JMBH2 and JMBH3, there is no potential for liquefaction both in cases of before scour and after scour.
- At Paturia Goalundo site of PDBH2 and PDBH3, there is some potential for liquefaction in some depths both in cases of before scour and after scour. As a result of the above analysis, some countermeasures against liquefaction are judged to be needed for guide bund and bridge substructure at Paturia Goalundo site.

Chapter 2 Geotechnical Investigations for Selected Mawa-Janjira Site

2.1 GENERAL

The geotechnical studies and investigations for the feasibility study of Padma Bridge were carried out for the following purposes:

1) Investigation for foundation of Padma Bridge
   To provide the design engineers with information on the engineering properties of the natural soils, which will permit the determination of the foundation type and foundation structure of Padma Bridge.
2) Investigation for foundation of access roads and minor bridges
   To provide the design engineers with information on the foundation of minor bridges over channels and embankment for access roads.
3) Investigation for embankment materials
   To provide the design engineers with information on the embankment materials for access roads.

The geotechnical investigation consists core drilling, Standard Penetration Test, Pressuremeter Test, laboratory tests of soil and laboratory tests of groundwater for bridges and access roads at Mawa Janjira site.

2.2 GEOLOGY

A comprehensive classification of Bangladesh physiography can be described in the following 23 geomorphic units as shown in Figure 2.2.1.

Floodplain Areas

1. Old Himalayan Piedmont Plain
2. Teesta Floodplain
3. Karatoya-Bangali Floodplain
4. Lower Atrai Floodplain
5. Lower Purnabhaba Floodplain
6. Young Brahmaputra Floodplain
7. Old Brahmaputra Floodplain
8. Ganges River Floodplain
9. Ganges Tidal Floodplain
10. Gopalganj-Khulna Beels
11. Arial Beel
12. Middle Meghna Floodplain
13. Lower Meghna River Floodplain
14. Young Meghna Estuarine Floodplain
15. Old Meghna Estuarine Floodplain
16. Surma-Kusiyara Floodplain
17. Sylhet Basin
18. Northern and Eastern Piedmont Plains
19. Chittagong Coastal Plain
20. St Martin’s Island

Terrace Areas

21. Madhupur Tract
22. Barind Tract

Hill Areas

23. Northern and Eastern Hills

In broad terms, there are three main geological formations in Bangladesh:

- **Tertiary sediments** in the northern and eastern hills;
- the **Madhupur Clay** of the Madhupur and Barind Tracts in the center and west; and
- **recent alluvial plain** underlying the floodplain and estuarine areas which occupy the remainder of the country.

Tertiary sediments in the northern and eastern hills, which occupy about 12 percent of Bangladesh, are underlain mainly by unconsolidated or little-consolidated beds of sandstones, siltstones and shales, together with minor beds of limestone and conglomerates. They have been uplifted and folded into a series of pitching anticlines and synclines. These are aligned approximately NNW to SSE in the Chittagong Hill Tracts and Chittagong regions and the south of Sylhet region, swinging round to almost east-west in the north of Sylhet and Mymensingh regions.

The Madhupur and Barind Tracts, which together occupy about 8 percent of the country, are underlain by the Madhupur Clay. The Madhupur Clay was earlier called the ‘older alluvium’ and was regarded as Pleistocene in age. The 1964 Geological Map of Pakistan gave the formation the name Madhupur Clay, and suggested that it might correlate with the Dupi Tila formation, regarded as of Mio-Pliocene age. In some places, the Madhupur Clay has been considerably altered by weathering and changed into red-mottled clay which forms the substratum of the overlying soils. Where it is less altered, it comprises gray, heavy clay with prominent slickensides, and usually with a few small, hard, ironstone (or iron-coated manganese) concretions scattered throughout.

Recent alluvial plain underlying unconsolidated floodplain sediments occupy about 80 percent of Bangladesh. The vast alluvial plain has emerged from the sedimentation process of the three mighty rivers, the Ganges, the Brahmaputra-Jamuna and the Meghna and their innumerable tributaries. No places in the flood plain can be seen to be of 30 feet above mean sea level and average slope is less than 5” to a mile.

Padma Bridge Project area is situated in the above Ganges flood plain, which is one of recent alluvial plains. The Ganges in Bangladesh is known as the Padma and occupies one of the largest area of land formation. The flood plain is characterized by the new char formation. The Ganges flood plain can be identified as active, moribund and meander flood plain on the basis of river activity. The active area include the newly built chars where soil formation is yet to develop. The Ganges flood plain especially the active flood plain is flooded in the month of June and flood water recedes in the month of September. The area is erosion prone with population displacement and other social problem is generated in the area due to severity of the hazard. Some parts of the greater Kushtia, Jessore and northern part of Khulna district is called as moribund area. The rivers are no longer active in the area and therefore no deposition occurs. The water level is also as high as the Padma and large scale siltation in the past has resulted the rising up of the bed. The levee formation by the distributaries has buried the irregular surfaces. The surface water erosion is feeding the ridges (Brammer, 1964).

The Padma flood plain is renamed by some as deltaic flood plain. With the extension of delta, the branching of the Padma has moved downward. The whole meander flood plain of the Padma can again be considered as old and new. The highest discharge of the river is 72,300m3/sec (1988). The active flood plain is sandy or silty and has no evidence of soil formation. The meander flood plain is composed of several deposits. The high ridges are sandy or silty and basins are clayey silt. The recently deposited alluvium of the Padma is obviously calcareous and annually recharged with nutrients. The flood plain is flooded during the monsoon season. Perched water table is seen in the basin. In the moribund region the soils become saturated due to capillary movement of water and with withdrawal of water surface salt cover is seen. The Padma flood plain is sometime mixed with Brahmaputra alluvium on the margin. The changing nature of the course on the Padma channel has left some imprint on the surface as well.

2.3 OUTLINE OF GEOTECHNICAL INVESTIGATION

The geotechnical investigation consists of core drilling, Standard Penetration Test, Lateral Loading Test, undisturbed soil sampling, groundwater sampling, laboratory tests of soil and groundwater and embankment material tests at bridge site and access road route.

The quantity and standard of each test item are described in Table 2.3.1.

At bridge site, four boreholes were conducted. A 120m deep borehole (JMBH21) was drilled on the left bank. On the char, two 120m deep boreholes (JMBH22 & JMBH23) were drilled. On the right bank, a 120m deep borehole (JMBH24) was drilled. Twelve boreholes (JMBH215 to JMBH216) of 20m or 40m in depth were drilled along a proposed access road route. Further, the test pitting was conducted at five locations for laboratory tests of embankment material. The locations of the boreholes and test pits are shown in Figure 2.3.1.

The Standard Penetration Test and Split-Barrel Sampling of soils (ASTM D 1586) were carried out at an interval of one meter and disturbed sampling was conducted for laboratory tests.

The Lateral Loading Test was conducted in four boreholes, comprising eight depths at JMBH21, six depths at JMBH22, six depths at JMBH23 and eight depths at JMBH24.

For cohesive soils, undisturbed samples were taken for laboratory tests using a thin wall sampling tube.

Sampling of groundwater was taken after 24 hours from the drilled boreholes for investigating the groundwater quality.

Laboratory test for soil consists of natural water content, specific gravity, unit weight, atterberg limits, grain size analysis, triaxial compression test, consolidation test, mica content, pH, total sulfate content, soluble sulfate content and total chloride content.

On the other hand, laboratory test for groundwater consists of pH, sulfate content and chloride content.

Laboratory test for embankment material consists of natural water content, specific gravity, atterberg limits, grain size analysis, compaction test and CBR test.

2.4 FOUNDATION OF BRIDGE SITE

2.4.1 Geological Profile

The following chronological and stratigraphical classification was used for drawing the geological profile of bridge site. Based on the results of grain size analysis, the following classification is proposed:

Stratum	Criteria
Unit-1a	Clay + Silt ≥ 50%
Unit-1b	20% ≤ Clay + Silt < 50%
Unit-2	Clay + Silt < 20% and Medium Sand < 10%
Unit-3	Clay + Silt < 20% and Medium Sand ≥ 10%

Physical properties of each stratum are summarized in Table 2.4.1. From these physical properties, each stratum can be characterized as follows:

Stratum	Description
Unit-1a	CLAY or SILT with fine sand
Unit-1b	very silty fine SAND
Unit-2	silty fine SAND
Unit-3	slightly silty fine and medium SAND

Uniformity coefficient of Unit-1a, Unit-1b, Unit-2 and Unit-3 are 11.2, 16.2, 4.7 and 2.2 in average respectively. As the gradation curves of Unit-2 and Unit-3 are steep and the uniformity coefficients are very small, the soils of Unit-2 and Unit-3 can be evaluated to be poorly graded. Therefore, the soils of Unit-2 and Unit-3 are estimated to be looser than that of Unit-1b.

Geological profile of Bridge Site is shown in Figure 2.4.1. This geological profile is drawn up, based on the results of grain size analysis and visual observation of the disturbed split spoon samples obtained from the Standard Penetration Tests.

On the left bank at Mawa site, at the borehole site of JMBH21, Unit-1a of CLAY or SILT with fine sand was found in the upper part up to El. -7.281m, 12m in thickness. On the right bank at Janjira site, at the borehole site of JMBH24, Unit-1a was found in the upper part up to El. 3.719m, 3m in thickness. On the char, at the borehole site of JMBH22, Unit-1a was found in the upper part up to El. 1.841m, 3m in thickness. On the other hand, at the borehole site of JMBH23, Unit-1a was not found in the upper part. Throughout the whole of bridge site, Unit-1b of very silty fine SAND predominates in the lower part below Unit-1a, where Unit-2 of silty fine SAND , Unit-3 of slightly silty fine and medium SAND and Unit-1a lie locally.

2.4.2 N-value

The Standard Penetration Test (SPT) was carried out at an interval of one meter for the full depth of each borehole.

The measured N-values have some problems because blow energy has kinds of losses on the way to the bed in the very deep position where the measurements are obtained imperfectly. A number of study results have been provided by Terzaghi - Peck (1948), Ikeda (1959), Thornburn (1963), Uto (1974) and others on the correction of such measured N-values. In this study, considering that the highest is the loss of blow energy caused on the way of its transmission to the bottom of a bore, the loss-error of the measured N-value was corrected by the formula of Uto (1974). Hereinafter this method is called Method-1.

The following formula (Uto, 1974) was applied for N-value correction:

$N' = N$ $(L < 20m)$
$N' = (1.06 - 0.003 \times L) \times N$ $(L \geq 20m)$

where,

N': corrected N-value
N: measured N-value

L: length of drill rods (m)

When the full test depth of 300 mm can not be obtained, the N-value is estimated to be the corresponding blow counts to the penetration of 300 mm. In cases that the test is halted with only first blow activity due to the stiff layer, the N-value is assumed to be 250.

The distribution of corrected N-value at bridge site is shown in Figure 2.4.2. This figure shows that N-value data scatter considerably among six boreholes. Therefore, lower line of corrected N-value distribution is proposed for the design of bridge substructure. In the practical design of bridge structure in the feasibility study, it is recommended that the design line on which the N-value is limited to 50 as shown in Figure 2.4.2 is used on the basis of Standards adopted by Japan Road Association.

For comparison with the Method-1, another method called Method-2 was applied for N-value correction. This method was also used in the pre-Feasibility Study of Padma Bridge. The applied formula is as follows:

$N' = N \times C_N \times R_L$

where,

N': corrected N-value

N: measured N-value

C_N: correction factor for overburden

$C_N = 200 / (100 + \sigma')$ for medium dense / loose sand

$C_N = 300 / (200 + \sigma')$ for dense / very dense sand

σ' = effective overburden pressure (kPa)

R_L: correction factor for drill rod length

$R_L = 0.75$ for $L < 3$ m

$R_L = 1.00$ for $L \geq 3$ m

L = drill rod length (m)

The distribution of corrected N-value by Method-2 is shown in Figure 2.4.3. The design line proposed above is situated nearly in the middle of the distribution of corrected N-values by Method-2. Therefore, the proposed design line is considered to be appropriate for the design of bridge structure in the feasibility study.

Additionally CPT (Cone Penetration Test) investigations were conducted at the borehole sites of JMBH21 and JMBH24 in order to check the reliability of N-value. The comparisons between CPT log and SPT log are shown in Figures 2.4.4 and 2.4.5. There are some big differences between CPT value and SPT value at depths of about 30 m of JMBH21 and about 5 m, 30 m and 39 m of JMBH24. Except for these depths, the distribution trend of SPT showing that the N-value is increasing with depth is almost the same as that of CPT. Considering from the above comparison the N-value is evaluated to be reliable in an allowable level.

Reduction in overburden pressure at the scoured bed level will induce a reduction in the density of soil, and hence the N-values at depths below scour level. The following equations were applied to obtain the reduced N-values after scour:

$Ns = N' \times B_1$

$$B_1 = 0.75 \times \sqrt{\frac{Z + 0.8 \times \sqrt{s \times z} + z \times z}{s + z}}$$

where,

B_1:	scour reduction factor
Ns:	N-value at depth after scour
N':	corrected N-value at depth before scour
s:	scour depth (m)
z:	depth below GL after scour (m)

The depths of scour in the middle of river section and adjacent to riverbank are summarized below:

Location	Maximum scour depth
In the middle of river section	-23.6 m PWD
Adjacent to riverbank	-37.6 m PWD

The distributions of N-value after scour up to -23.6m PWD and -37.6 m PWD are shown in Figures 2.4.6 and 2.4.7 respectively. Further, lower line and design line of N-value distribution after scour are proposed for the design of bridge substructure in both figures. It is recommended that the bridge design engineer uses the design line for the design of bridge structure after scour in the feasibility study.

2.4.3 Lateral Loading Test

To determine the lateral reaction of soil, there are several methods as follows:

1) empirical calculation from N-value,
2) measurement by loading on bore wall with rubber tube,
3) measurement by plate load test, and
4) measurement with test pile.

For the rubber tube method 2), the DOKEN (Public Works Research Institute under the government of Japan) system, the lateral loading test system and the pressio-meter system are generally used in Japan. In this study, the lateral loading test was adopted.

The results of lateral loading test in both Phase-1 and Phase-2 are summarized in Table 2.4.2. Based on the above test results, the correlation between corrected N-value and modulus of elasticity (Em) obtained from lateral loading test is shown in Figure 2.4.8. There is a definite tendency that Em increases gradually with N-value. From the above tendency, the formula of N – Em relation, Em = 2.89 N, was obtained for the design of substructure.

For comparison, the correlation between N-value corrected by Method-2 and Em is shown in Figure 2.4.9. This figure presents that the correlation coefficient between N-value of Method-2 and Em (R=0.341) is lower than that between N-value of Method-1 and Em (R=0.653).

2.4.4 Laboratory Test Results

(1) Chemical Properties of Soil Samples

Table 2.4.3 shows the results of chemical property tests carried out in Phase-1 and Phase-2. Chemical property tests consisting of mica content, pH, total chloride content, soluble sulfate content and total sulfate content were carried out employing the SPT samples.

The value of pH ranges from 6.9 to 8.5 and the soil in bridge site is nearly neutral.

Total chloride content, soluble sulfate content and total sulfate content range from 0.0272 to 0.0341 %, from 0.0026 to 0.0140 % and from 0.0309 to 0.1402 % respectively.

Judging from the above values of chemical property, it is evaluated that the soil in bridge site does not have a significant degree of attack on the concrete structures such as piles.

Regarding mica content, it ranges from 3.5 to 52.7 % much widely. At the site of JMBH21, the mica content was found to be very high, 52.7 %. Thus it is considered that there are some layers having a high content of mica locally.

In Jamuna Bridge Project, it is reported that some flow slidings occurred during excavation works for guide bund foundation of which soil contains some mica. Judging from these failure accidents, also in Padma Bridge Project, enough attention needs to be paid to excavation works for guide bund construction.

(2) Chemical Properties of Groundwater

Table 2.4.4 shows the results of chemical property tests of groundwater carried out in Phase-1 and Phase-2. Chemical property of groundwater consists of pH, chloride content and sulfate content.

The value of pH ranges from 6.5 to 7.8 and the groundwater in bridge site is nearly neutral. Chloride content and sulfate content range from 10.0 to 27.0 mg/L and from 2.0 to 38.0 mg/L respectively.

Judging from the above values of chemical property, it is evaluated that the groundwater in bridge site does not have a significant degree of attack on the concrete structures such as piles.

(3) Undisturbed Sample Tests

Table 2.4.5 shows the laboratory test results of undisturbed samples carried out in Phase-1 and Phase-2. Laboratory tests consisting of natural water content, specific gravity, grain size analysis, atterberg limit, triaxial compression test and consolidation were carried out employing undisturbed sample taken at the borehole site of JMBH2, JMBH3 and JMBH21.

Regarding shear strengths of JMBH21, cohesion is 19.0 kPa and internal friction angle is 26.7 degrees. On the other hand, shear strengths of JMBH2 and JMBH3 are 30.0 kPa of cohesion and 15.8 degrees of internal friction angle.

Regarding consolidation properties, initial void ratio (eo) ranges from 0.86 to 1.07 and compression index (Cc) ranges from 0.098 to 0.270. Further, e ~ log P curves are shown in Figure 2.4.10 and log Cv ~ log P curves are shown in Figure 2.4.11. Figure 2.4.11 indicates that coefficient of consolidation (Cv) ranges from 2×10^{-3} to 1×10^{-1} cm^2/sec independent of consolidation pressures.

2.4.5 Design Values

There is some possibility that the river bed can be scoured. The depths of scour in the middle of river section and adjacent to riverbank are estimated to be -23.6m PWD and -37.6m PWD respectively. Thus the design values for bridge substructure are proposed in both cases of scour depth of -23.6m PWD and scour depth of -37.6m PWD.

Design values of each layer consist of N-value, saturated density, strength parameters and modulus of elasticity. Each design value was determined as follows:

1) N-value was determined using the lower line and design line shown in Figures 2.4.6 and 2.4.7.
2) Laboratory investigations were carried out to assess the reduction of ϕ value for micacious sand. All the details of laboratory investigations are compiled in VOLUME XI SUPPORTING STUDIES. Comparison between the "ϕ - relative density" relationship for two types of micacious sand and non-mica sand revealed that ϕ values for micacious sand are about 4 to 6 degrees less than those of the non-mica sand as shown in Figure 2.4.12. Therefore, the design ϕ values for micacious sand were determined by reducing the ϕ values derived from available "N value - ϕ" correlation by 6 degrees.
3) The maximum of estimated ϕ values was assumed to be 37 degrees because the sand layers contain few gravels.
4) The modulus of elasticity (Em) was determined based on the results of Lateral Loading Test.
5) Based on the above considerations, strength parameters (c, ϕ) and modulus of elasticity were estimated from N-value using the below formulas.
   - $c = 0$
   - $\phi = 15 + \sqrt{15Nm} - 6 \leq 37$ (degrees)
   - $Em = 289 \times Nm$ (kN/m^2)

   Where, Nm is the mean N value of each layer

The proposed design values for bridge substructure in case of scour depth of -23.6m PWD and -37.6m PWD are shown in Tables 2.4.6 and 2.4.7 respectively.

2.5 FOUNDATION OF ACCESS ROAD ROUTE

2.5.1 Geological Profile

The same chronological and stratigraphical classification as that of bridge site was used for drawing the geological profile of access road route. Four classifications of Unit-1a, Unit-1b, Unit-2 and Unit-3 were used to determine each stratum based on the results of grain size analysis. The criterion of each stratum is explained in Section 2.4.1.

Physical properties of each stratum are summarized in Table 2.5.1. Uniformity coefficient of Unit-1a, Unit-1b and Unit-2 are 5.5, 5.5 and 2.9 in average respectively. As the uniformity coefficient of Unit-2 is very small, the soil of Unit-2 is evaluated to be very poorly graded. Therefore, the soil of Unit-2 is estimated to be looser than that of Unit-1b.

Geological profile of Access Road Route is shown in Figure 2.5.1. This geological profile is drawn up, based on the results of grain size analysis and visual observation of the disturbed split spoon samples obtained from the Standard Penetration Tests.

In some areas such as JMBH26, JMBH27, JMBH212 and JMBH215, Unit-1a of CLAY or SILT with fine sand was found to be 4m to 7m in thickness. Unit-1b of very silty fine SAND or Unit-2 of silty fine SAND predominates throughout the whole of access road route. In the area of JMBH25 to JMBH210 and JMBH215, Unit-2 predominates. On the other hand, in the area of JMBH211 to JMBH214 and JMBH216, Unit-1b predominates.

2.5.2 N-value

In the study of access road route foundation, considering that the highest is the loss of blow energy caused on the way of its transmission to the bottom of a bore, the loss-error of the measured N-value was corrected by the formula of Uto (1974) in the same way as bridge site foundation. The applied formula (Uto, 1974) is already explained in Section 2.4.2.

The distribution of corrected N-value at access road route is shown in Figure 2.5.2. This figure shows that there is a wide scatter in N-value among 12 boreholes along the proposed alignment of access road. Therefore, the lower design line of corrected N-value distribution is proposed for the design of access road. It might be better that the design engineer uses the lower design line for the design of access road in the feasibility study.

On the other hand, it is recommended that the distribution of corrected N-value of the nearest borehole to the construction site should be used for the design of minor bridges.

2.5.3 Laboratory Test Results

(1) Chemical Properties of Soil Samples

Table 2.5.2 shows the results of chemical property tests carried out in Phase-1 and Phase-2. Chemical property tests consisting of mica content, pH, total chloride content, soluble sulfate content and total sulfate content were carried out employing the SPT samples.

The value of pH ranges from 6.5 to 8.1 and the soil in access road route is nearly neutral.

Total chloride content, soluble sulfate content and total sulfate content range from 0.0293 to 0.0310 %, from 0.0030 to 0.0170 % and from 0.0380 to 0.1749 % respectively.

Judging from the above values of chemical property, it is evaluated that the soil in access road route does not have a significant degree of attack on the concrete structures such as piles and culverts.

Regarding mica content, it was found to be 64.7 % at the site of JMBH4 and 37.0 % at the site of JMBH26. From these results, it is considered that there are some layers having a high content of mica locally.

(2) Chemical Properties of Groundwater

Table 2.5.3 shows the results of chemical property tests of groundwater carried out in Phase-1 and Phase-2. Chemical property of groundwater consists of pH, chloride content and sulfate content.

The value of pH ranges from 6.8 to 7.6 and the groundwater in access road route is nearly neutral. Chloride content and sulfate content range from 11.0 to 165.0 mg/L and from 1.0 to 125.0 mg/L respectively.

Judging from the above values of chemical property, it is evaluated that the groundwater in access road route does not have a significant degree of attack on the concrete structures such as piles and culverts.

(3) Undisturbed Sample Tests

Table 2.5.4 shows the laboratory test results of undisturbed samples carried out in Phase-2. Laboratory tests consisting of natural water content, specific gravity, grain size analysis, atterberg limit, triaxial compression test and consolidation were carried out employing undisturbed sample taken at the borehole site of JMBH26, JMBH212, JMBH215 and JMBH216.

Regarding shear strengths, cohesion ranges from 15 to 50 kPa and internal friction angle is zero.

Regarding consolidation properties, initial void ratio (eo) ranges from 0.78 to 1.24 and compression index (Cc) ranges from 0.116 to 0.332. Further, e ~ log P curves are shown in Figure 2.5.3 and log Cv ~ log P curves are shown in Figure 2.5.4. Figure 2.5.4 indicates that coefficient of consolidation (Cv) ranges from 4×10^{-4} to 3×10^{-3} cm^2/sec independent of consolidation pressures.

2.5.4 Design Values

Design values of each stratum (Unit-1a, Unit-1b, Unit-2 and Unit-3) for access road consist of N-value, saturated density, strength parameters. N-value was determined using the lower design line shown in Figure 2.5.2. Strength parameters (c, ϕ) were estimated from N-value using the below formulas. The formula for ϕ values of sand layers of Unit-1b, 2 and 3 is the same as that of the bridge site.

1) $c = 10 \times N$ (kN/m^2) for Unit-1a
   $c = 0$ for Unit-1b, 2 and 3
2) $\phi = 0$ for Unit-1a
   $\phi = 15 + \sqrt{15N} - 6 \leq 37$ (degrees) for Unit-1b, 2 and 3

The proposed design values for access road are shown in Table 2.5.5.

2.6 EMBANKMENT MATERIALS

Laboratory tests comprising natural water content, specific gravity, atterberg limits, grain size analysis, compaction test and CBR test were carried out to evaluate the suitability of excavated soil or dredged soil for embankment material.

Compaction tests were conducted with two compaction energy of 1 Ec (standard proctor energy) and 4.5 Ec. The above compaction energy were given by the following condition:

Compaction Energy	Test Condition
1 Ec	· Weight of Rammer: 2.5 kg · Height of Drop: 305 mm · Volume of Mould: 947 mL · Number of Layers: 3 · Blows of Each Layer: 25
4.5 Ec	· Weight of Rammer: 4.54 kg · Height of Drop: 457 mm · Volume of Mould: 947 mL · Number of Layers: 5 · Blows of Each Layer: 25

Laboratory test results of embankment material are summarized in Table 2.6.1.

Gradation curves of five embankment material samples are shown in Figure 2.6.1. The soil material of TP-4 is classified into silty sand. On the other hand, four others are classified into sandy silt.

Natural water content ranges from 22.4% to 32.0%.

The compaction properties, i.e. optimum moisture content (Wopt), maximum dry density (γdmax), γd (90%) and γd (95%) are summarized in Table 3.6.1. In this table, γd (90%) denotes the dry density of 90% of γdmax and γd (95%) denotes the dry density of 95% of γdmax. Compaction curves of five samples under 1 Ec and 4.5 Ec are shown in Figure 2.6.2. Optimum moisture content of compaction tests under 1 Ec ranges from 20% to 24%.

Maximum dry density of compaction tests under 1 Ec ranges from 1.43 g/cm^3 to 1.60 g/cm^3. On the other hand, optimum moisture content of compaction tests under 4.5 Ec ranges from 17% to 19%. Maximum dry density of compaction tests under 1 Ec ranges from 1.52 g/cm^3 to 1.73 g/cm^3. As a result of the above compaction tests, it is obvious that 4.5 Ec compaction energy makes higher maximum dry density than 1 Ec compaction energy does.

As a result of CBR tests, correlation between CBR and γd is shown in Figure 2.6.3. Based on the above correlation, CBR values corresponding to γd (90%) and γd (95%) under 1 Ec and 4.5 Ec are summarized in Table 2.6.1. As a subgrade material, embankment material is required to be more than 8% of CBR. Judging from the above CBR test results, compacted density of γd (95%) under 4.5 Ec is required of embankment material for subgrade. However, soil material of TP-1 is evaluated to be unsuitable for subgrade because it contains very few sands.

2.7 LIQUEFACTION POTENTIAL ANALYSIS

Liquefaction potential has been evaluated using the Seed method (ref. Seed and Idriss, 1971) and the Iwasaki method (ref. Iwasaki and Tatsuoka, 1978). The method consists of evaluating the cyclic stress ratio (L) in an element of soil resulting from an earthquake acceleration and comparing it with the cyclic resistance ratio (R). The liquefaction resistance (F_L) is defined as $F_L = R / L$. If F_L is less than 1.0, liquefaction may occur.

The liquefaction resistance (F_L) is conventionally determined from the following equations:

$$F_L = R / L$$

$$R = R_1 + R_2 + R_3$$

$$L = 0.65 \times \alpha_{max} \times \gamma d \times \sigma v / \sigma v'$$

$$R_1 = 0.0882 \times \sqrt{\frac{N}{\sigma v' + 0.7}}$$

$$R_2 = \begin{cases} 0.19 & (0.02mm \le D_{50} \le 0.05mm) \\ 0.225 \times \log_{10}(0.35 / D_{50}) & (0.05mm < D_{50} \le 0.6mm) \\ -0.05 & (0.6mm < D_{50} \le 2.0mm) \end{cases}$$

$$R3 = \begin{cases} 0.0 & (0\% \le FC \le 40\%) \\ 0.004 \times FC - 0.16 & (40\% < FC \le 100\%) \end{cases}$$

$$\gamma d = 1.0 - 0.015x$$

where,

F_L:	liquefaction resistance
R:	cyclic resistance ratio
L:	cyclic stress ratio
α_{max}:	maximum horizontal acceleration coefficient
γd:	stress reduction coefficient
σv:	total vertical stress (tf/m^2)
σv':	effective vertical stress (tf/m^2)
N:	N-value
D_{50}:	diameter at which 50% of the soil is finer (mm)
FC:	fine particle content (%)
x:	depth less than 20m (m)

The estimated maximum horizontal accelerations for the bridge design have been assessed at 0.125g at Mawa Janjira site in the pre-feasibility study of Padma Bridge, 2000. Therefore, the above maximum horizontal acceleration was adopted for the liquefaction potential analysis in the feasibility study.

The liquefaction potential analysis was carried out on four borehole sections of JMBH21, JMBH22, JMBH23 and JMBH24 in three cases of before scour, after scour up to -23.6m PWD and -37.6 m PWD.

The results of liquefaction potential analysis are shown in Tables 2.7.1 to 2.7.12. As a result of analysis, the following conclusions have been obtained:

1) On borehole sections of JMBH21, JMBH23 and JMBH24, there is no potential for liquefaction both in cases of before scour and after scour. This result is due to the ground condition of Unit-1b layer containing more than 20 % of fine particles, such as clay and silt.
2) On borehole section of JMBH22, there is some potential for liquefaction in depth of about 5 m before scour because the N-value in the depth is very low. However, it is not a serious problem because this liquefaction potential occurs locally.

Table 2.3.1 Contents of Geotechnical Investigation

Item			Left Bank	Sand Bar		Right Bank													Test Pit	Total
			JMBH21	JMBH22	JMBH23	JMBH24	JMBH25	JMBH26	JMBH27	JMBH28	JMBH29	JMBH210	JMBH211	JMBH212	JMBH213	JMBH214	JMBH215	JMBH216		
Mechanical Boring	Drilling Depth	(m)	120	120	120	117	40	40	40	40	40	20	40	40	20	40	20	20		877
	Standard Penetration Test	(test)	120	120	120	117	40	40	40	40	40	20	40	40	20	40	20	20		877
	Pressuremeter Test	(test)	8	6	6	8														28
	Undisturbed Soil Sample	(sample)	1					3						2			2	1		9
	Groundwater Sample	(sample)	1	1		1						1						1		5
Foundation	Natural Water Content	(sample)	14	12	12	13	4	5	4	4	4	2	4	5	2	4	2	2		93
	Specific Gravity of Soil	(sample)	14	12	12	13	4	5	4	4	4	2	4	5	2	4	2	2		93
	Unit Weight	(sample)	1					3						2			2	1		9
	Atterberg Limit	(sample)	2			2	2	2						2			2	2		14
	Grain Size Analysis	(sample)	14	12	12	13	4	5	4	4	4	2	4	5	2	4	2	2		93
	Triaxial Compression (UU)	(sample)	1					1						1			2			5
	Consolidation	(sample)	1					2						2				1		6
	Mica Content	(sample)	1	1	1	1		1												5
	pH	(sample)	1	1	1	1		1												5
	Total Sulfate Content	(sample)	1	1	1	1		1												5
	Soluble Sulfate Content	(sample)	1	1	1	1		1												5
	Total Chloride Content	(sample)	1	1	1	1		1												5
Groundwater	pH	(sample)	1	1		1						1						1		5
	Sulfate Content	(sample)	1	1		1						1						1		5
	Chloride Content	(sample)	1	1		1						1						1		5
Embankment Material	Natural Water Content	(sample)																	5	5
	Specific Gravity of Soil	(sample)																	5	5
	Atterberg Limit	(sample)																	5	5
	Grain Size Analysis	(sample)																	5	5
	Compaction Test (2.5kg Rammer)	(sample)																	5	5
	Compaction Test (4.5kg Rammer)	(sample)																	5	5
	CBR Test	(sample)																	5	5

Table 2.4.1 Summary of Physical Properties of Each Stratum (Bridge Site)

			Unit - 1a	Unit - 1b	Unit - 2	Unit - 3
Natural Water Content Wn (%)		Min.	29.0	9.2	18.0	
		Max.	37.0	36.0	47.0	
		Ave.	32.8	18.6	24.0	23.0
Specific Gravity Gs		Min.	2.68	2.67	2.69	
		Max.	2.76	2.75	2.77	
		Ave.	2.72	2.71	2.72	2.69
Gradation	Clay + Silt (%)	Min.	63.0	20.0	8.0	
		Max.	100.0	45.0	19.0	
		Ave.	91.2	27.0	14.4	1.0
	Sand (%)	Min.	0.4	55.2	81.8	
		Max.	37.0	80.1	92.0	
		Ave.	8.9	71.8	85.6	99.0
	D_{50} (mm)	Min.	0.003	0.082	0.120	
		Max.	0.047	0.320	0.230	
		Ave.	0.017	0.164	0.170	0.230
	Uniformity Coefficient Uc	Min.	8.6	3.9	2.6	
		Max.	13.8	44.4	9.6	
		Ave.	11.2	16.2	4.7	2.2
Atterberg Limit	Liquid Limit LL (%)	Min.	27.0	-	-	-
		Max.	39.0	-	-	-
		Ave.	34.0	-	-	-
	Plastic Limit PL (%)	Min.	23.0	-	-	-
		Max.	25.0	-	-	-
		Ave.	24.0	-	-	-
	Plasticity Index I_P (%)	Min.	2.0	-	-	-
		Max.	15.0	-	-	-
		Ave.	10.0	-	-	-

Table 2.4.2 Measured Results of Lateral Loading Test

Stage	Borehole No.	Depth (m)	Strata Unit	Corrected N-value	Coefficient of soil reaction Km (MPa/cm)	Mean radius of K value calculation r_m (cm)	Modulus of elasticity *1 Em (kgf/cm^2)
Phase-1	JMBH2	31.0	1b	28.1	2.92	3.83	145
		41.0	1b	34.7	1.96	4.63	118
		51.0	1b	35.4	1.94	4.42	111
	JMBH3	21.0	1b	18.0	1.10	4.27	61
		31.0	1b	44.4	1.70	4.14	92
		41.0	1b	59.1	1.85	4.57	110
		51.0	1b	32.7	3.91	4.12	209
		61.0	1b	51.8	3.10	3.89	157
Phase-2	JMBH21	10.9	1a	8.0	0.18	5.92	14
		16.0	2	14.0	0.95	4.68	58
		22.0	1b	49.7	2.21	4.09	118
		32.8	1b	34.6	1.23	4.12	66
		41.3	1b	26.3	1.05	4.82	66
		52.5	1b	68.5	3.19	4.73	196
		62.0	1b	49.0	2.45	5.16	164
		70.3	1b	65.5	2.84	4.76	176
	JMBH22	21.9	1b	30.8	1.27	4.33	72
		32.0	1b	49.2	1.26	4.04	66
		41.2	1b	55.3	3.05	3.76	149
		51.2	1b	69.9	3.50	3.84	175
		61.3	1b	56.9	5.33	4.40	305
		69.3	2	105.5 *2	3.76	3.95	193 *2
	JMBH23	10.7	1b	35.0	1.53	3.79	75
		20.8	1b	40.9	1.97	3.94	101
		25.8	1b	31.4	1.57	3.88	79
		31.0	1b	49.4	3.90	3.83	194
		35.8	1b	59.1	2.59	3.77	127
		41.0	1b	55.3	2.73	3.75	133
	JMBH24	11.0	2	30.0	0.89	4.08	47
		21.4	2	20.9	1.13	4.29	63
		30.9	1b	26.1	1.58	4.00	82
		41.5	1b	34.6	1.73	4.05	91
		45.7	1b	48.9	2.03	5.44	144
		51.0	1a	45.4	2.65	3.80	131
		61.7	1b	43.7	2.58	4.16	140
		65.9	1b	38.0	4.00	3.82	199

Note:

*1) $Em = (1+\nu) \times Km \times r_m$

*2) This data is excluded from the analysis of releationship between N-value and Em because N-value of 105.5 is calculated from the blows of 150mm penetration

Table 2.4.3 Chemical Properties of Soil Samples (Bridge Site)

Stage	Borehole No.	Sample Depth (m)	Mica Content (%)	pH	Total Chloride Content (%)	Soluble Sulfate Content (%)	Total Sulfate Content (%)
Phase-1	JMBH2	49.55 - 50.00		7.2	0.0307	0.0140	0.1402
		58.55 - 59.00	17.2				
	JMBH3	58.55 - 59.00		6.9	0.0272	0.0135	0.1325
		46.55 - 47.00	3.5				
Phase-2	JMBH21	32.55 - 33.00		8.5	0.0341	0.0026	0.0309
		33.55 - 34.00	52.7				
	JMBH22	30.55 - 31.00		7.5	0.0300	0.0100	0.0500
		33.55 - 34.00	19.3				
	JMBH23	29.55 - 30.00		7.8	0.0300	0.0100	0.0400
		35.55 - 36.00	26.6				
	JMBH24	31.55 - 32.00		7.2	0.0290	0.0040	0.0480
		35.55 - 36.00	5.7				

Table 2.4.4 Chemical Properties of Groundwater (Bridge Site)

Stage	Borehole No.	pH	Chloride Content (mg/L)	Sulfate Content (mg/L)
Phase-1	JMBH2	7.00	18.00	2.00
	JMBH3	7.80	17.00	12.00
Phase-2	JMBH21	7.40	27.00	38.00
	JMBH22	7.19	10.00	21.00
	JMBH24	6.54	17.00	3.00

Table 2.4.5 Summary of Laboratory Test Results of Undisturbed Samples (Bridge Site)

Phase			Phase-1			Phase-2
Borehole	No.		JMBH2	JMBH2	JMBH3	JMBH21
Depth		(m)	1.55 ~ 2.00	4.05 ~ 4.50	0.60 ~ 1.10	2.00 ~ 2.45
N-value			2	3	2	4
Natural Water Content	Wn	(%)	47.5	38.8	33.0	31.0
Specific Gravity	Gs		2.74	2.74	2.75	2.70
Dry Unit Weight	γd	(kN/m^3)	12.2	13.0	13.8	15.2
Wet Unit Weight	γt	(kN/m^3)	18.0	18.0	18.3	19.6
Gradation	Gravel	(%)	0.0	0.0	0.0	0.0
	Sand	(%)	3.0	46.4	4.5	1.0
	Silt	(%)	64.5	51.9	87.0	70.0
	Clay	(%)	32.5	1.7	9.0	29.0
Consistency	LL	(%)	50.0	Non-Plastic	Non-Plastic	36.0
	PL	(%)	27.3	Non-Plastic	Non-Plastic	23.0
	PI	(%)	22.7	Non-Plastic	Non-Plastic	13.0
Triaxial Compression Test	Cohesion	(kPa)	(	30.0	)	19.0
	Internal Friction Angle	(degree)	(	15.8	)	26.7
Consolidation	eo		0.86	0.99	1.07	0.87
	Cc		0.270	0.098	0.182	0.230

Table 2.4.6 Design Values for Bridge Substructure (Scour Depth of -23.6m)

Layer	Depth	Thickness	N-value		Density	Strength Parameters		Modulus of Elasticity
	PWD (m)	(m)	Mean	Design	γt (kN/m^3)	c (kN/m^2)	ϕ (degree)	Em (kN/m^2)
(1)*1	1.425 ~ -23.6	25.025	-	-	-	-	-	-
(2)	-23.6 ~ -46.5	22.900	17	17	19.0	0	25	4,913
(3)	-46.5 ~ -64.1	17.600	40	40	19.5	0	33	11,560
(4)	-64.1 ~ -80.0	15.900	59	50	20.0	0	37	14,450
(5)	below -80.0		68	50	20.0	0	37	14,450

Note:

*1) The design values of layer (1) are not proposed because the layer will be eroded by river scouring

Table 2.4.7 Design Values for Bridge Substructure (Scour Depth of -37.6m)

Layer	Depth	Thickness	N-value		Density	Strength Parameters		Modulus of Elasticity
	PWD (m)	(m)	Mean	Design	γt (kN/m^3)	c (kN/m^2)	ϕ (degree)	Em (kN/m^2)
(1)[*1]	1.425 ~ -37.6	39.025	-	-	-	-	-	-
(2)	-37.6 ~ -54.4	16.800	20	20	19.0	0	26	5,780
(3)	-54.4 ~ -70.4	16.000	40	40	19.5	0	33	11,560
(4)	-70.4 ~ -80.0	9.600	56	50	20.0	0	37	14,450
(5)	below -80.0		62	50	20.0	0	37	14,450

Note:

*1) The design values of layer (1) are not proposed because the layer will be eroded by river scouring

Table 2.5.1 Summary of Physical Properties of Each Stratum (Access Road Route)

			Unit - 1a	Unit - 1b	Unit - 2	Unit - 3
Natural Water Content Wn (%)		Min.	22.4	21.1	19.5	-
		Max.	43.6	37.9	32.6	-
		Ave.	33.5	26.8	24.6	-
Specific Gravity Gs		Min.	2.60	2.60	2.61	-
		Max.	2.66	2.70	2.70	-
		Ave.	2.64	2.66	2.66	-
Gradation	Clay + Silt (%)	Min.	54.0	20.0	4.0	-
		Max.	95.5	46.0	18.0	-
		Ave.	80.7	28.1	12.6	-
	Sand (%)	Min.	4.5	54.0	82.0	-
		Max.	46.0	80.0	96.0	-
		Ave.	19.4	71.9	87.4	-
	D_{50} (mm)	Min.	0.012	0.080	0.100	-
		Max.	0.072	0.130	0.205	-
		Ave.	0.025	0.096	0.141	-
	Uniformity Coefficient Uc	Min.		3.0	1.6	-
		Max.		10.8	5.3	-
		Ave.	5.5	5.5	2.9	-
Atterberg Limit	Liquid Limit LL (%)	Min.	40.0	-	-	-
		Max.	46.0	-	-	-
		Ave.	43.0	-	-	-
	Plastic Limit PL (%)	Min.	20.0	-	-	-
		Max.	24.0	-	-	-
		Ave.	22.0	-	-	-
	Plasticity Index I_p (%)	Min.	20.0	-	-	-
		Max.	22.0	-	-	-
		Ave.	21.0	-	-	-

Table 2.5.2 Chemical Properties of Soil Samples (Access Road Route)

Stage	Borehole No.	Sample Depth (m)	Mica Content (%)	pH	Total Chloride Content (%)	Soluble Sulfate Content (%)	Total Sulfate Content (%)
Phase-1	JMBH4	6.55 - 7.00		8.1	0.0293	0.0170	0.1749
		27.55 - 28.00	64.7				
Phase-2	JMBH26	35.85 - 36.30	37.0	6.5	0.0310	0.0030	0.0380

Table 2.5.3 Chemical Properties of Groundwater (Access Road Route)

Stage	Borehole No.	pH	Chloride Content (mg/L)	Sulfate Content (mg/L)
Phase-1	JMBH4	7.60	11.00	1.00
Phase-2	JMBH210	6.82	165.00	125.00
	JMBH216	7.10	26.00	34.00

Table 2.5.4 Summary of Laboratory Test Results of Undisturbed Samples (Access Road Route)

Phase			Phase-2							
Borehole	No.		JMBH26	JMBH26	JMBH26	JMBH212	JMBH212	JMBH215	JMBH215	JMBH216
Depth		(m)	3.35 ~ 3.80	6.40 ~ 6.85	9.40 ~ 9.85	3.35 ~ 3.80	5.35 ~ 5.80	1.35 ~ 1.80	2.35 ~ 2.80	0.40 ~ 0.85
N-value			2	2	3	2	3	2	2	2
Natural Water Content	Wn	(%)	29.6	35.5	37.2	33.1	45.3	31.7	36.3	35.0
Specific Gravity	Gs		2.63	2.62		2.67	2.64	2.66	2.65	2.66
Dry Unit Weight	γd	(kN/m^3)	14.4	11.5	13.3	11.7	11.6	13.7	13.1	12.4
Wet Unit Weight	γt	(kN/m^3)	18.7	15.6	18.2	15.6	16.9	18.0	17.9	16.9
Gradation	Gravel	(%)		0.0		0.0	0.0	0.0	0.0	0.0
	Sand	(%)		8.0		2.0	7.0	2.8	1.6	2.2
	Silt	(%)		68.0		89.5	75.2	92.2	92.4	79.3
	Clay	(%)		24.0		8.5	17.8	5.0	6.0	18.5
Consistency	LL	(%)			44.0	47.0	51.0	40.0	36.0	56.0
	PL	(%)			23.0	22.0	29.0	19.0	18.0	30.0
	PI	(%)			21.0	25.0	22.0	21.0	18.0	26.0
Triaxial Compression Test	Cohesion	(kPa)			15.0		22.0	50.0	27.0	
	Internal Friction Angle	(degree)			0.0		0.0	0.0	0.0	
Consolidation	eo		0.78	1.22		1.24	1.12			1.15
	Cc		0.149	0.116		0.332	0.182			0.149

Table 2.5.5 Design Values for Access Road

Stratum	N-value	Density	Strength Parameters	
		γt (kN/m^3)	c (kN/m^2)	ϕ (degree)
Unit - 1a	Lower Design Line in Figure 4.5.2	18.0	10 x N	0
Unit - 1b	Lower Design Line in Figure 4.5.2	19.0	0	$15 + \sqrt{(15N)} - 6$ *1
Unit - 2	Lower Design Line in Figure 4.5.2	19.0	0	$15 + \sqrt{(15N)} - 6$ *1
Unit - 3	Lower Design Line in Figure 4.5.2	19.0	0	$15 + \sqrt{(15N)} - 6$ *1

Note:

*1) The maximum of estimated ϕ values is assumed to be 37 degrees

Table 2.6.1 Summary of Embankment Material Tests

TP No.		TP-1	TP-2	TP-3	TP-4	TP-5
Depth (m)		2.4 ~ 3.0	2.0 ~ 2.5	2.4 ~ 2.8	2.4 ~ 3.0	2.4 ~ 3.0
Water Content (%)		30.0	28.0	24.0	32.0	22.4
Specific Gravity Gs		2.74	2.74	2.74	2.66	2.72
Gradation	Clay (%)	17.0	3.0	10.0	0.5	3.0
	Silt (%)	81.0	70.0	77.0	17.0	61.0
	Sand (%)	2.0	27.0	13.0	82.5	36.0
	D_{50} (mm)	0.016	0.050	0.028	0.110	0.058
	Uc	10.3	3.5	7.0	2.1	2.8
Atterberg Limits	Liquid Limit (%)	34	NP	28	NP	NP
	Plastic Limit (%)	23	NP	21	NP	NP
	Plasticity Index (%)	11	NP	7	NP	NP
Soil Classification		CL	ML	ML-CL	SM	ML
Compaction (A)	Wopt (%)	22.0	21.0	20.0	24.0	21.0
· 1 Ec	γdmax (g/cm^3)	1.58	1.51	1.60	1.43	1.51
· 2.5 kg Rammer	γd (90%) (g/cm^3)	1.42	1.36	1.44	1.29	1.36
· 305 mm Drop	γd (95%) (g/cm^3)	1.50	1.43	1.52	1.36	1.43
Compaction (B)	Wopt (%)	17.0	19.0	17.0	18.0	18.0
· 4.5 Ec	γdmax (g/cm^3)	1.73	1.60	1.72	1.52	1.63
· 4.54 kg Rammer	γd (90%) (g/cm^3)	1.56	1.44	1.55	1.37	1.47
· 457 mm Drop	γd (95%) (g/cm^3)	1.64	1.52	1.63	1.44	1.55
CBR corresponding to Compaction (A)	CBR_{90} (%)	-	-	-	-	-
	CBR_{95} (%)	1.6	7.1	4.2	5.1	3.8
CBR corresponding to Compaction (B)	CBR_{90} (%)	4.0	7.8	7.5	5.7	9.5
	CBR_{95} (%)	7.2	13.4	16.2	9.5	20.8

Table 2.7.1 Liquefaction Potential Analysis (JMBH21)

Borehole No.: JMBH21
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth	Stratum	γ	γ'	σv	σv'	N-value	D50	FC	Cyclic Resistance Ratio				Stress Reduction Coefficient	CyclicStressRatio	FL=R/L	Liquefaction
(m)		(tf/m^3)	(tf/m^3)	(tf/m^2)	(tf/m^2)		(mm)	(%)	R1	R2	R3	R	γd	L		Potential
0.000																
0.775	1a	1.80	0.80	1.395	0.620	3	0.047	63	0.133	0.190	0.092	0.415	0.988	0.181	2.297	Not possible
1.775	1a	1.80	0.80	3.195	1.420	2	0.047	63	0.086	0.190	0.092	0.368	0.973	0.178	2.066	Not possible
2.775	1a	1.80	0.80	4.995	2.220	7	0.047	63	0.137	0.190	0.092	0.419	0.958	0.175	2.389	Not possible
3.775	1a	1.80	0.80	6.795	3.020	5	0.047	63	0.102	0.190	0.092	0.384	0.943	0.172	2.228	Not possible
4.775	1a	1.80	0.80	8.595	3.820	6	0.047	63	0.102	0.190	0.092	0.384	0.928	0.170	2.260	Not possible
5.775	1a	1.80	0.80	10.395	4.620	8	0.047	63	0.108	0.190	0.092	0.390	0.913	0.167	2.337	Not possible
6.775	1a	1.80	0.80	12.195	5.420	8	0.047	63	0.101	0.190	0.092	0.383	0.898	0.164	2.331	Not possible
7.775	1a	1.80	0.80	13.995	6.220	2	0.047	63	0.047	0.190	0.092	0.329	0.883	0.161	2.040	Not possible
8.775	1a	1.80	0.80	15.795	7.020	7	0.047	63	0.084	0.190	0.092	0.366	0.868	0.159	2.305	Not possible
9.775	1a	1.80	0.80	17.595	7.820	9	0.047	63	0.091	0.190	0.092	0.373	0.853	0.156	2.389	Not possible
10.775	1a	1.80	0.80	19.395	8.620	8	0.047	63	0.082	0.190	0.092	0.364	0.838	0.153	2.373	Not possible
11.775	1a	1.80	0.80	21.195	9.420	11	0.047	63	0.092	0.190	0.092	0.374	0.823	0.151	2.484	Not possible
12.000	1a	1.80	0.80	21.600	9.600				0.000				0.820			
	1b	1.90	0.90													
12.775	1b	1.90	0.90	23.073	10.298	17	0.13	25	0.110	0.097	0.000	0.206	0.808	0.147	1.403	Not possible
13.775	1b	1.90	0.90	24.973	11.198	14	0.13	25	0.096	0.097	0.000	0.192	0.793	0.144	1.339	Not possible
14.775	1b	1.90	0.90	26.873	12.098	14	0.13	25	0.092	0.097	0.000	0.189	0.778	0.140	1.346	Not possible
15.000	1b	1.90	0.90	27.300	12.300								0.775			
	2	1.90	0.90										1.000			
15.775	2	1.90	0.90	28.773	12.998	14	0.18	10	0.089	0.065	0.000	0.154	0.763	0.137	1.123	Not possible
16.775	2	1.90	0.90	30.673	13.898	15	0.18	10	0.089	0.065	0.000	0.154	0.748	0.134	1.150	Not possible
17.775	2	1.90	0.90	32.573	14.798	17	0.18	10	0.092	0.065	0.000	0.157	0.733	0.131	1.200	Not possible
18.775	2	1.90	0.90	34.473	15.698	23	0.18	10	0.104	0.065	0.000	0.169	0.718	0.128	1.322	Not possible
19.775	2	1.90	0.90	36.373	16.598	22	0.18	10	0.099	0.065	0.000	0.164	0.703	0.125	1.313	Not possible

Table 2.7.2 Liquefaction Potential Analysis (JMBH22)

Borehole No.: JMBH22
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth (m)	Stratum	γ (tf/m³)	γ' (tf/m³)	σv (tf/m²)	σv' (tf/m²)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio R1	R2	R3	R	Stress Reduction Coefficient γd	CyclicStressRatio L	FL=R/L	Liquefaction Potential
0.000																
0.775	1a	1.80	0.80	1.395	0.620	1	0.013	95	0.077	0.190	0.220	0.487	0.988	0.181	2.694	Not possible
1.775	1a	1.80	0.80	3.195	1.420	1	0.013	95	0.061	0.190	0.220	0.471	0.973	0.178	2.645	Not possible
2.775	1a	1.80	0.80	4.995	2.220	1	0.013	95	0.052	0.190	0.220	0.462	0.958	0.175	2.635	Not possible
3.000	1a	1.80	0.80	5.400	2.400											
	2	1.90	0.90													
3.775	2	1.90	0.90	6.873	3.098	10	0.16	15	0.143	0.076	0.000	0.220	0.943	0.170	1.291	Not possible
4.775	2	1.90	0.90	8.773	3.998	15	0.16	15	0.158	0.076	0.000	0.234	0.928	0.166	1.414	Not possible
5.775	2	1.90	0.90	10.673	4.898	2	0.16	15	0.053	0.076	0.000	0.129	0.913	0.162	0.799	Possible
6.775	2	1.90	0.90	12.573	5.798	7	0.16	15	0.092	0.076	0.000	0.168	0.898	0.158	1.062	Not possible
7.775	2	1.90	0.90	14.473	6.698	19	0.16	15	0.141	0.076	0.000	0.218	0.883	0.155	1.405	Not possible
8.775	2	1.90	0.90	16.373	7.598	7	0.16	15	0.081	0.076	0.000	0.157	0.868	0.152	1.036	Not possible
9.775	2	1.90	0.90	18.273	8.498	7	0.16	15	0.077	0.076	0.000	0.153	0.853	0.149	1.029	Not possible
10.775	2	1.90	0.90	20.173	9.398	8	0.16	15	0.079	0.076	0.000	0.155	0.838	0.146	1.060	Not possible
11.775	2	1.90	0.90	22.073	10.298	41	0.16	15	0.170	0.076	0.000	0.247	0.823	0.143	1.721	Not possible
12.775	2	1.90	0.90	23.973	11.198	32	0.16	15	0.145	0.076	0.000	0.221	0.808	0.141	1.573	Not possible
13.000	2	1.90	0.90	24.400	11.400								0.805			
	1b	1.90	0.90													
13.775	1b	1.90	0.90	25.873	12.098	41	0.09	38	0.158	0.133	0.000	0.291	0.793	0.138	2.108	Not possible
14.775	1b	1.90	0.90	27.773	12.998	46	0.09	38	0.162	0.133	0.000	0.294	0.778	0.135	2.178	Not possible
15.775	1b	1.90	0.90	29.673	13.898	52	0.09	38	0.166	0.133	0.000	0.299	0.763	0.132	2.259	Not possible
16.775	1b	1.90	0.90	31.573	14.798	45	0.09	38	0.150	0.133	0.000	0.283	0.748	0.130	2.181	Not possible
17.775	1b	1.90	0.90	33.473	15.698	41	0.09	38	0.139	0.133	0.000	0.272	0.733	0.127	2.142	Not possible
18.775	1b	1.90	0.90	35.373	16.598	12	0.09	38	0.073	0.133	0.000	0.206	0.718	0.124	1.657	Not possible
19.775	1b	1.90	0.90	37.273	17.498	21	0.09	38	0.095	0.133	0.000	0.227	0.703	0.122	1.868	Not possible

Table 2.7.3 Liquefaction Potential Analysis (JMBH23)

Borehole No.:
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth (m)	Stratum	γ (tf/m^3)	γ' (tf/m^3)	σv (tf/m^2)	σv' (tf/m^2)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio R1	R2	R3	R	Stress Reduction Coefficient γd	CyclicStressRatio L	FL=R/L	Liquefaction Potential
0.000																
0.775	1b	1.90	0.90	1.473	0.698	5	0.098	29	0.167	0.124	0.000	0.291	0.988	0.170	1.718	Not possible
1.775	1b	1.90	0.90	3.373	1.598	7	0.098	29	0.154	0.124	0.000	0.278	0.973	0.167	1.667	Not possible
2.775	1b	1.90	0.90	5.273	2.498	8	0.098	29	0.140	0.124	0.000	0.264	0.958	0.164	1.605	Not possible
3.775	1b	1.90	0.90	7.173	3.398	7	0.098	29	0.115	0.124	0.000	0.240	0.943	0.162	1.481	Not possible
4.775	1b	1.90	0.90	9.073	4.298	36	0.098	29	0.237	0.124	0.000	0.361	0.928	0.159	2.268	Not possible
5.775	1b	1.90	0.90	10.973	5.198	29	0.098	29	0.196	0.124	0.000	0.320	0.913	0.157	2.042	Not possible
6.775	1b	1.90	0.90	12.873	6.098	18	0.098	29	0.144	0.124	0.000	0.268	0.898	0.154	1.739	Not possible
7.775	1b	1.90	0.90	14.773	6.998	23	0.098	29	0.152	0.124	0.000	0.277	0.883	0.152	1.827	Not possible
8.775	1b	1.90	0.90	16.673	7.898	38	0.098	29	0.185	0.124	0.000	0.310	0.868	0.149	2.080	Not possible
9.775	1b	1.90	0.90	18.573	8.798	38	0.098	29	0.176	0.124	0.000	0.301	0.853	0.146	2.055	Not possible
10.775	1b	1.90	0.90	20.473	9.698	35	0.098	29	0.162	0.124	0.000	0.286	0.838	0.144	1.990	Not possible
11.775	1b	1.90	0.90	22.373	10.598	31	0.098	29	0.146	0.124	0.000	0.270	0.823	0.141	1.915	Not possible
12.775	1b	1.90	0.90	24.273	11.498	25	0.098	29	0.126	0.124	0.000	0.251	0.808	0.139	1.808	Not possible
13.775	1b	1.90	0.90	26.173	12.398	32	0.098	29	0.138	0.124	0.000	0.262	0.793	0.136	1.927	Not possible
14.775	1b	1.90	0.90	28.073	13.298	49	0.098	29	0.165	0.124	0.000	0.289	0.778	0.134	2.168	Not possible
15.775	1b	1.90	0.90	29.973	14.198	43	0.098	29	0.150	0.124	0.000	0.274	0.763	0.131	2.094	Not possible
16.775	1b	1.90	0.90	31.873	15.098	41	0.098	29	0.142	0.124	0.000	0.266	0.748	0.128	2.076	Not possible
17.000	1b	1.90	0.90	32.300	15.300								0.745			
	2	1.90	0.90													
17.775	2	1.90	0.90	33.773	15.998	31	0.14	14	0.120	0.090	0.000	0.210	0.733	0.126	1.667	Not possible
18.775	2	1.90	0.90	35.673	16.898	19	0.14	14	0.092	0.090	0.000	0.181	0.718	0.123	1.470	Not possible
19.775	2	1.90	0.90	37.573	17.798	24	0.14	14	0.100	0.090	0.000	0.190	0.703	0.121	1.575	Not possible

Table 2.7.4 Liquefaction Potential Analysis (JMBH24)

Borehole No.: JMBH24
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth	Stratum	γ	γ'	σv	$\sigma v'$	N-value	D50	FC	Cyclic Resistance Ratio				Stress Reduction Coefficient	CyclicStressRatio	FL=R/L	Liquefaction
(m)		(tf/m^3)	(tf/m^3)	(tf/m^2)	(tf/m^2)		(mm)	(%)	R1	R2	R3	R	γd	L		Potential
0.000																
0.775	1a	1.80	0.80	1.395	0.620	1	0.011	99	0.077	0.190	0.236	0.503	0.988	0.181	2.783	Not possible
1.775	1a	1.80	0.80	3.195	1.420	2	0.011	99	0.086	0.190	0.236	0.512	0.973	0.178	2.875	Not possible
2.775	1a	1.80	0.80	4.995	2.220	0	0.011	99	0.000	0.190	0.236	0.426	0.958	0.175	2.431	Not possible
3.000	1a	1.80	0.80	5.400	2.400											
	1b	1.90	0.90													
3.775	1b	1.90	0.90	6.873	3.098	7	0.09	38	0.120	0.133	0.000	0.252	0.943	0.170	1.484	Not possible
4.775	1b	1.90	0.90	8.773	3.998	17	0.09	38	0.168	0.133	0.000	0.300	0.928	0.166	1.815	Not possible
5.775	1b	1.90	0.90	10.673	4.898	7	0.09	38	0.099	0.133	0.000	0.231	0.913	0.162	1.431	Not possible
6.775	1b	1.90	0.90	12.573	5.798	8	0.09	38	0.098	0.133	0.000	0.231	0.898	0.158	1.457	Not possible
7.775	1b	1.90	0.90	14.473	6.698	11	0.09	38	0.108	0.133	0.000	0.240	0.883	0.155	1.549	Not possible
8.775	1b	1.90	0.90	16.373	7.598	12	0.09	38	0.106	0.133	0.000	0.239	0.868	0.152	1.570	Not possible
9.775	1b	1.90	0.90	18.273	8.498	31	0.09	38	0.162	0.133	0.000	0.295	0.853	0.149	1.976	Not possible
10.775	1b	1.90	0.90	20.173	9.398	30	0.09	38	0.152	0.133	0.000	0.285	0.838	0.146	1.947	Not possible
11.000	1b	1.90	0.90	20.600	9.600								0.835			
	2	1.90	0.90													
11.775	2	1.90	0.90	22.073	10.298	9	0.16	18	0.080	0.076	0.000	0.156	0.823	0.143	1.090	Not possible
12.775	2	1.90	0.90	23.973	11.198	24	0.16	18	0.125	0.076	0.000	0.202	0.808	0.141	1.435	Not possible
13.775	2	1.90	0.90	25.873	12.098	31	0.16	18	0.137	0.076	0.000	0.214	0.793	0.138	1.551	Not possible
14.775	2	1.90	0.90	27.773	12.998	36	0.16	18	0.143	0.076	0.000	0.219	0.778	0.135	1.624	Not possible
15.775	2	1.90	0.90	29.673	13.898	44	0.16	18	0.153	0.076	0.000	0.230	0.763	0.132	1.734	Not possible
16.775	2	1.90	0.90	31.573	14.798	22	0.16	17	0.105	0.076	0.000	0.182	0.748	0.130	1.400	Not possible
17.775	2	1.90	0.90	33.473	15.698	19	0.16	17	0.095	0.076	0.000	0.171	0.733	0.127	1.349	Not possible
18.775	2	1.90	0.90	35.373	16.598	23	0.16	17	0.102	0.076	0.000	0.178	0.718	0.124	1.432	Not possible
19.775	2	1.90	0.90	37.273	17.498	22	0.16	17	0.097	0.076	0.000	0.173	0.703	0.122	1.425	Not possible

Table 2.7.5 Liquefaction Potential Analysis after Scour:-23.6m PWD (JMBH21)

Borehole No.:
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth	Stratum	γ	γ'	σv	σv'	N-value	D50	FC	Cyclic Resistance Ratio				Stress Reduction Coefficient	CyclicStressRatio	FL=R/L	Liquefaction
(m)		(tf/m^3)	(tf/m^3)	(tf/m^2)	(tf/m^2)		(mm)	(%)	R1	R2	R3	R	γd	L		Potential
0.000																
0.456	1b	1.90	0.90	0.866	0.410	7	0.11	24	0.221	0.113	0.000	0.335	0.993	0.170	1.964	Not possible
1.456	1b	1.90	0.90	2.766	1.310	5.5	0.11	24	0.146	0.113	0.000	0.259	0.978	0.168	1.544	Not possible
2.456	1b	1.90	0.90	4.666	2.210	11.2	0.11	24	0.173	0.113	0.000	0.286	0.963	0.165	1.732	Not possible
3.456	1b	1.90	0.90	6.566	3.110	12.8	0.11	24	0.162	0.113	0.000	0.275	0.948	0.163	1.689	Not possible
4.456	1b	1.90	0.90	8.466	4.010	17	0.11	24	0.168	0.113	0.000	0.281	0.933	0.160	1.753	Not possible
5.456	1b	1.90	0.90	10.366	4.910	10.5	0.11	24	0.121	0.113	0.000	0.234	0.918	0.157	1.484	Not possible
6.456	1b	1.90	0.90	12.266	5.810	31.8	0.11	24	0.195	0.113	0.000	0.308	0.903	0.155	1.988	Not possible
7.456	1b	1.90	0.90	14.166	6.710	26.5	0.11	24	0.167	0.113	0.000	0.280	0.888	0.152	1.837	Not possible
8.456	1b	1.90	0.90	16.066	7.610	21.8	0.11	29	0.143	0.113	0.000	0.256	0.873	0.150	1.709	Not possible
9.456	1b	1.90	0.90	17.966	8.510	25.8	0.11	29	0.148	0.113	0.000	0.261	0.858	0.147	1.771	Not possible
10.456	1b	1.90	0.90	19.866	9.410	14.6	0.11	29	0.106	0.113	0.000	0.219	0.843	0.145	1.515	Not possible
11.456	1b	1.90	0.90	21.766	10.310	16.7	0.11	29	0.109	0.113	0.000	0.222	0.828	0.142	1.561	Not possible
12.456	1b	1.90	0.90	23.666	11.210	17	0.11	29	0.105	0.113	0.000	0.218	0.813	0.139	1.566	Not possible
13.456	1b	1.90	0.90	25.566	12.110	27.2	0.11	29	0.129	0.113	0.000	0.242	0.798	0.137	1.765	Not possible
14.456	1b	1.90	0.90	27.466	13.010	26.3	0.11	29	0.122	0.113	0.000	0.235	0.783	0.134	1.751	Not possible
15.456	1b	1.90	0.90	29.366	13.910	20.3	0.11	29	0.104	0.113	0.000	0.217	0.768	0.132	1.647	Not possible
16.456	1b	1.90	0.90	31.266	14.810	12.2	0.11	29	0.078	0.113	0.000	0.191	0.753	0.129	1.481	Not possible
17.456	1b	1.90	0.90	33.166	15.710	33.7	0.11	29	0.126	0.113	0.000	0.239	0.738	0.127	1.892	Not possible
18.456	1b	1.90	0.90	35.066	16.610	28.7	0.11	29	0.114	0.113	0.000	0.227	0.723	0.124	1.827	Not possible
19.456	1b	1.90	0.90	36.966	17.510	34.9	0.11	29	0.122	0.113	0.000	0.235	0.708	0.121	1.936	Not possible

Table 2.7.6 Liquefaction Potential Analysis after Scour:-23.6m PWD (JMBH22)

Borehole No.: JMBH22
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth (m)	Stratum	γ (tf/m^3)	γ' (tf/m^3)	σv (tf/m^2)	σv' (tf/m^2)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio R1	R2	R3	R	Stress Reduction Coefficient γd	CyclicStressRatio L	FL=R/L	Liquefaction Potential
0.000																
0.334	1a	1.80	0.80	0.601	0.267	3.9	0.013	95	0.177	0.190	0.220	0.587	0.995	0.182	3.228	Not possible
1.334	1a	1.80	0.80	2.401	1.067	4.7	0.013	95	0.144	0.190	0.220	0.554	0.980	0.179	3.091	Not possible
2.334	1a	1.80	0.80	4.201	1.867	8.7	0.013	95	0.162	0.190	0.220	0.572	0.965	0.176	3.244	Not possible
2.559	1a	1.80	0.80	4.606	2.047											
	1b	1.90	0.90													
3.334	1b	1.90	0.90	6.079	2.745	22.3	0.088	41.5	0.224	0.135	0.006	0.365	0.950	0.171	2.137	Not possible
4.334	1b	1.90	0.90	7.979	3.645	16.4	0.088	41.5	0.171	0.135	0.006	0.312	0.935	0.166	1.878	Not possible
5.334	1b	1.90	0.90	9.879	4.545	22.3	0.088	41.5	0.182	0.135	0.006	0.323	0.920	0.162	1.987	Not possible
6.334	1b	1.90	0.90	11.779	5.445	26.5	0.088	41.5	0.183	0.135	0.006	0.324	0.905	0.159	2.037	Not possible
7.334	1b	1.90	0.90	13.679	6.345	32.3	0.088	41.5	0.189	0.135	0.006	0.330	0.890	0.156	2.115	Not possible
8.334	1b	1.90	0.90	15.579	7.245	22.2	0.088	41.5	0.147	0.135	0.006	0.288	0.875	0.153	1.886	Not possible
9.334	1b	1.90	0.90	17.479	8.145	20	0.088	41.5	0.133	0.135	0.006	0.274	0.860	0.150	1.824	Not possible
10.334	1b	1.90	0.90	19.379	9.045	42.6	0.088	41.5	0.184	0.135	0.006	0.325	0.845	0.147	2.212	Not possible
11.334	1b	1.90	0.90	21.279	9.945	33.9	0.088	41.5	0.157	0.135	0.006	0.298	0.830	0.144	2.067	Not possible
12.334	1b	1.90	0.90	23.179	10.845	35.8	0.088	41.5	0.155	0.135	0.006	0.296	0.815	0.142	2.093	Not possible
13.334	1b	1.90	0.90	25.079	11.745	39.4	0.088	41.5	0.157	0.135	0.006	0.298	0.800	0.139	2.146	Not possible
14.334	1b	1.90	0.90	26.979	12.645	48.7	0.088	41.5	0.168	0.135	0.006	0.309	0.785	0.136	2.274	Not possible
15.334	1b	1.90	0.90	28.879	13.545	36	0.088	41.5	0.140	0.135	0.006	0.281	0.770	0.133	2.108	Not possible
16.334	1b	1.90	0.90	30.779	14.445	35.8	0.088	41.5	0.136	0.135	0.006	0.277	0.755	0.131	2.115	Not possible
17.334	1b	1.90	0.90	32.679	15.345	38.1	0.088	41.5	0.136	0.135	0.006	0.277	0.740	0.128	2.162	Not possible
18.334	1b	1.90	0.90	34.579	16.245	43.7	0.088	41.5	0.142	0.135	0.006	0.283	0.725	0.125	2.253	Not possible
19.334	1b	1.90	0.90	36.479	17.145	32.9	0.088	41.5	0.120	0.135	0.006	0.261	0.710	0.123	2.124	Not possible

Table 2.7.7 Liquefaction Potential Analysis after Scour:-23.6m PWD (JMBH23)

Borehole No.: JMBH23
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth (m)	Stratum	γ (tf/m^3)	γ' (tf/m^3)	σv (tf/m^2)	σv' (tf/m^2)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio R1	R2	R3	R	Stress Reduction Coefficient γd	CyclicStressRatio L	FL=R/L	Liquefaction Potential
0.000																
0.825	1b	1.90	0.90	1.568	0.743	18.1	0.11	31	0.312	0.113	0.000	0.426	0.988	0.169	2.512	Not possible
1.825	1b	1.90	0.90	3.468	1.643	18.7	0.11	31	0.249	0.113	0.000	0.362	0.973	0.167	2.172	Not possible
2.825	1b	1.90	0.90	5.368	2.543	20.3	0.11	31	0.221	0.113	0.000	0.334	0.958	0.164	2.032	Not possible
3.825	1b	1.90	0.90	7.268	3.443	33.3	0.11	31	0.250	0.113	0.000	0.363	0.943	0.162	2.246	Not possible
4.825	1b	1.90	0.90	9.168	4.343	26.4	0.11	31	0.202	0.113	0.000	0.315	0.928	0.159	1.979	Not possible
5.825	1b	1.90	0.90	11.068	5.243	28.7	0.11	31	0.194	0.113	0.000	0.307	0.913	0.157	1.961	Not possible
6.825	1b	1.90	0.90	12.968	6.143	32.6	0.11	31	0.193	0.113	0.000	0.306	0.898	0.154	1.985	Not possible
7.825	1b	1.90	0.90	14.868	7.043	23.9	0.11	31	0.155	0.113	0.000	0.268	0.883	0.151	1.771	Not possible
8.825	1b	1.90	0.90	16.768	7.943	21.8	0.11	31	0.140	0.113	0.000	0.253	0.868	0.149	1.701	Not possible
9.825	1b	1.90	0.90	18.668	8.843	21.2	0.11	31	0.131	0.113	0.000	0.245	0.853	0.146	1.672	Not possible
10.825	1b	1.90	0.90	20.568	9.743	35.7	0.11	31	0.163	0.113	0.000	0.276	0.838	0.144	1.922	Not possible
11.825	1b	1.90	0.90	22.468	10.643	35.2	0.11	31	0.155	0.113	0.000	0.268	0.823	0.141	1.903	Not possible
12.825	1b	1.90	0.90	24.368	11.543	28.5	0.11	31	0.135	0.113	0.000	0.248	0.808	0.139	1.788	Not possible
13.825	1b	1.90	0.90	26.268	12.443	35.1	0.11	31	0.144	0.113	0.000	0.257	0.793	0.136	1.892	Not possible
14.825	1b	1.90	0.90	28.168	13.343	34.4	0.11	31	0.138	0.113	0.000	0.251	0.778	0.133	1.883	Not possible
15.825	1b	1.90	0.90	30.068	14.243	29.7	0.11	31	0.124	0.113	0.000	0.237	0.763	0.131	1.815	Not possible
16.825	1b	1.90	0.90	31.968	15.143	33.9	0.11	31	0.129	0.113	0.000	0.242	0.748	0.128	1.888	Not possible
17.825	1b	1.90	0.90	33.868	16.043	67.1	0.11	31	0.177	0.113	0.000	0.290	0.733	0.126	2.305	Not possible
18.825	1b	1.90	0.90	35.768	16.943	53.4	0.11	31	0.153	0.113	0.000	0.267	0.718	0.123	2.165	Not possible
19.825	1b	1.90	0.90	37.668	17.843	66.9	0.11	31	0.168	0.113	0.000	0.281	0.703	0.121	2.329	Not possible

Table 2.7.8 Liquefaction Potential Analysis after Scour:-23.6m PWD (JMBH24)

Borehole No.: JMBH24
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth	Stratum	γ	γ'	σv	σv'	N-value	D50	FC	Cyclic Resistance Ratio				Stress Reduction Coefficient	CyclicStressRatio	FL=R/L	Liquefaction
(m)		(tf/m^3)	(tf/m^3)	(tf/m^2)	(tf/m^2)		(mm)	(%)	R1	R2	R3	R	γd	L		Potential
0.000																
0.456	1b	1.90	0.90	0.866	0.410	6.6	0.18	22	0.215	0.065	0.000	0.280	0.993	0.170	1.644	Not possible
1.456	1b	1.90	0.90	2.766	1.310	9.1	0.18	22	0.188	0.065	0.000	0.253	0.978	0.168	1.506	Not possible
2.456	1b	1.90	0.90	4.666	2.210	12.1	0.18	22	0.180	0.065	0.000	0.245	0.963	0.165	1.482	Not possible
3.456	1b	1.90	0.90	6.566	3.110	12.5	0.18	22	0.160	0.065	0.000	0.225	0.948	0.163	1.382	Not possible
4.456	1b	1.90	0.90	8.466	4.010	13.8	0.18	22	0.151	0.065	0.000	0.216	0.933	0.160	1.349	Not possible
5.456	1b	1.90	0.90	10.366	4.910	18	0.18	22	0.158	0.065	0.000	0.223	0.918	0.157	1.416	Not possible
6.456	1b	1.90	0.90	12.266	5.810	20.4	0.18	22	0.156	0.065	0.000	0.221	0.903	0.155	1.427	Not possible
7.456	1b	1.90	0.90	14.166	6.710	19.5	0.18	22	0.143	0.065	0.000	0.208	0.888	0.152	1.366	Not possible
8.456	1b	1.90	0.90	16.066	7.610	34.8	0.18	22	0.180	0.065	0.000	0.245	0.873	0.150	1.639	Not possible
9.456	1b	1.90	0.90	17.966	8.510	28	0.18	22	0.154	0.065	0.000	0.219	0.858	0.147	1.486	Not possible
10.456	1b	1.90	0.90	19.866	9.410	29.2	0.18	22	0.150	0.065	0.000	0.215	0.843	0.145	1.486	Not possible
11.456	1b	1.90	0.90	21.766	10.310	21.6	0.18	22	0.124	0.065	0.000	0.189	0.828	0.142	1.327	Not possible
12.456	1b	1.90	0.90	23.666	11.210	29.1	0.18	22	0.138	0.065	0.000	0.203	0.813	0.139	1.454	Not possible
13.456	1b	1.90	0.90	25.566	12.110	33.2	0.12	32	0.142	0.105	0.000	0.247	0.798	0.137	1.801	Not possible
14.456	1b	1.90	0.90	27.466	13.010	31.2	0.12	32	0.133	0.105	0.000	0.238	0.783	0.134	1.769	Not possible
15.456	1b	1.90	0.90	29.366	13.910	32.9	0.12	32	0.132	0.105	0.000	0.237	0.768	0.132	1.798	Not possible
16.456	1b	1.90	0.90	31.266	14.810	33.9	0.12	32	0.130	0.105	0.000	0.235	0.753	0.129	1.819	Not possible
17.456	1b	1.90	0.90	33.166	15.710	17.1	0.12	32	0.090	0.105	0.000	0.195	0.738	0.127	1.537	Not possible
17.681	1b	1.90	0.90	33.594	15.913								0.735			
	1a	1.80	0.80													
18.456	1a	1.80	0.80	34.989	16.533	16	0.011	99	0.085	0.190	0.236	0.511	0.723	0.124	4.109	Not possible
19.456	1a	1.80	0.80	36.789	17.333	30.9	0.011	99	0.115	0.190	0.236	0.541	0.708	0.122	4.434	Not possible

Table 2.7.9 Liquefaction Potential Analysis after Scour:-37.6m PWD (JMBH21)

Borehole No.: JMB
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth (m)	Stratum	γ (tf/m^3)	γ' (tf/m^3)	σv (tf/m^2)	σv' (tf/m^2)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio R1	R2	R3	R	Stress Reduction Coefficient γd	CyclicStressRatio L	FL=R/L	Liquefaction Potential
0.000																
0.456	1b	1.90	0.90	0.866	0.410	9	0.15	20	0.251	0.083	0.000	0.334	0.993	0.170	1.960	Not possible
1.456	1b	1.90	0.90	2.766	1.310	9.4	0.15	20	0.191	0.083	0.000	0.274	0.978	0.168	1.630	Not possible
2.456	1b	1.90	0.90	4.666	2.210	6.5	0.15	20	0.132	0.083	0.000	0.215	0.963	0.165	1.299	Not possible
3.456	1b	1.90	0.90	6.566	3.110	19.6	0.15	20	0.200	0.083	0.000	0.283	0.948	0.163	1.739	Not possible
4.456	1b	1.90	0.90	8.466	4.010	17.8	0.15	20	0.171	0.083	0.000	0.254	0.933	0.160	1.588	Not possible
5.456	1b	1.90	0.90	10.366	4.910	22.6	0.15	20	0.177	0.083	0.000	0.260	0.918	0.157	1.650	Not possible
6.456	1b	1.90	0.90	12.266	5.810	26.8	0.15	20	0.179	0.083	0.000	0.262	0.903	0.155	1.690	Not possible
7.456	1b	1.90	0.90	14.166	6.710	21.3	0.15	20	0.150	0.083	0.000	0.232	0.888	0.152	1.525	Not possible
8.456	1b	1.90	0.90	16.066	7.610	34.4	0.15	20	0.179	0.083	0.000	0.262	0.873	0.150	1.751	Not possible
9.456	1b	1.90	0.90	17.966	8.510	35.9	0.15	20	0.174	0.083	0.000	0.257	0.858	0.147	1.745	Not possible
10.456	1b	1.90	0.90	19.866	9.410	38.3	0.15	20	0.172	0.083	0.000	0.254	0.843	0.145	1.759	Not possible
11.456	1b	1.90	0.90	21.766	10.310	38.1	0.15	20	0.164	0.083	0.000	0.247	0.828	0.142	1.738	Not possible
12.456	1b	1.90	0.90	23.666	11.210	71.3	0.15	20	0.216	0.083	0.000	0.299	0.813	0.139	2.141	Not possible
13.456	1b	1.90	0.90	25.566	12.110	77.8	0.15	20	0.217	0.083	0.000	0.300	0.798	0.137	2.192	Not possible
14.456	1b	1.90	0.90	27.466	13.010	81.2	0.15	20	0.215	0.083	0.000	0.297	0.783	0.134	2.214	Not possible
15.456	1b	1.90	0.90	29.366	13.910	37.9	0.15	20	0.142	0.083	0.000	0.225	0.768	0.132	1.707	Not possible
16.456	1b	1.90	0.90	31.266	14.810	26.1	0.15	20	0.114	0.083	0.000	0.197	0.753	0.129	1.527	Not possible
17.456	1b	1.90	0.90	33.166	15.710	87.7	0.15	20	0.204	0.083	0.000	0.287	0.738	0.127	2.264	Not possible
18.456	1b	1.90	0.90	35.066	16.610	32.9	0.15	20	0.122	0.083	0.000	0.204	0.723	0.124	1.648	Not possible
19.456	1b	1.90	0.90	36.966	17.510	32.1	0.15	20	0.117	0.083	0.000	0.200	0.708	0.121	1.646	Not possible

Table 2.7.10 Liquefaction Potential Analysis after Scour:-37.6m PWD (JMBH22)

Borehole No.:
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth (m)	Stratum	γ (tf/m^3)	γ' (tf/m^3)	σv (tf/m^2)	σv' (tf/m^2)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio R1	R2	R3	R	Stress Reduction Coefficient γd	CyclicStressRatio L	FL=R/L	Liquefaction Potential
0.000																
0.334	1b	1.90	0.90	0.635	0.301	15.3	0.13	25	0.345	0.097	0.000	0.442	0.995	0.171	2.588	Not possible
1.334	1b	1.90	0.90	2.535	1.201	16.4	0.13	25	0.259	0.097	0.000	0.356	0.980	0.168	2.117	Not possible
2.334	1b	1.90	0.90	4.435	2.101	18.8	0.13	25	0.229	0.097	0.000	0.325	0.965	0.166	1.965	Not possible
3.334	1b	1.90	0.90	6.335	3.001	21.9	0.13	25	0.215	0.097	0.000	0.311	0.950	0.163	1.911	Not possible
4.334	1b	1.90	0.90	8.235	3.901	26.8	0.13	25	0.213	0.097	0.000	0.310	0.935	0.160	1.931	Not possible
5.334	1b	1.90	0.90	10.135	4.801	21.2	0.13	25	0.173	0.097	0.000	0.270	0.920	0.158	1.711	Not possible
6.334	1b	1.90	0.90	12.035	5.701	27	0.13	25	0.181	0.097	0.000	0.278	0.905	0.155	1.790	Not possible
7.334	1b	1.90	0.90	13.935	6.601	36.8	0.13	25	0.198	0.097	0.000	0.295	0.890	0.153	1.931	Not possible
8.334	1b	1.90	0.90	15.835	7.501	36.6	0.13	25	0.186	0.097	0.000	0.283	0.875	0.150	1.886	Not possible
9.334	1b	1.90	0.90	17.735	8.401	32.3	0.13	25	0.166	0.097	0.000	0.263	0.860	0.148	1.783	Not possible
10.334	1b	1.90	0.90	19.635	9.301	32.6	0.13	25	0.159	0.097	0.000	0.256	0.845	0.145	1.766	Not possible
10.559	1b	1.90	0.90	20.062	9.503								0.842			
	1a	1.80	0.80													
11.334	1a	1.80	0.80	21.457	10.123	37.4	0.013	95	0.164	0.190	0.220	0.574	0.830	0.143	4.015	Not possible
12.334	1a	1.80	0.80	23.257	10.923	39.2	0.013	95	0.162	0.190	0.220	0.572	0.815	0.141	4.057	Not possible
12.559	1a	1.80	0.80	23.662	11.103								0.812			
	2	1.90	0.90													
13.334	2	1.90	0.90	25.135	11.801	36.7	0.23	19	0.151	0.041	0.000	0.192	0.800	0.138	1.388	Not possible
14.334	2	1.90	0.90	27.035	12.701	38.3	0.23	19	0.149	0.041	0.000	0.190	0.785	0.136	1.400	Not possible
15.334	2	1.90	0.90	28.935	13.601	33.4	0.23	19	0.135	0.041	0.000	0.176	0.770	0.133	1.321	Not possible
16.334	2	1.90	0.90	30.835	14.501	26.1	0.23	19	0.116	0.041	0.000	0.157	0.755	0.130	1.201	Not possible
17.334	2	1.90	0.90	32.735	15.401	21.3	0.23	19	0.101	0.041	0.000	0.142	0.740	0.128	1.115	Not possible
18.334	2	1.90	0.90	34.635	16.301	34.6	0.23	19	0.126	0.041	0.000	0.167	0.725	0.125	1.333	Not possible
19.334	2	1.90	0.90	36.535	17.201	37.2	0.23	19	0.127	0.041	0.000	0.168	0.710	0.123	1.373	Not possible

Table 2.7.11 Liquefaction Potential Analysis after Scour:-37.6m PWD (JMBH23)

Borehole No.: JMBH23
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth (m)	Stratum	γ (tf/m³)	γ' (tf/m³)	σv (tf/m²)	σv' (tf/m²)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio R1	R2	R3	R	Stress Reduction Coefficient γd	CyclicStressRatio L	FL=R/L	Liquefaction Potential
0.000																
0.825	1b	1.90	0.90	1.568	0.743	13.7	0.14	21	0.272	0.090	0.000	0.361	0.988	0.169	2.133	Not possible
1.825	1b	1.90	0.90	3.468	1.643	14.7	0.14	21	0.221	0.090	0.000	0.310	0.973	0.167	1.861	Not possible
2.825	1b	1.90	0.90	5.368	2.543	18.7	0.14	21	0.212	0.090	0.000	0.301	0.958	0.164	1.835	Not possible
3.825	1b	1.90	0.90	7.268	3.443	40	0.14	21	0.274	0.090	0.000	0.364	0.943	0.162	2.249	Not possible
4.825	1b	1.90	0.90	9.168	4.343	33.6	0.14	21	0.228	0.090	0.000	0.317	0.928	0.159	1.994	Not possible
5.825	1b	1.90	0.90	11.068	5.243	44	0.14	21	0.240	0.090	0.000	0.330	0.913	0.157	2.105	Not possible
6.825	1b	1.90	0.90	12.968	6.143	52.2	0.14	21	0.244	0.090	0.000	0.333	0.898	0.154	2.164	Not possible
7.825	1b	1.90	0.90	14.868	7.043	30.3	0.14	21	0.174	0.090	0.000	0.264	0.883	0.151	1.744	Not possible
8.825	1b	1.90	0.90	16.768	7.943	26.4	0.14	21	0.154	0.090	0.000	0.244	0.868	0.149	1.637	Not possible
9.825	1b	1.90	0.90	18.668	8.843	39.4	0.14	21	0.179	0.090	0.000	0.269	0.853	0.146	1.838	Not possible
10.825	1b	1.90	0.90	20.568	9.743	40.9	0.14	21	0.175	0.090	0.000	0.264	0.838	0.144	1.838	Not possible
11.825	1b	1.90	0.90	22.468	10.643	41.2	0.14	21	0.168	0.090	0.000	0.258	0.823	0.141	1.826	Not possible
12.825	1b	1.90	0.90	24.368	11.543	38.8	0.14	21	0.157	0.090	0.000	0.247	0.808	0.139	1.780	Not possible
13.825	1b	1.90	0.90	26.268	12.443	36.8	0.14	21	0.148	0.090	0.000	0.237	0.793	0.136	1.744	Not possible
14.825	1b	1.90	0.90	28.168	13.343	36.8	0.14	21	0.143	0.090	0.000	0.232	0.778	0.133	1.742	Not possible
15.050	1b	1.90	0.90	28.595	13.545								0.774			
	1a	1.80	0.80													
15.825	1a	1.80	0.80	29.990	14.165	13.2	0.013	95	0.083	0.190	0.220	0.493	0.763	0.131	3.759	Not possible
16.825	1a	1.80	0.80	31.790	14.965	14.4	0.013	95	0.085	0.190	0.220	0.495	0.748	0.129	3.833	Not possible
17.825	1a	1.80	0.80	33.590	15.765	11.8	0.013	95	0.075	0.190	0.220	0.485	0.733	0.127	3.821	Not possible
18.825	1a	1.80	0.80	35.390	16.565	16.4	0.013	95	0.086	0.190	0.220	0.496	0.718	0.125	3.981	Not possible
19.825	1a	1.80	0.80	37.190	17.365	35.5	0.013	95	0.124	0.190	0.220	0.534	0.703	0.122	4.365	Not possible

Table 2.7.12 Liquefaction Potential Analysis after Scour:-37.6m PWD (JMBH24)

Borehole No.: JMBH24
Maximum horizontal acceleration coefficient: 0.125g
Groundwater Level: Ground surface

Depth (m)	Stratum	γ (tf/m³)	γ' (tf/m³)	σv (tf/m²)	σv' (tf/m²)	N-value	D50 (mm)	FC (%)	Cyclic Resistance Ratio R1	R2	R3	R	Stress Reduction Coefficient γd	CyclicStressRatio L	FL=R/L	Liquefaction Potential
0.000																
0.456	1b	1.90	0.90	0.866	0.410	10.7	0.12	33	0.274	0.105	0.000	0.378	0.993	0.170	2.221	Not possible
1.456	1b	1.90	0.90	2.766	1.310	15.3	0.12	33	0.243	0.105	0.000	0.348	0.978	0.168	2.074	Not possible
2.456	1b	1.90	0.90	4.666	2.210	18.1	0.12	33	0.220	0.105	0.000	0.325	0.963	0.165	1.965	Not possible
3.456	1b	1.90	0.90	6.566	3.110	10	0.12	33	0.143	0.105	0.000	0.247	0.948	0.163	1.522	Not possible
3.681	1b	1.90	0.90	6.994	3.313								0.945			
	1a	1.80	0.80													
4.456	1a	1.80	0.80	8.389	3.933	9.9	0.011	99	0.129	0.190	0.236	0.555	0.933	0.162	3.431	Not possible
5.456	1a	1.80	0.80	10.189	4.733	20.1	0.011	99	0.170	0.190	0.236	0.596	0.918	0.161	3.709	Not possible
6.456	1a	1.80	0.80	11.989	5.533	21.9	0.011	99	0.165	0.190	0.236	0.591	0.903	0.159	3.719	Not possible
7.456	1a	1.80	0.80	13.789	6.333	20.4	0.011	99	0.150	0.190	0.236	0.576	0.888	0.157	3.667	Not possible
8.456	1a	1.80	0.80	15.589	7.133	28.1	0.011	99	0.167	0.190	0.236	0.593	0.873	0.155	3.825	Not possible
8.681	1a	1.80	0.80	15.994	7.313								0.870			
	1b	1.90	0.90													
9.456	1b	1.90	0.90	17.466	8.010	31.8	0.082	45	0.169	0.142	0.020	0.330	0.858	0.152	2.173	Not possible
10.456	1b	1.90	0.90	19.366	8.910	28.6	0.082	45	0.152	0.142	0.020	0.314	0.843	0.149	2.109	Not possible
11.456	1b	1.90	0.90	21.266	9.810	29.3	0.082	45	0.147	0.142	0.020	0.309	0.828	0.146	2.119	Not possible
12.456	1b	1.90	0.90	23.166	10.710	30.3	0.082	45	0.144	0.142	0.020	0.306	0.813	0.143	2.138	Not possible
13.456	1b	1.90	0.90	25.066	11.610	46.6	0.082	45	0.172	0.142	0.020	-	-	-	-	-
14.456	1b	1.90	0.90	26.966	12.510	51	0.082	45	0.173	0.142	0.020	0.335	0.783	0.137	2.443	Not possible
15.456	1b	1.90	0.90	28.866	13.410	35	0.082	45	0.139	0.142	0.020	0.301	0.768	0.134	2.238	Not possible
16.456	1b	1.90	0.90	30.766	14.310	35.5	0.082	45	0.136	0.142	0.020	0.297	0.753	0.132	2.261	Not possible
17.456	1b	1.90	0.90	32.666	15.210	27.6	0.082	45	0.116	0.142	0.020	0.278	0.738	0.129	2.158	Not possible
18.456	1b	1.90	0.90	34.566	16.110	29.6	0.082	45	0.117	0.142	0.020	0.279	0.723	0.126	2.212	Not possible
19.456	1b	1.90	0.90	36.466	17.010	29.3	0.082	45	0.113	0.142	0.020	0.275	0.708	0.123	2.232	Not possible

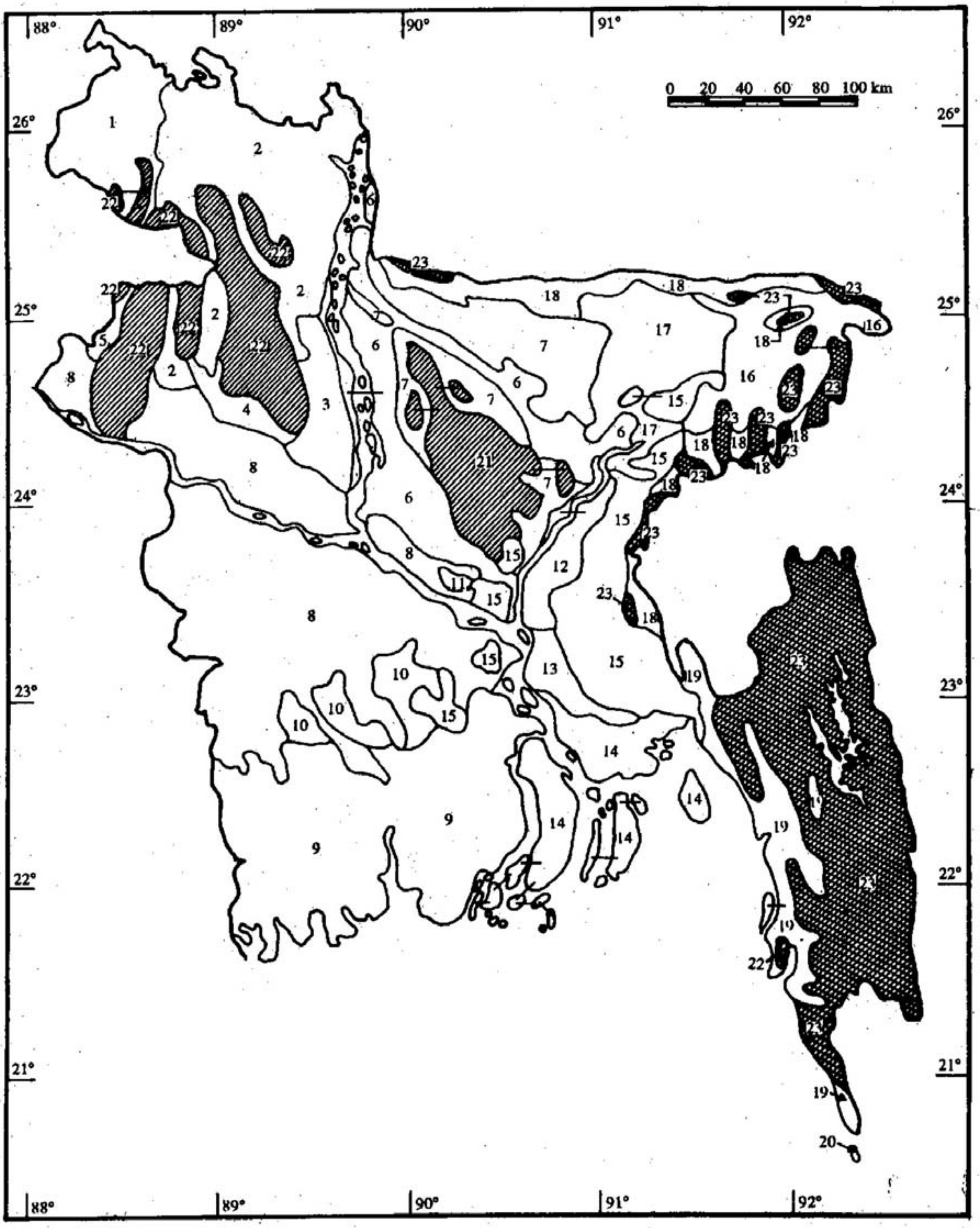


Figure 2.2.1 Bangladesh Physiography

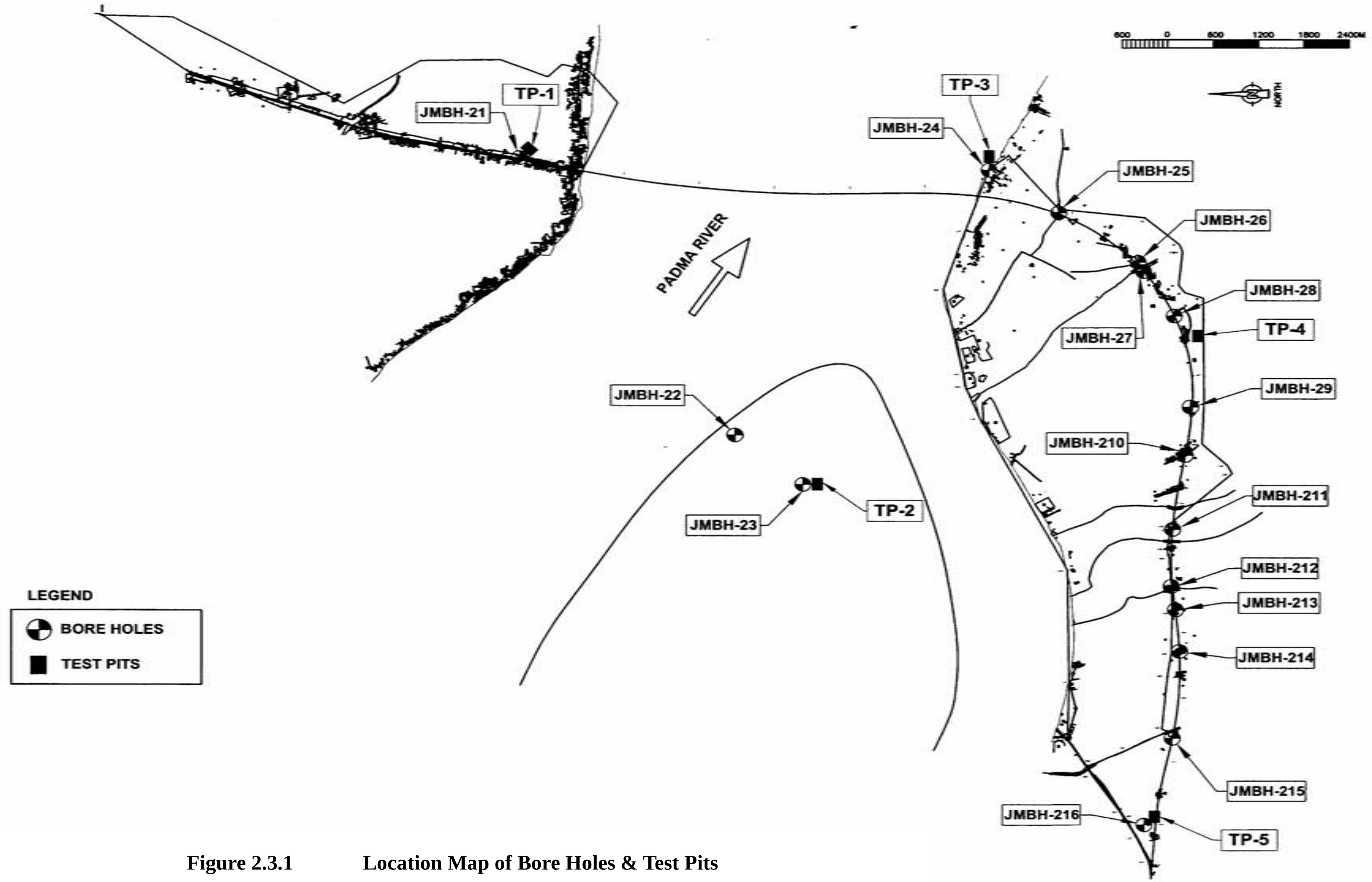
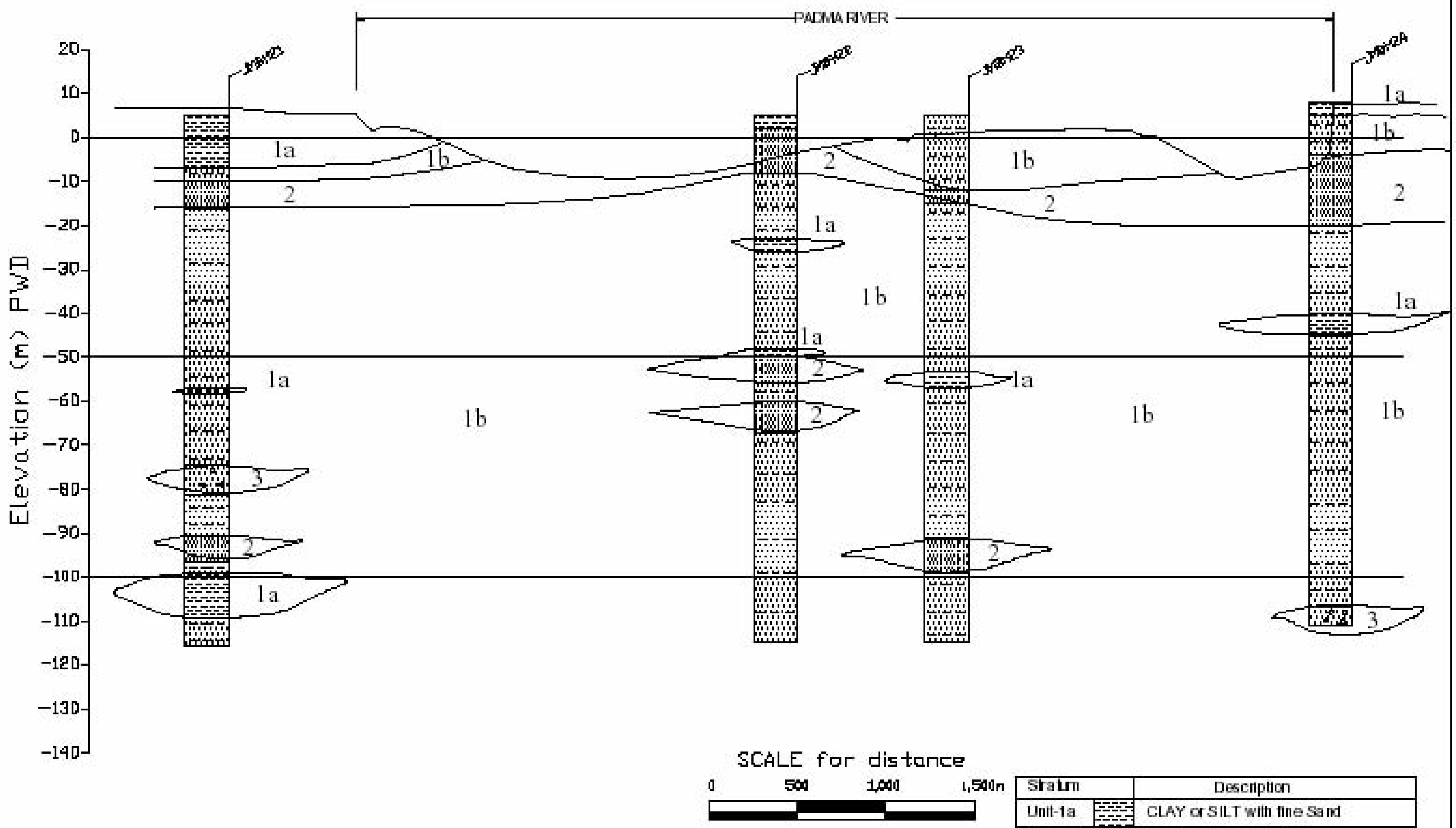


Figure 2.3.1 Location Map of Bore Holes & Test Pits



Stratum		Description
Unit-1a		CLAY or SILT with fine Sand
Unit-1b		Very Silty fine SAND
Unit-2		Silty fine SAND
Unit-3		Slightly Silty fine and medium SAND

Figure 2.4.1 Geological Profile of Main Bridge Site

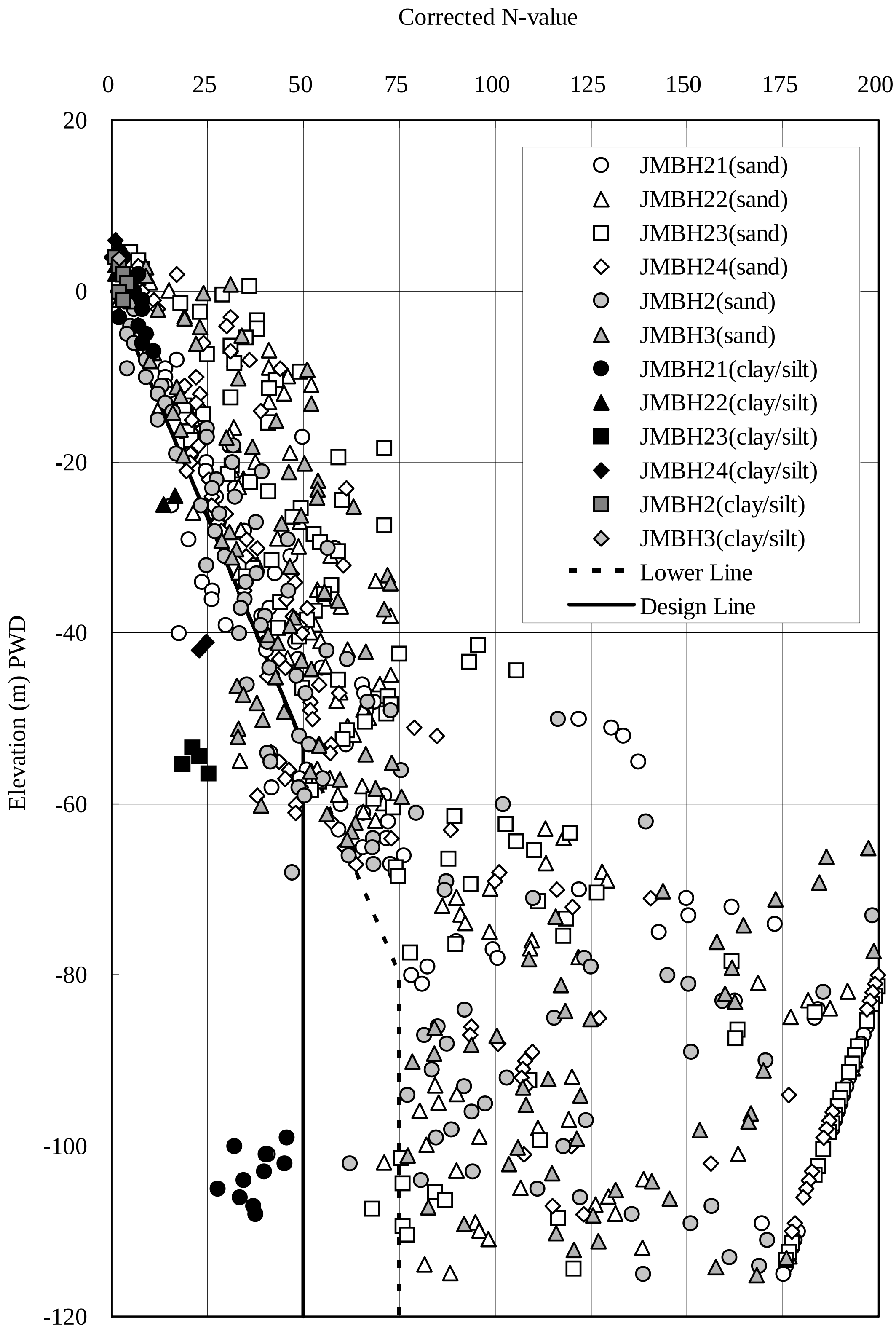


Figure 2.4.2 Distribution of Corrected N-value (Bridge Site:Method-1)

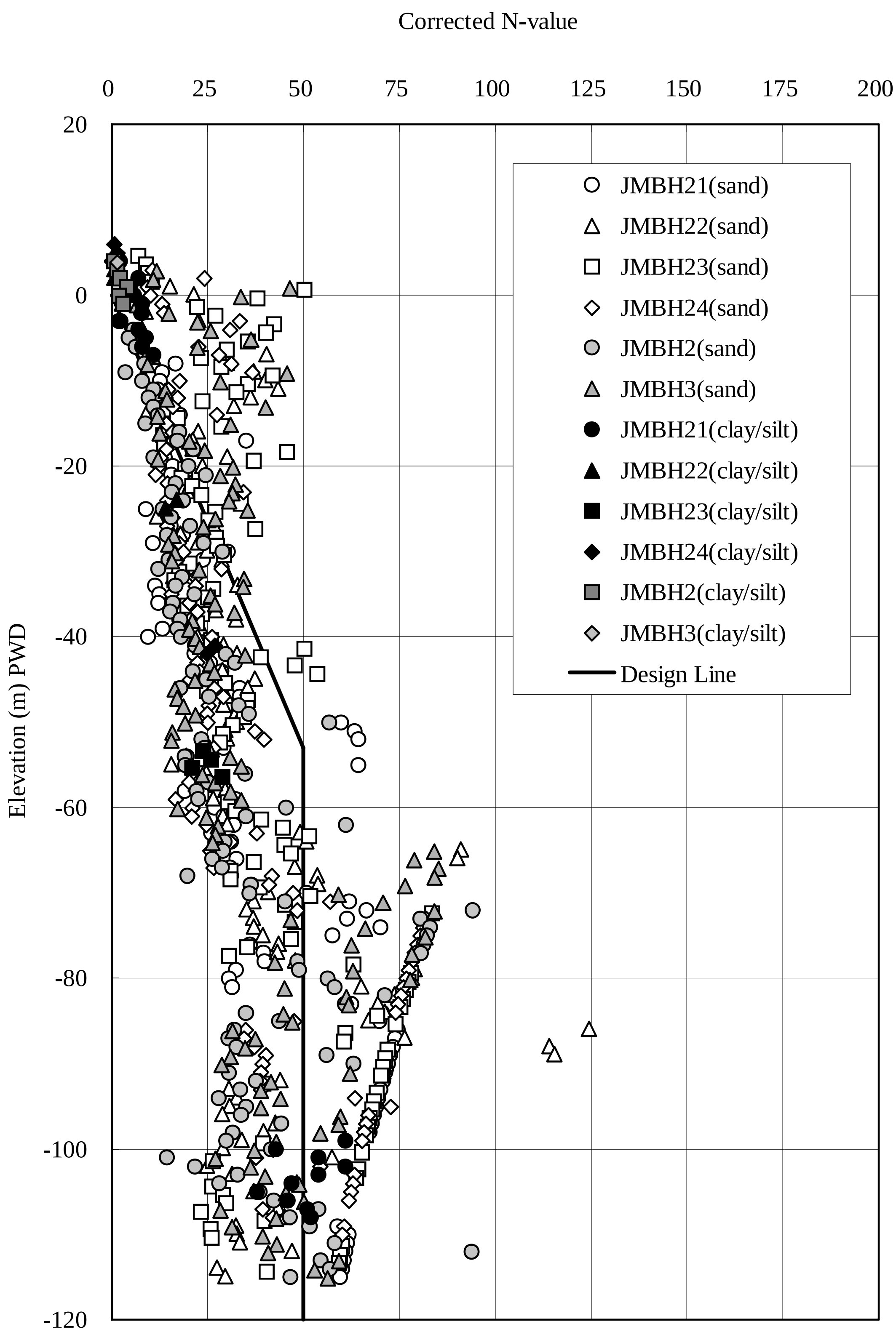


Figure 2.4.3 Distribution of Corrected N-value (Bridge Site:Method-2)

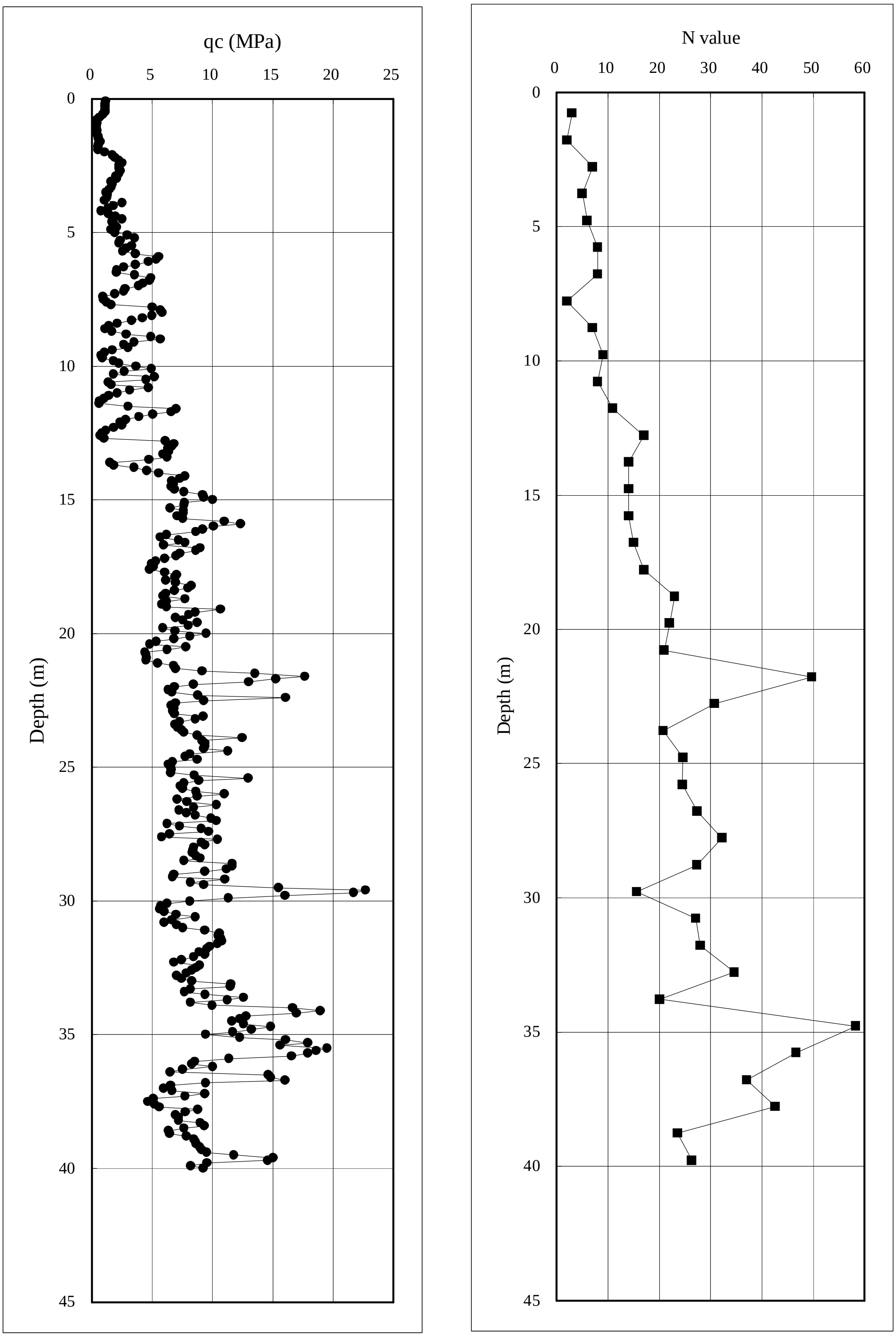
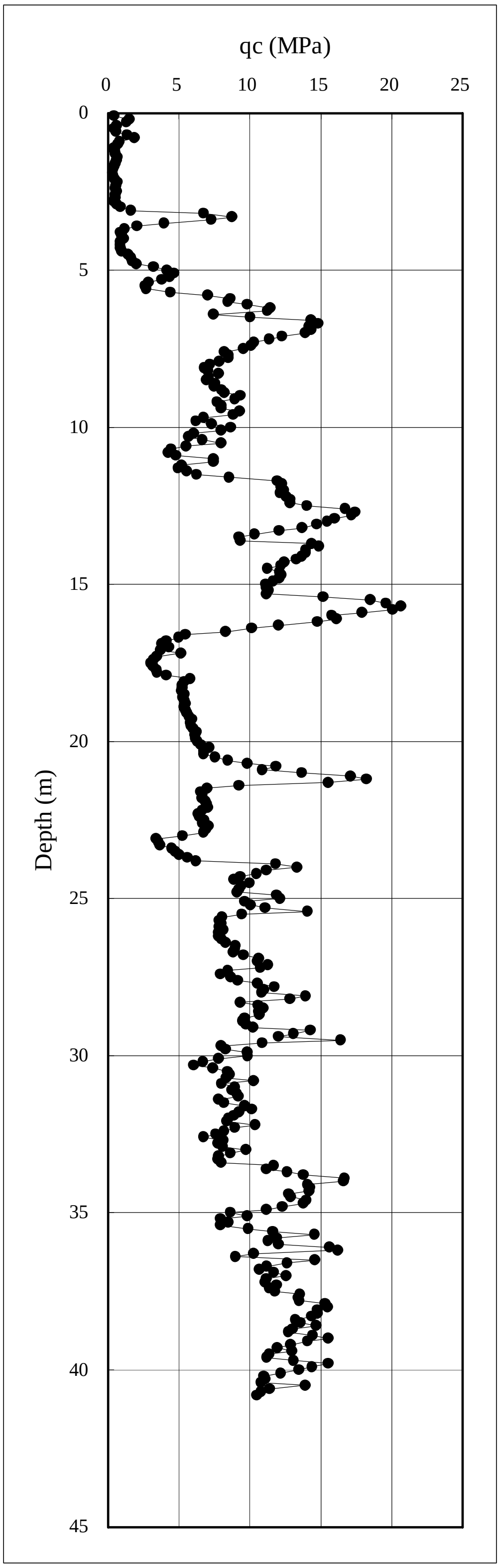


Figure 2.4.4 Comparison between CPT Log and SPT Log (JMBH21)



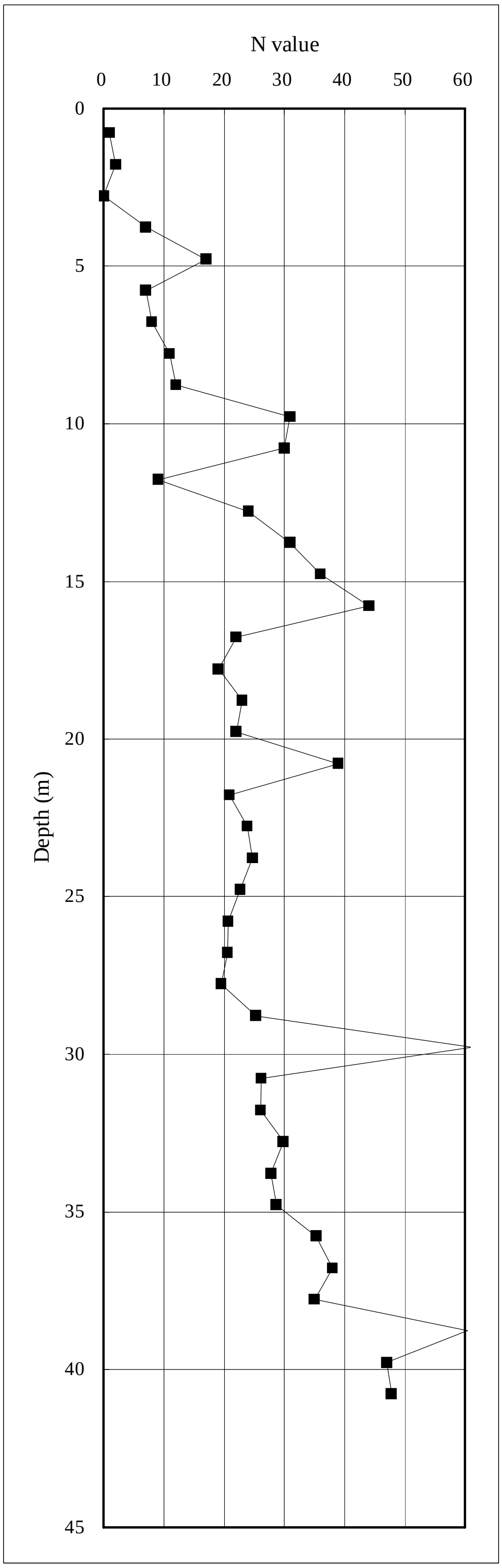


Figure 2.4.5 Comparison between CPT Log and SPT Log (JMBH24)

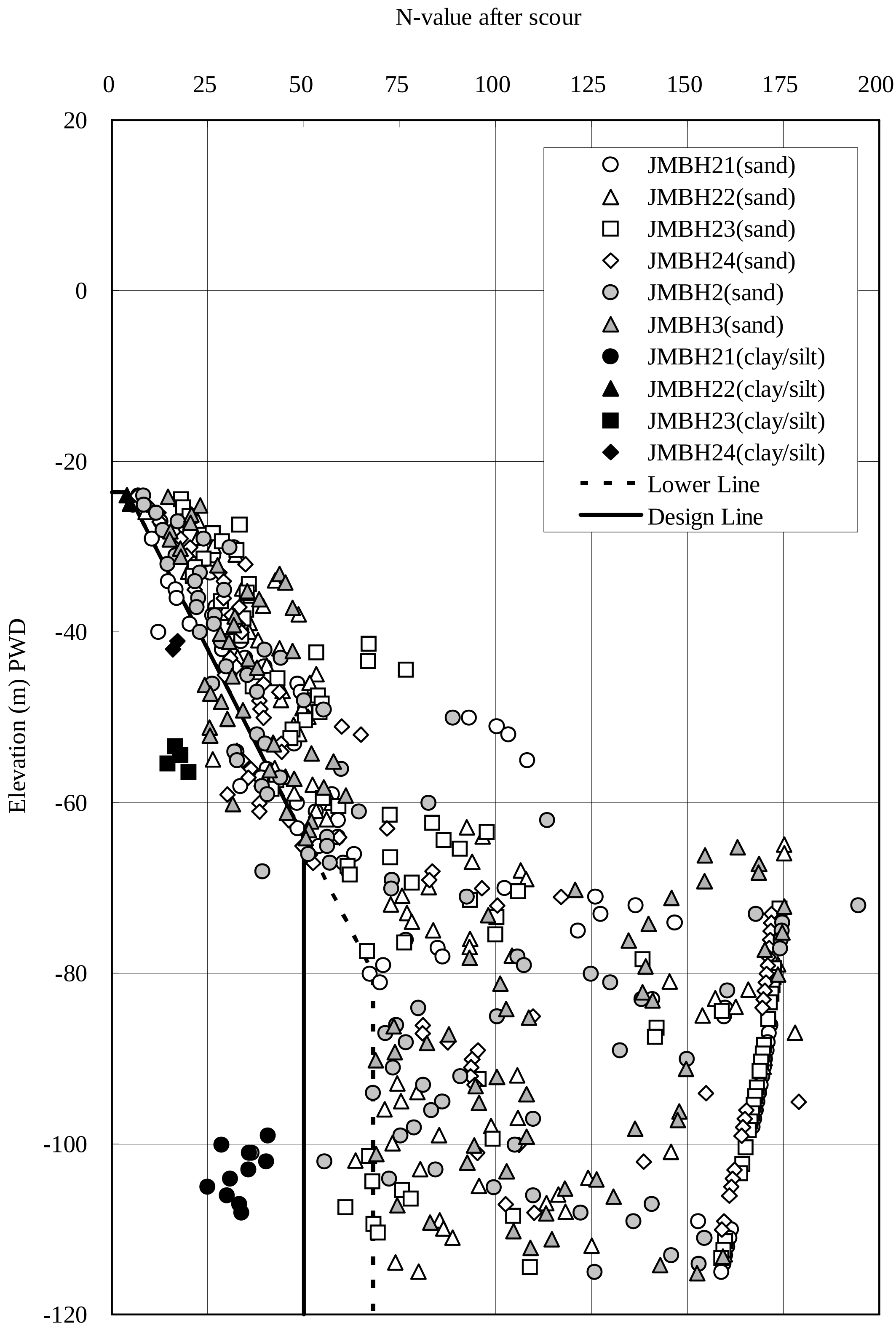


Figure 2.4.6 Distribution of N-value after Scour (River Scour to -23.6m)

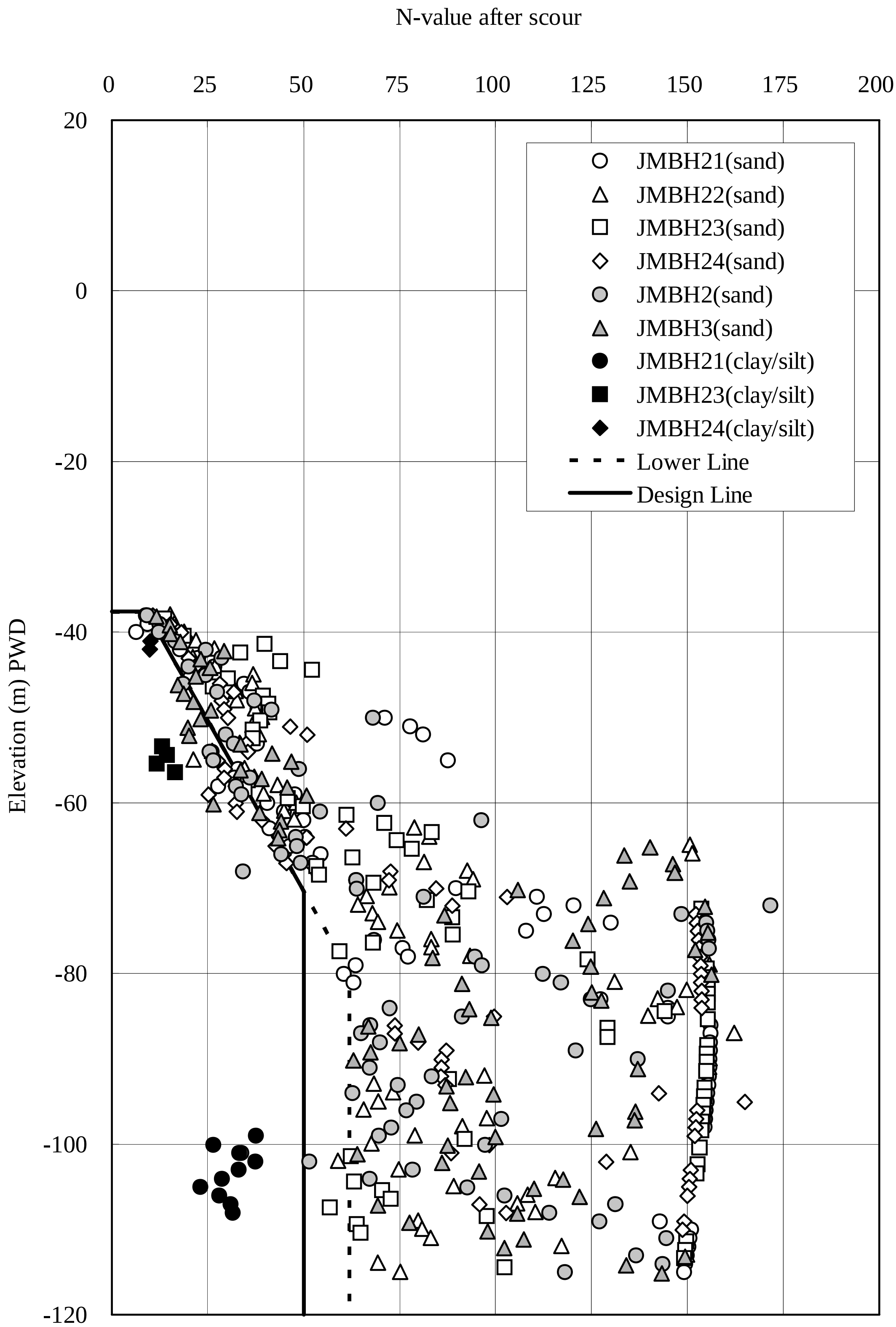


Figure 2.4.7 Distribution of N-value after Scour (River Scour to -37.6m)

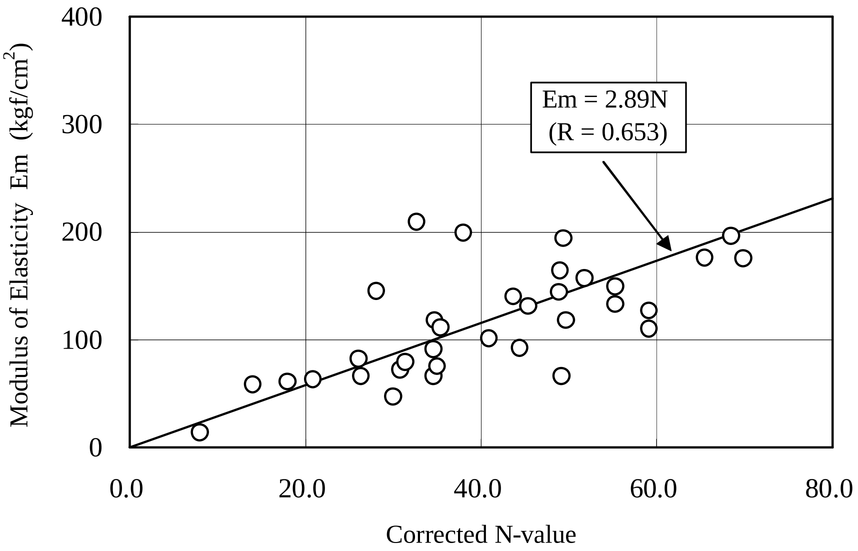


Figure 2.4.8 Correlation between N-value and Modulus of elasticity (Method-1)

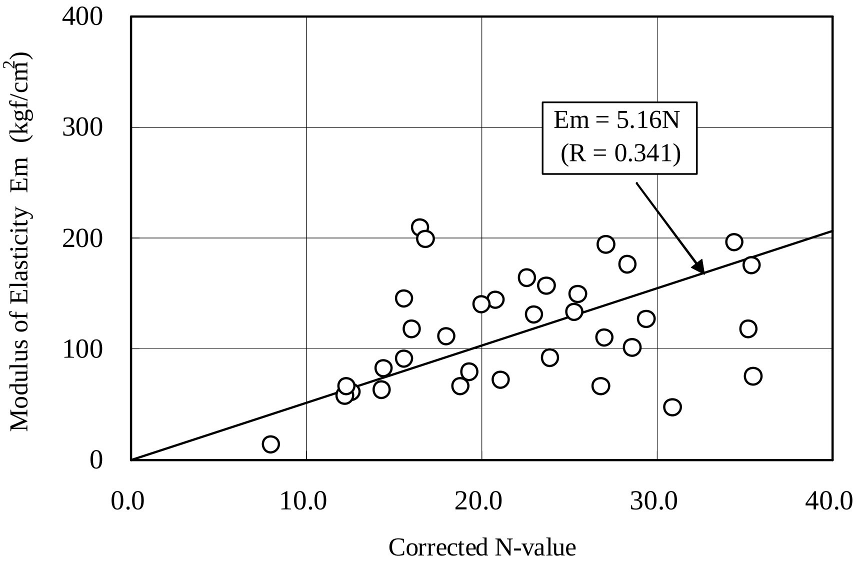


Figure 2.4.9 Correlation between N-value and Modulus of elasticity (Method-2)

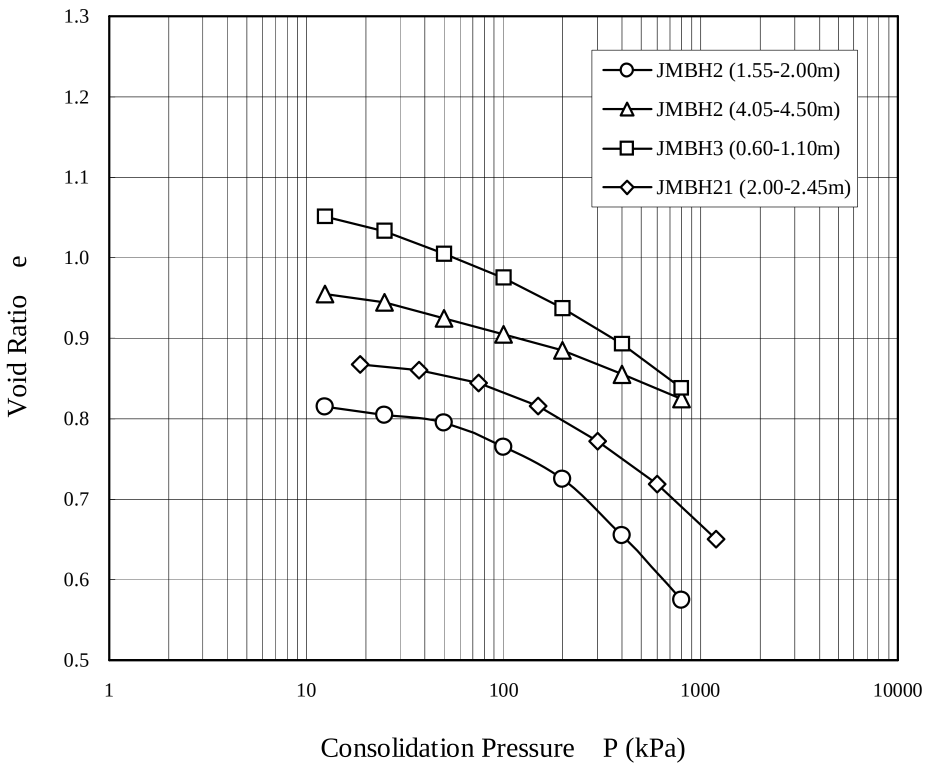


Figure 2.4.10 e ~ log P Curves (Bridge Site)

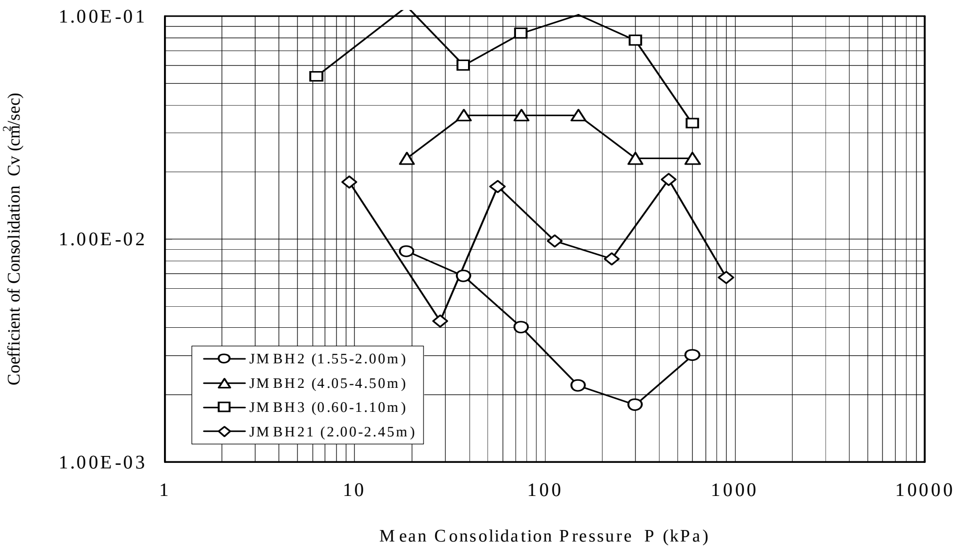


Figure 2.4.11 log Cv ~ log P Curves (Bridge Site)

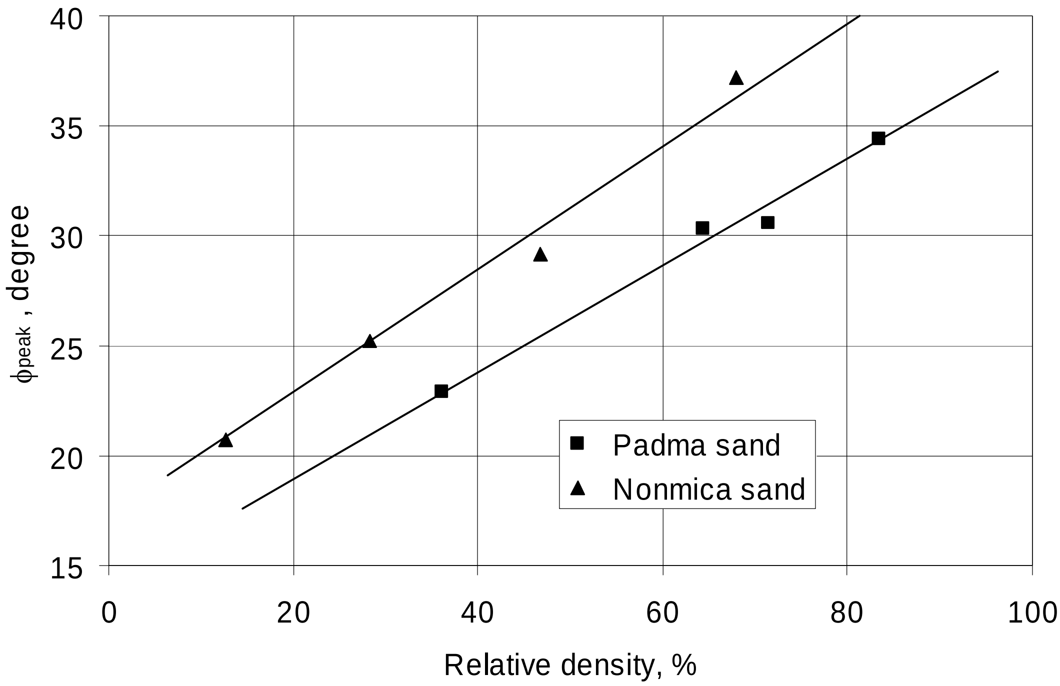


Figure 2.4.12 Variation of ϕ Value for Micacious and Non-mica Sand

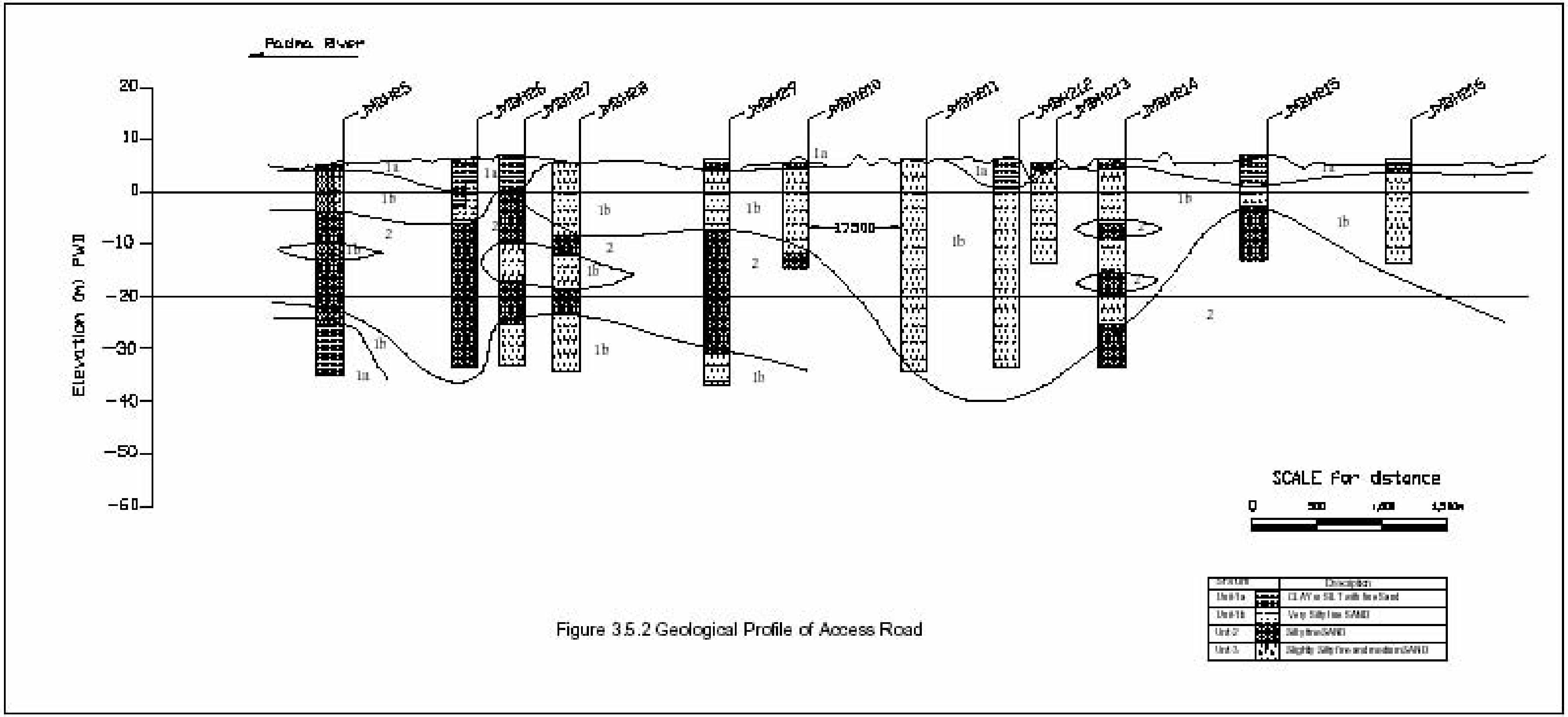


Figure 3.5.2 Geological Profile of Access Road

Figure 2.5.1 Geological Profile of Approach Road Route

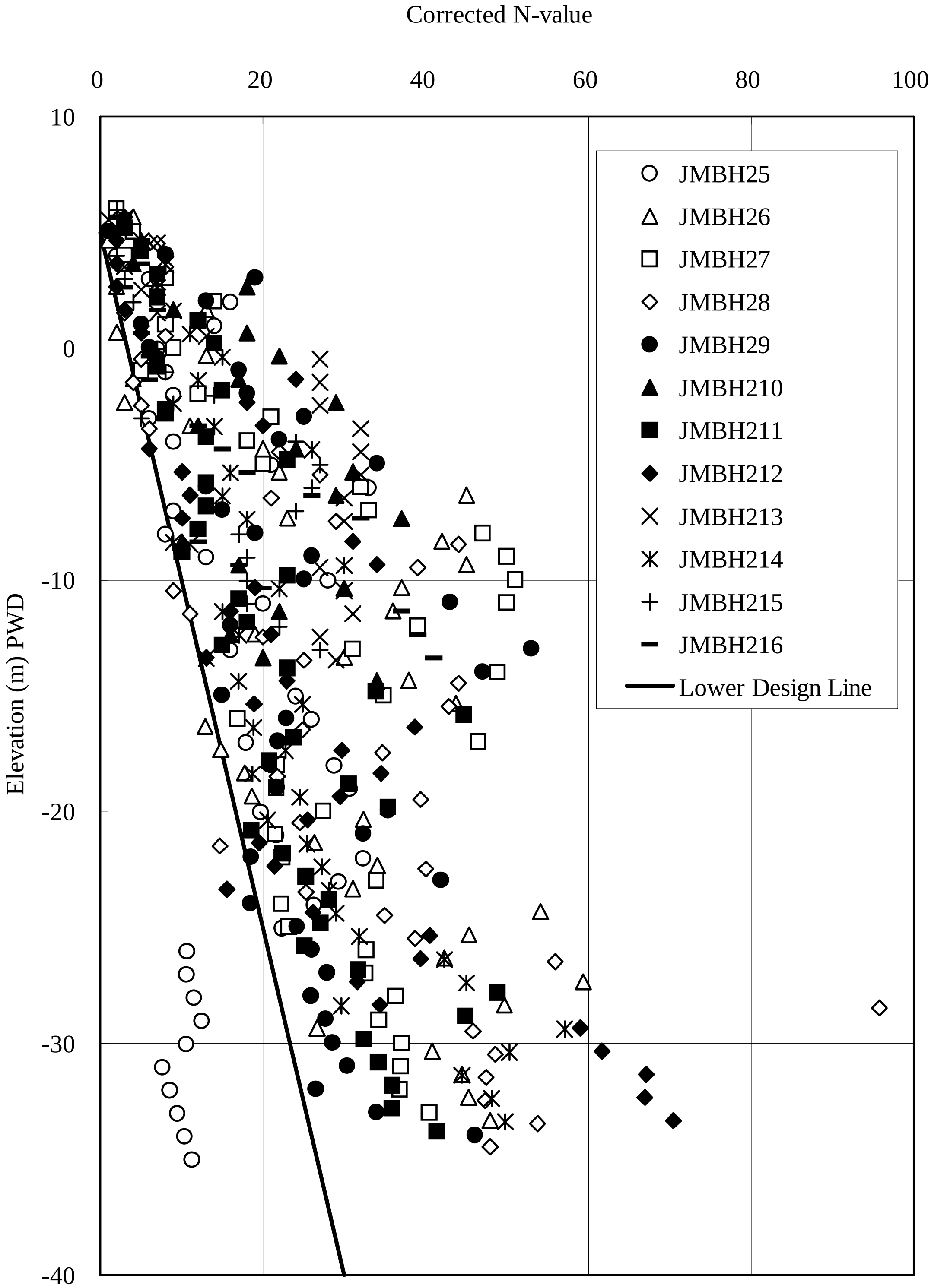


Figure 2.5.2 Distribution of Corrected N-value (Access Road Route)

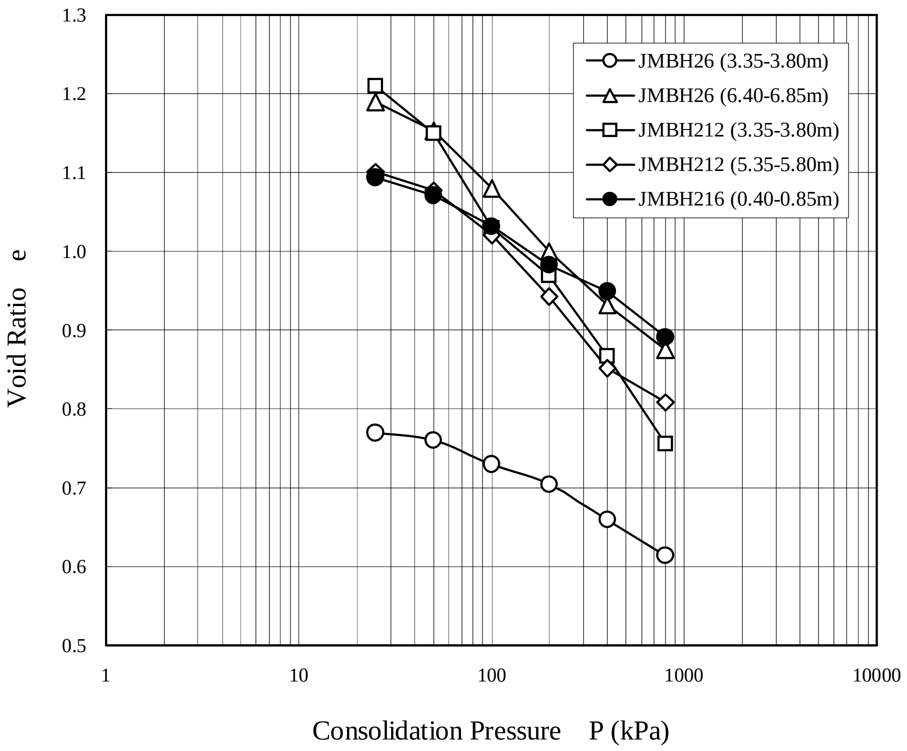


Figure 2.5.3 e ~ log P Curves (Access Road Route)

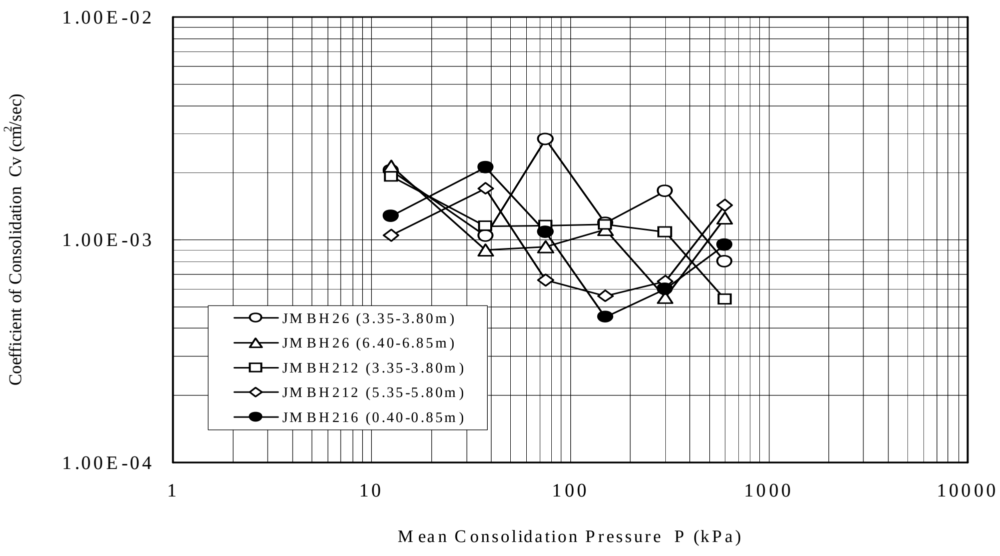


Figure 2.5.4 log Cv ~ log P Curves (Access Road Route)

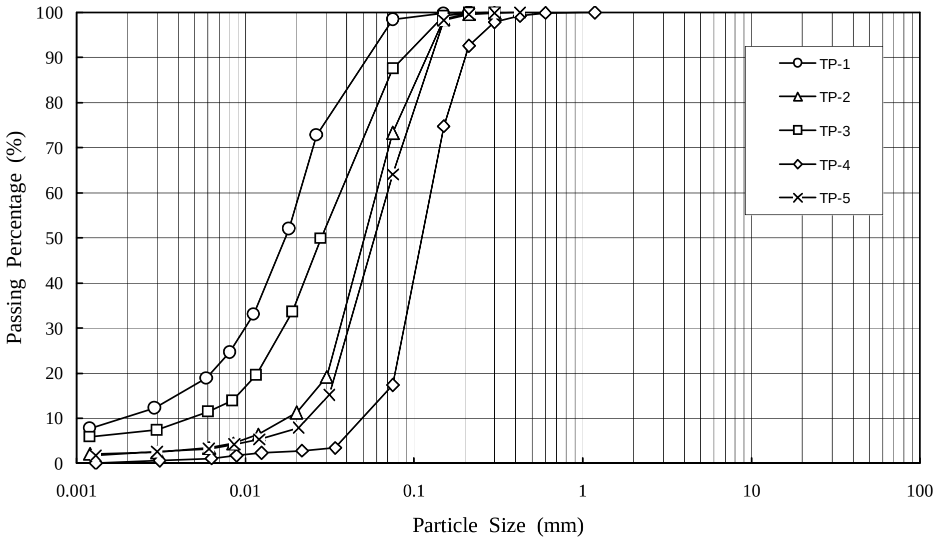


Figure 2.6.1 Gradation Curves of Embankment Materials

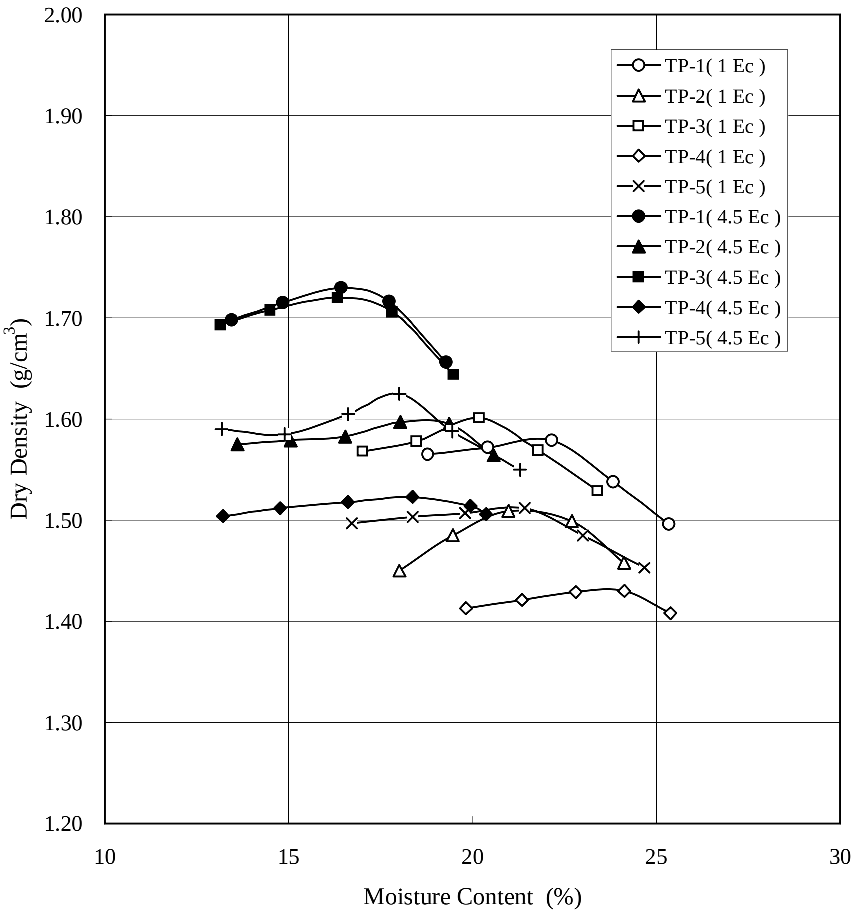


Figure 2.6.2 Compaction Curves of Embankment Materials

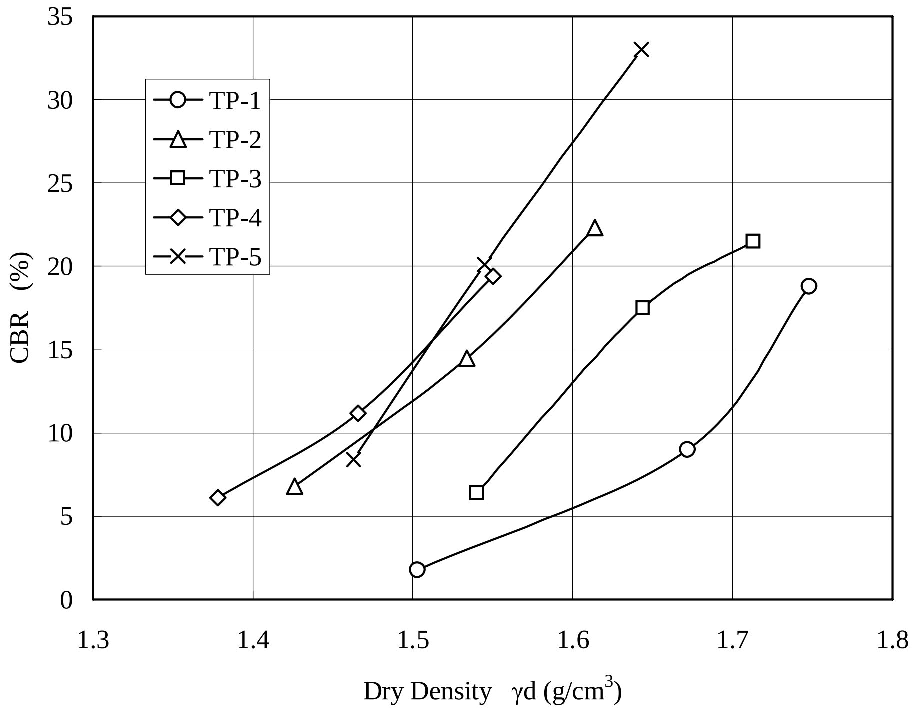


Figure 2.6.3 Correlation between CBR and γd