Investigation of Geotechnical Reasons for Bank Failure on Daulatdia and Paturia Side of Padma River of Bangladesh.

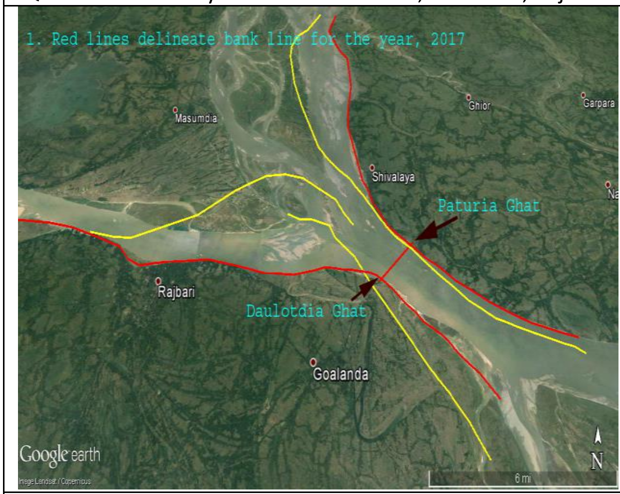
June 2020

RIVER RESEARCH INSTITUTE, FARIDPUR

Ministry of Water Resources
Government of the People's Republic of Bangladesh

Questionaire servey at Afsarsheiker Para, Daulatdia, Rajbari

Bank failure at Afsarsheiker Para, Daulatdia, Rajbari



Bankline in the year 1984 and 2017

Arrangement for sample collection by wash boring method

Seminar on research output

Measurement of ground water level at Daskandi

Conducting Hydrometer test at laboratory

Conducting field density test in field

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Preface

This report presents the outcomes of the research '**Investigation of geotechnical reasons for bank failure on Daulatdia and Paturia side of Padma river of Bangladesh'.** The research has been carried out by the Geotechnical Research Directorate of River Research Institute (RRI) funded by Government of Bangladesh (GoB) during the financial year 2017-18 and 2018-19.

Bangladesh is a broad deltaic plain and it has complex river system. The plain is largely formed by the Ganges, the Brahmaputra and the Meghna. Different rivers bring sediments from areas of different geology.

The failure of riverbank is a common problem in Bangladesh. Devastating flood and excessive rainfall accelerate the failure process which results in immense damage to river bank, agriculture and infrastructures every year.

Riverbank erosion occurs both for hydraulic and geotechnical instability. As river bank failure occurs both for hydraulic and geotechnical instability so, an investigation is necessary to analysis the geotechnical condition of river bank, the reasons of bank failure and improvement of the conventional river bank protection. Under such circumstances, this research study has undertaken. The main objective of the research is to find out geotechnical reasons for why bank fails and what type of geotechnical stability needs for preventing the river bank failure.

In this research, the methodology is adopted through reconnaissance survey, questionnaire survey, field investigation, and laboratory investigation and analyzing data. It is found that the soil strata at Daulatdia ghat of Goalanda of Rajbari district is non-cohesive from very beginning of the depth increment compare to Paturia ghat of Shibaloy of Manikgonj district. As a result, the results of the geotechnical parameters have been demonstrated accordingly and their vulnerabilities have been visualized as well.

I am grateful to the expert from outsourcing for his all-time advices, suggestions and cooperation during the study period.

I highly appreciate Director, Geotechnical Research Directorate of RRI for his valuable guidance, encouragement and cooperation throughout the study period.

Special thanks are extended to Md. Lokman Hossain Mrida, Member, BoG of RRI for providing valuable advice regarding research study and its importance.

I like to be particular in my appreciation for the research team members who have worked hard for completion of the research within the stipulated time. Sincere thanks are extended to all who have given all assistance directly and help us indirectly in connection with this study.

21.06.20

(Md. Alimuddin)
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Abbreviation

ϕ	Angle of Internal Friction
BH	Bore Hole
BIWTA	Bangladesh Inland Water Transport Authority
BWDB	Bangladesh Water Development Board
c	Cohesion
Cc	Compression index
cm	Centimeter
cm/sec	Centimeter per Second
CSO	Chief Scientific Officer
d/s	Downstream
E	Easting
FAO	Food and Agriculture Organization
G	Specific Gravity
G_s	Specific Gravity
GWL	Ground Water Level
ha	Hector
I_d	Density Index
kg	Kilogram
km	Kilometer
kN/ m^3	Kilo Newton per meter cube
m	Meter
m^3	Cubic meter
mm	Milimeter
PWD	Public Works Datum
N	Northing
NMC	Natural Moisture content
pH	Hydrogen Ion Activity in Aqueous Solution
PSO	Principal Scientific Officer
q_u	Compressive Strength
RRI	River Research Institute
S.T	Soil Technician
SO	Scientific Officer
SPT	Standard Penetration Resistance for Test
Sq. ft	Square Feet
SSO	Senior Scientific Officer
SWL	Surface Water Level
T_{50}	Time for Fifty Percent Settlement
T_{90}	Time for Ninety Percent Settlement
UCT	Unconfined Compression Test
UNDP	United Nations for Development Program
WL	Water Level

Executive Summary

Introduction

The major part of Bangladesh is on the delta formed by three major rivers Brahmaputra, Ganges and Meghna. These rivers and many of the country's other minor rivers originate outside the national boundary of the country and make up the Ganges-Brahmaputra-Meghna river system (River, Banglapedia). Over millennia, the sediments carried by the huge discharges of these rivers have built a broad delta, forming most of the large area of Bangladesh and the submerged delta-plain in the Bay of Bengal. These sediments are the major sources of formation of 80% soils of the country. The remaining 20% of soils have been formed in Tertiary and Quaternary sediments of hills (12%) and in uplifted Pleistocene terrace (8%) (Bangladesh Soil, Banglapedia).

Riverbank erosion is a common scenario at monsoon in Bangladesh. All river banks experience erosion, but failure is dependent on the location and the rate at which erosion is occurring. Although each mode of failure is clearly defined, investigation into soil types, bank composition, and environment must be clearly defined in order to establish the mode of failure, of which multiple types may be present on the same area at different times. Once failure has been classified, steps may be taken in order to prevent further erosion.

As river bank failure occurs both for hydraulic and geotechnical instability so, an investigation is necessary to analysis the stability of geotechnical condition of river bank. Though some researchers already tried to characterize geotechnical properties of soil facing mass failure problem like landslides or containing organic matters even it is necessary to know more geotechnical reasons of river bank which can assist the protection works for preventing them from failure.

The scientists also envisage that if the study is done through investigation of geotechnical reasons in this region properly then it will be easier to find out the ways of protection of failure of bank. The analysis of this study will associate with river engineering as a major tool to accomplish bank protection. As a result people will live and travel smoothly. In light of that major point of view, this research study has been undertaken in the fiscal year 2017-18 and 2018-19.

Aims of the Study

The present study aimed i) to investigate the physical and index properties of the bank material of Padma river located at Daulatdia Ghat of Rajbari district and Paturia Ghat of Padma river in Manikgonj district of Bangladesh ii) to determine the strength of soil of

Daulatdia Ghat of Padma riverbank and Paturia Ghat of Padma riverbank in Manikgonj district iii) clarify the bank-failure mechanism at those area through a study as well as how to mitigate this failure and stabilize the river bank of the study area.

Approaches and Methodologies

The research was carried out on following methods i) reconnaissance survey and questionnaire survey from the river bank community's ii) samples collection iii) in-situ investigation iv) laboratory investigation. After completion of survey the site Daskandi and Baruria of Paturia side and CharBahirdia, Launchghat & Afsarsheikher Para of Daulatdia side have been selected. The samples have been collected from the selected three coordinates/holes of each location/site by wash boring method through in-situ investigation from January'18 to February'18. The SPT-N value has been counted for every 1" penetration. The ground water level has been recorded after 24 hours of boring and certain interval of time. Field densities of the soils of each coordinates are carried out and compaction tests are conducted. As a laboratory investigation the parameters natural moisture content, grain size analysis, Atterberg's limit test, consolidation test, tri-axial shear test, direct shear test, permeability test, compaction test, mica count test, pH and EC tests are conducted in the laboratory. The relevant data of study areas such as ground water level of the study areas, surface water level and discharge of the Padma river are collected from WARPO and BWDB from year 2016-2019.

Key Findings and Recommendations

The bank failure reasons at Paturia and Daulatdia side have been investigated in geotechnical aspects. Geotechnical investigation reveals that Paturia side is less affected due to geotechnical reasons in comparison with Daulatdia side. The soil profile and their properties are different from each other. Indeed Afsarsheikher Para is severely affected area of Daulatdia side. Its soil layers are significantly different from any other layers. The bank failure is being happened in this area as its geotechnical character is in favor to identical.

The research will explored the geotechnical reasons of why river bank failed at Daulatdia and Paturia side of Padma river. The outcome of this research will assist the design of the protection works of the river bank which has been made conventional method and further river bank protection works at the same strata. The research states the view to obligate the geotechnical investigation on any river bank protection works prior to planning and design as geotechnical investigation makes the design of the structure confirm.

Geotechnical Reasons of Bank Failure at Paturia Side

The investigation is found out cohesive soil layers up to (0-9)m depth wherever SPT-N values of varies from 3 to 14 and non-cohesive soil layers with mica content are dominant after that depth wherever SPT-N values vary from 4 to 55. At that side water level varies from 2mPWD to 9mPWD around all the year from dry to monsoon. Ground water level varies from 3.3142mPWD to 6.444mPWD where ground level (boring point) varies from 6.667mPWD to 9.492mPWD. Geotechnical properties have been varied in accordance with soil strata and the water level. From the investigation it is found that the main geotechnical reasons of bank failure are i) variation of particle sizes as well as their moisture content, ii) increasing trend of saturation iii) increasing trend of pore pressure iv) decreasing trend of shear strength v) variation of density & vi) variation of permeability. Ground water fluctuation at the study area shows various gradient causing seepage failures during dry season. Due to wave action and overpressure on the bank of traffic loading and unloading causes bank failure.

Bank Failure Mechanism at Paturia side of Padma River

The stratification of the materials from the bank line to the ground surface consists of cohesive layer wherever the high flood level varies from 7m to 9m. In this layer, about 30% of clay particles are presented over this layer which has been observed. Due to presence of such amounts of clay particles create a higher level of bonding between the particles. Consequently, these soils are more resistant to surface erosion because they are less permeable. This reduces the effects of seepage, piping. However, because of low permeability, these soils are more susceptible to failure during rapid drawdown of water levels due to the increase in soil pore water pressures. Here it is mentioned that the maximum bank height with respect to bank full height is more. That’s why the bank failure tendency is low.

It is noticed that waves are created by ferry and launch traffic near the bank line at Paturia side. Waves vary with wind speeds and duration, water depth, and the continuous length of water over which winds blow in one direction. As wave action is the impact of waves hitting directly on exposed soil as well as trafficking ferry and launch. So, it follows the bank failure action in addition with the remaining pore water pressures of cohesive soil at the Paturia side.

Geotechnical Reasons of bank Failure at Daulatdia Side

In Daulatdia side, cohesive soil layers are observed up to (0-12.5)m. Especially, cohesive soil layers are observed up to (0-2)m. SPT-N values of cohesive soils varies from 2 to 7. A number of amount of non-cohesive soil layers are presented. Non-cohesive soil layers with mica content are dominant after that depth. SPT-N values of non-cohesive soils vary from 3 to 50. Water level varies from 2mPWD to 9.5mPWD around all the year from dry to monsoon. Ground water level varies from 1.5132mPWD to 6.7828mPWD where ground level varies from 6.753mPWD to 9.526mPWD. Geotechnical properties have been varied in accordance with soil strata and the water level. From the investigation it is found that the main geotechnical reasons of bank failure are i) variation of particle sizes as well as their moisture content, ii) increasing trend of saturation iii) increasing trend of pore pressure iv) decreasing trend of shear strength v) variation of density & vi) variation of permeability. In that side seepage is more as there are numerous permeable soil layer. Seepage line effect the bank. At the very beginning of monsoon, failure occurs due to raise of surface water and seepage causes mass failure as the gravitational force less than the soil mass. At full monsoon, failure occurs for hydraulic condition mainly flow concentration and increased velocity and high stream causes liquefaction of soil as there are several non-cohesive layers whose SPT values are less than 15. At recession period, ground water level does not drawdown as surface water level due to various soil types and layers and their properties. Slope is not sufficient as much as need. Bank is very steep (1:0.5 -1:1). At recession period, there is no confining pressure. These are the reasons of river bank failure at recession period. Due to wave action and overpressure on the bank of traffic loading and unloading causes bank failure.

Bank Failure Mechanism at Daulatdia side of Padma River

The stratification of soil at two bank lines 7.219m and 6.753m, SILT particles together with CLAY particles make cohesive soils so a medium level of bonding between the particles. Consequently, these soils are moderately resistant to surface erosion because they are moderate permeable. This reduces the moderately effects of seepage, piping. However, because of moderate permeability, these soils are as susceptible to failure during rapid drawdown of water levels due to the increase in soil pore water pressures as well as soil erosion from toe zone. As a result, the river bank fails as base failure due to water pressure. On the other hand, the maximum bank height with respect to bank full height is so small. That’s why the bank failure tendency is high.

It is observed that waves are created by ferry, launch and trawler boat traffic near the two bank lines at Daulatdia side. Waves vary with wind speeds and duration, water depth, and the continuous length of water over which winds blow in one direction. As wave action is the impact of waves hitting directly on exposed soil as well as trafficking ferry and launch. So, it expedites the bank failure action in addition with the remaining pore water pressures of cohesive soil at the Daulatdia side.

On the bank line 7.914m, the low flood level is 5.914m and high flood level is 8m. In the low flood level soil layer contains SAND particles together with little amount of silt particles make non-cohesive soils layer. So, there is no bonding between the particles as CLAY particles are absent. The standard penetration resistance–N values have been altered which make the soil layers sometime loose and sometime dense. Consequently, rising water level intensify water pressure resultant the loose layer bank fails due to liquefaction. As a result, the river bank as well as the homogeneous soil zone as long will liquefy due to water pressure.

Questionnaire survey from the river bank community reveals that Daulatdia side is more vulnerable than the Paturia side of Padma river. The entire respondent opined that the river bank fails for additional sand layer. They said that river bank failure phenomena depend on soil quality. They also mentioned that when water level drawdown the river bank fails.

Geotechnical investigation in depth at the study area is needed to adopt any stabilization/bank protection works. Wave action needs to be considered during the design of the ferry ghat protection works. Sand drain should be implemented up to low water level at the study area. River bank slope should be horizontal 3 and vertical 1. Water level fluctuation in the river of the study area is much higher during low and high flow, which requires special attention. Investigation needs for knowing soil profile and its properties as well as its hydrology. Continuous research needs for finding precise bank failure reasons. The research study is situated at the same soil strata as BWDB's undergoing project. So, any of the banks protective structures at the similar soil strata may apply the result.

Chapter 1
Introduction

1.1 Background

The major part of Bangladesh is on the delta formed by three major rivers Brahmaputra, Ganges and Meghna. These rivers and many of the country's other minor rivers originate outside the national boundary of the country and make up the Ganges-Brahmaputra-Meghna river system (River, Banglapedia). Over millennia, the sediments carried by the huge discharges of these rivers have built a broad delta, forming most of the large area of Bangladesh and the submerged delta-plain in the Bay of Bengal. These sediments are the major sources of formation of 80% soils of the country. The remaining 20% of soils have been formed in Tertiary and Quaternary sediments of hills (12%) and in uplifted Pleistocene terrace (8%) (Bangladesh Soil, Banglapedia).

In many areas, the soil surveys recognized active, young, and old floodplain landscapes. Active floodplains occupy land within and adjacent to the main rivers where shifting channels deposit and erode new sediments during the annual floods.

The failure of riverbank is a common problem in Bangladesh. Devastating flood and excessive rainfall accelerate the failure process which results immense damage to agriculture and infrastructures every year.

Riverbank erosion is a common scenario at monsoon in Bangladesh. Almost every year river banks are facing problems like erosion. Riverbank erosion occurs both for hydraulic and geotechnical instability. Besides, constructed bridge crossings or other encroachments that involve acceleration and concentration of flood flows tends to cause 'back eddies' or reverse circulation downstream, which can sometimes erode river banks. Experts believe that hydraulic instability is caused by scour at the toe of a marginally stable bank, flood propagation and flood recession, debris and vegetation, removal of bank vegetation, detachment of coarse sediment by wave action, secondary current etc. In case of geotechnical instability experts also believe that the major causes are due to the use of geotechnical unstable materials, improper method of construction, seepage and sliding etc. among many reasons. (Bellal et al,2011).All river banks experience erosion, but failure is dependent on the location and the rate at which erosion is occurring. Although each mode of failure is clearly defined, investigation into soil types, bank composition, and environment must be clearly defined in order to establish the mode of failure, of which multiple types may be present on the same area at different times. Once failure has been classified, steps may be taken in order to prevent further erosion.

As river bank failure occurs both for hydraulic and geotechnical instability so, an investigation is necessary to analysis the stability of geotechnical condition of river bank. Though some researchers already tried to characterize geotechnical properties of soil facing mass failure problem like landslides or containing organic matters even it is necessary to know more geotechnical reasons of river bank which can assist the protection works for preventing them from failure.

The scientists also predict that if the study is done through investigation of geotechnical reasons in this region properly then it will be easier to find out the ways of protection of failure of bank. The analysis of this study will associate with river engineering as a major tool to accomplish bank protection. As a result people will live and travel smoothly. In light of that major point of view, this research study has been undertaken and desiring that expected outcome will assist the implementing authority for protection of works as well as people.

1.2 Need and Justification

The riverbank failure in Bangladesh is a general problem and usual phenomena. Devastating flood and excessive rainfall accelerate the failure process which results immense damage to agriculture and infrastructures every year. There is active bank erosion almost in all major rivers in the country causing damage to valuable land, settlements and infrastructures from year to year. Because of high density of population along the river banks a great numbers of people are also displaced due to this continuous bank erosion process. These poor displaced people migrate to nearby towns and cities and live sub-human life in the slump areas. This has created a great natural and social problem in the country. Bank protection is therefore, one of the prime necessities for poverty alleviation and national growth. Before that stability analysis is an utmost important work for any of the bank protection.

Over the last few decades, a many numbers of river bank are protected through many engineering ways. In this regard, it is often noticed that conventional designs are adapted to protecting the river bank. Such protecting works are failed before the return period. As a result, government has to finance many more than that. So, it needs appropriate measure through proper investigation and engineering implication. Under such circumstances, an attempt has been made to find out the geotechnical reasons for why bank fails. The undertaken study seems to meet up the analysis of the stability as geotechnical reasons are utmost important engineering aspects for stability analysis. As a result, the issue may be the safety of lives, land & sustainability of the infrastructures against the forces acting in the rivers.

Among the major rivers Padma is one of the mighty rivers in Bangladesh. Padma river is the main channel of the greater Ganges (Ganga) river in Bangladesh. The Padma River originates from the southern slopes of Himalayas with the name as Ganges and after crossing from India to Bangladesh, it is known as Upper Padma River. About 200 km downstream from Indian boarder, it joined with Jamuna River. From this confluence river changes its direction and joins with Meghna River at Chandpur. This 120 km stretch is named as Padma River. The upper Padma flows southeast ward to receive the mighty Jamuna river (the name of the Brahmaputra in Bangladesh) near Rajbari.(Padma River, Banglapedia).

Generally the Padma River has high current and velocity during monsoon season and becomes very ferocious and wild. Riverbank's erosion and accretion are taking place on Padma River watershed as a common phenomenon. From the main stream of river, a number of tributaries, channels and canals are developed. Arial khan is one of the biggest distributaries on the right bank of the Padma River at Shibchar thana in Madaripur District.

A number of chars have developed along the main stream of the Padma River. Settlement and secondary vegetation have started to develop in many of the aged chars such as Char Daulatdia, Char Bhadrasan, Shibchar, Char Janajat, etc. Seasonal flooding is a common phenomenon in the char lands and floodplains adjacent to the banks of the Padma River. Tidal influence of the Padma River varies from upstream to downstream of the mainstream. Tidal flow in the upstream is comparatively lower than downstream. Field investigation indicated that tidal influence is 3-6 inches at Goalando and Charbadrasan. (Feasibility Study, 2005)

Bank erosion is a common scenario at Goalanda upazilla of Rajbari of Bangladesh. In 2016, this situation was more worsen among the couple of years. People suffered unbearable sufferings out of tolerance both in living and journey. As Padma bridge has not yet ready and all the vehicles would have to depend on ferry at Daulatdia ghat and there was no way to halt the ferry at the ghat due to massive bank erosion as well as bank failure. A few of these failure scene are shown in Fig-1.1 & Fig-1.2 respectively. From these figures it is apparently clear that this bank erosion is for morphological changes at which geotechnical stability plays an important role.

Figure1.1: Bank erosion at Daulatdia Ghat, Goalanda

(Source: Padma River, Banglapedia)

But the failure scenario of these figures also indicates that this failure has been occurred due to rise in water level and its stream which causes of geotechnical instability.

Figure 1.2: Daulatdia Ghat, Goalanda, Rajbari (Photo 6 May, 2017)

The bank erosion phenomenon is being changed year by year. Two satellite images are shown below which are indicating these scenario.

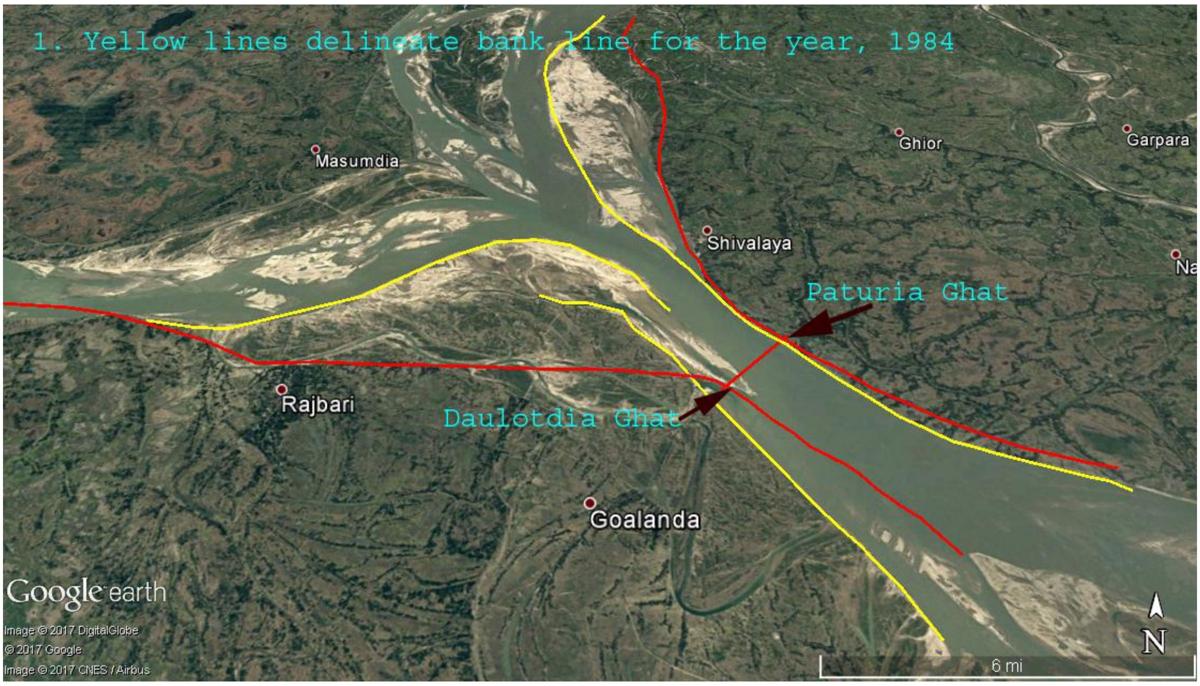


Figure 1.3: Historical Google earth Pro image of Padma river around Daulatdia–Paturia Ghat, 1984

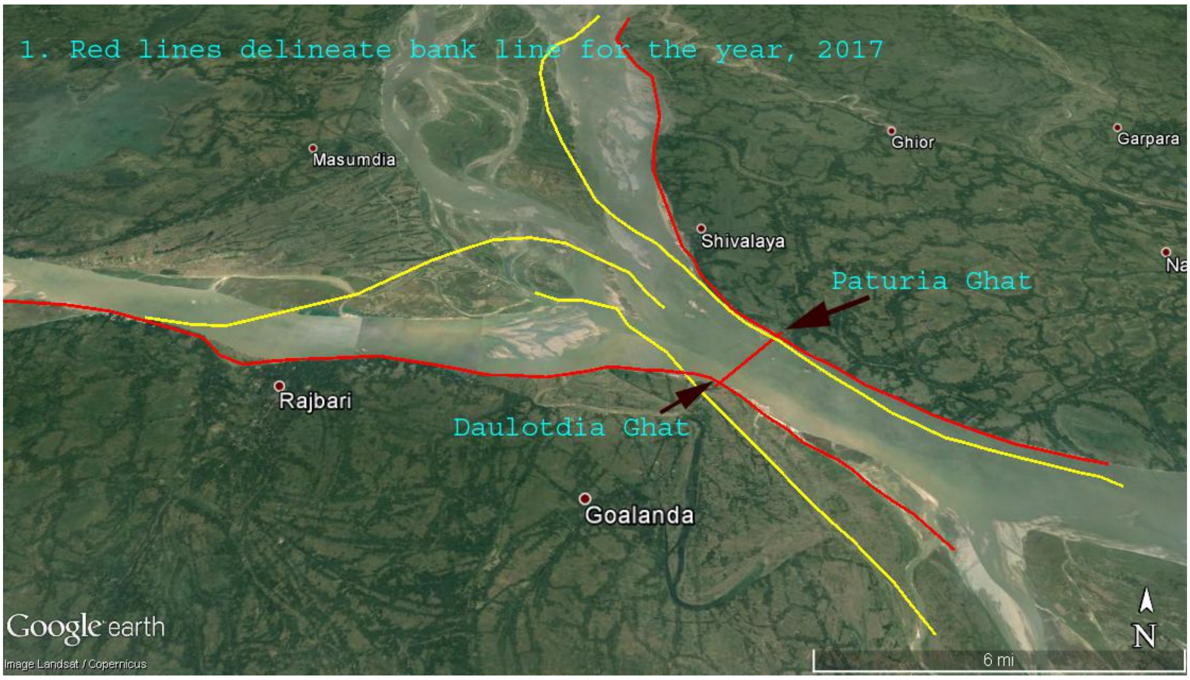


Figure 1.4: Historical Google earth Pro image of Padma river around Daulatdia–Paturia Ghat, 2017.

Historical map of satellite images of Google earth Pro. show up that the bank erosion of Daulatdia Ghat of Goalanda at Rajbari district is more worsen than that of Paturia ghat of Manikgonj district of Padma river. In the satellite image, it is found that Padma river has not been shifted profoundly at Paturia from 1984 to till date. But the Padma river has shifted significantly at the Daulatdia ghat and silted up. At that side, it has reclaimed land as a char. People are residing on that char as their livelihood. The image photo has been shown in Fig-1.3 & Fig-1.4 respectively.

Considering all the situation and scenarios, the location Daulatdia Ghat of Padma river in Rajbari district has been selected as well as its opposite side Paturia Ghat of Padma river in Manikgonj district.

1.3 Aims

The present study aimed

- To investigate the physical and index properties of the bank material of Padma river located at Daulatdia Ghat of Rajbari district and Paturia Ghat of Padma river in Manikgonj district of Bangladesh
- To determine the strength of soil of Daulatdia Ghat of Padma riverbank and Paturia Ghat of Padma riverbank in Manikgonj district
- Clarify the bank-failure mechanism at those areas through a study as well as how to mitigate this failure and stabilize the river bank of the study area.

1.4 Specific objectives

- Knowing geotechnical history and bank failure phenomena
- Geotechnical investigation in the field and the laboratory
- Recommendations through analysis of geotechnical reasons.

Chapter 2

Literature Review

2.1 Formation of Soil

Soils are formed by the disintegration of rocks. The disintegrated materials is found deposited at its own place of origin or transported by water, wind, ice etc. The soil transported by water is called transported soil. Transported soils are classified according to the method of deposition. The method of deposition from suspension in running water is called alluvial soils (S.K.Garg,2010).

2.1.1 The Ways of Operation of Soil Forming Process

The original material can alter its mineral composition in three main ways
i) the weathering of minerals changes the chemical composition

- the weathering of biotite releases iron, calcium, magnesium and other chemical elements and compound.

ii) Weathering can alter the relative proportions of sand, silt and clay from the original material

- The weathering of biotite sand grains reduces the amount of sand grains and increases the amount of silt and clay in the soil material.

iii) Weathering can release minerals in water and transferred to another part of material

- The weathering are dissolved in water and transferred either vertically below or laterally in a different place I.e., deposited as new minerals. These are so-called secondary formations such as iron or lime concentrations. They change not only the chemical composition of the materials but they may also change its texture and other physical properties. (Brammer,1996)

Soil Structure is the geometrical arrangement of soil particles in a soil mass. It is connected with the shape, size and orientation of particles. Engineering properties and behavior of both coarse grained and fine-grained depend upon the structure (Arora,2005). In general, a soil mass consists of solid particles, water and air. The three constituents are blended together to form a complex material.

2.1.2 Formation of Soils in Bangladesh

The major part of Bangladesh is on the delta formed by three major rivers Brahmaputra, Ganges and Meghna. These rivers and many of the country's other minor rivers originate outside the national boundary of the country and make up the Ganges-Brahmaputra-Meghna river system (River, Banglapedia).

The river system drains a basin of some 1.76 million sq. km and carries not only snowmelt water from the Himalayas but also runoff water from some of the highest rainfall areas of the world. Over millennia, the sediments carried by the huge discharges of these rivers have built a broad delta, forming most of the large area of Bangladesh and the submerged delta-plain in the Bay of Bengal. These huge sediments are the major sources of formation of 80% soils of the country. The remaining 20% of soils have been formed in Tertiary and Quaternary sediments of hills (12%) and in uplifted Pleistocene terrace (8%) (Bangladesh Soil, Banglapedia).

Regarding soil formation, two distinct conditions occur in Bangladesh: alternating seasonal wet or inundated and dry conditions, as prevalent on most of the floodplain areas, and intermittently wet or moist or dry conditions as on the upland areas of hills and terraces. This is due to variation of agro climatic parameters in different seasons. The soil formation process differs significantly between floodplain, hill and uplifted terrace.

In many areas, the soil surveys recognized active, young, and old floodplain landscapes. Active floodplains occupy land within and adjacent to the main rivers where shifting channels deposit and erode new sediments during the annual floods. Newly deposited alluvium within this floodplain is stratified in different layers. Usually, silty and clay deposits are finely stratified, and sandy deposits, as well as mixed sandy and silty deposits are coarsely stratified. This is a state from where the soil forming factors are yet to activate the soil forming processes.

The young and old floodplains are virtually stable land that the main river channel has moved away, but they are crossed by tributary or distributaries channels that vary from active to moribund delta. On these floodplains, the process of soil formation dominates over sediment deposition, as evidenced by soil characteristics i.e., the original alluvial stratification has been broken up by biological mixing; the subsoil has developed structure and oxidized mottles; and, in older soils, the topsoil has become acidic (Bangladesh Soil, Banglapedia).

The failure of riverbank is a common problem in Bangladesh. Devastating flood and excessive rainfall are accelerating the failure process which results immense damage to agriculture and infrastructures every year.

This international soil classification is very important to the soil scientists at national and international levels. The benefit of the advancement of soil resources in any part of the world could easily be translated or harvested through the understanding of this international classification. But this classification is highly technical for the common users in the field of agriculture. In order to simplify the technical soil classification of Bangladesh for the common users, a total of 21 general soil types have been recognized.

2.1.3. General soil type

A non-technical grouping of soils, made originally to enable non-specialists to make use of the technical information provided by the FAO/UNDP Soil Survey Project in the 1960s. These general soil types give a very broad level of generalization of soil characteristics. Each general soil type includes several kinds of soil series, developed in more than one kind of parent materials and may include a wide range of chemical and physical properties. The objective of this classification is to classify together soils with broadly similar characteristics so as to provide an overview of soil conditions of a whole country or a region.

2.1.3.1 Floodplain soils

They are divided into different sub-types, such as - calcareous alluvium, non-calcareous alluvium, calcareous brown floodplain soils, calcareous grey floodplain soils, calcareous dark grey floodplain soils, non-calcareous grey floodplain soils, non-calcareous brown floodplain soils, non-calcareous dark grey floodplain soils, black terai soils, acid basin clays, acid sulphate soils, peat, grey piedmont soils, made-land.

Table 2.1: General soil types of Bangladesh.

General soil type	Area (ha)	(%)
Floodplain soils	9,718,722	78.96
Calcareous Alluvium	591,796	4.81
Non-calcareous Alluvium	562,242	4.57
Calcareous Brown Floodplain soils	478,518	3.89
Calcareous Grey Floodplain soils	170,767	1.39
Calcareous Dark Grey Floodplain soils	1,434,678	11.66
Non Calcareous Grey Floodplain soils	3,387,153	27.52
Non Calcareous Brown Floodplain soils	383,312	3.11
Non Calcareous Dark Grey Floodplain soils	1,599,645	13.00
Black Terai soils	83,408	0.68
Acid Basin clays	348,994	2.84
Acid Sulphate soils	226,647	1.84

General soil type	Area (ha)	(%)
Peat	130,005	1.06
Grey Piedmont Soils	215,279	1.75
Made-land	106,278	0.86
Hill soils (Brown Hill Soils)	1,561,472	12.69
Terrace soils	1,028,030	8.35
Shallow Red-Brown Terrace soils	72,549	0.59
Deep Red-Brown Terrace soils	189,380	1.54
Brown Mottled Terrace soils	34,235	0.28
Shallow Grey Terrace soils	265,427	2.16
Deep Grey Terrace soils	352,152	2.86
Grey Valley soils	114,287	0.93
Total soil area	12,308,224	100.00

(Bangladesh soil-Banglapedia,), **Source: FAO/UNDP, 1988.**

2.1.3.2 Calcareous Alluvium

Soils are stratified or raw alluvium throughout or below the cultivated layer. They are calcareous throughout or part of it and lack in having diagnostic subsoil horizon. This alluvium on the active Ganges floodplain mainly comprises brownish grey to pale brown sandy and silty deposits, which are moderately calcareous. Soils on the Lower Meghna estuarine floodplain are slightly calcareous grey to olive, finely stratified silts. They are mainly Calcaric Fluvisols.

2.1.3.3 Non-calcareous Alluvium

Similar to calcareous alluvium, except they are non-calcareous in soil profiles. These soils occupy extensive areas on the active Tista and Brahmaputra-Jamuna floodplains. They are sandy or silty, grey or olive, neutral to slightly alkaline. Most of these soils have been included as Eutric Fluvisols.

2.1.3.4 Calcareous Brown Floodplain soils

They have cambic B-horizon that is predominantly oxidised, containing lime in the profiles. They comprise pale brown to olive brown, friable, loamy and clay soils occurring on the upper parts of ridges on the Ganges river floodplain and on the river bank of the Ganges tidal floodplain. Most of these soils belong to Calcaric Gleysols.

2.1.3.5 Calcareous Grey Floodplain soils

They have grey matrix cambric B-horizon and lime in the profiles. They range from silt loam and silty clay loam on riverbanks and floodplain ridges to silty clays in basins. Soils of this group mainly occur on the Ganges tidal floodplain in the southwest, also minor areas on the river floodplain of the Ganges and Lower Meghna. They are Calcaric Gleysols.

2.1.3.6 Calcareous Dark Grey Soils

Floodplain soils Occur extensively on the Ganges floodplain and locally on the soils that comprise cambic B-horizon and lime in part or throughout the solum and with a dark grey topsoil and/or upper subsoil. There are continuous dark grey gleans as well in the Ganges tidal floodplain. They are Calcaric Gleysols. (Bangladesh soil-Banglapedia,)

2.1.3.7 Gangetic Alluvium Soils

The soil comprises the former greater districts of Jessore and Kushtia and some parts of Rajshahi, Pabna, Faridpur, Khulna, Barisal and Dhaka. This tract occupies an area of 27,000 sq km. It represents the riverine lands of the Gangetic plains. Soil texture varies from clay loam to sandy loam. The pH of the soils ranges from 7.0 to 8.5. The soils are moderately fertile and are characterized by calcium carbonate content and are well supplied with phosphate and potassium.

Table 2.2: Soil Tract of Bangladesh

No.	Soil tract	Physiography units	General soil types
1.	Madhupur Tract	Madhupur Tract	Red-brown terrace soil
2.	Barind Tract	Barind Tract	Grey terrace soil
			Deep red-brown terrace soil
3.	Gangetic Alluvium	Ganges river floodplain	Calcareous dark grey floodplain soil
		Arial Beel	Acid basin clay
		Gopalganj-Khulna peat basins	Peat
		Ganges tidal floodplain (non-saline part)	Grey floodplain soil
4.	Tista Silt Tract	Old Himalayan piedmont plain	Black terai soil
		Tista floodplain	Non-calcareous brown floodplain and grey floodplain soil
			Grey floodplain and non-calcareous brown floodplain soil
			Non-calcareous dark grey floodplain soil
			Non-calcareous alluvium
			Non-calcareous grey floodplain soil (non-saline phase)

No.	Soil tract	Physiography units	General soil types
			Non-calcareous alluvium
5.	Brahmaputra Alluvium	Jamuna floodplain	Non-calcareous brown floodplain and grey
		Old Brahmaputra floodplain	floodplain soil
		Haor Basin	Grey floodplain and
		Surma-Kushiyara floodplain	Non-calcareous brown floodplain soil
		Middle Meghna floodplain	Non-calcareous dark grey floodplain soil
		Old Meghna estuarine floodplain	Grey floodplain soil
		Young Meghna estuarine floodplain (northern part)	Acid basin clay Surma-Kushiyara floodplain soil
		Chittagong coastal plain	Comilla basin soil
		Northern and eastern piedmont plain	Grey floodplain and non-calcareous dark grey floodplain soil
			Calcareous alluvium (non-saline part)
			Non-calcareous alluvium
			Floodplain soil
			Old Piedmont plain soil
6.	Coastal Saline Tract	Young Meghna estuarine floodplain	Calcareous alluvium (saline phase)
		Ganges tidal floodplain (saline part)	Acid sulphate soil
		Sundarban	Grey floodplain soil (saline phase)
		Chittagong coastal plain (partly)	Grey Piedmont Soils (saline part)
7.	Hill Tract	Northern and eastern hills	Brown hill soil

2.1.4 Soil Formation in different rivers of Bangladesh

Bangladesh is a broad deltaic plain and it has complex river system. The plain is largely formed by the Ganges, the Brahmaputra and the Meghna (Sajjadur Rasid, 2008). Different rivers bring sediments from areas of different geology. Accordingly the alluvial sediments of different rivers contain different amount of micas, feldspars, hornblende etc.(rock minerals) which can weather in the soil to produce clay and chemical elements such as iron, calcium, phosphorus etc.

The different amounts of sand, silt and clay occur in the soils in different parts of Bangladesh as the rivers deposit different amounts of these particles in different parts of their floodplains when they over flood the land. Sandy material is deposited to near the river banks and silty material further away from the banks whereas clay in the furthest away from the river. When rivers change their courses, the pattern of sandy and silty materials are seen on the slightly higher ridges of the rivers and clay materials are seen left behind of the adjoining basins (Brammer, 1996).

Brahmaputra alluvial deposits contain large amounts of biotite (black mica) which is easily weatherable mineral but don't contain lime. On the other hand, Ganges alluvium contains lesser amounts of biotite but significant amounts of lime. The other rivers draining the eastern hills contain little biotite and no lime (Brammer, 1996).

Md. Shamsul Islam et al (2009) emphasis that soil formation below the foundation in any place is needed to be identified. So, it is necessary to make a link between subsoil exploration data and geological information. Tectonic setting and geology of Bangladesh is also important to assess the Earthquake Hazards of this region. Bangladesh occupies major part of the Ganga-Brahmaputra delta, the largest delta in the world in terms of sediment load (sediment load per year is 1670 million tons) carried to the sea (Orton and Reading, 1993). The rate of growth of the delta is, however believed to have been retarded because of the bypassing of most of the river sediments through the Swatch of no ground submarine canyon into the deep sea (Kuehl et al, 1989). A process of deltaic sedimentation, into a slowly and continuously subsiding tectonic basin has developed the geology of Bangladesh.

They also importance that soil formation below the foundation is needed to be identified for proper selection and design of foundation.

The feasibility study of Padma bridge explores (2005) that the Ganges river deposits are characterized by the presence of non-calcareous minerals (calcite and dolomite), while the Jamuna River sediments are rich in mica and biotite (alluvia of other rivers are less micaceous). The soil of Paturia-Goalundo site mainly consists of sandy SILT (Paturia) and silty SAND (Goalundo) whereas the soil of Mawa-Janjira site consists of clayey sandy SILT (Mawa) and sandy SILT (Janjira).

2.2 Hydrology

The feasibility study of Padma bridge explore (2005) that River System Bangladesh is a riverine and flood prone country and vulnerable to yearly flooding during the monsoon season. The major river systems in Bangladesh are the Jamuna, Padma and Meghna and their vast networks of tributaries and distributaries. The river system of Bangladesh usually carries an average of approx. 1,400 million tons of sediment every year. The average water level slope of the Padma is about 5 cm/km.

2.3 Groundwater

Ground water is widely used for drinking as well as for irrigation purposes in the study areas. The Hand Tube wells in the rural areas and pipe water in the urban areas are used for drinking purpose. The Shallow and Deep Tube wells are used for irrigation. The ground level goes down in dry and winter period (December to May) due to use of large quantities of ground water for irrigation and household requirement. The ground water level is located closed to the ground elevation at Paturia and Mawa sites as these sites are located just on and close to the river bank of the Padma. Groundwater table data were collected from BWDB for 20 years periods (1982-2002). Ground water table below measuring point varies from 0.05m (27 July, 1998) to 7.95m (29 March, 1999) at Paturia site and 0.05m (5 September, 1988) to 7.85m (21 January, 1985) at Goalundo site.

2.4 Flooding

The feasibility study of Padma bridge explore (2005) that Floods in Bangladesh are caused by: (1) normal flood due to upstream water, (2) flash flood in hilly areas, (3) heavy rainfall within the boundaries of Bangladesh, and (4) coastal storm surge. The areas of the Padma Bridge Project suffer from flood of type (1) and (3). The recorded maximum flow of the Padma at Mawa (60 km d/s of confluence at Goalundo) is 115,700 m3/s and at Baruria transit (about 5 km d/s of confluence at Goalundo) is 141,900 m3/s during 1998 flood. The maximum water level at Mawa and Goalundo transit are 6.34 m PWD and 10.21 m PWD, respectively. The width of the river at Mawa and Paturia are 4.9 km and 4.8 km during January 2003. The river width was ranged from 2 to 4.92 km at Mawa and 2.44 to 5 km at Goalundo during past 30 years (1973-2003)

2.5 Characteristics of Bed and Bank Material

The resistance of natural river banks to erosion is closely related to the characteristics of the bank material, where the materials are highly variable. They can be mainly classified as cohesion less Banks and cohesive Banks.
Cohesion less Banks: Stream banks composed of cohesion less soils normally are highly stratified heterogeneous deposits. Cohesion less soils consist of mixtures of silts, sands, and gravels. These soils have no electrical or chemical bonding between particles and are eroded grain by grain. Erosion of cohesion less soils is controlled by gravitational forces and particle characteristics such as size, grain shape, gradation, moisture content, and relative density. Other factors include the direction and magnitude of flow velocities next to the bank, fluctuations in water turbulence, the magnitude and fluctuations in the shear stress exerted on the banks, seepage force, and piping and wave forces.

Cohesive Banks: Erosion of cohesive stream banks is more complex to analyze than cohesion less banks because of the characteristics of soil particle bonding. Cohesive soils contain large quantities of fine clay particles composed of chemically active minerals that create strong chemical and electrochemical bonds between particles. Cohesive material is generally more resistant to surface erosion because its low permeability reduces the effects of seepage, piping, frost heaving, and subsurface flow on the stability of the banks. Because of the low permeability, this material is more susceptible to failure during rapid lowering of water levels.

2.6 Bank Failure Mechanism

The multiple types of failure may be present on the same area at different times. They are i) Hydraulically induced failure ii) Geotechnical failure iii) Tectonic failure & iv) Gravitational failure.

2.6.1 Hydraulically induced failure

Hydraulic processes at or below the surface of the water may entrain sediment and directly cause erosion. Non-cohesive banks are particularly vulnerable to this type of failure, due to bank undercutting, bed degradation, and basal clean-out.

Hydraulic toe erosion occurs when flow is in the direction of a bank at the bend of the river and the highest velocity is at the outer edge and in the center depth of the water. Centrifugal forces raise the water elevation so that it is highest on the outside bend, and as gravity pulls the water downward, a rolling, helical spiral happens, with downward velocities against the bank (erosive force). It will be highest in tight bends. The worst erosion will be immediately downstream from the point of maximum curvature. In cases with non-cohesive layers, currents remove the material and create a cantilever overhang of cohesive material. Shear exceeds the critical shear at the toe of the bank, and particles are eroded. This then causes an overhang eventually resulting in bank retreat and failure. (Wikipedia)

2.6.2 Geotechnical failure

Geotechnical failure usually occurs due to stresses on the bank exceeding the forces the bank can accommodate. One example is oversaturation of the bank following a lowering of the water level from the floodplain to normal bank levels. Pore water pressure in the saturated bank reduces the frictional shear strength of the soil and increases sliding forces. This type of failure is most common in fine grained soils because they cannot drain as rapidly as coarse grained soils. This can be accentuated if the banks had already been destabilized due to erosion of cohesion less sands, which undermines the bank material and leads to bank collapse. If the bank has been exposed to freeze thaw, tension cracks may lay lead to bank failure. Subsurface moisture weakens internal shear. Capillary action can also decrease the angle of repose of the bank to less than the existing bank slope. This over steepens the slope and can lead to collapse when the soil dries.

Piping failure may occur when high groundwater seepage pressure increases, as well as the rate of flow. This causes collapse of part of the bank. Failure is usually due to selective groundwater flow along interbedded saturated layers within stratified river banks, with lenses of sand and coarser material in between layers of finer cohesive material. (Wikipedia)

2.6.3 Tectonic failure

Changes in the valley floor slope can influence alluvial rivers, which can happen due to tectonics. This may cause river bank failure, resulting in hazards to people living near to the river and to structures such as bridges, pipelines, and power line crossings. While large and fast flowing rivers should maintain their original flow paths, low gradients makes effects caused by slope changes larger. Bank failure as the result of tectonics may also lead to avulsion, in which a river abandons its own river channel in favor of forming a new one. Avulsion due to tectonics is most common in rivers experiencing a high stand, in which bank failure has led to a loss of natural levees due to liquefaction and fractures from an earthquake.

2.6.4 Gravitational failure

Gravitational failure includes shallow and rotational slides, slab and cantilever failures, and earthflows and dry granular flows. It is the process of detaching sediment primarily from a cohesive bank and transporting it fluvially.

Shallow failure occurs where a layer of material moves along planes parallel to bank surfaces. Failure is typical of soils with low cohesion, and occurs when the angle of the bank exceeds the angle of internal friction.[5] Small to medium-sized blocks are forced out at or near the base of the river bank due to excessive pore water pressure and overburden. The slab of material in the lower half of the bank will fall out, leaving an alcove shaped cavity. Failure is usually associated with steep banks and saturated finer grained cohesive bank materials that allow buildup of positive pore water pressure and strong seepage within structure.

Popout failure is when small to medium-sized blocks are forced out at or near the base of the river bank due to excessive pore water pressure and overburden. The slab of material in the lower half of the bank will fall out, leaving an alcove shaped cavity. Failure is usually associated with steep banks and saturated finer grained cohesive bank materials that allow buildup of positive pore water pressure and strong seepage within structure. Small to medium-sized blocks are forced out at, or near the base of the river bank due to excessive pore water pressure and overburden.

Slab failure is the sliding and forward toppling of deep seated mass into the river channel. Failures are associated with steep, low height, fine grained cohesive banks and occur during low flow conditions. They are the result of a combination of scour at the bank toe, high pore water pressure in the bank material, and tension crack at the top of the bank.

Cantilever failures occur when an overhanging blocks collapses into the channel.[5] Failure often occurs after the bank has experienced undercutting. Failure is usually in a composite of fine and coarse grained material, and is active during low flow conditions.

Failure caused by dry **granular flow** occurs typically on non-cohesive banks at, or near to, the angle of repose, which are undercut. This increases the local bank angle above the friction angle, and individual grains roll, slide, and bounce down the bank in a layer. Accumulation usually occurs at the toe.

A wet earthflow occurs where the loss of strength of a section of bank due to saturation increases the weight of the bank and decreases the banks material strength so that the soil flows as a viscous liquid.[2] This type of failure usually occurs on low angle banks and the affected material flows down the bank to form lobes of material at the toe.

Beam failure happens as the result of tension cracks in the overhang, and occurs only when the lower part of an overhang block fails along an almost horizontal failure surface.
As observed by Terzaghi & Peck (1948), seepage-induced slope instability is a complex phenomenon, which has not been quantified, and likely not even fully understood. The purpose of this work has been to at least narrow the gap between engineering practice and the literature available on seepage-induced slope instability. A wide range of factors affect a slope's ability to resist seepage-induced instability, with a number of factors still yet to be fully defined. Furthermore, the available numerical codes are not currently suitable for modelling seepage-induced instability in slopes. The development of new numerical methods to model seepage-induced erosion will provide practitioners with a means to better identify slopes susceptible to seepage-induced erosion, particularly in urban areas encroaching on sloping topography. This work provides a possible solution to describe seepage-induced slope instability utilizing Critical State Soil Mechanics. Further work is required to determine if in fact this solution is valid for natural slopes.
Bank erosion is a key process in fluvial dynamics, affecting a wide range of physical, ecological and socio-economic issues in the fluvial environment. These include the establishment and evolution of river and floodplain morphology and their associated habitats (e.g. Hooke, 1980; Millar and Quick, 1993; Darby and Thorne, 1996a; Barker et al., 1997; Millar, 2000; Goodson et al., 2002), turbidity problems (e.g. Bull, 1997; Eaton et al.,

2004), sediment, nutrient and contaminant dynamics (e.g. Reneau et al., 2004), loss of riparian lands (e.g. Amir i-Tokaldany et al., 2003), and associated threats to flood defense and transportation infrastructure (e.g. Simon, 1995). Moreover, recent studies have shown that the contribution of bank-derived sediments to catchment sediment budgets may be higher than previously thought. Walling et al.(1999) showed that bank sediments contribute up to 37% of the basin suspended sediment yield, even in the relatively low-energy catchments of the UK, with the contribution rising to values as high as 80% in some highly unstable, incised, channel systems (e.g. Simon and Darby, 2002). With such a significant fraction of material within the alluvial sedimentary system derived from river banks, it is evident that knowledge of the rates, patterns and controls on bank erosion events that release sediment to river systems is a pre-requisite for a complete understanding of the fluvial sediment transport regime. This report seeks to address two main objectives. First, a synthetic state of the art review on bank erosion processes are attempted, (Harrison et al.)

Inamul (2010) explains that the river bank can collapse depends on a number of factors predominating the geotechnical characteristics. For design of protection work the types of failure are- Rotational slip, Slab failure, Cantilever failure, Pop-out failure, Piping, Dry granular flow, Wet earth flow etc.
River bank failure can be caused when the gravitational forces acting on a bank exceed the forces which hold the sediment together. Failure depends on sediment type, layering, and moisture content.

2.5. Impact of Geotechnical Parameter

2.5.1. Impact of Geotechnical Parameter on Construction

Md. Safiullah (2009) concluded about the Bangladesh soil and drew the main points such as, Bangladesh is formed predominantly by alluvial sediments which can be classified into six broad soil units. Of these the Recent Alluvial Flood Plain deposits and the estuarine and Tidal Flood Plain deposits provide considerable challenge to geotechnical interpretation and consideration for design parameters. He also suggests that geotechnical correlation for foundation design in many texts should be used with caution as these may not be applicable for our alluvial soil deposits. There is a need for development of new correlation consistent with our soil conditions. He desired that some ground testing and sampling procedures and techniques followed in this country need to be seriously reviewed and a Code of Practice should be established in this respect.

Md. Safiullah (2009) asked that more rigorous quality control practice should be introduced for geotechnical construction works such as cast-in-situ bored piles. He also instructed that specifications are necessary for Md. Shamsul Islam et al stable boreholes, good quality slurry concrete, and pile load test should be enforced in all such construction works. He advised that ground improvement techniques should be developed and its use encouraged meeting the challenging needs of a highly populated and expanding urban population.

Salma Akter et al (2018) studied on geomorphologic, geologic and engineering context. They comment that geological and its engineering parameters are very much crucial to be considered prior to any planning. Lack of such adequate data during planning and early stages of site investigations for specific structure e.g. building, bridges, roads, utility supply systems, etc. leads to significant damages and failure of structures, cost derived reparations of the structure and reclamation of the natural environment.

Mohammad A. Mollah (1993) assessed the geotechnical characteristics of the subsoil of the deltaic alluvial plains of Bangladesh which provides a useful guide for development planning and construction. He found that the subsoil comprises sandy material, although it varies significantly over short lateral distances as a result of frequent and erratic occurrences of compressible organic silt and peat mixtures. He also assessed that the foundation competency of the upper 6–10 m has been varied between low to very low.

2.6. Impact of Geotechnical Parameter on riverbank Failure

2.6.1. Effect of pore pressure on geotechnical properties

Taylor (1948) found by observation that two samples have been taken at points a short distance apart in a soil which appears to be fairly uniform but may have permeability differ greatly. The properties of soils depend to a large degree on the amounts of pore water they contain. The facility with which water is able to travel through the pores is called permeability. The permeability of a soil depends on the grain size, properties of pore fluid, void ratio, shapes and arrangement of pores or soil structure. The permeability also depends on the amount of undissolved gas within the pore water.

Shih-Wei Chiang et al (2010) recognized the role and the importance of pore-water pressure on riverbank stability with respect to mass failure wherever determining the precise groundwater table within the riverbank is quite essential.

Shih-Wei Chiang et al (2010) presented a new approach based on earlier developments. Such as, a combination of groundwater flow and stability analysis to obtain a more realistic groundwater table in order to define the effect of negative and positive pore-water pressures on river bank stability. The advantage of this approach is that the effects of material properties of riverbanks and infiltration on pore-water pressure distribution are taken into account by applying groundwater modeling. The researchers mentioned that other researchers have previously proposed, bank failure is generally considered to occur particularly during the recession of hydrographs when the riverbank material is under nearly or totally saturated conditions. In addition, the effect of matric suction has a significant impact on riverbank stability and should be taken into consideration especially under lower groundwater level conditions.

Under considering the concepts, the researchers simulated results presented in this study on the basis of a series of analyses. They concluded that any factor can make the riverbank retain high groundwater levels relative to the river stage, such as riverbank material with low permeability; heavy infiltration and rapid stage falling have a tendency to make riverbanks unstable. Riverbank failure may or may not occur depending on soil properties even during the falling stage. Consequently they recommend that particular attention needs to be paid to the material characteristics of banks because they not only determine shear strength, but directly influence groundwater table distribution.

Garey A. Fox & Rachel G. Felice (2013) studied on constant-head, seepage soil box packed with more cohesive (6% and 15% clay) sandy loam soils at prescribed bulk densities (1.30 to 1.70 $Mg\ m^{-3}$) and with a bank angle of 90° to investigate the controls on failure mechanisms due to seepage forces.

They observed that a dimensionless seepage mechanism (SM) number was derived and evaluated based on the ratio of resistive cohesion forces to the driving forces leading to instability including seepage gradients with an assumed steady-state seepage angle. They observed that tension failures and undercutting dependent primarily on the saturated hydraulic conductivity, effective cohesion, and seepage gradient. It is also observed that shapes of seepage undercuts for these more cohesive soils were wider and less deep compared to undercuts in sand and loamy sand soils.

They also used direct shear tests to quantify the geotechnical properties of the soils packed at the various bulk densities and observed that she SM number reasonably predicted the seepage failure mechanism (tension failure versus undercutting) based on the geotechnical properties. It is hypothesized that the SM number can be used to evaluate seepage failure mechanisms when a stream bank or hill slope experiences steady-state seepage forces. When prevalent, seepage gradient forces should be considered when analyzing bank stability, and therefore should be incorporated into commonly used stability models.

Yee-Meng Chiew et al (2010) found at their study that increase in channel flow velocity (hence increase in bed shear stresses) enhances slope failure causing it to collapse at a lower hydraulic gradient than that in a quiescent condition or with very low flow velocity. The study provides an improved understanding on slope failure in river channels, particularly for cases when there is a rapid drawdown of the flow stage during the recession period of the flood hydrograph.

Oya et al (2015) conducted a numerical study on the factors of affecting the riverbank failure. As results of analysis, they observed that the safety factors of the slopes are degraded during water level descent and the low water level period, which is a typical phenomenon that is observed in the analyses of rapid drawdown of reservoir level in the dam. These results suggest that river water fluctuation affect the stability of a riverbank, especially during water level descent because the phreatic level in the river water level goes down, the phreatic level in the ground remains at a high level because of the ground's low permeability, and the weight of the soil remains high, the slope is stable when water level is higher on the other hand. They concluded that future investigation should be needed for slope stability and seepage behavior as cyclic water level fluctuates.

Nick Lindow et al (2009) conducted laboratory experiments on reconstructed, non-vegetated stream banks with layered soils experiencing seepage with the objective to determine the effect of seepage, pore water pressure, and bank geometry on erosion and bank stability of layered stream banks. Researchers analyzed the laboratory experiments using the Bank Stability and Toe Erosion Model, version 4·1. They observed that steeper initial bank slopes and undercut banks decreased the bank factor of safety. They found that observed failure mechanisms and measured saturation data indicated an interaction between overburden pressure, seepage forces, and bank slope on bank stability.

Stefano Dapporto et al(2001) studied mechanisms of failure occurring in two portions of a riverbank along the Arno River (Central Italy) are investigated in detail starting by a series of periodic field observations and bank profile measurements. They observed that two dominant mechanisms involving the silty sand portion of the bank such as, alcove-shaped failure in the middle portion of the bank and slab failure involving the middle–upper bank.

Stefano Dapporto et al (2003) investigated the riverbanks along the Arno river with the aims of defining the main mechanisms of failure and retreat, their spatial distribution, and their causes. They also investigated geomorphological aspects by a reconnaissance of riverbank processes. Based on the material characteristics, six main typologies of riverbanks have been defined, with homogeneous fine-grained and composite banks representing the most frequent types. They observed that slab-type failures are the most frequent mechanism on fine-grained banks, while cantilever failures prevail on composite banks. They also observed that the role of river stage and related pore water pressure distributions triggering the main mechanisms of failure.

Fox et.al (2007) synthesized the research data on seepage flow and erosion occurring at two stream banks in northern Mississippi and investigated the impact of seepage undercutting on stream bank stability. They observed that the loss of supporting material brought about by seepage undercutting can be a major cause of slope instability and, depending on site-specific conditions, may be of equal or greater importance than the impact of increased soil water pressure on soil strength.

Fauzi Baharuddin et al (2015) focused that riverbank failure is a common issue whereby almost every year riverbanks are prone with problems, such as erosion, breaching or retirements. Among the major causes are due to the use of geotechnical unstable materials, seepage and sliding of soil. Therefore, the main issue which they explained to be tackled is to evaluate riverbank soil properties. Soil properties evaluation is significant for riverbank assessment and this study gives better justification for problem arise at their study on the characterization of soil properties and the identification of the physical and mechanical soil properties of undisturbed soil sample. They observed that the strength of riverbank soil is low due to the condition of soil properties which is sand.

Rinaldi, M. et. al (2004) studied on pore water pressures (positive and negative) were monitored for four years (1996–1999) using a series of tensiometer-piezometers at increasing depths in a riverbank of the Sieve River, Tuscany (central Italy), with the overall objective of investigating pore pressure changes in response to flow events and their effects on bank stability.

Their study simulation according to monitored data shows that the failure occurred three hours after the peak stage, during the inversion of flow (from the bank towards the river). They also observed that a relatively limited development of positive pore pressures reduced the effective stress and annulling the shear strength term due to the matric suction and the sudden loss of the confining pressure of the river during the initial drawdown was responsible for triggering the mass failure.

Midgley. T. L. et al (2013) studied on a stream bank of Dry Creek, a deeply incised stream with near-vertical banks located in Mississippi. Bank stratigraphy consisted of a sloping, conductive loamy sand layer between cohesive stream bank layers. Experiments included installing a trench (2.8 m from the bank and 2 m below ground surface) and a network of tensiometers and observation wells to measure soil-water pressures and water table elevations. They monitored ground-water conditions during a series of induced-seepage experiments. They observed that the effects of seepage on stream bank erosion and failure are less understood compared to fluvial processes, especially the linkage between surface water and groundwater mechanisms.

Medhat Aziz (2003) studied the effect of seeping water from Nile banks to the river on their stability. He mentioned that many factors affect Nile River bank erosion such as soil characteristics, bank height and slope, navigation waves, river bends, river contractions, and spur dike effects and other factors. A very important factor that affects the bank stability and it is not considered by traditional methods of slope stability analysis is the seepage forces through banks due to the differences in Nile River and subsurface water levels. He observed that the reduction of the suspended sediment concentration after the construction of the High Aswan Dam has increased the ability of the flowing water to erode banks and reduce their stability and mentioned that the seeping water causes some more additional forces and should be considered in river bank stability analysis.

Chapter 3

Approaches and Methods

3.1 Background of the Selection of Study area

The riverbank failure in Bangladesh is a general problem and usual phenomena. Devastating flood and excessive rainfall are accelerating the failure process which results immense damage to agriculture and infrastructures every year. There is active bank erosion almost in all major rivers in the country causing damage to valuable land, settlements and infrastructures from year to year. Because of high density of population along the river banks a great numbers of people are also displaced due to this continuous bank erosion process. These poor displaced people migrate to nearby towns and cities and live sub-human life in the slump areas. This has created a great natural and social problem in the country. Bank protection is therefore, one of the prime necessities for poverty alleviation and national growth. Before that bank failure reasons are the utmost important works for any of the bank protection.

Among the major rivers Padma is one of the mighty river in Bangladesh. Padma river is the main channel of the greater Ganges (Ganga) river in Bangladesh. For some 90 miles (145 km) the Ganges River forms the western boundary between India and Bangladesh before it enters Bangladesh at the northern edge of the Kushtia district as the upper segment of the Padma river. The upper Padma flows southeast ward to receive the mighty Jamuna river (the name of the Brahmaputra in Bangladesh) near Rajbari.

Bank failure is a common scenario at Goalanda upazilla in Rajbari of Bangladesh. In 2016, this situation was more worsen among the couple of years. People suffered unbearable sufferings out of tolerance both in living and journey. As Padma bridge has not yet ready and all the vehicles would have to depend on ferry at Daulatdia ghat and there was no way to halt the ferry at the ghat due to bank failure. In such circumstances, Daulatdia side of Goalanda of Rajbari district is selected for study area as well as Paturia side side of Shibaloy of Manikgonj district.

3.2 Selection of study area

The study areas are selected according to the reconnaissance survey and the questionnaire survey. The study areas are the banks of the Padma river situated at Daulatdia side of Goalanda thana of Rajbari district and Paturia side of Shibaloy thana of Manikgonj district which have been shown in Fig-3.1 & Fig-3.2 respectively. The study area is mainly

Daulatdia side of Goalanda thana of Rajbari district as the side is severely affected. The opposite side of the river is selected at Paturia side of Shibaloy thana of Manikgonj district.

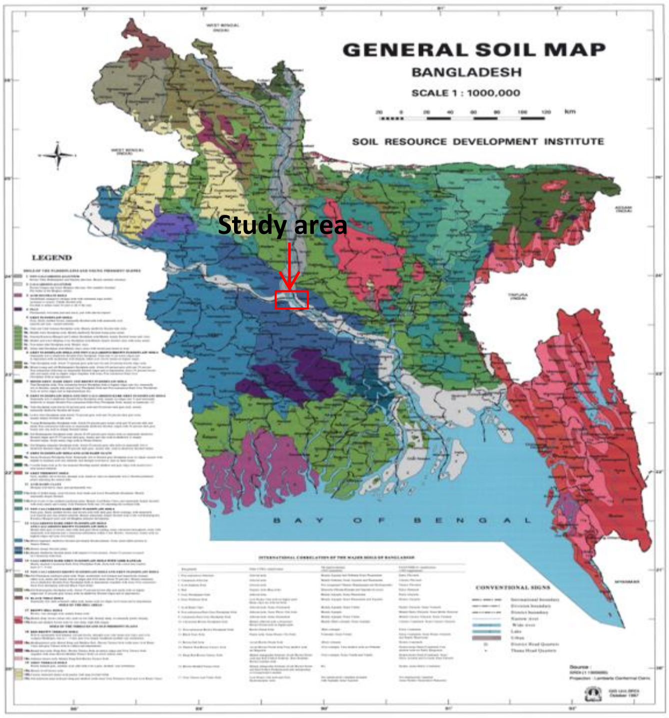


Figure 3.1: General soil map of Bangladesh

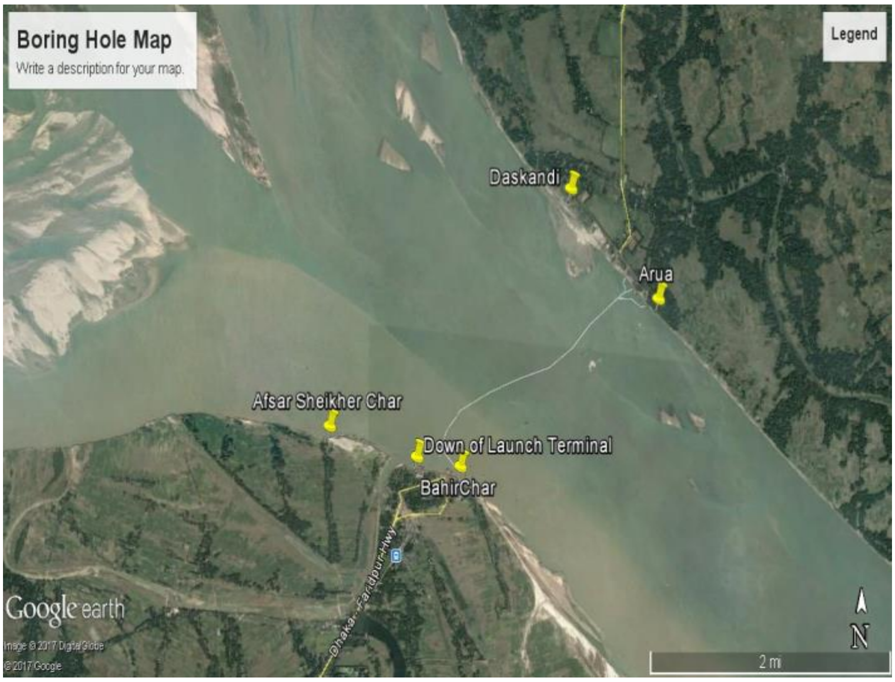


Figure 3.2: Study area map of investigation sites

3.2.1 Soils of study area

The soils of the study areas are calcareous alluvium soils. These are young alluvial deposits of the Ganges and lower Meghna rivers, which contain lime and are stratified within 25cm from the surface. The principal areas where these soils are found are the active floodplain of the Ganges and the Meghna Estuarine Floodplain. The soils are olive-gray to olive brown, with little or no mottling. They are mainly silty in texture, though, along the Ganges, they are locally interstratified with sand layers. The agricultural potential is moderate to low, but higher than non-calcareous alluviums. Limitations include seasonal flooding and bank erosion.

3.2.2 Water level at study area

The water level at the study areas start rising severely in July and attains the peak in late August or early September (Sajjadur,R,2008)

3.3 Visit to study areas for site selection at Paturia Side

Before selection of the study area, the research team has visited the bank failure prone area of Manikgonj district on 17 October 2017 and Rajbari district on 18 October 2017 for watching the physical condition of the site regarding bank failure through questionnaire of the relevant official as well as local people. The pictures have been shown in Fig-3.3.

In this context, the team has met with the BIWTA official at Shibaloy, Manikgonj on 17.10.2017 at time 10.30am.The research team has discussed with Md. Abdus Salam, join director, BIWTA, Shibaloy, Manikgonj and Sheikh Md. Selim Reza, Port Officer, BIWTA, Manikganj. The team has consulted with them about bank failure, causes, constraint and solution of the bank failure. The official of BIWTA has explained that the bank usually would become failed during extreme current in monsoon up to two to three months of the year. Jamuna river located at the downstream of the ghat and the bank has become failed due to current. Their perception in physically like this “At first, current hit the bank and the same back speedily then it would develop long eddy over there. As a result, the eddy make a scour below the certain depth of bank wherever a remarkable crack has visualized at the bank line. Finally river bank fails. Sometimes bank fails instantaneously and sometimes bank failure has been occurred at a certain interval of time. The bank also become fails during the period of decreasing of water level. The turbulence has occurred during this period and bank has become eroded. The erosion occurs continuous in the monsoon though the erosion process quick or time being which depends on soil types. Whatever it is, bank would become fail in the monsoon (i.e. June to September)”.

3.3.1 A discussion with BIWTA officials of Shibaloy Thana at Paturia side

Discussion with BIWTA official about bank erosion

BIWTA official is in brief about their activities

Point Guage of BIWTA and BWDB at Shibaloy

Research team is in discussion among them at Shibaloy speed boat Ghat

Questionnaire survey at the Shibaloy speed boat counter Ghat

Questionnaire survey at the Shibaloy speed boat counter Ghat

Figure 3.3: Discussion and Questionnaire Survey with BIWTA officials and local people at Paturia side of Shibaloy Upazila

A question of bank erosion of about comparison erosion of Daulatdia and Paturia side of Padma river, BIWTA official said that bank erosion around the confluence of Jamuna and Padma river is more than that of other areas. They also express that as Jamuna and Padma are non-tidal rivers that are why erosion occurs more in this areas as they observed. BIWTA official mentioned that the volume of Jamuna River is more than that of Padma River in between the Daulatdia and Paturia side. Due to the much volumetric reasons, the failure occurs more in the Daulatdia side than that of Paturia side as Jamuna can resist the current which is flowing from the Padma river. Apparently it seems that the tide is more in the Padma River than that of Jamuna river though the current is more in the Jamuna river as they explained.

They specified that there was no bank failure since last 14(fourteen) years. However, these situation has been intensified since 2(two) years. By this time some chars have been developed. Although these chars are being more worsen in failure.

In search of protecting the bank side from failure, they said that BWDB has implemented the river bank protection work. However, BIWTA has piling the ferry ghat side and dumping khoa instantaneously for bank protection. Though, BWDB has would protect the ferry ghat as well as bank side on the river through dumping geo-bag.

In a question of sub-soil exploration, they said that they have not carried out any sub-soil boring work in the river side according to their rule of BIWTA. They mainly maintained the navigation channel. They have mentioned that navigation road is extended during monsoon and shortened during dry season. BIWTA official also said that river is shifted in the interval after 10-12 years.

Finally, in a question of protect the river bank in the ghat area, they recommended in word that it should be controlled main flow line in the aggressive flow followed by relevant technical ways.

The research team then have visited the Shibaloy speed boat counter Ghat and watched the point gauge as a measuring tool of water level. The team also asked the local people about river bank failure and its remedial measurements. In a question of bank erosion they told that the bank usually would become failed during extreme current in monsoon up to two to three months of the year. The situation would be intensified in the mid June to mid-August. They also told that the bank mainly eroded at the upstream of Jafargonj of Aricha of the Paturia Ghat and Harirampur of the downstream of Paturia ghat. They also expressed that the bank has been failed when current hit the bank and the same has become back which develop long eddy over there and making scour below the certain depth of bank. At that time a remarkable crack has been visualize over there and bank fails. Sometimes bank fails instantaneously and sometimes bank failure would have been occurred at a certain interval of time. They pointed out that upstream bank failure causes decrease navigation channel and there have been developed chars along the river side. These chars are also failed during monsoon. At that time the local people explained that the bank would become failed during increase in water level and also decrease in water level. However, the river bank has not failed if the water level is above the bank level. Whatever it is, bank would become failed in the monsoon (June to September).

A question of bank failure on about comparison on Daulatdia and Paturia side of Padma river, they said that bank failure occurs more at Daulatdia side than Paturia side. They specified that there was no bank failure since last five years except the Jafargonj side. The failure occurs at the side around two to 2.5km of the areas wherever, hat, bazar, school and colleges were succumbed to the river.

The team had asked the question in order to protect the bank side from failure, the answer has been obtained that BWDB has done the river bank protection. Though, local administration would be taken instant measurement. They also mentioned that BWDB has protected the Jafargonj side technically. Accordingly, if the bank failure prone prone areas are protected like Jafargonj side then the river bank will not be failed. In a question of about sub-soil exploration, they said that they have not seen any sub-soil boring work carried out by any organization in the river side rather than Jafargonj. Finally, in a question of protect the river bank in the ferry ghat area, they opine that it should be resisted the flow line through dredging and river training works.

The research team has visited the Jafargonj, Daulatpur, Manikgonj subjected to observe the protection work which have been shown in Fig-3.4. They have watched the area and asked some questions to the people along the river side. The team has discussed with the local people about river bank failure and the remedy of bank failure. In a question of bank failure they told that the riverbank of Jafargonj side had been failed before three to four years due to extreme current in monsoon. The bank failure would be occurred in the mid June to mid-August and frequent failure has been found recently at the Baghutia, Daulatpur, Manikgonj. The bank failure has been running since 3 to 4 years and it is still running up to 5km. The local people have said that the bank of Baghutia fails massively in recent.

In a question about depth at Jafargonj side they said that the depth is about 20 feet. In search of protecting the bank side from failure the answer has been obtained that BWDB has implemented the river bank protection works. In a question of sub-soil exploration, they said that protection work at Jafargonj side has been carried out by BWDB following all technical aspects as they observed.

Finally, in a question of protection of the river bank they explained their opinion that after construction of Jamuna Bridge at Jamuna River, flow has been lessened of the river. They also commented that river bank can be protected through dumping concrete block and river dredging. The research team has physically observed that the soils at Jafargonj side are light brown color clay on the upper layer and the bed materials are sandy clay.

Figure 3.4: Discussion with local people at Jafargonj side of Shibaloy Upazila

3.3.2: A visit to Daskandi of Shibaloy Thana for site selection at Paturia side

Figure 3.5: Site selection and questionnaire survey at Daskandi, Shibaloy, Manikgonj

The research team has visited then Daskandi of Shibaloy thana and asked some questions to the local people which has been shown in Fig-3.5. They told that the char has developed due to siltation and all the soils here are silt and clay and the sand layer may be obtained below 20 feet of this layer. In a question of a comparison of bank failure at Daulatdia ghat of Rajbari district and the Paturia ghat of Manikgonj district, they answered that the bank failure is massive at the Daulatdia ghat of Rajbari district than the Paturia ghat of Manikgonj district.

3.3.3: A visit to Paturia ferry ghat of Baruria of Paturia side

The team then visited the Paturia site a little down of the ferry ghat which has been shown in Fig-3.6. The team has discussed with local people about river bank failure and its remedial measurement. In a question of bank failure they told that the bank usually would become failed during extreme current in monsoon up to two to three months of the year. The failure would be reached extreme in the mid June to mid-August. At that time the local people explained that the bank is failed when water level rise. A question of about comparison of depth of Daulatdia and Paturia side, they said that the depth is more at Daulatdia side. Another question was about bank failure since last ten years. In reply, they told that the bank failure was more worsen in 1988 and in 2017.

In search of protecting the bank side from failure, they have been replied that it should be constructed embankment along the bank side and river has to train up. In a question of sub-soil exploration, they said that they have not seen any sub-soil boring work carried out by any organization along the river side. In a question of soil layer at Arua location, the people mentioned that sand layer is obtained at 20 feet and the drinking water is obtained from 40 feet.

Figure 3.6: Floating Workshop of BIWTA and bank erosion at Arua (down of the Paturia ghat)

3.4 Visit to study areas for site selection at Daulatdia Side

The team has visited the BWDB office of Goalanda, Rajbari and met with the official which has been shown in Fig-3.7. The team asked them and queried about bank failure of Daulatdia ferry ghat of Padma River. They told that river bank failure has been occurred from launch ghat to ferry ghat at Daulatdia. They also mentioned that when water level rises bank failure would be intensified and it has lowered when water level decreased. They also express that the river bank has been falling since six years due to pressure of water. The navigation depth has been decreased significantly and the rate is added or reduced about 0.5km. They supplemented that when current is reduced than siltation occurs and this siltation is occurring due to construction of bridge. They also specified that the current increases in July and August. In a question about sub-soil exploration at the side, they told that they did not observe any sub-soil exploration work done at this side. In a question of about comparison of bank erosion at Daulatdia and Paturia ghat, they told that the failure is as much Daulatdia as Paturia side. The new char is also failed at Daulatdia side.

The team has discussed with official of BWDB and asked them about bank failure and its remedial measures. They expressed that the bank usually would become failed during extreme current in monsoon when water level rises. They also said that the bank has been failed due to confluence effect of the rivers. They pointed out that river bank is mainly formed of sandy soil. So, when the current is intensified the bank fails. The current is increased in August to September. They finally concluded that whatever it is, bank has become failed in the monsoon (July to October).The team has discussed about the point gauge and maintaining the level of surface water of the river. In this regard the BWDB official has told that they have point gauge and water level data would has been collected regularly after certain interval of time. The point guage has been shown in Fig-3.8. In connection of water level, discharge, sediment collection and depth measurement, the BWDB official said that they have point gauge at Shibaloy speed boat counter, Manikgonj as well as Daulatdia launch ghat, Goalanda, Rajbari and the discharge is measured through Katamara as well as sediment is collected simultaneously. In connection of collecting discharge, water level, sediment collection and depth the BWDB official said that data will be available at the selected BWDB office.

The BWDB official added that the failure has been increased since 2(two) years. In a question of bank protection they said that BWDB instantly has would protect the ferry ghat as well as bank side on the river through dumping geo-bag.

3.4.1: A visit to Goalanda, Rajbari and point gauge for water level measurement

Figure 3.7: Research Team at BWDB office, Goalanda, Rajbari

Figure 3.8: Research Team observes the point gauge of BWDB at Daulatdia Ghat, Goalanda, Rajbari.

The team has visited Urakanda Govt. Primary School, Barat, Thana: Rajbari, District. Rajbari. The photos have been shown in Fig-3.9 & Fig-3.10 respectively. The team has asked the teachers about bank failure. They said that the river bank failure starts from June or July but in this year it has stared from May. They also said that after monsoon when water level decreases the failure occurs. They remarked that the failure has significantly increased here due to removal of sand from the bank of the river.

They said that the erosion intensified in 2016 and 2017 and river bank felt down in the river in a question of about bank failure for last ten years. There are a number of areas have been succumbed into the river last two years and the primary school has somehow protected through performing survey and dumping geo-bag by BWDB. The river was 1.5km far from the Urakanda Primary School. Now the river is very adjacent to the school. The failure is being continued from the west of the school. Now, the school is in the main failure prone area. In a question of char development, they told that the char has been developed. When water level will decrease then it will be visualized that how long the char has been developed. In a question of sub-soil exploration, they said that they have not seen to carry out any sub-soil boring work along the river side of Urakanda Primary School. Finally, in a question about protection of the river bank, they said in a word that it should be protected river bank following relevant technical ways.

3.4.2: A visit to Urakandi Govt. Primary School, Rajbari

Figure 3.9: Bank protection work of BWDB at Urakandi Primary School, Rajbari, Rajbari

Figure 3.10: Questionnaire survey with the Headmaster of Urakandi Primary School, Rajbari, Rajbari

Then the team has visited the location Char Bahirdia Daulatdia, union: Daulatdia, Goalanda, Rajbari adjacent to the ferry ghat which has been shown in Fig-3.11 & 3.12 respectively. The research team asked the people about bank failure. They said that the extensive failure occurs in the month of mid-June to August but the water pressure increases in August. The failure increases when water level rises and the decreases when water level decreases. The bank failure is more at the site of ferry ghat which has been shown in Fig-3.13. The bank failure has been occurred since two years long (2016-2017) and 1.5km failed from the existing river. A question about bank erosion of last ten years, they said that the erosion has been intensified from 2016 to date (during monsoon).As a result the river bank succumbed into the river. They added that four years past, Afsarsheikher Para (Dakatpara) was failure prone area and last two years (2016 & 2017) this tendency is up-coming to ferry ghat no-6.

They said that the failure is more at Daulatdia ferry ghat in comparison to Paturia ferry ghat regarding a question of comparison of bank failure at Daulatdia and Paturia side of Padma River. They pointed out that the failure has been intensified since 2(two) years. Some chars have been developed at the Daulatdia side of the Padma river bank. In search of protecting the river bank side from failure the answer has been obtained that BWDB would be done the river bank protection works. They protect the ferry ghat as well as river bank side on the river through dumping geo-bag. In a question of sub-soil exploration, they said that BWDB had not carried out any sub-soil boring work along the river bank side.

Finally, in a question of protect the river bank in the ferry ghat area, they recommended in a word that it should be done through river training work permanently and dumping geo-bag and block through proper design with the help of government. Erosion prone area and instant protection has been shown in the table.

3.4.3: A visit to Daulatdia ferry ghat, Goalanda, Rajbari

Figure 3.11: Questionnaire survey at erosion prone area, Bahir Char Daulatdia, Goalanda, Rajbari

Figure 3.12: Protection work to safe Daulatdia ferry ghat through geo-bag dumping

3.4.4 A visit to Daulatdia side, Goalanda, Rajbari

Figure 3.13: Research team visits Daulatdia ferry ghat area, Goalanda, Rajbari

The team has visited the Afsar Sheikher Para, Daulatdia, Goalanda, Rajbari which have been shown in Fig-3.14 & 3.15 respectively. There is a channel between the launch ghat and this char. This Char Dakatpara has been succumbed into the river since five years ago due to failure and the bank line is now at Afsar Sheikher Para which is more or less 1.5km (appr.) far from previous Dakatpara. The failure is being intensified from two to three years. There is no char of this char. The bank is failed more when current is more which creates eddy. They also said that the bank fails when water level decreases. In search of protecting the bank side from failure, the answer has been obtained that they don't protect the river bank themselves and also no organization. In a question of about sub-soil exploration, they said that they did not observe to carry out any sub-soil boring work along the river side. Finally, in a question of protect the river bank in the ferry ghat area, they replied in a word that it should be done through government.

3.4.5: A Visit at Afsar Sheikher Para of Daulatdia ferry ghat,Goalanda,Rajbari.

Figure 3.14: Questionnaire survey with the local people of Afsar Sheikher Para, Goalanda, Rajbari

Figure 3.15: Bank line during the field visit September 2018 at Afsar Sheikher Char

After completing the field visit at Daulatdia and Paturia side, research team has reviewed the questionnaire survey and considers the observations. Daulatdia side is greatly vulnerable through bank failure in comparison to Paturia side as the team observed. They also observed that the river has been shifted to the Daulatdia side significantly whereas it has been less shifted at the Paturia side. The same has been observed at the satellite image. Apart from that, river bank would become protected instantly through dumping geo-bag by BWDB which is most temporary. As a result the bank failure phenomena are occurring year by year and people are losing their valuable lands and livelihoods as a whole.

It needs permanent solution as the people can survive their livelihood and commodity in their lives. We know bank fails for both geotechnical and hydraulic means. However, it has been seen that it has not been properly followed the geotechnical means to the design as well as implementation of the river bank protection work. Eventually this type of water structures would become failed as a whole. So, the research team thinks that why the river bank fails as a cause of geotechnical means. That’s why the following sites are selected for sub-soil exploration. Considering visiting the locations physically and reviewing the questionnaire and reconnaissance survey the research team has made decision to explore the sub soil to following locations. The locations have been shown in the general soil map of Bangladesh and the image map in Fig-3.1 and Fig-3.2 respectively. The coordinates of the locations were also recorded and shown to the Table-3.1

Table 3.1: Sampling and In-situ testing location in order of coordinates at the Padma river sides

River name	Location	Side	Upazila	District	Bore Hole	Coordinate	Reasons for selecting location
Padma	Daskandi,Paturia	1km up of Paturia ferry ghat	Shibaloy	Manikgonj	#1	N-2634213 E-785657	According to visit the locations physically and review the questionnaires, the sides are selected; The holes and their distances from one to another are selected for observing the soil layers homogeneity and their properties also.
					#2	N-2634208 E-785731	
					#3	N-2634193 E-785853	
	Baroria,Paturia	1km/800m down of Paturia ghat	Shibaloy	Manikgonj	#1	N-2633143 E-786834	
					#2	N-2633178 E-786856	
					#3	N-2633216 E-787003	
	Char Bahirdia, Daulatdia	100m up of 4nos. Daulatdia ferry ghat	Goalanda	Rajbari	#1	N-2631241 E-784402	
					#2	N-2631237 E-784349	
					#3	N-2631205 E-784152	
	Launchghat, Daulatdia	Near launch ghat of Daulatdia	Goalanda	Rajbari	#1	N-2631452 E-783303	
					#2	N-2631430 E-783338	
					#3	N-2631141 E-783525	
	Afsar Sheikher Para,Daulatdia	1km up of Daulatdia Ghat	Goalanda	Rajbari	#1	N-2631766 E-782439	
					#2	N-2631715 E-782452	
					#3	N-2631566 E-782475	

3.5 Locations

The Table-3.1 summarizes selected locations with northing and easting and reasons for selecting location. According to visit the locations physically and review the questionnaires, the sites 1. Daskandi, Paturia 2. Baroria, Paturia 3. CharBahirdia, Daulatdia, 4. Launchghat, Daulatdia and 5. Afsar Sheikher Para, Daulatdia are selected. The holes and their distances from one to another are selected for observing the soil layers homogeneity and their properties.

3.6 Research Methods

The research was carried out on following methods

- Questionnaire survey from the river bank communities
- Samples collection
- In-situ investigation
- Laboratory investigation

Boring distances from the bank line to the hole of the study area of Paturia and Daulatdia side

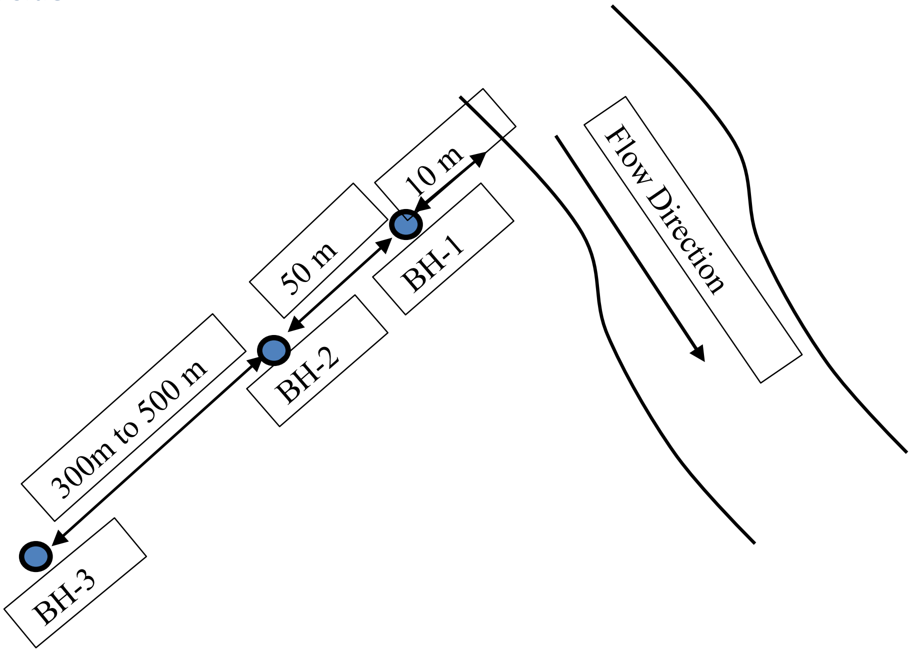


Figure 3.16: Boring hole Sketch (Not to Scale)

3.6.1 Sample collection

The samples have been collected from the selected coordinates of the locations by wash boring method. The drilling was done by Delta Soil Engineers with the association of the study team. The samples have been collected according to the rough hole sketch in all locations shown in Fig-3.16. The holes are made by driving the casings of 10.16cm (4’’) and 7.62 cm(3”) diameter.

Wash Boring Method: In this method a piece of casing pipe of about 1.5m length and 10cm diameter is first driven into the ground, keeping a little length above the surface, so as to connect this pipe to a sump, or a settling tank, as shown in Figure-3.17.

Figure 3.17: Wash Boring setup and disturbed soil sample collection using split spoon sampler

This casing pipe is then cleaned by means of a rising and falling chopping bit, connected to the lower end of a hollow drill rod (called wash pipe), which is inserted inside the casing. The drill rod is connected at its upper end to a very simple hand operated arrangement, consisting of a tripod, winch, pulley blocked for moving the bit up and down, to produce cutting action in the soil mass. This chopping action is also supported by a water–jet, forced through the pump into the hollow drill rod, which emerges out at the bottom of the bit at a high velocity through the openings in the bit. This water, containing the chiseled soil, rises upward through the space between the drill rod and the casing pipe, and flows out to a sump well, where the cuttings settle, and water is reused for pumping into the hollow drill rod. When one casing length is cleaned, another casing length is attached to the first one by a socket, and it is driven into the ground by hammering.

The wash boring method is a good method for in situ testing. Moreover, the washings that come out of the hole in the settling tank, can also be visually examined, and any change in colour, particle sizes and shapes, may sometimes indicate a change in the type of stratum.(S.K.Garg, p-764-765)

The disturbed and undisturbed samples have been collected from the boring points. The disturbed samples have been collected in polythene bag and the undisturbed samples have been collected in the Shelby tube and covered through wax for maintained natural moisture content which has been shown in Fig-3.18. The disturbed samples have been collected in the interval of 1.5m up to the depth 22m. The undisturbed samples are collected from the depth of 2m and the depth 3.5m. The undisturbed samples have been collected occasionally where the soil layers are cohesive. The SPT (standard penetration for resistance) values are recorded for blows on spoon per 6 inch penetration of every disturbed samples collection. The plasticity, moisture and colour have also been observed in field condition and recorded in the boring log. The ground level has been recorded by RTK method according to Fig-3.19 and their reduced level has been determined. The ground water level has been recorded after 24hours of boring which is shown in Fig-3.20.

Figure 3.18: Collection of disturbed and undisturbed soil samples

Disturbed samples: These are the samples in which the natural structure of the soil gets disturbed during sampling. However, these samples represent the composition and the mineral content of soil. Disturbed samples can be used to determine the index properties of the soil, such as grain size, plasticity characteristics, and specific gravity.

Undisturbed samples: These are the samples in which the natural structure of the soil and the water content are retained. Although it is impossible to get real undisturbed samples as some disturbance is inevitable during sampling. Undisturbed samples are used for determining the engineering properties of the soil, such as compressibility, shear strength and permeability.

Figure 3.19: Measurement of ground level by RTK method

Figure 3.20: Measurement of ground water level

3.6.2 In-situ Investigation

The in-situ investigation is carried out by the study team in the month of January/2018 to February/2018 which has been shown in Fig-3.21, 3.22, 3.23 and 3.24 respectively. The three holes are drilled on each location up to the maximum depth of about 22m from the existing ground surface.

Figure 3.21: SPT count for each 6 inch penetration of soil

Figure 3.22: Visual inspection of soil sample in the field

The disturbed samples are collected by driving standards split spoon sampler of 3.49 cm(1 3/4") inner diameter with a 63.5kg (140lbs) hammer dropping freely a height of 76.2cm (30") in an average and the number of blows required to drive the sampler for every 15.24cm(6") penetration over 0.61 m(2") depth was recorded as a measure of standard penetration resistance-N (SPT-value) per 0.31m(1") depth. All the samples are collected at an interval of 1.52m (5") depth. The field density test has been conducted in-situ and the soil has been collected for compaction test.

Figure 3.23: Recording of ground water level

Figure 3.24: Field density test

Field boring logs are prepared on the basis of field test data such as depth, visual classification of soil, colour, moist condition, plasticity, SPT value, ground level, ground water level etc. depth, well as laboratory test data.

3.6.3 Sample Preparation for Laboratory Testing

Sample preparation for laboratory testing and their relevant procedure have been allocated with photos and graph in their respective section.

3.6.3.1 Visual Examination

All the disturbed and undisturbed samples are visually examined for selecting necessary testing.

Figure 3.25: Disturbed samples are sorted for visual inspection at the laboratory

A number of tests are planned to conduct in the laboratory for disturbed and undisturbed soil samples which are shown below.

Table 3.2 : A plan to conduct tests

Name of the testing parameters	Disturbed soil	Undisturbed soil
Natural moisture content	√	√
Atterberg limits test	√	√
Specific gravity	√	√
Grain size analysis	√	√
Triaxial shear test		√
Direct shear test		√
Unconfined compression test		√
Consolidation test		√
Permeability test		√
Mica count test	√	√
Compaction test	√	
pH test	√	√

3.6.3.2 Natural Moisture Content Test

The test is conducted for as received moisture content of the selected soil samples. The water content is determined as the ratio of the weight of water to the weight of dry soil grains in the mass by equation,

$$w=W_1-W_2/W_2-W_c$$

in which, W_1=weight of container of moist soil

W_2=weight of container plus oven-dry soil

W_c= weight of container (Lambe,p-8)

Figure 3.26: Arrangement for determining natural moisture content

3.6.3.3 Attterberg Limits Test

Liquid limit and plastic limits of the cohesive samples have been determined for determining plasticity index as plasticity is measured from the plasticity index which is equal to the liquid limit minus the plastic limit. The limits are expressed as water contents are obtained from the followings,

i) Liquid Limit: The liquid limit w_l is read from the flow curve as the water content at twenty –five blows

ii) W_p is the water content of the soil which crumbled when 1/8-inch threads are rolled.(Lambe, p22, 26)

Figure 3.27: Arrangement for Atterberg Limits test

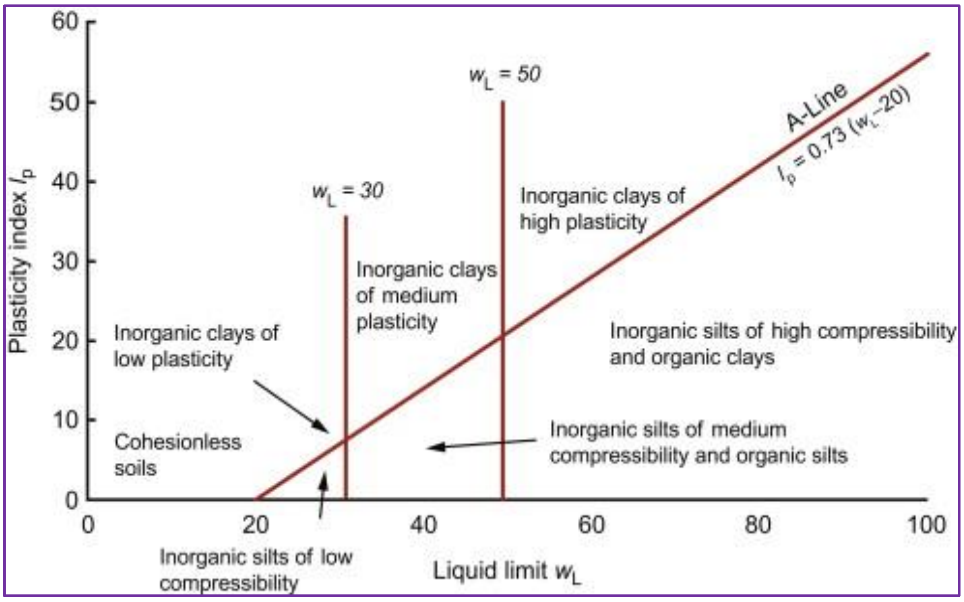


Figure 3.28: Atterberg limits Chart

Figure 3.29: Plastic limit and Liquid limit tests at laboratory

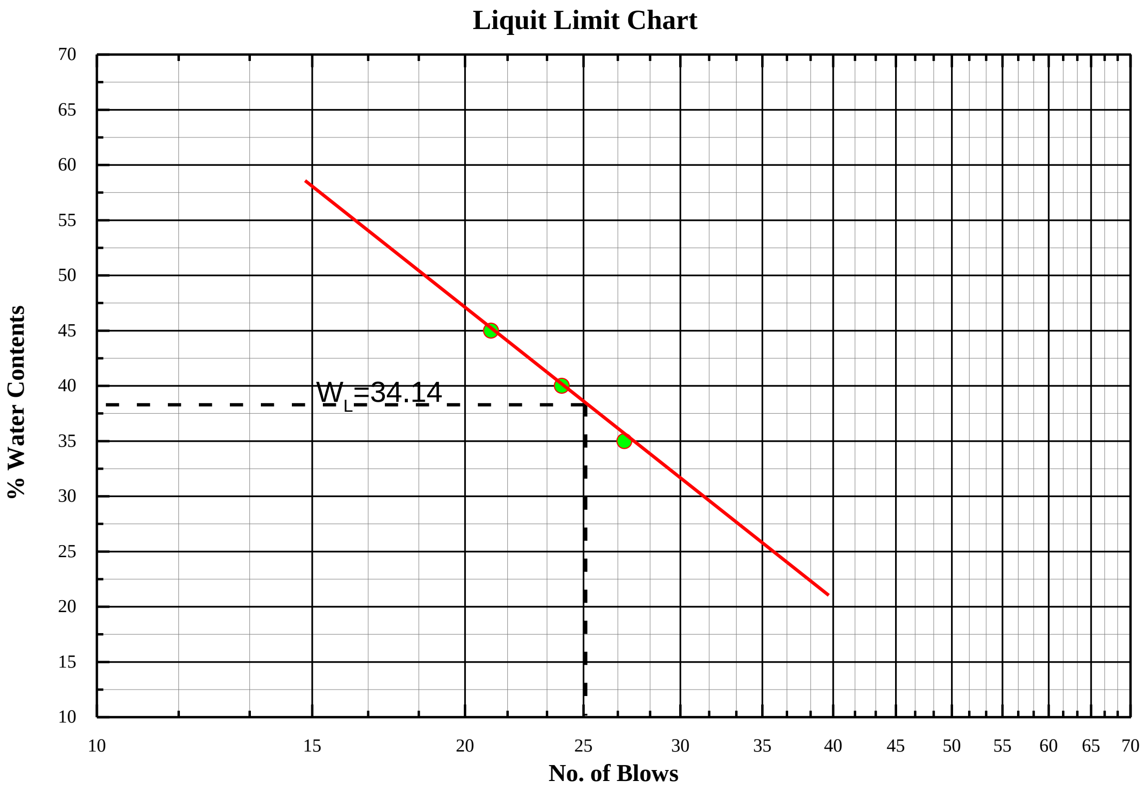


Figure 3.30: Blow graph

3.6.3.4 Specific Gravity

The specific gravity of soil G_s is determined from the equation,

$$G_s = \frac{W_S G_T}{W_S - W_1 + W_2}$$

In which G_T = specific gravity of distilled water at temperature T

W_s = dry weight of soil

W_1=weight of pycnometer,soil and water

W_2= weight of pycnometer plus water(Lambe,p18-19)

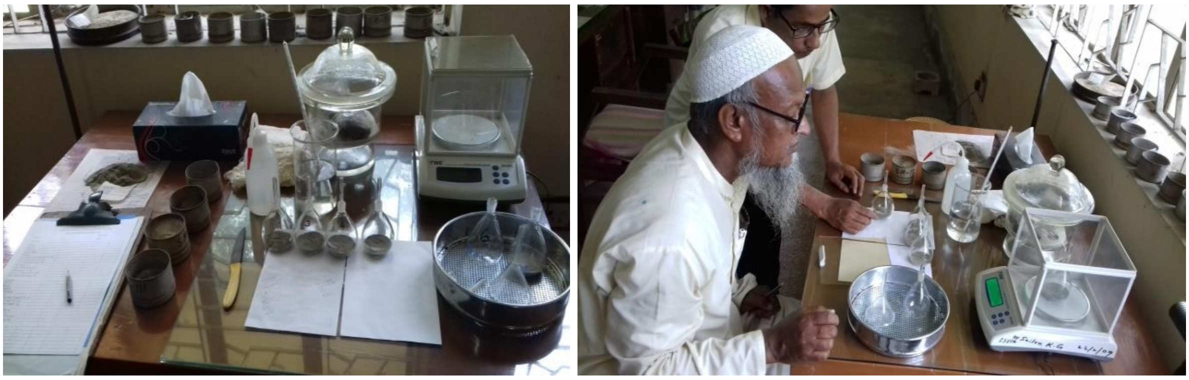


Figure 3.31: Arrangement for determining specific gravity of soil

Grain size analysis: The grain size analysis is determined through the three general procedures such as i) sieve analysis ii) hydrometer analysis iii) combined analysis.

i) Sieve analysis: A sieve analysis consists of shaking the soil through a stack of wire screens with openings of known sizes. So, the definition of particle diameter for a sieve test is, therefore, the side dimension of a square hole. If nearly all its grains are so large that they cannot pass through square openings of 0.074mm (No.200 screen), the sieve analysis is preferable.

iii) Hydrometer analysis: The hydrometer method is based on Stokes' equation

$$D = \frac{\sqrt{(1800\mu . Z_r)}}{\sqrt{(\gamma_s - \gamma_f) . t}}$$

for the velocity of a freely falling sphere. So, the definition of particle diameter for a hydrometer test is therefore the diameter of a sphere of the same density which falls at the same velocity as the particle in question. For those soils which are nearly all finer than a No.200 screen, the hydrometer test is recommended.

iii) Combined analysis: The combined analysis employs both the sieve and the hydrometer tests; thus the definition of particle size is the size of a square opening for the larger grains and the diameter of the equivalent sphere for the smaller soil particles. For silts, silty clays, etc., which has a measurable portion of their grains both coarser and finer than a No. 200 sieve, the combined analysis is needed.

Figure 3.32: Arrangement of sieve and hydrometer for grain size analysis

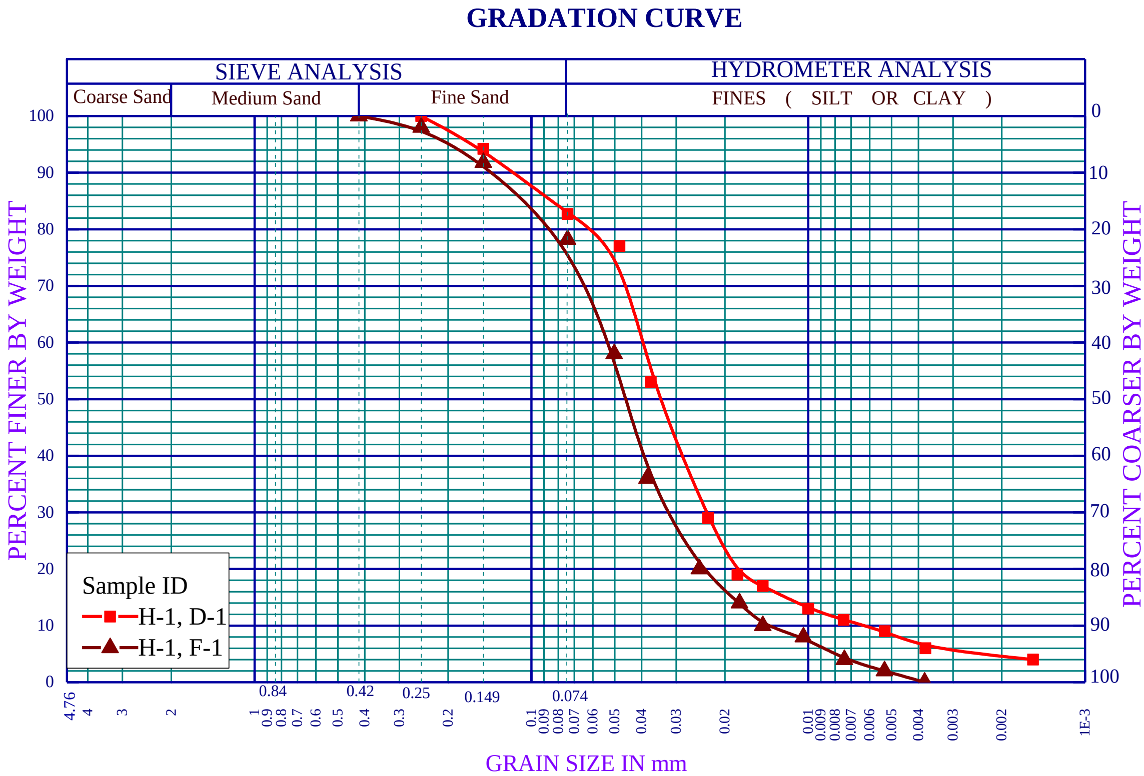


Figure 3.33 Grain size analysis curve

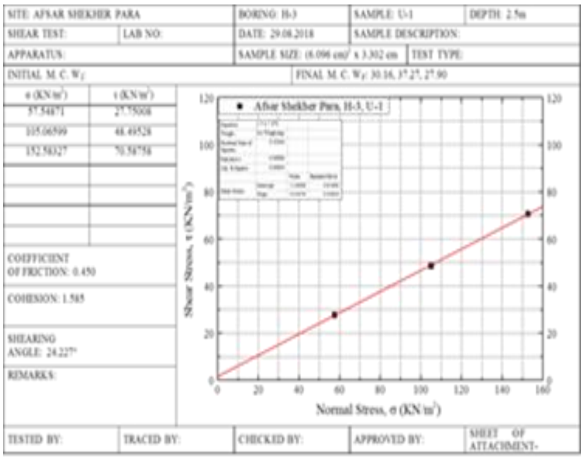
3.6.3.5 Shear Test

There are three types of shear tests for determining shear strength. The two most widely used tests are the direct shear test and the tri-axial shear test.

Unconfined Compression Test: The unconfined compression test is a special form of the triaxial test. The unconfined compression test measures the compressive strength of a cylinder of soil to which no lateral support is offered. It is commonly used to measure the strength of a cohesive soil as cohesion less soil will not form an unsupported cylinder.

Figure 3.34: Arrangement for conducting UCT and Direct shear Test

Direct Shear Test: The test is performed for cohesion less soil. From this test angle of internal friction ϕ and cohesion c is determined. Stress vs. strain graph



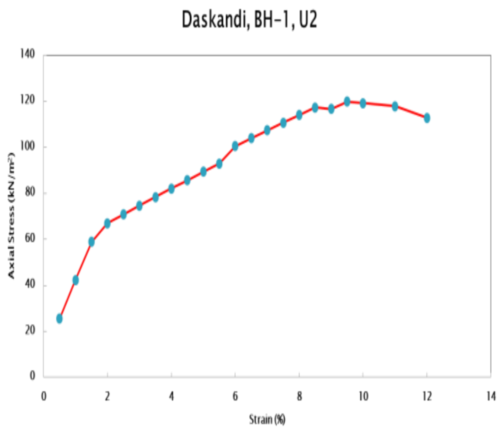
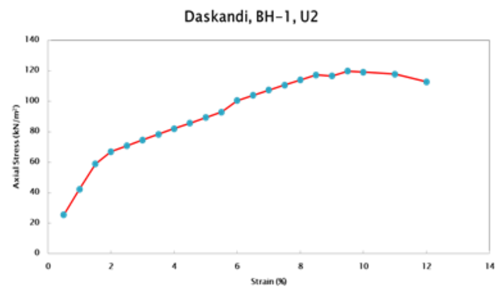


Figure 3.35: Stress vs. strain graph and Shear stress vs. normal stress graph

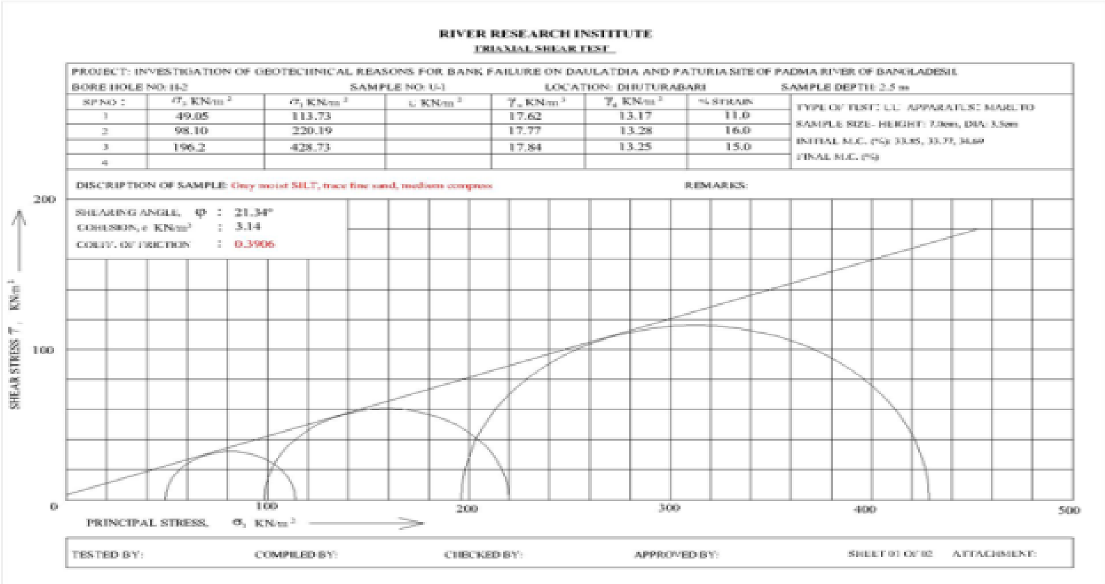
3.6.3.6 Triaxial Shear Test

The test is performed for cohesive and non-cohesive soil. From this test angle of internal friction ϕ and cohesion c is determined.

Triaxial shear test is conducted of cohesive soil in the laboratory



Stress vs. strain graph



RIVER RESEARCH INSTITUTE
TRIAXIAL SHEAR TEST

PROJECT: INVESTIGATION OF GEOTECHNICAL REASONS FOR BANK FAILURE ON DAULATDIA AND PATURIA SITE OF PADMA RIVER OF BANGLADESH
BORE HOLE NO: H-2 SAMPLE NO: U-1 LOCATION: DHUTURABARI SAMPLE DEPTH: 2.5 m

SP NO :	σ_3 KN/m^2	σ_1 KN/m^2	u KN/m^2	γ_m KN/m^3	γ_d KN/m^3	% STRAIN
1	49.05	113.73		17.62	13.17	11.0
2	98.10	220.19		17.77	13.28	16.0
3	196.2	428.73		17.84	13.25	15.0
4						

TYPE OF TEST: UU APPARATUS: MARUTO
SAMPLE SIZE- HEIGHT: 7.0cm, DIA: 3.5cm
INITIAL M.C. (%): 33.85, 33.77, 34.69
FINAL M.C. (%)

DISCRIPTION OF SAMPLE: Grey moist SILT, trace fine sand, medium compress
REMARKS:

SHEARING ANGLE, φ : 21.34°
COHESION, c KN/m^2 : 3.14
COEFF. OF FRICTION : 0.3906

TESTED BY: COMPILED BY: CHECKED BY: APPROVED BY: SHEET 01 OF 02 ATTACHMENT:

Figure 3.36: Arrangement of triaxial shear test for determining c and ϕ value of fine grained soil

3.6.3.7 Consolidation Test

Consolidation test is an important phenomenon to gain knowledge of soil behavior. The main purpose of consolidation tests is to obtain soil data which are used in predicting the rate and the amount of settlement of structures founded on clay.

Figure 3.37: Consolidation test for settlement analysis

The two most important soil properties furnished by a consolidation test are i) compression index Cc, which indicates the compressibility of the specimen and ii) the coefficient of consolidation, c_v which indicates the rate of compression under a load increment.

The coefficient of consolidation c_v is computed from the following equations

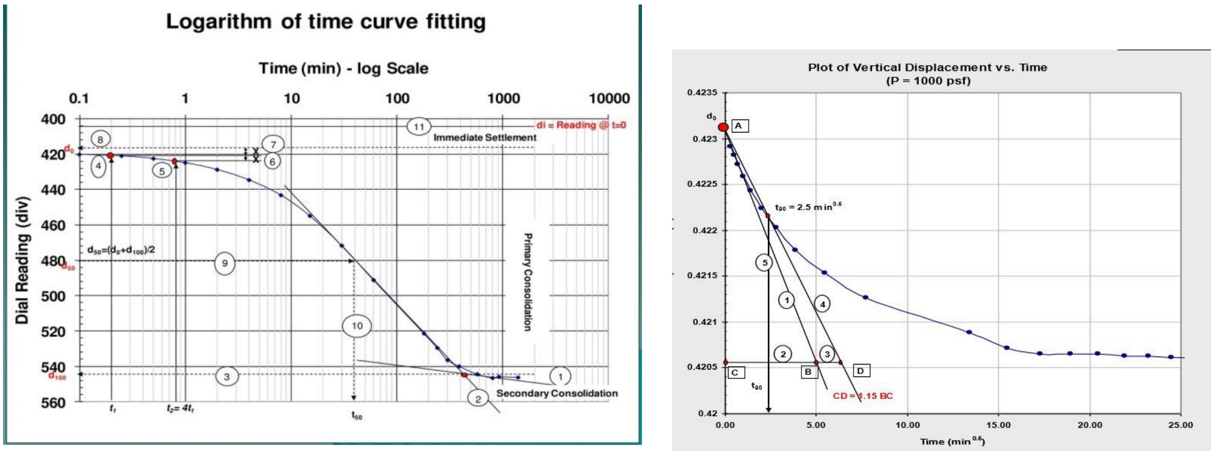
1. Square Root Fitting Method:

$$c_v = \frac{0.848H^2}{t_{90}}$$

2. Log Fitting Method:

$$c_v = \frac{0.197H^2}{t_{50}}$$

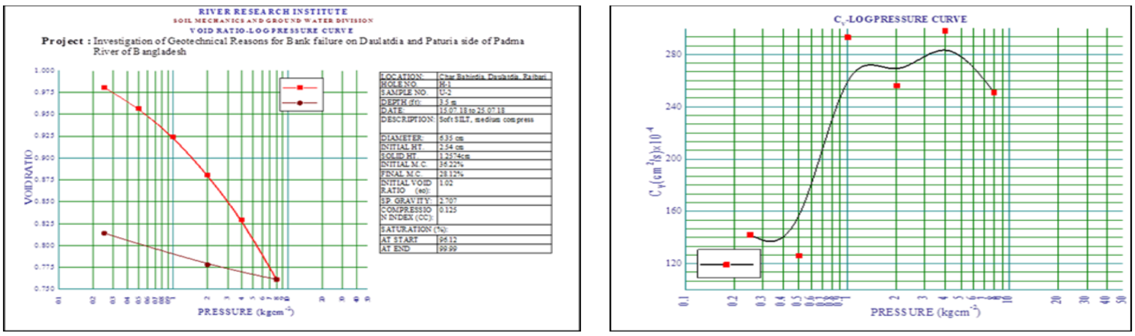
Where, H is the average thickness per drainage surface for the load increment. t_{50} is the time for 50% settlement of the soil and t_{90} is the time for 90% settlement of the soil.



T_{50} Curve

T_{90} Curve

Figure 3.38: T_{50} Curve and T_{90} Curve



Void ratio & log pressure curve

Cv & log pressure curve

Figure 3.39: Void ratio & Cv –log pressure curve

From the void ratio and log pressure curve, the compression index Cc is determined by the equation,

$$Cc = -\frac{de}{d(log_{10}p)}$$

The coefficient of compressibility, a_v is calculated from the equation,

$$a_v = \frac{0.435Cc}{p}$$

3.6.3.8 Permeability Test

The permeability is a soil property which indicates the ease with which water will flow through the soil. Darcy showed experimentally that the rate of water q flowing through soil of cross sectional area A was proportional to the imposed gradient i or

$$\frac{q}{A} \propto i$$

$$q = kiA$$

The coefficient of proportionality k is called the Darcy's coefficient of permeability or permeability. There are several methods for measuring the permeability of a soil. Generally, the variable head test is more convenient for cohesion less soils and the constant head test is convenient for cohesive soils.

The permeability of the consolidation specimen can be computed at each void ratio by the equation,

$$k = \frac{C_v a_v \gamma_w}{1+e}$$

in which c_v is the coefficient of consolidation, a_v is the coefficient of compressibility, γ_w is the unit weight of water, and e is the void ratio.

Variable head test   Constant head test

Figure 3.40 Variable head test and Constant head test of permeability test

In variable head test, the coefficient of permeability k can be computed from the equation,

$$k = 2.3 \frac{aL}{A(t_1 - t_2)} log_{10} \frac{h_0}{h_1}$$

in which, a=cross-sectional area of the standpipe,

L= length of soil sample in permeameter,

A= cross-sectional area of the permeameter,
t_0= time when water in standpipe is at h_0,
t_1= time when water in standpipe is at h_1,
h_0, h_1= the heads between which the permeability is determined

In constant head test, the coefficient of permeability k can be computed from the equation,

$$k=\frac{QL}{thA}$$

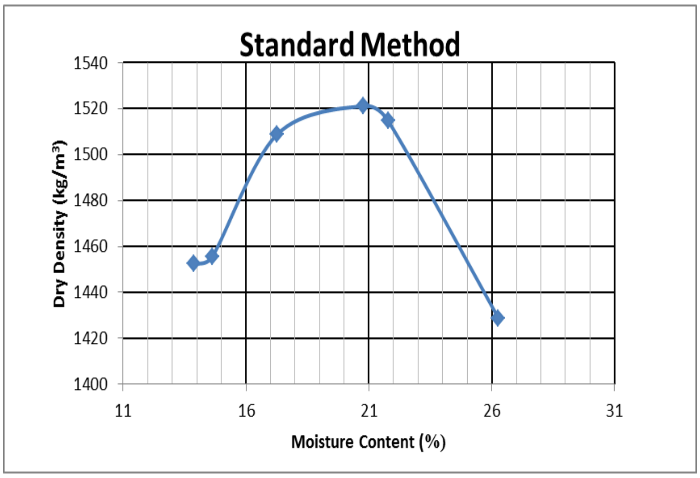
in which, Q= total quantity of water which flowed through in elapsed time, t
h=total head lost
A= cross-sectional area of the permeameter,
L= length of soil sample in permeameter,

3.6.3.9 Compaction Test

Compaction is defined as the process of packing the soil particles by reducing the air voids in the soil by means of mechanical means. The results of a laboratory dynamic compaction test are usually presented in a plot of dry density versus water content.

Conducting Field density measurement

Compaction test is running at laboratory



Compaction Curve

Figure 3.41: Field density measurement and Compaction test at laboratory and its graph

The dry density γ_d is computed by the equation,

$$\gamma_d = \frac{W}{V(1+w)}$$

in which, W=total weight of moist compacted soil in cylinder,
V=volume of the mold,
w=water content of moist compacted soil.

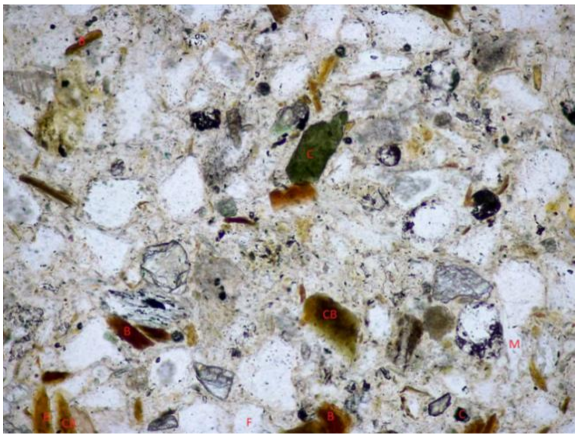
3.6.3.10 Mica Content

The petrographic examinations of the supplied samples have been performed to find the percentage of Micas within the samples studied. Thin sections from each of the samples have been prepared and analyzed under polarizing microscope.

A complete description of the process of sample preparation and petrographic analysis has been given the Methodology document. Following sections include the results of the laboratory analyses.

Petrographic tests have been carried out at the Department of Geology, University of Dhaka following the ‘STD. ASTM C295-98’ method. All together 11 samples from different locations: i) Bahir Char Daulatdia, ii) Daulatdia Launch Ghat; iii) Arua, Baroria, iv) Bahir CharDaulatdia and v) Afsar Sheikherchar have been studied.

Petrographic Tests for Mica count at DU



Mica count by petrographic Analysis

Figure 3.42: Mica count tests at the department of geology in Dhaka University

3.6.3.10.1 Identifying characteristics of Muscovite, Biotite and Chlorite

3.6.3.10.1.1 Muscovite

Elongated and flaky nature are the most striking characteristics of a Muscovite grain. Colorless appearance, low relief and absence of cleavage under plane polarized light. Variegated color, straight extinction under cross-polarized light. In some cases, I-order light grey color are also observed.

3.6.3.10.1.2 Biotite

Elongated and flaky nature are also the most striking characteristics of a Biotite grain. Brown color, moderate relief and absence of cleavage and weak pleochroism under plane polarized light. Dark brown color, straight extinction under cross-polarized light.

3.6.3.10.1.3 Chlorite

Green color, moderate relief and absence of cleavage and strong pleochroism under plane polarized light. Dark green color, straight extinction under cross-polarized light.

3.6.3.11 pH

pH is a measure of hydrogen ion concentration, a measure of the acidity or alkalinity of a solution. The pH scale usually ranges from 0 to 14. Aqueous solutions at 25°C with a pH less than 7 are acidic, while those with a pH greater than 7 are basic or alkaline. (Source: Internet: May 7, 2019), 26.11.2019

The pH scale is alternatively sometimes called the pH-acid-base scale and sometimes just the acid-base scale. In neutral solutions, i.e. those that are neither acidic nor basic, pH = 7.0.

Acidic solutions are those with pH less than 7, while basic solutions have pH greater than 7. A solution is:

- acidic when there are more H^+ ions than OH^- ions present
- basic when there are more OH^- ions than H^+ ions present
- neutral when there are equal number of H^+ and OH^- ions present

pH is a measure of the hydrogen ion activity, typically in aqueous solution. In pH, the p stands for $-\log_{10}$ and the H stands for hydrogen ion activity:

$$pH = -\log_{10} a_H{}^+$$

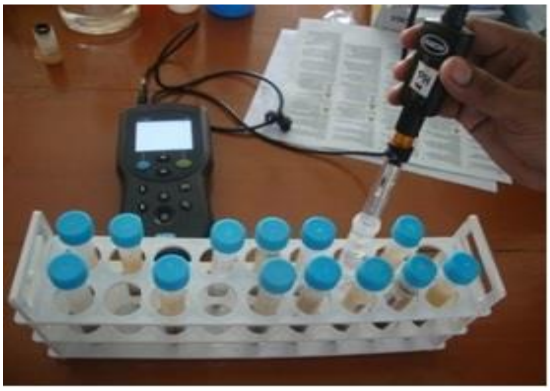
In dilute solutions, the activity of hydrogen ions can be approximated by their molar concentration, and it is in this form that pH is normally used:

$$pH = -\log_{10}[H^+]$$

Acid and Base pH

Acid solutions have pH < 7. pH values lower than 0 are possible.Basic solutions have pH > 7. pH values greater than 14 are possible(Internet, Definition of pH).

Samples are selected for pH test



pH tests are running in the laboratory

Figure 3.43: pH tests at the laboratory

3.6.4 Data from outsource

The relevant data such as ground water level, surface water level and discharge are collected from WARPO and BWDB from year 2016-2019.

Chapter 4

Data Analysis and Interpretation of Results

In order to investigate geotechnical properties of this study, natural moisture content, Atterberg limits, specific gravity, grain size analysis, tri-axial shear test, direct shear test, unconfined compression test, consolidation test, permeability test, compaction test, mica count and pH tests are done in the laboratory from the collecting soil samples. The results are presented in the tabular form and their strata are presented in the boring log form. Both the table and the logs are arranged according to in-situ as well as laboratory findings. As three borings are holed in each location, the results are allocated accordingly and their graphical presentations also.

The number of soil samples are tested have been shown in depth and hole wise in Annexure-1.

Table 4.1: Table showing the summary of the results of range of soil properties of the different locations of Paturia side

Name of the parameter	Daskandi		Baruria	
	Cohesive	Non-cohesive	Cohesive	Non-cohesive
N.M.C in %	26.30-41.53	24.53-26.57	31.59-39.7	21.48-30.33
SPT value	2-12	9-50	3-14	4-55
Unit Weight in kN/m^3	Wet –(17.24-25.81) Dry-(13.44-19.14)	-	Wet-14.66-19.54 Dry-11.81-15.16	
Specific Gravity,Gs	2.599-2.693		2.646-2.81	
Sand in (%)	0-25	4-93	2-19	22-92
Silt in (%)	57-87	7-93	56-84	8-77
Clay in (%)	6-37	0-3	3-40	0-4
Mica in (%)				8.5
Colour	Light brown to grey		Light brown to grey	

Table 4.2 : Table showing the summary of the results of range of soil properties of the different locations of Paturia side

Name of the parameter	Daskandi		Baruria	
	Cohesive	Non-cohesive	Cohesive	Non-cohesive
q_u in kN/m2	30.78-71.45 at (2-9)% strain	-	(13.58-151.16) at (2.5-17)% strain	-
Cohesion, c in kN/m^2	22-40	1	18-20	
Angle of internal friction,Ø in degree	12-21	21	15-19	
Compression index Cc	0.146-0.21		0.129-0.240	
Permeability,k in mm/sec	1.08x10-4- 1.20x10-3	5.29x10-3-8.27x10-2	1.56x10-4-5.88x10-4	1.08x10-2-2.65x10-2
Saturation in (%)	88-93		93-100	
Pore pressure in kN/m^2	0-167		0-170	
pH	7.72-8.14		7.90-8.14	
Maximum dry density in kg/cm3	1622-1666		1450-1602	
Optimum Moisture Content in (%)	16-17		18-21	

Table 4.3: Table showing the summary of the results of range of soil properties of the different locations of Daulatdia side

Name of the parameter	CharBahirdia		Launchghat		Afsarsheikher Para	
	Cohesive	Non-cohesive	Cohesive	Non-cohesive	Cohesive	Non-cohesive
N.M.C in %	28.74-36.51	12.31-32.75	36.25-38.64	22.52-26.81	24.24-34.63	6.87-33.95
SPT value	2-7	3-47	2-4	3-39	3-7	5-50
Unit Weight in kN/m^3	Wet-(17.14-19.37) Dry-(13.02-14.80)	Wet-18.62 Dry-19.32	Wet-19.02-19.09 Dry-13.48-13.73	Wet-15.86-19.04 Dry-12.95-15.01		Wet-15.91-18.83) Dry-(13.08-15.56)
Specific Gravity, Gs	2.66-2.70		2.663-2.721		2.646-2.70	
Sand in (%)	5-27	49-92	1-23	30-94	5-16	23-97
Silt in (%)	69-89	8-50	66-82	6-70	66-84	3-77
Clay in (%)	1-9	0-1	6-16	0	10-18	0-1
Mica in (%)		8-10		8-10		6-12
Colour	Grey		Grey		Grey	

Table 4.4: Table showing the summary of the results of range of soil properties of the different locations of Daulatdia side

Name of parameter	CharBahirdia		Launchghat		Afsarsheikher Para	
	Cohesive	Non-cohesive	Cohesive	Non-cohesive	Cohesive	Non-cohesive
q_u in kN/m2	-	(18.36-103.06) at (6.5-15)% strain	30.63-69.10 at (2.5-14%) strain	33.96-147.69 at 19% strain	-	-
Cohesion, c in kN/m^2		5	1	1		0-2
Angle of internal friction,Ø in degree		6	31	31		19-24
Compression index Cc	0.11-0.18					
Permeability,k in mm/sec	7.50x10-5-1.67x10-2	3.37x10-5-7.87x10-2	3.43x10-3	8.27x10-2	7.15 x10-5	2.28x10-3-8.07x10-2
Saturation in (%)	93-95		90-98		87-95	
Pore pressure in kN/m^2	0-177		0-163		0-164	
pH	8.01-8.57		7.71-8.70		8.10-8.42	
Maximum dry density in kg/cm3	1738		1687		1702-1862	
Optimum Moisture Content in (%)	16-17		18		13-18	

Table 4.5: Soil reaction is measured by laboratory or field tests and expressed on a logarithmic scale referred to as pH. Degrees of acidity and alkalinity corresponding with particular pH levels are given below

Extremely acid	Below pH 4.5	Neutral	pH 6.6-7.6
Very strongly acid	pH 4.5-5.0	Mildly alkaline	pH 7.4-7.8
Strongly acid	pH 5.1-5.5	Moderately alkaline	pH 7.9-8.4
Medium acid	pH 5.6-6.0	Strongly alkaline	pH 8.5-9.0
Slightly acid	pH 6.1-6.5	Very Strongly alkaline	pH>9.0

(Source: Brammer 1996)

4.1 Variation of Natural Moisture Content with corresponding depth

The water content is one of the easiest and most useful properties of a soil. The characteristics of a soil especially a fine grained soil, changed to a marked degree with a variation of its water content. The water content of the fine-grained soils, such as silt and clays, is generally more than that of the coarse grained soils, such as gravel and sands(Source: Arora,2010).Water content is a good indication of the shear strength of saturated clay. In sedimentary clays there may be major difference in water content between adjacent strata.

4.1.1. Variation of Natural Moisture Content with corresponding depth at Paturia Side

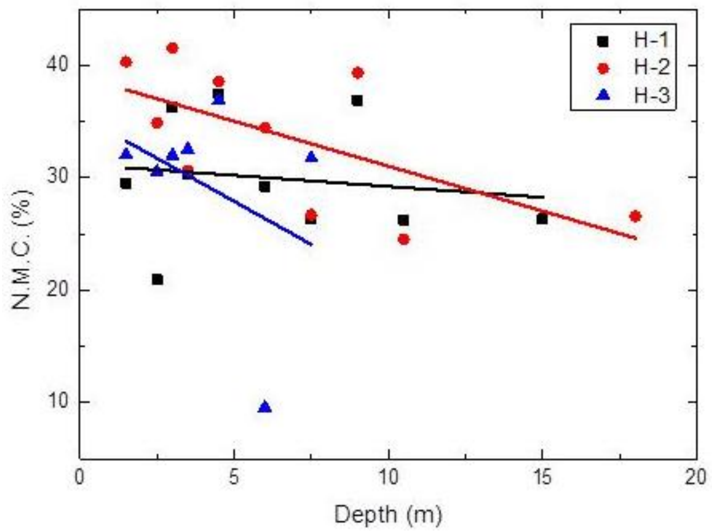


Figure 4.1: Natural moisture content (N.M.C) vs. depth graph for soil of Daskandi at Paturia side

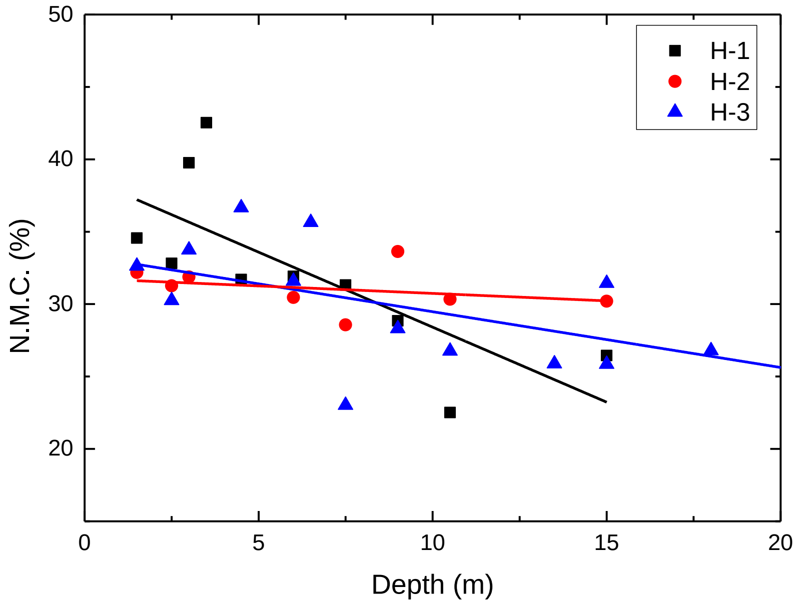


Figure 4.2: : Natural moisture content (N.M.C) vs. depth graph for soil of Baruria at Paturia side

In the location of Paturia side, it has been observed that natural moisture content has been lessened with the increases of depth. The soil strata has been varied from cohesive layer to non-cohesive layer and their particle sizes has been varied from small to high trend.

4.1.1.2 Variation of Natural Moisture Content with corresponding depth at Daulatdia Side

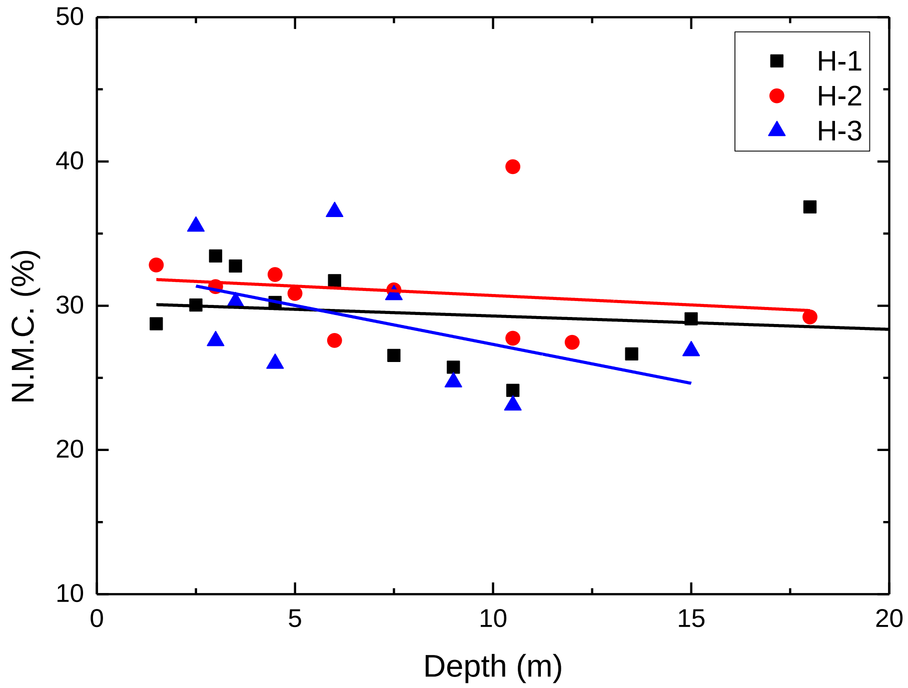


Figure 4.3: Natural moisture content (N.M.C) vs. depth graph for soil of CharBahirdia at Daulatdia side

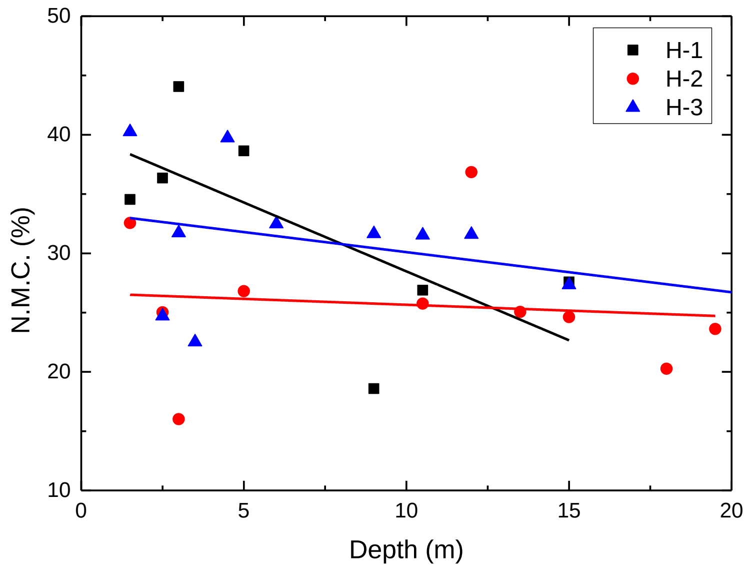


Figure 4.4: Natural moisture content (N.M.C) vs. depth graph for soil of Launchghat at Daulatdia side

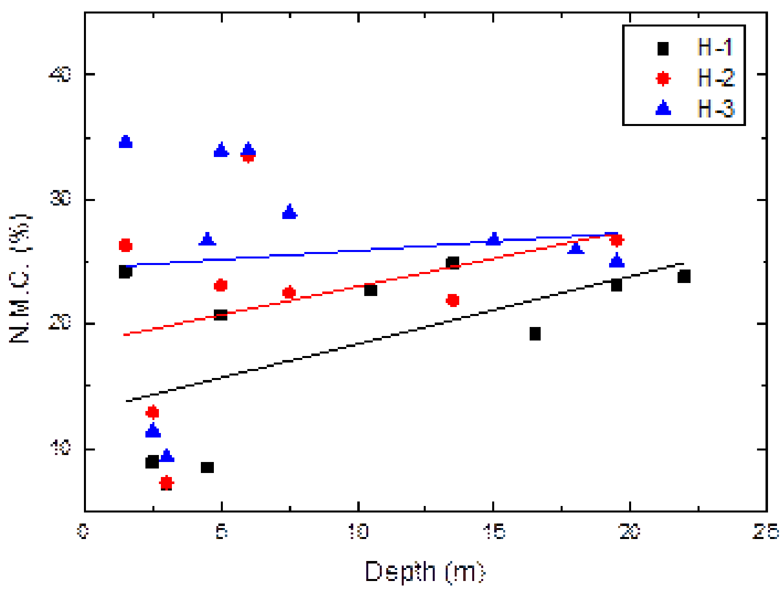


Figure 4.5**:** Natural moisture content (N.M.C) vs. depth graph for soil of of Afsarsheikher Para at Daulatdia side

In the location of Daulatdia side, it has been observed that natural moisture content has been lessened with the increases of depth except in location Afsarsheikher Para. The soil strata has been varied from cohesive layer to non-cohesive layer and their particle sizes has been varied from small to high trend at CharBahirdia and Launchghat however, the soil strata i,e cohesive up to the depth 1.5m and the deposit below up to the depth of exploration consists of non-cohesive strata with variable particle sizes.

Permeability is a very important engineering property of soils. Knowledge of permeability is essential in a number of soil engineering problems, such as settlement of buildings, yield of wells, seepage through and below the earth structures. It controls the hydraulic stability of the soil masses. The permeability of soils is also required in the design of filters used to prevent piping in hydraulic structures.

The coefficient of permeability depends upon the particle size and upon many other factors.

Table 4.6: Typical Values of the Coefficient of Permeability

Sl. No.	Soil Type	Coefficient of permeability(mm/sec)	Drainage properties
1	Clean gravel	10^{+1} to 10^{+2}	Very good
2	Coarse and medium sands	10^{-2} to 10^{+1}	Good
3	Fine sands, loose silt	10^{-4} to 10^{-2}	Fair
4	Dense silt, clayey silts	10^{-5} to 10^{-4}	Poor
5	Silty clay, clay	10^{-8} to 10^{-5}	Very poor

According to USBR, the soils having the coefficient of permeability greater than 10-3 mm/sec are classified as pervious and those with a value less than 10-5 mm/sec as impervious. The soils with the coefficient of permeability between 10-5 to 10-3 mm/sec are designated as semi-pervious. (Source: Arora, 2010)

Table 4.7: Unified soil Classification system

Major Division			Group Symbols	Typical Names
Coarse –Grained Soils [More than 50% retained on No.200 sieve(0.075mm)]	Sand[more than 50% of coarse fraction passing No. 4 sieve(4.75mm)]	Clean Sand	SP	Poorly graded sands
			SW	Well graded sands
		Sands with fine	SM	Silty sands
Fine –Grained Soils [50% or more passing No.200 sieve(0.075mm)]	Silts and clays Liquid limit 50% or less		ML	Inorganic silts of low plasticity

(Source: Arora, 2010)

Liquefaction occurs when all the following five conditions must be satisfied-

1. The soil is cohesionless
2. The soil is loose
3. The soil is saturated
4. There is a shaking of ground of the required intensity and duration
5. The undrained conditions develop in the soil due to its limited permeability

Liquefaction can occur in the soil deposit at any depth where these conditions are satisfied. It is observed that liquefaction normally occurs in the soil classified as SP in Indian Standard Classifications when the SPT number N is less than 15.However, sometimes liquefaction may also occur in the soil classified as SW, SM, and ML.

Fine grained soils do no compress readily under dynamic loadings to cause a high dynamic pore water pressure. Moreover, they also possess the shear strength due to cohesion. Therefore liquefaction does not occur in the fine grained soils. (Source: Arora, 2010)

Specific Gravity (G_s) of soils is an important parameter. Whenever the specific gravity of a soil mass is indicated, it is the average value of all the solid particles present in the soil mass. It may be mentioned here that the specific gravity of solids is an important parameter.

Table 4.8: Typical values of G

Sl. No.	Soil Type	Specific Gravity
1	Gravel	2.65-2.68
2	Sand	2.65-268
3	Silty Sands	2.66-2.70
4	Silt	2.66-2.70
5	Inorganic Clays	2.68-2.80
6	Organic Soils	Variable, may fall below2.00

(Source: Arora, 2010)

Table 4.9: Relation of Consistency of Clay, Number of Blows N on Sampling spoon and Unconfined Compressive Strength, q_u in tons per sq ft

Consistency	Very soft	Soft	Medium Stiff	Stiff	Very stiff	Hard
Unconfined Compressive Strength, q_u (TSF)	0-0.25	0.25-0.50	0.50-1.00	1.00-2.00	2.00-4.00	>4.00
Compressive Strength (kN/m2)	0-23.94	23.94-47.88	47.88-95.76	95.76-191.52	191.52-383.04	>383.04
Standard Penetration Resistance-'N'	0-2	2-4	4-8	8-16	16-32	>32

Table 4.10: Density Index (I_D) of Sand

Number of blows	Density Index(ID)
0-4	Very loose
4-10	Loose
10-30	Medium Dense
30-50	Dense
Over 50	Very dense

(Source: Terzaghi & Peck, 1948)

4.1.2 Standard penetration Resistance-N value (SPT) in order of depth

4.1.2.1 N value (SPT) at Paturia side of Padma River

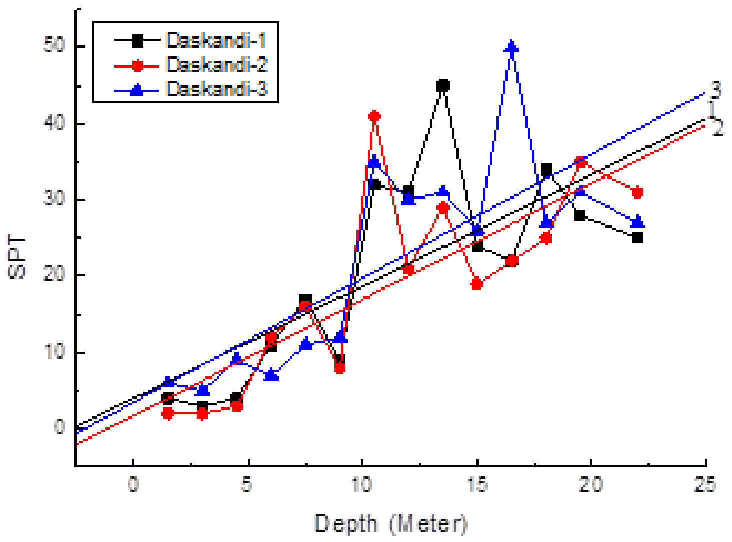


Figure 4.6: Standard Penetration Resistance-N (SPT) value vs. depth for soil of Daskandi at Paturia side

Figure-4.6 represents the variation of SPT value with depth. From the graph it is found that SPT values increases with depth in all the holes however, SPT decreases several times in all the holes as observation states. After analyzing the bore holes of Daskandi at Paturia side, it is decided that these SPT variation has been followed the natural moisture content, density, plasticity, particle size, stiffness, age of deposition and other geotechnical properties. By analyzing the soil profile it is also observed that the same depth of the study area does not contain same soil layer as their ground level is not homogeneous in mPWD.

In hole no.1 –no.3 of Daskandi site, it has been found that cohesive soil layers are up to the depth of about (0-6) m and the layers are non-cohesive up to the depth of exploration. The ground level varies from (6.667-7.617) mPWD where the ground water level varies from (3.3528-3.9624)m on date 30.01.18-01.02.18 at 9hrs. The SPT values are (2-11) for cohesive soils where the SPT values are (9-45) for non-cohesive soils. The consistency of cohesive soils varies from very soft to stiff and the plasticity varies from low to high plasticity. The clay particle varies from (6-31)%, silt particle varies from(64-84)% and sand particle varies from (4-16)% for cohesive soils. The density index of non-cohesive soils varies from loose to dense and the plasticity is non-plastic. The clay particle varies from(0-1)%,silt particle varies from(7-79)% and sand particle varies from(19-93)%.The cohesion varies from (0-76)kN/m2 and the angle of internal friction varies from (12-21)degree. The permeability varies from (1.08E-04-8.27E-02)mm/sec. The specific gravity varies from 2.599-2.715. The pH values vary from (7.72-8.14).The moisture content varies all about (9-42)%.

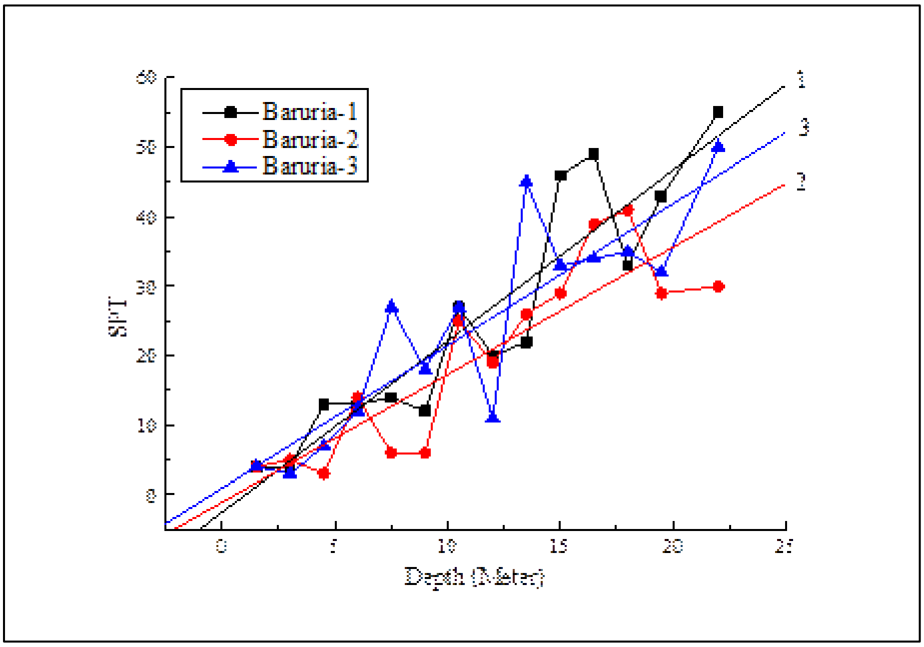


Figure 4.7: Standard Penetration Resistance-N (SPT) vs. depth graph for soil of Baruria site at Paturia side

Figure-4.7 represents the variation of SPT value with depth. From the graph it is found that SPT values increases with depth in all the holes however, SPT fluctuates several times in all the holes as investigation states. After analyzing the bore holes of Baruria at Paturia side, it is decided that these SPT variation has been followed the natural moisture content, density, plasticity, particle size, stiffness, age of deposition and other geotechnical properties. By analyzing the soil profile it is also observed that the same depth of the study area does not contain same soil layer as their ground level is not homogeneous in mPWD.

In hole no.1 –no.3 of Baruria site, it has been found that cohesive soil layers are up to the depth of about (0-9)m and the layers are non-cohesive up to the depth of exploration. The ground level varies from (6.935-9.492)mPWD where the ground water level varies from (3.048-3.6576)mPWD on date 02.02.18-04.02.18 at 9hrs. The SPT values are (3-12) for cohesive soils where the SPT values are (5-55) for non-cohesive soils. The consistency of cohesive soils varies from very soft to stiff and the plasticity varies from medium compressibility to high plasticity. The clay particle varies from (6-40)%,silt particle varies from(56-84)% and sand particle varies from (2-20)% for cohesive soils. The density index of non-cohesive soils varies from loose to dense and the plasticity is non-plastic. The clay particle varies from(0-1)%,silt particle varies from(8-20)% and sand particle varies from(80-91)%.The cohesion varies from (5-19) kN/m^2 and the angle of internal friction varies from (15-18)degree. The permeability varies from (1.56E-04-6.68E-02)mm/sec. The specific gravity varies from 2.55-2.693. The pH values varies from (7.90-8.04).The mica contents about 8.5%(M-2%,B-5%,C-1.5%). The moisture content varies all about (20-43)%.

4.1.2.2 N value (SPT) at Daulatdia side of Padma River

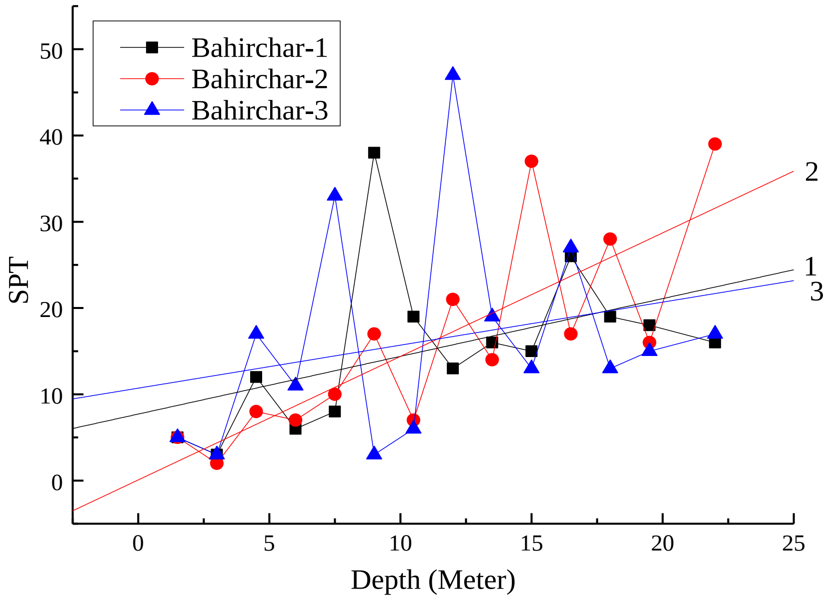


Figure 4.8: Standard Penetration Resistance-N (SPT) vs. depth graph for soil of CharBahirdia at Daulatdia side

Figure-4.8 represents the variation of SPT value with depth. From the graph it is found that SPT values increases with depth in all the holes however, SPT fluctuates several times in all the holes as investigation states. After analyzing the bore holes of CharBahirdia at Daulatdia side, it is decided that these SPT variation has been followed the natural moisture content, density, plasticity, particle size, stiffness, age of deposition and other geotechnical properties. By analyzing the soil profile it is also observed that the same depth of the study area does not contain same soil layer as their ground level is not homogeneous in mPWD.

In hole no.1 –no.3 of CharBahirdia site, it has been found that alternate layer of cohesive and non-cohesive soil layers are up to the depth of about (0-9)m and the layers are non-cohesive up to the depth of exploration. The ground level varies from (7.219-8.241)mPWD where the ground water level varies from (3.048-4.572)m on date 05.02.18-07.02.18 at

9hrs. The SPT values are (2-6) for cohesive soils where the SPT values are (3-39) for non-cohesive soils. The consistency of cohesive soils varies from very soft to medium stiff and the plasticity varies from low compressibility to high plasticity. The clay particle varies from (3-9)%,silt particle varies from(68-88)% and sand particle varies from (5-27)% for cohesive soils. The density index of non-cohesive soils varies from very loose to dense and the plasticity is non-plastic. The clay particle varies from(0-1)%,silt particle varies from(7-25)% and sand particle varies from(48-92)%.The cohesion varies from (3-4)kN/m^2 and the angle of internal friction varies from (5-20)degree. The permeability varies from (7.5E-05-1.67E-02)mm/sec. The specific gravity varies from 2.623-2.77. The pH values varies from (8.01-8.57). The mica contents about (8-10)% (M-2-3%,B-5%,C-1-2%). The moisture content varies all about (12-40)%.

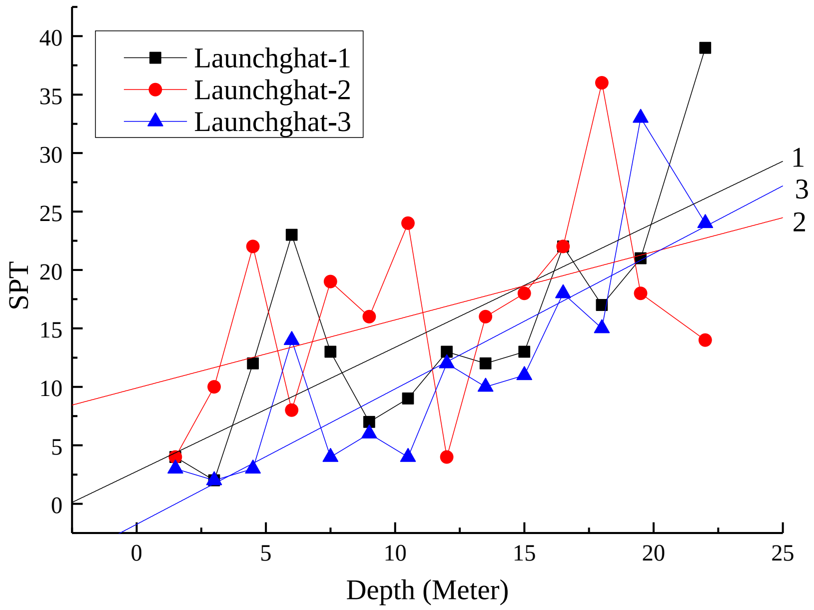


Figure 4.9 Standard Penetration Resistance-N (SPT) vs. depth graph for soil of Launchghat at Daulatdia side

Figure-4.9 represents the variation of SPT value with depth. From the graph it is found that SPT values increases with depth in all the holes however, SPT fluctuates several times in all the holes as investigation states. After analyzing the bore holes of Launchghat at Daulatdia side, it is decided that these SPT variation has been followed the natural moisture content, density, plasticity, particle size, stiffness, age of deposition and other geotechnical properties. By analyzing the soil profile it is also observed that the same depth of the study area does not contain same soil layer as their ground level is not homogeneous in mPWD.

In hole no.1–no.3 of Launchghat site, it has been found that alternate layer of cohesive and non-cohesive soil layers are up to the depth of about (0-12)m and the layers are non-cohesive up to the depth of exploration. The ground level varies from (6.753-9.526) mPWD where the ground water level varies from (2.7432-5.7912)m on date 08.02.18-10.02.18 at 9hrs. The SPT values are (3-14) for cohesive soils where the SPT values are (3-39) for non-cohesive soils. The consistency of cohesive soils varies from soft to stiff and the plasticity is medium. The clay particle varies from (10-18)%,silt particle varies from(75-79)% and sand particle varies from (8-18)% for cohesive soils. The density index of non-cohesive soils varies from very loose to dense and the plasticity is non-plastic. The clay particle varies from(0-2)%,silt particle varies from(7-64)% and sand particle varies from(18-93)%.The cohesion varies from (1-25)kN/m^2 and the angle of internal friction varies from (4-31)degree. The permeability varies from (4.8E-05-8.27E-02)mm/sec. The specific gravity varies from 2.646-2.70. The pH values varies from (7.71-8.70).The mica contents about (8-10)% (M-4-5%,B-2-3%,C-2%). The moisture content varies all about (16-44)%.

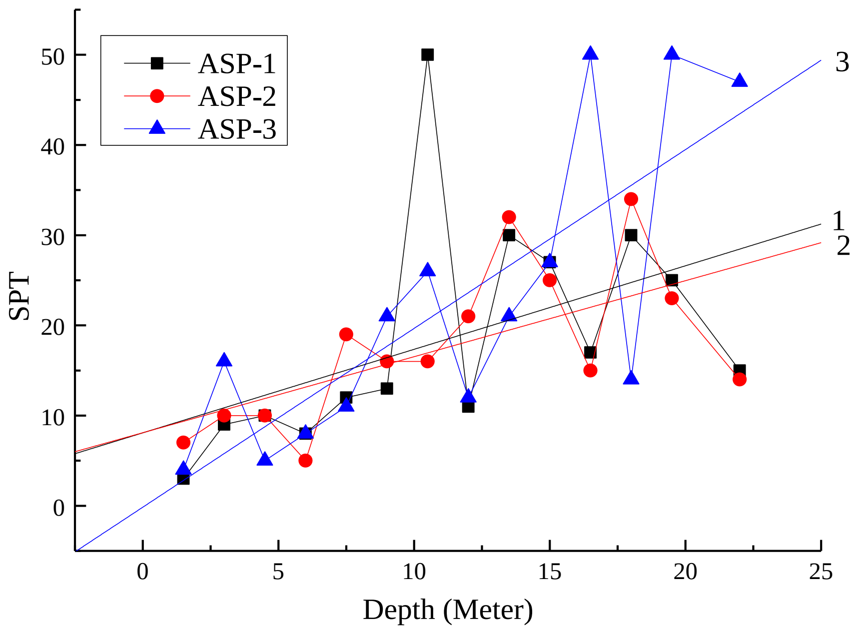


Figure 4.10: Standard Penetration Resistance-N (SPT) vs. depth graph for soil of Afsarsheikher Para at Daulatdia side

Figure-4.10 represents the variation of SPT value with depth. From the graph it is found that SPT values increases with depth in all the holes however, SPT fluctuates several times in all the holes as investigation states. After analyzing the bore holes of Afsarsheikher Para at Daulatdia side, it is decided that these SPT variation has been followed the natural moisture content, density, plasticity, particle size, stiffness, age of deposition and other geotechnical properties. By analyzing the soil profile it is also observed that the same depth of the study area does not contain same soil layer as their ground level is not homogeneous in mPWD.

In hole no.1 –no.3 of Afsarsheikher Para site, it has been found that cohesive soil layer is up to the depth of about (0-2) m and the layers after that are non-cohesive up to the depth of exploration. The ground level varies from (7.353-8.073) mPWD where the ground water level varies from (4.2672-6.4008)m on date 10.02.18-12.02.18 at 9hrs. The SPT values are (3-7) for cohesive soils where the SPT values are (5-50) for non-cohesive soils. The consistency of cohesive soils varies from soft to medium stiff and the plasticity is medium. The clay particle varies from (9-18)%,silt particle varies from(66-84)% and sand particle varies from (4-16)% for cohesive soils. The density index of non-cohesive soils varies from loose to dense and the plasticity is non-plastic. The clay particle varies from(0-1)%,silt particle varies from(3-76)% and sand particle varies from(23-97)%.The cohesion varies from (0-6)kN/m^2 and the angle of internal friction varies from (17-24)degree. The permeability varies from (7.15E-05-8.07E-02)mm/sec. The specific gravity varies from (2.663-2.721). The pH values varies from (8.10-8.42).The mica contents about (6-12)% (Where, Muscovite-(1-5)%,Biotite-(3-6)%,Chlorite-(1-2)%. The moisture content varies all about (7-34)%.

4.1.3 Variation of Ground Water level with Time

4.1.3.1 Variation of Ground Water level with Time at Paturia Side

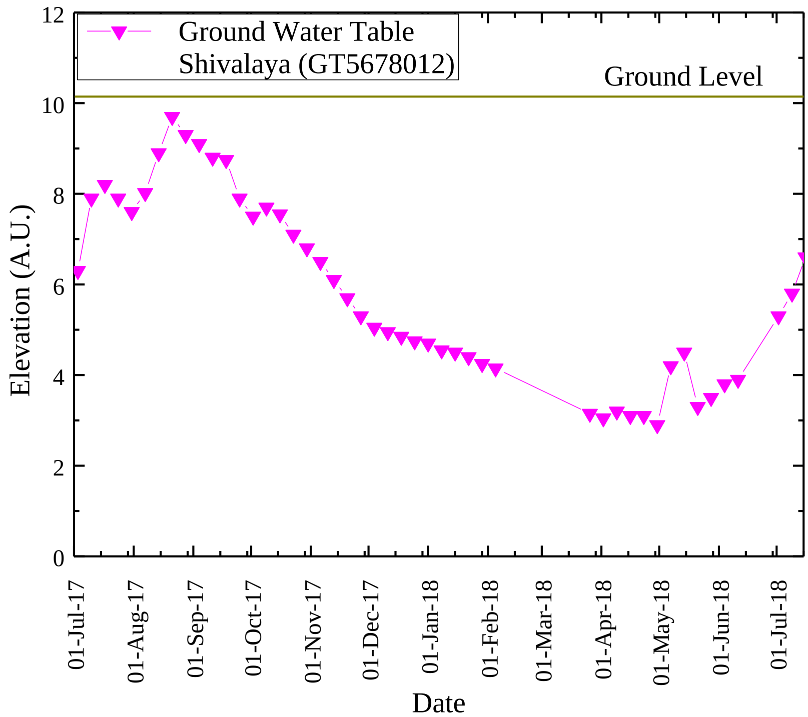


Figure 4.11: Graph showing the variation of Ground Water Level from July'17 To July'18 at Paturia side of Padma River (Source: BWDB)

In figure-4.11 ground water level with time has been presented. From this graph it has been observed that ground water level is adjacent to ground level on the mid of August'17 and then the ground water level has been decreased up to April. The level has been raised after then.

4.1.3.2 Variation of Ground Water level with Time at Daulatdia Side

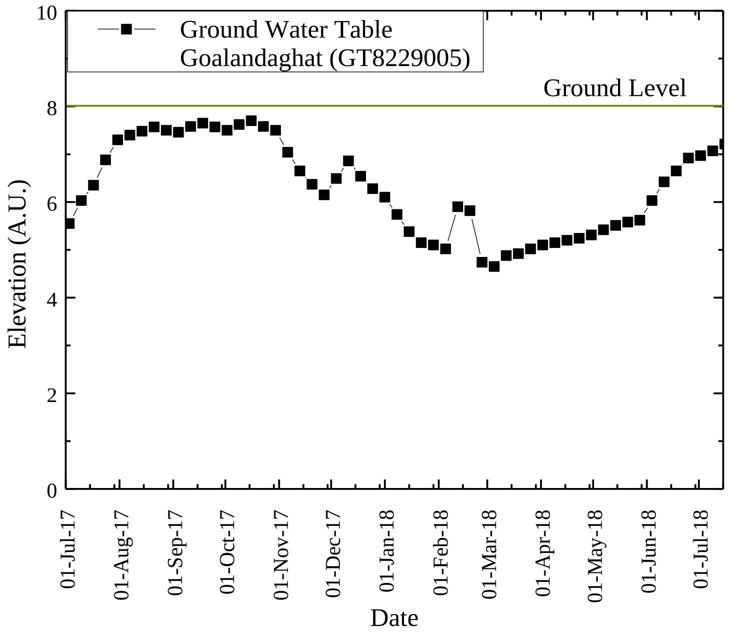


Figure 4.12: Graph showing the variation of Ground Water Level from July'17 To July'18 at Daulatdia side of Padma River (Source: BWDB)

In figure-4.12 ground water level with time has been presented. From this graph it has been observed that ground water level is adjacent to ground level on the mid of August'17 to mid of October'17 and then the ground water level has been decreased up to April'18. The level has been raised after then.

4.1.4 Variation of Ground Water Level with Surface Water Level

4.1.4.1: Variation of Ground Water Level with Surface Water Level at Paturia side

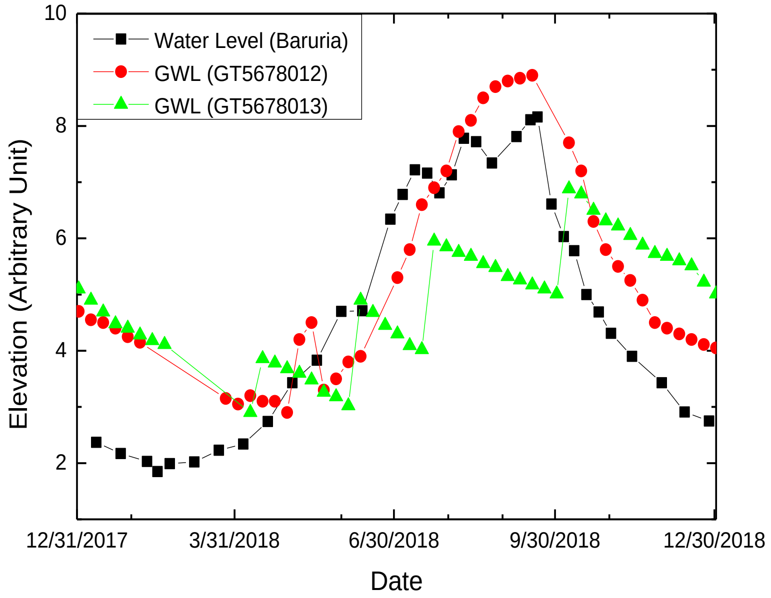


Figure 4.13: Graph represents the surface water level(SWL) of Baruria and ground water level(GWL)of 2 stations of Shivalaya, Manikganj with time (Source: BWDB).

4.1.4.2: Variation of Ground Water Level with Surface Water Level at Daulatdia side

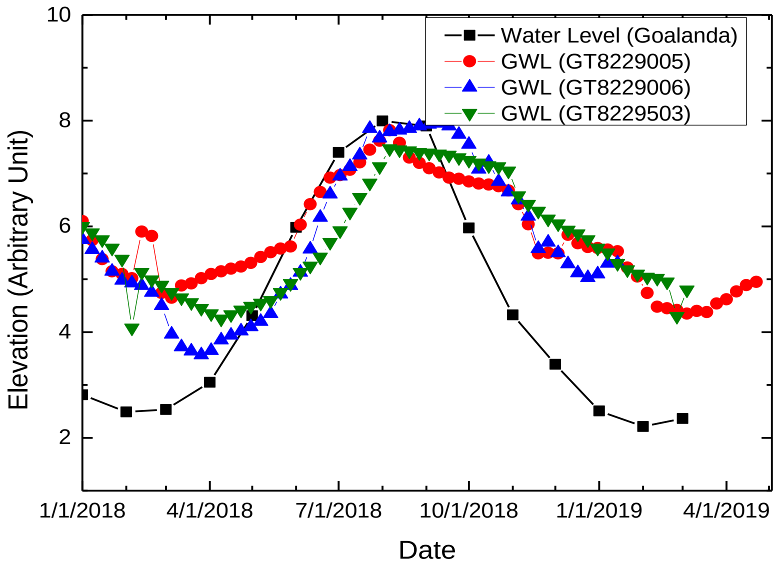


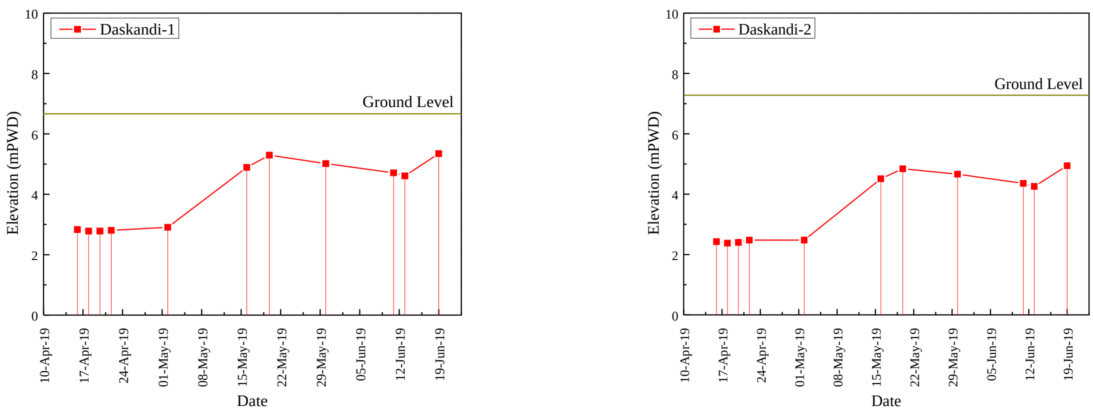
Figure 4.14: Surface water level (SWL)of Goalandaghat and ground water level (GWL) of 3 stations of Goalandaghat, Rajbari with time (Source:BWDB).

In figure-4.13 the variation of ground water table of two stations of Shivalaya of Manikgonj and the surface water level of Baruria of Paturia side of Manikgonj on March’2017 to March’2018 have been shown in the graph. In the graph it has been found that ground water level changes with the change in surface water level. In the month of mid of March surface water level is lower where it has been gradually increased after then. The increasing trend of water level is up to the month of September’18.The water level has been decreased rapidly up to the month of December’18. On the other hand, the ground water level decreases up to May’18 and gradually increases up to the month June’18 and then rapidly increases up to the mid of September,18 and then decreased rapidly up to the month of November’18 and gradually decreased up to the month December,18.

In Figure-4.14 the variation of ground water table of three stations of Goalanda of Rajbari and the surface water level of Goalanda of Daulatdia side of Rajbari on January’2018 to April’2019 have been shown in the graph. In the graph it has been found that ground water level changes with the change in surface water level. In the month of March surface water level is lower where it has been gradually increased after then. The increasing trend of water level is up to the month of September’18.The water level has been decreased rapidly up to the month of December’18. On the other hand, the ground water level decreases up to April’18 and gradually increases up to the month June’18 and then rapidly increases up to the mid of September,18 and then decreased gradually decreased up to the month March’19.

4.1.5: A few observation of ground water level at study area during the period of investigation

4.1.5.1(a): Ground Water Level at Daskandi from April To June’2019 of Paturia side



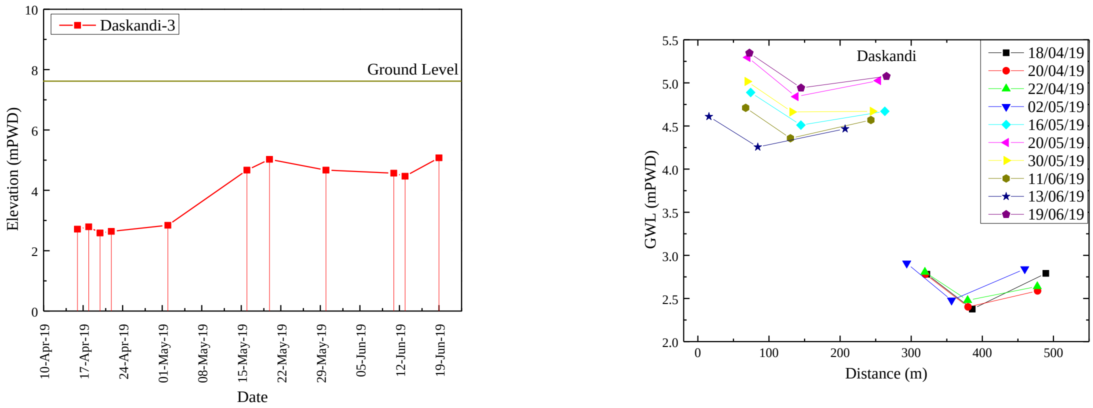


Figure 4.15: Graph showing the ground water level of three holes of Daskandi at Paturia side from April to June'2019

From Figure-4.15 it has been observed that ground water level of different holes at Daskandi of Paturia side has been varied at the same time as the bank line is altered and another is, as soil profile is not homogeneous due to various coordinates. As a result, gradient is different from one to another. Here it is remarkable that the increasing and decreasing tendency is comparable.

4.1.5.1(b): Ground Water Level at Baruria side From April To June'2019

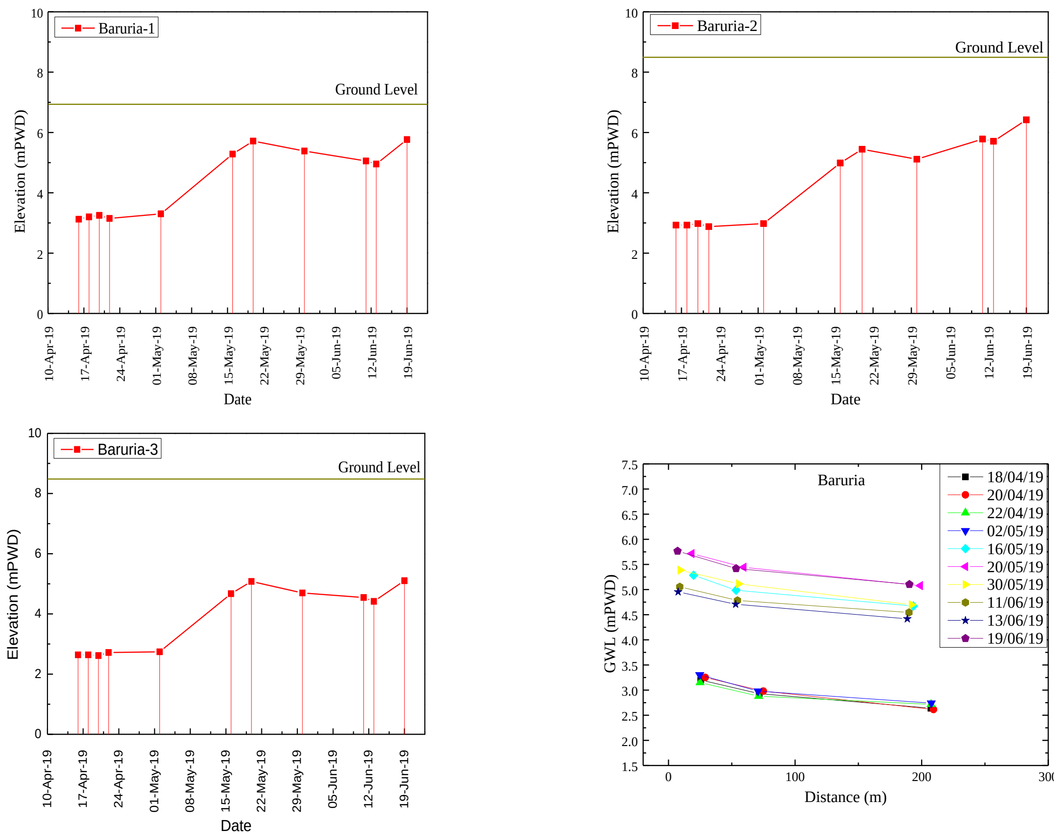


Figure 4.16: Graph showing the ground water level of three holes of Baruria at Paturia side from April to June' 2019

From Figure-4.16 it has been observed that ground water level of different holes at Baroria of Paturia side has been varied at the same time as the bank line is altered and another is, as soil profile is not homogeneous due to various coordinates. As a result, gradient has differed from one to another. Here it is remarkable that the increasing and decreasing tendency is comparable.

4.1.5.2 (a): Ground Water Level at CharBahirdia site of Daulatdia side From April To June'2019

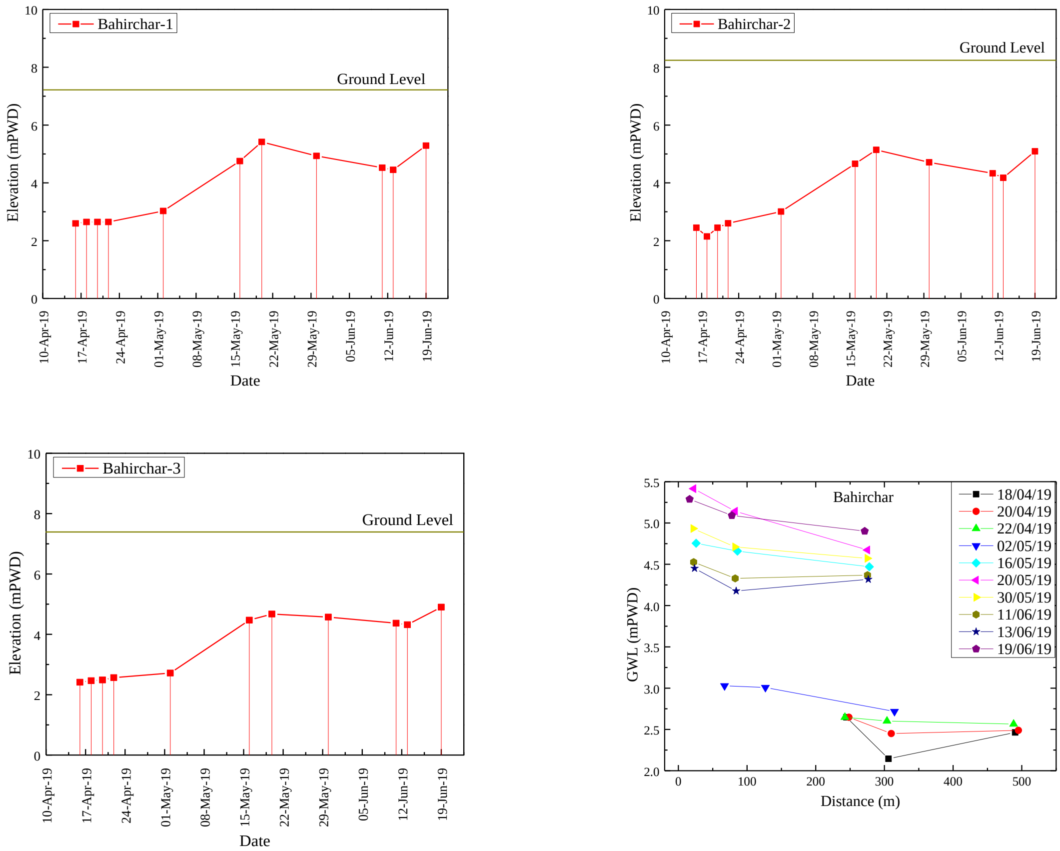


Figure 4.17: Graph showing the ground water level of three holes of CharBahirdia at Daulatdia side from April to June'2019

From Figure-4.17 it has been observed that ground water level of different holes at CharBahirdia of Daulatdia side has been varied at the same time as the bank line is altered and another is, as soil profile is not homogeneous due to various coordinates. As a result, gradient is different from one to another. Here it is remarkable that the increasing and decreasing tendency is comparable.

4.1.5.2 (b): Ground Water Level at Launchghat site of Daulatdia side From April To June'2019

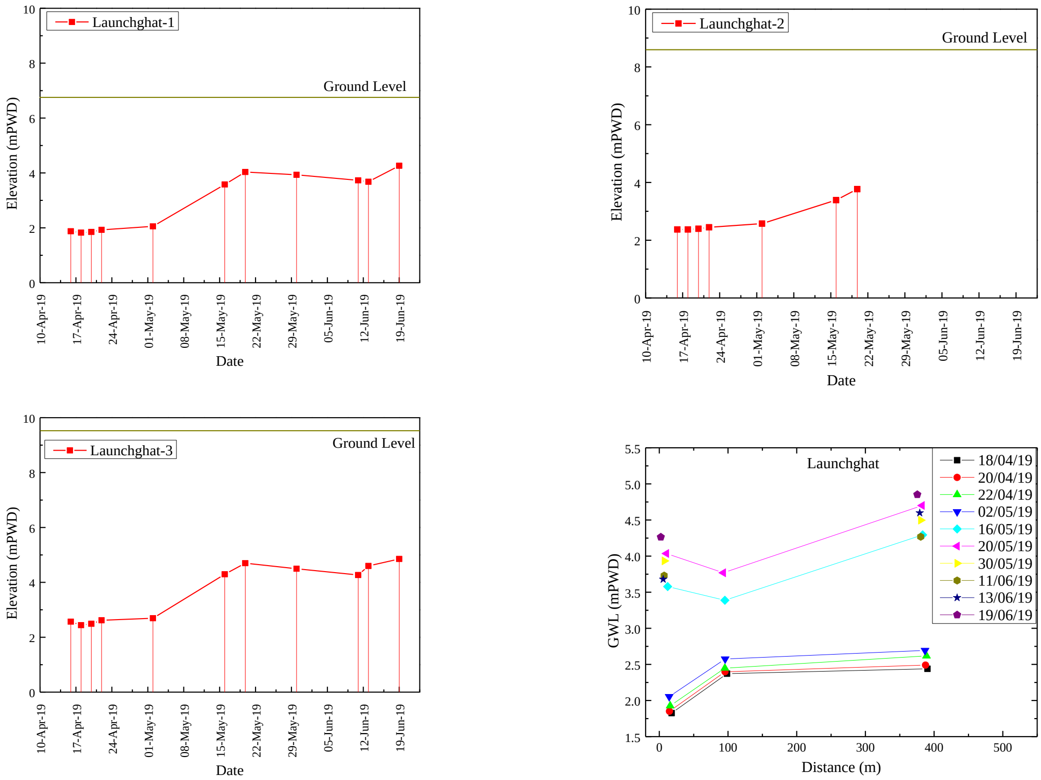


Figure 4.18: Graph showing the ground water level of three holes of Launchghat at Daulatdia side from April to June'2019

From Figure-4.18 it has been observed that ground water level of different holes at Launchghat of Daulatdia side has been varied at the same time as the bank line is altered and another is, as soil profile is not homogeneous due to various coordinates. As a result, gradient is different from one to another. Here it is remarkable that the increasing and decreasing tendency is comparable.

4.1.5.2 (c): Ground Water Level at Afsarsheikher Para site of Daulatdia side From April To June'2019

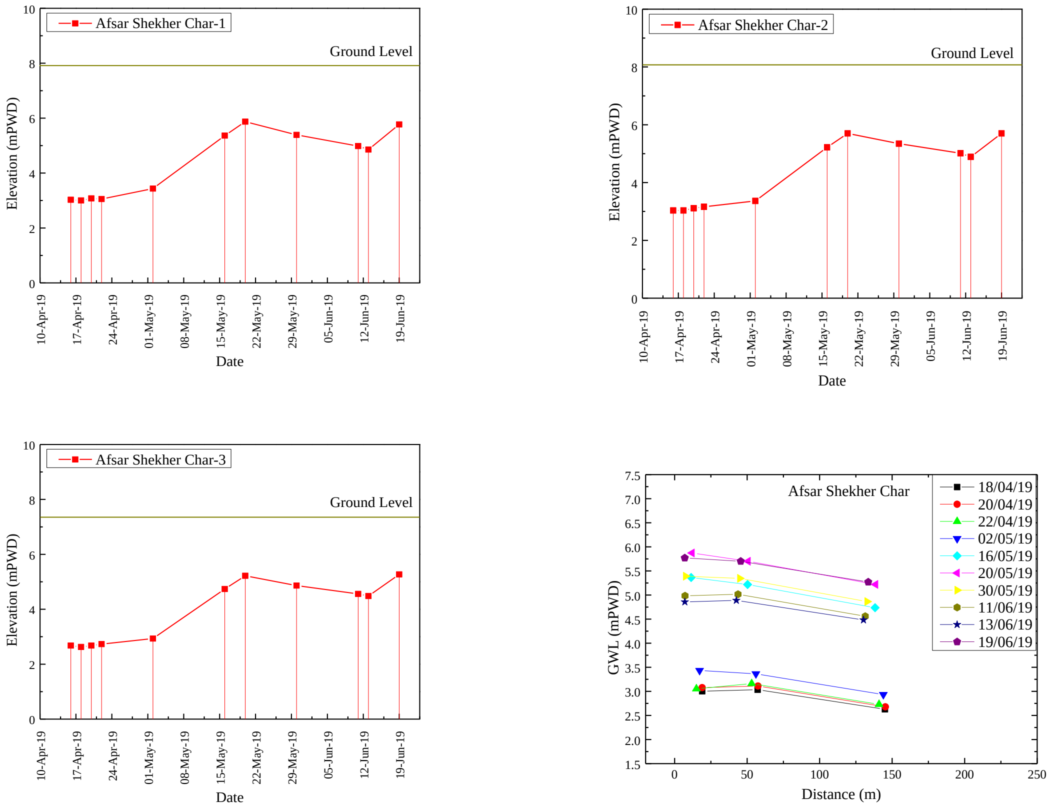
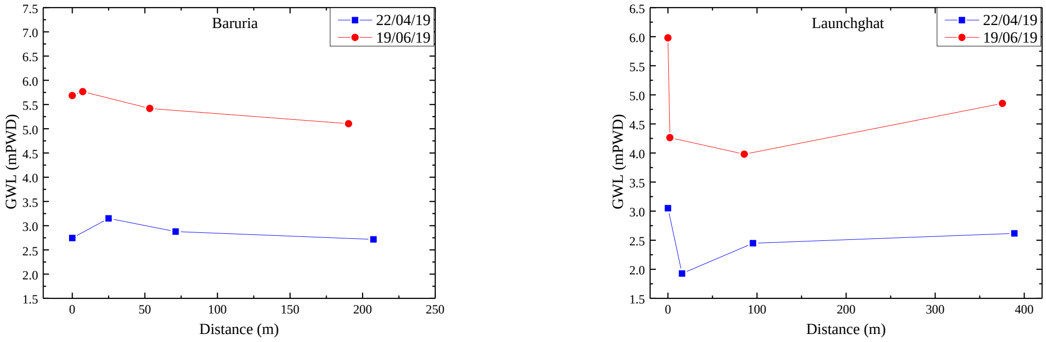
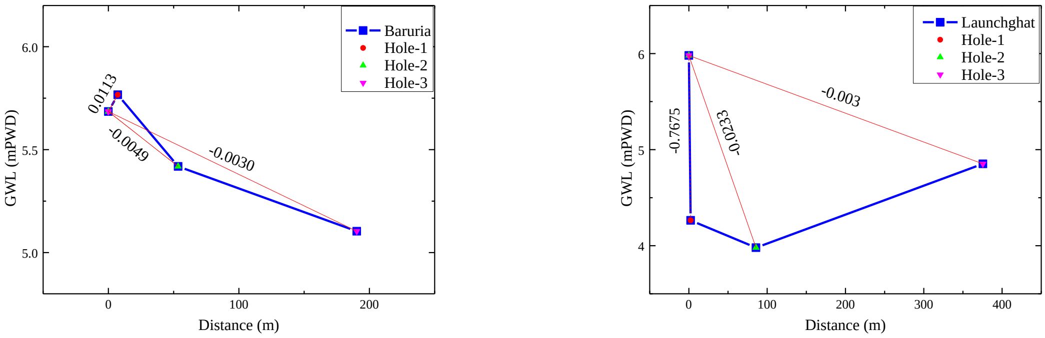


Figure 4. 19: Graph showing the ground water level of three holes of Afsarsheikher Para at Daulatdia side from April to June'2019

From Figure-4.19 it has been observed that ground water level of different holes at Afsarsheikher Para of Daulatdia side has been varied at the same time as the bank line is altered and another is, as soil profile is not homogeneous due to various coordinates. As a result, gradient is different from one to another. Here it is remarkable that the increasing and decreasing tendency is comparable.

4.1.6 A few scenarios of Ground water level as well as bank line (surface water level) in order to find out the gradient of Daulatdia and Paturia ghat of Padma river





Gradient between surface water level and ground water level at Baruria.

Gradient between surface water level and ground water level at Launchghat.

Figure 4.20: Graph showing the elevation of ground water level at Paturia side with respect its bank line

4.1.7 Effect of Saturation on Pore Pressure

4.1.7.1 Effect of Saturation on Pore Pressure at Paturia Side

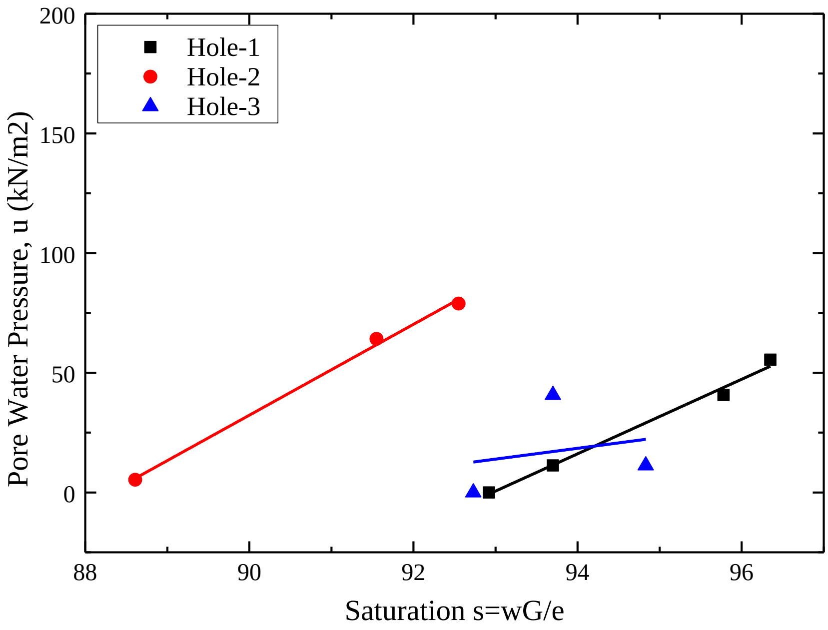


Figure 4.21: Graph showing the effect of saturation on pore pressure at Daskandi of Paturia side of Padma river

In Figure-4.21 the pore water pressure has been plotted with respect of its saturation. The data have been considered here on the month of February'18. From fig it is observed that the pore water pressure has been increased with the increases of saturation. It is mentionable that the data would become changed monthly as the location is situated on the river bank and the distance of the holes adjacent to the bank line. The saturation becomes full when the soil is submerged. The saturation has been increased I,e, from 85% to 97% in accordance with its soil properties as it depends on specific gravity as well as void ratio of the soils and its density. Their corresponding pore water pressures have been increased from 0 to 100kN/m2 accordingly. However, the saturation at hole no.-3 of Daskandi site has not been changed significantly in comparison with other two holes. It has also been happened due to its soil layers and properties and its ground water level as well as coordinates. In here the ground water level has been changed in accordance with surface water level. Here it is remarkable that reduced level was not existed at the alike coordinate and ground level. That's why the soil layer was not homogeneous however, the location was identical.

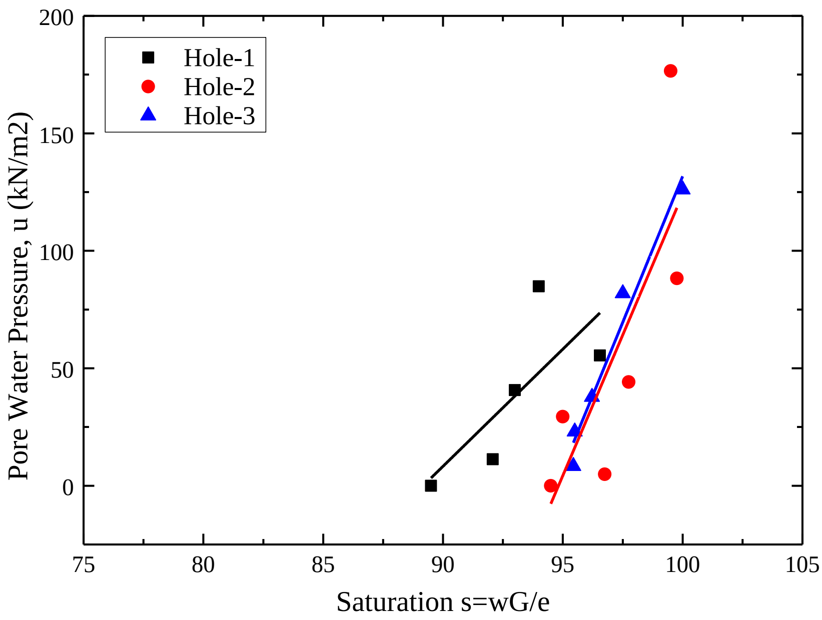


Figure 4.22: Graph showing the effect of saturation on pore prerssure at Baruria of Paturia side of Padma river

In Figure-4.22 the pore water pressure has been plotted with its respective saturation. The data have been considered here on the month of February'18. From fig it is observed that the pore water pressure has been increased with the increases of saturation. It is mentionable that the data would become changed monthly as the location is situated on the river bank and the distance of the holes adjacent to the bank line. The saturation becomes full when the soil is submerged. The saturation has been increased I,e, from 88% to 100% in accordance with its soil properties as it depends on specific gravity as well as void ratio of the soils and its density. Their corresponding pore water pressures have been increased from 0 to 170kN/m2 accordingly. However, the saturation at hole no.-1 of Baruria site is slightly dissimilar in comparison with other two holes. It has also been happened due to its soil layers and properties and its ground water level as well as coordinates. In here the ground water level has been changed in accordance with surface water level. Here it is remarkable that reduced level was not existed at the alike coordinate and ground level. That's why the soil layer was not homogeneous however, the location was identical.

4.1.7.2 Effect of Saturation on Pore Pressure at Daulatdia Side

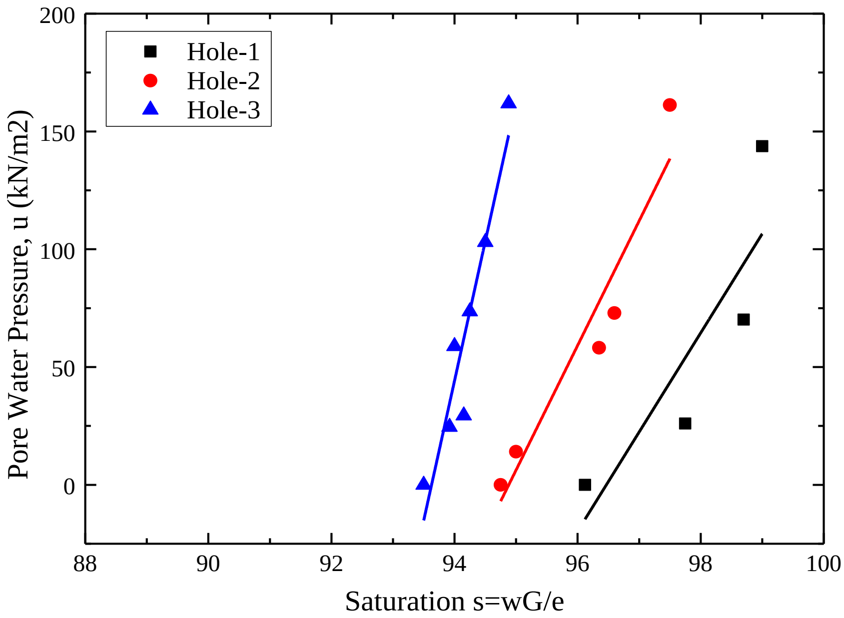


Figure 4.23: Graph showing the effect of saturation on pore pressure at CharBahirdia of Daulatdia side of Padma river

In Figure-4.23 the pore water pressure has been plotted with its respective saturation. The data have been considered here on the month of February'18. From figure it is observed that the pore water pressure has been increased with the increases of saturation. It is mentionable that the data would become changed monthly as the location is situated on the river bank and the distance of the holes adjacent to the bank line. The saturation becomes full when the soil is submerged. The saturation has been increased I,e from 93% to 99% in accordance with its soil properties as it depends on specific gravity as well as void ratio of the soils and its density. Their corresponding pore water pressures have been increased from 0 to 177kN/m2 accordingly. Here the small variation of saturation has been occurred due to its soil layers and properties and its ground water level as well as coordinate. In here the ground water level has been changed in accordance with surface water level. Here it is remarkable that reduced level was not existed at the alike coordinate and ground level. That's why the soil layer was not homogeneous however, the location was identical.

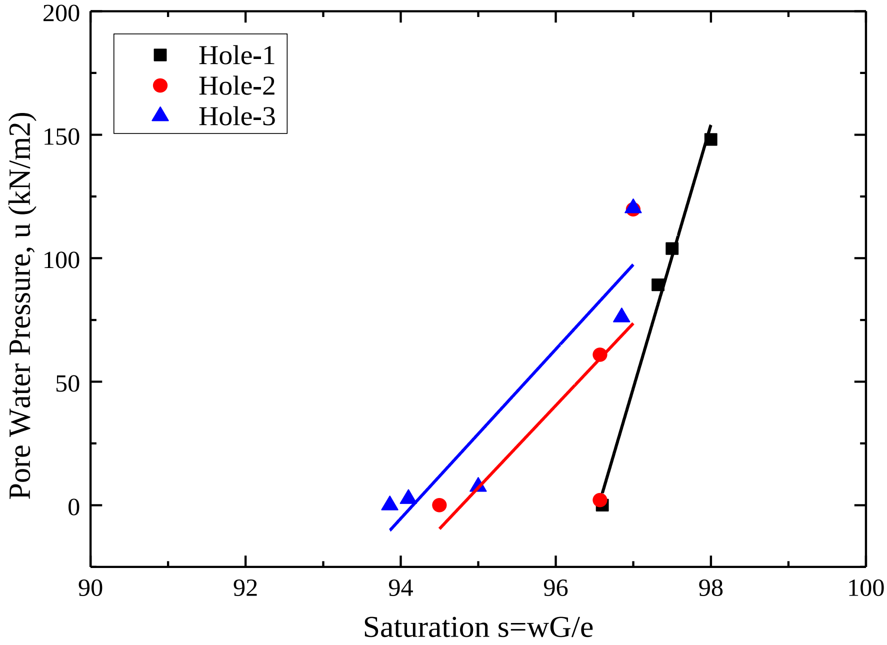


Figure 4.24: Graph showing the effect of saturation on pore pressure at Launchghat of Daulatdia side of Padma river

In Figure-4.24 the pore water pressure has been plotted with its respective saturation. The data have been considered here on the month of February'18. From figure it is observed that the pore water pressure has been increased with the increases of saturation. It is mentionable that the data would become changed monthly as the location is situated on the river bank and the distance of the holes adjacent to the bank line. The saturation becomes full when the soil is submerged. The saturation has been increased i,e from 93% to 97% in accordance with its soil properties as it depends on specific gravity as well as void ratio of the soils and its density. Their corresponding pore water pressures have been increased from 0 to 163kN/m2 accordingly. However, the saturation at hole no.-1 of Launch Ghat site has been varied in comparison with other two holes. The variation has been occurred especially here as the hole was very close to bank line. In addition the soil layers, soil properties and its ground water level as well as coordinates were also differed. The most important effect was the ground water level has been changed in accordance with surface water level. Here it is remarkable that reduced level was not existed at the alike coordinate and ground level. That's why the soil layer was not homogeneous however, the location was identical.

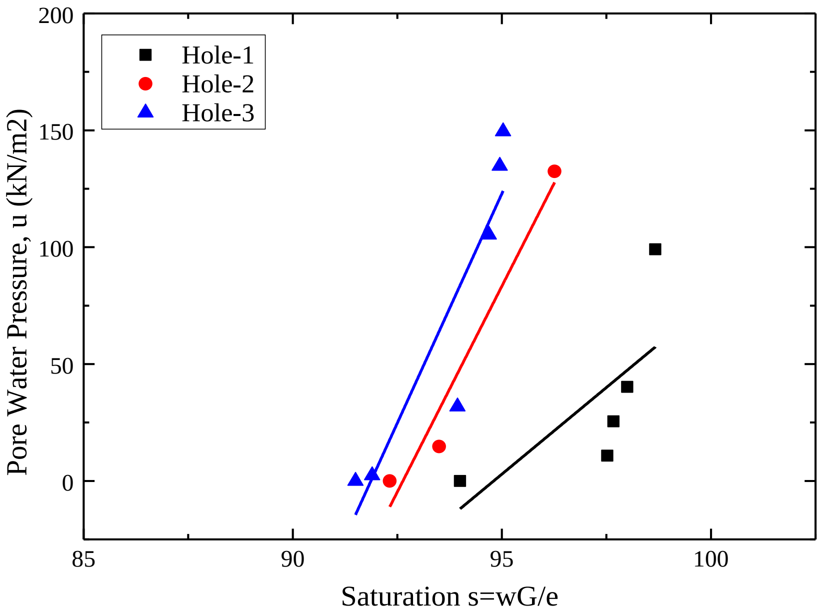


Figure 4.25: Graph showing the effect of saturation on pore pressure at Afsarsheikher Para of Daulatdia side of Padma river

In Figure-4.25 the pore water pressure has been plotted with its respective saturation. The data have been considered here on the month of February'18. From figure it is observed that the pore water pressure has been increased with the increases of saturation. It is mentionable that the data would become changed monthly as the location is situated on the river bank and the distance of the holes adjacent to the bank line. The saturation becomes full when the soil is submerged. The saturation has been increased I, e from 91% to 98% in accordance with its soil properties as it depends on specific gravity as well as void ratio of the soils and its density. Their corresponding pore water pressures have been increased from 0 to 164kN/m2 accordingly. However, the saturation at hole no.-1 of Afsarsheikherchar site is slightly different in comparison with other two holes. Here one reason is the hole-No.1 is very adjacent to bank line and another reasons are soil layers and its properties. As a result, saturation increased as well as ground water and water level. It is noticed that the ground water level has been changed in accordance with surface water level. Here it is remarkable that reduced level was not existed at the alike coordinate and ground level. That's why the soil layer was not homogeneous however, the location was identical.

4.1.8 Effect of Pore Pressure on Shear Strength

4.1.8.1 Effect of Pore Pressure on Shear Strength at Paturia Side of Padma river

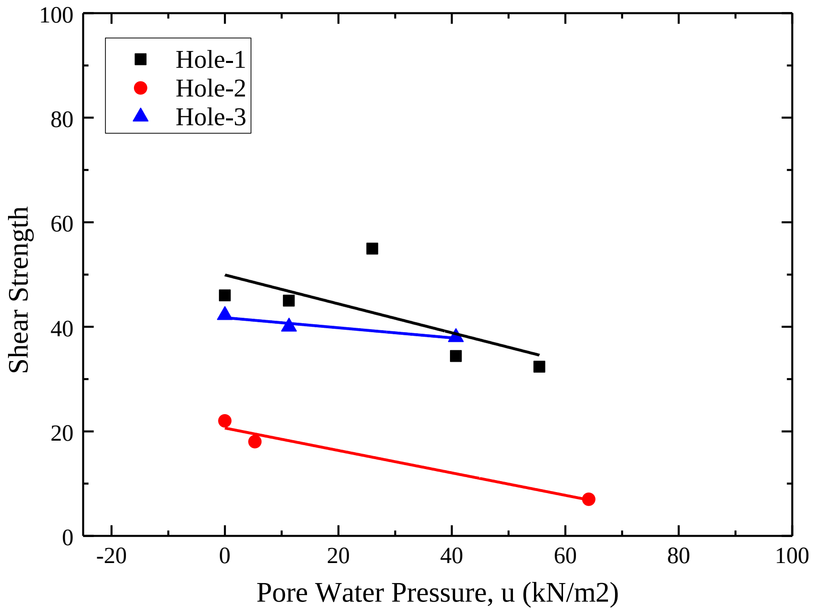


Figure 4.26: Graph showing the effect of pore pressure on shear strength at Daskandi of Paturia side of Padma river

In Figure-4.26 Shear strength has been plotted with corresponding pore pressure. From the graph it is observed that shear strength decreases with the increases of pore water pressure in different pattern in three holes. Such as shear strength of the soils of hole no-1 is more than that of hole no.-2 and hole no.-3 is more or less constant with the increases of pore pressure. The shear strength of the soil of hole no.-2 is less than that of other two holes. Here it is noticed that reduced level was not existed at the alike coordinate and ground level. That's why the soil strength is not homogeneous however, the location was identical.

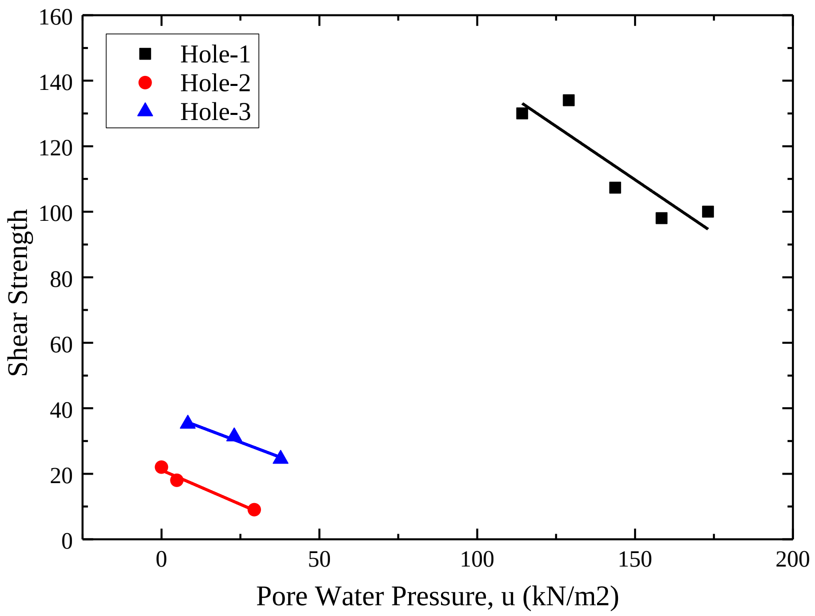


Figure 4.27: Graph showing the effect of pore pressure on shear strength at Baruria of Paturia side of Padma river

In Figure-4.27 Shear strength has been plotted with corresponding pore pressure. From the graph it is observed that shear strength decreases with the increases of pore water pressure in different pattern in three holes. Such as shear strength of the soils of hole no-1 decreases rapidly with the increases of pore water pressure whereas this tendency is slow in case of hole no. 2 & 3.This rapid tendency is due to high percentage of saturation limit. The shear strength of the soil of hole no.-3 is more than that of other two holes. Here it is noticed that ground level was not existed at the alike coordinate and ground level. That's why the soil strength is not homogeneous however, the location was identical.

4.1.8.2 Effect of Pore Pressure on Shear Strength at Daulatdia Side of Padma river

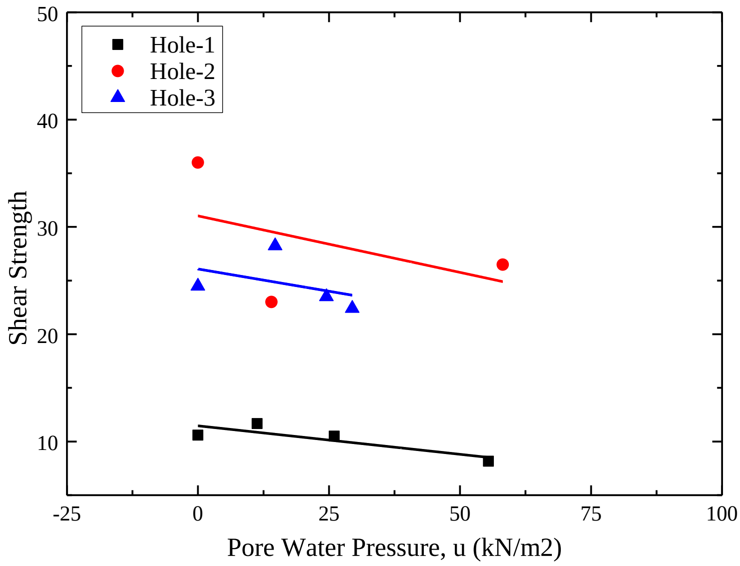


Figure 4.28: Graph showing the effect of pore pressure on shear strength at CharBahirdia of Daulatdia side of Padma river

In Figure-4.28 Shear strength has been plotted with corresponding pore pressure. From the graph it is observed that shear strength decreases with the increases of pore water pressure in both the holes. Shear strength of the soils of hole no-1 is less than that of hole no.-2 and hole no.-3. The shear strength of the hole no.-3 has been varied in a certain limit and the strength is more in hole no. 2.Here it is noticed that reduced level was not existed at the alike coordinate and ground water level as well as water level. That’s why the soil strength is not homogeneous however, the location was identical.

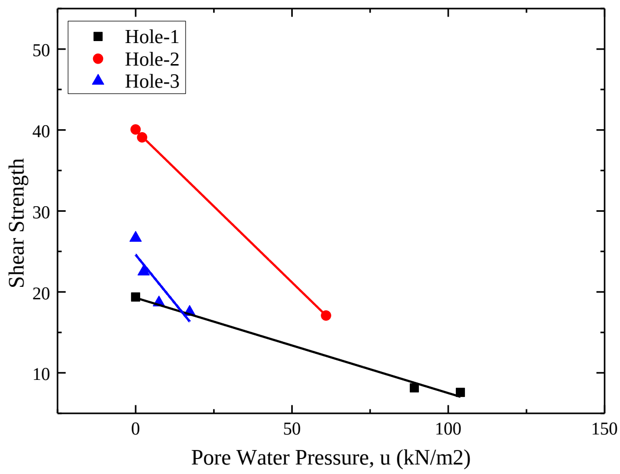


Figure 4.29: Graph showing the effect of pore pressure on shear strength at Launchghat of Daulatdia side of Padma river

In Figure-4.29 Shear strength has been plotted with corresponding pore pressure. From the graph it is observed that shear strength decreases with the increases of pore water pressure in both the holes. Shear strength of the soils of hole no-1 is less than that of hole no.-2 and hole no.-3. The shear strength of the hole no.-3 has been varied in a certain limit and the strength is more in hole no. 2.Here it is noticed that ground level was not at the alike coordinate and ground water level as well as water level. That's why the soil strength is not homogeneous however, the location was identical.

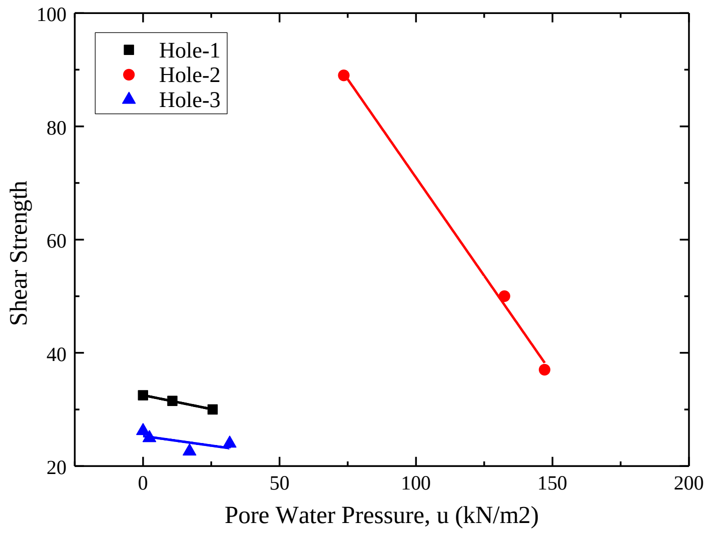


Figure 4.30: Graph showing the effect of pore pressure on shear strength at Afsarsheikher Para of Daulatdia side of Padma river

In Figure-4.30 Shear strength has been plotted with corresponding pore pressure. From the graph it is observed that shear strength decreases with the increases of pore water pressure in both the holes. Shear strength of the soils of hole no.-1 and hole no-3 are less than that of hole no.-2. The shear strength of the hole no.-2 has been varied rapidly with pore pressure. The variation of particle sizes of the soils effects the pore pressure as well as shear strength. The ground level was not existed at the alike coordinate and ground water level as well as water level. That's why the soil strength is not homogeneous however, the location was identical.

4.2 The sign of river bank Failure

The failure of a mass of soil located beneath a slope is called a slide. It involves a downward and outward movement of the entire mass of soil that participates in the failure. The failure of a slope in a cohesive material is commonly preceded by the formation of tension cracks behind the upper edge of the slope. If the failure occurs along a surface of sliding that intersects the slope at or above its toe, the slide is known as a slope failure.

On the other hand, if the soil beneath the level of the toe of the slope is unable to sustain the weight of the overlying material, the failure occurs along a surface that passes at some distance below the toe of the slope, a failure of this type is known as a base failure.(Terzaghi&Peck,1948).

Streambank Materials and Erosion

Streambank failure is closely related to the composition of the streambank material. Although these materials can be highly variable, they can be broadly divided into four categories.

Bedrock- Outcrops of bedrock are generally quite stable; however, they can cause erosion in the opposite bank if it is softer material.

Cohesionless Banks- Cohesionless soils are heterogeneous mixtures of silts, sands, and gravels. These soils have no electrical or chemical bonding between particles and are eroded particle by particle. Erosion of cohesionless soils is determined by gravitational forces, bank moisture, and particle characteristics. Factors influencing erosion also include seepage forces, piping, and fluctuations in shear stress.

Cohesive Banks- These banks generally contain large quantities of clay particles which create a higher level of bonding between the particles. Consequently, cohesive soils are more resistant to surface erosion because they are less permeable. This reduces the effects of seepage, piping, and frost heaving. However, because of low permeability, these soils are more susceptible to failure during rapid drawdown of water levels due to the increase in soil pore water pressures.

Stratified or Interbedded Banks- These banks are generally the most common bank type in fluvial systems because of the natural layering process. These soils consist of layers of materials of various textures, permeability, and cohesion. When cohesionless layers are interbedded with cohesive soils, the erosion potential is determined by the characteristics of the cohesionless soil. When the cohesionless soil is at the toe of the bank, it will generally control the erosion rate of the overlaying cohesive layer. When a cohesive soil is at the toe of the slope, it will generally protect any cohesionless layers above (although these layers will still be subject to surface erosion.

Human actions are often responsible. Channelization and constrictions caused by bridges are examples that will change velocities. Changes in flow direction often result from an obstruction along or in the channel. Any unnatural destruction of bank vegetation promotes erosion by hydraulic forces. Geotechnical failures are usually the result of moisture conditions in the stream bank which create forces that exceed bank resistance. Common examples of the causes include (Hagerty 1991; USACE 1981):

• Banks are destabilized by the piping of cohesionless soil from lenses (Figure 2).

• Capillary action temporarily decreases the angle of repose of the bank material to less than the existing bank slope.
• Liquefaction of fine-grained material causes fluid-like failures of the bank from pore pressure increase during rapid drawdown.
• Shrinking and swelling of clay soils during wetting and drying cycles causes tension cracks.
• Freezing and thawing of soil which weakens the shear strength.
• Subsurface moisture changes weaken the internal shear strength of the soil mass at the interface of different soil types.

Wave action-Wave action is the impact of waves hitting directly on exposed soil. Waves vary with wind speeds and duration, water depth, and the continuous length of water over which winds blow in one direction. Wave heights can be calculated when these properties are known. Choosing and designing a shoreline stabilization method requires knowing the maximum height of waves affecting the property. Waves can also be created by heavy boat traffic near shorelines

Stream bank Erosion Factors

The Wisconsin Department of Natural Resources (WDNR) adapted Dave Rosgen's Bank Erosion Hazard Index procedure to rate the potential severity of stream bank erosion. The following seven factors are used in the Bank Erosion Potential Index:
1. Bank Materials
2. Hydraulic Influence of Structures
3. Maximum bank height divided by the OHWM (bank full) height
4. Bank Slope
5. Stratification/Bank Layering
6. Bank Vegetation
7. Thalweg Location

Bank failure mechanism at Paturia side of Padma River

The low flood level at Paturia side generally varies from 1.8m to 2.0m and high flood level varies from 7m to 9m. The elevation at Paturia side adjacent to the bank line is 6.667m to 6.935m. It becomes submerge at monsoon. From the low flood level the bank height is 4.867m to 4.935m. In this bank line, the layering of the bank material is FINE SAND mixed with some silt and trace mica. On the other hand, the stratification of the materials from the bank line to the ground surface consists of cohesive layer wherever the high flood level varies from 7m to 9m. In this layer, about 30% of clay particles are presented over this layer which has been observed. Due to presence of such amounts of clay particles create a higher level of bonding between the particles. Consequently, these soils are more resistant to surface erosion because they are less permeable. This reduces the effects of seepage, piping. However, because of low permeability, these soils are more susceptible to failure during rapid drawdown of water levels due to the increase in soil pore water pressures.

Here it is mentioned that the maximum bank height with respect to bank full height is more. That's why the bank failure tendency is low.

It is noticed that waves are created by ferry and launch traffic near the bank line at Paturia side. Waves vary with wind speeds and duration, water depth, and the continuous length of water over which winds blow in one direction. As wave action is the impact of waves hitting directly on exposed soil as well as trafficking ferry and launch. So, it expedites the bank failure action in addition with the remaining pore water pressures of cohesive soil at the Paturia side.

Failure mechanism at Daulatdia side of Padma River

The low flood level at Daulatdia side generally varies from 2m to 2.5m and high flood level varies from 8m to 9.5m. The elevation at Daulatdia side adjacent to the bank line is 7.219m, 6.753m and 7.914m. It would become submerge at monsoon. From the low flood level the bank height remains 5.219m, 4.753m and 5.914m to 4.719m, 4.253m and 5.414m. In these bank lines, the layering of the bank material is FINE SAND mixed with some silt and trace mica.

On the other hand, the stratification of the materials from the bank line 5.219m to the ground surface consists of cohesive layer wherever SILT particles are dominant. The soil strata from the bank line 4.753m to the ground surface consists of alternate layer of cohesive and non-cohesive soil layer. The cohesive soil layers dominate SILT particles together with CLAY particles in comparison with the presence of SAND particles. The stratification of the materials from the bank line 5.219m to the ground surface consists of non-cohesive layer wherever clay particles are zero except upper 1.5m layer which is cohesive soil layer. At Daulatdia side, high flood level varies from 8m to 9.5m.

On the two bank lines 7.219m and 6.753m, as SILT particles together with CLAY particles make cohesive soils so a medium level of bonding between the particles. Consequently, these soils are moderately resistant to surface erosion because they are moderate permeable. This reduces the moderately effects of seepage, piping. However, because of moderate permeability, these soils are as susceptible to failure during rapid drawdown of water levels due to the increase in soil pore water pressures as well as soil erosion from toe zone. As a result, the river bank fails as base failure due to water pressure.

In measurement of bank slope, it is observed that the bank is very steep as toe soils are eroded due to soil their characteristics. On the other hand, the maximum bank height with respect to bank full height is so small. That's why the bank failure tendency is high.

It is observed that waves are created by ferry, launch and trawler boat traffic near the two bank lines at Daulatdia side. Waves vary with wind speeds and duration, water depth, and the continuous length of water over which winds blow in one direction. As wave action is the impact of waves hitting directly on exposed soil as well as trafficking ferry and launch. So, it expedites the bank failure action in addition with the remaining pore water pressures of cohesive soil at the Daulatdia side.

On the bank line 7.914m, the low flood level is 5.914m and high flood level is 8m. In the low flood level soil layer contains SAND particles together with little amount of silt particles make non-cohesive soils layer. So, there is no bonding between the particles as CLAY particles are absent. The standard penetration resistance–N values have been altered which make the soil layers sometime loose and sometime dense. Consequently, rising water level intensify water pressure resultant the bank failure due to liquefaction. As a result, the river bank as well as the homogeneous soil zone as long liquefies due to water pressure.

The questionnaire survey of the river bank community reveals that the bank of Daulatdia side is more vulnerable than the Paturia side of Padma River. The key findings of questionnaire surveys are given below:

- All respondent of river bank community said that the bank fail on July and river bank fail when flow begins. They also said that when surface water decreases the river bank fails. They mentioned that due to heavy current and velocity create turbulence and bank fails. They also stated that river bank failure phenomena depend on soil quality.

- BIWTA official said that the erosion is more in Jamuna and Padma Rivers as these rivers are non-tidal. As a result, the bank failure tendency is more.

- All the respondents said that the river bank fails for additional sand layer.

Chapter 5

Conclusions

5.1 Bank Failure

The bank failure reasons at Paturia and Daulatdia side have been investigated in geotechnical aspects. Geotechnical investigation reveals that Paturia side is less affected due to geotechnical reasons in comparison with Daulatdia side. The soil profile and their properties are different from each other. Due to soil profile and their properties the pore pressure, saturation, permeability as well as their seepage also has been different. Indeed Afsarsheikher Para is severely affected area of Daulatdia side. Its soil layers are significantly different from any other layers. The bank failure is being occurred in this area as its geotechnical character is in favor to identical.

5.2 Geotechnical parameters at the bank of Paturia Side

From the field and laboratory investigation the following geotechnical parameters are found out:

- Cohesive soil layers are observed up to (0-9)m
- SPT-N values of cohesive soils varies from 3 to 14
- Cohesive soils contain sand-(0-25)%, silt-(60-87)%, clay-(5-40)%
- Non-cohesive soil layers are dominant after that depth
- SPT-N values of non-cohesive soils varies from 4 to 55
- Non-cohesive soils contain sand-(19-93)%, silt-(7-79)%, clay-(0-2)%
- Mica Content 8.5% in which Muscovite-2%, Biotite-5%, Chlorite-1.5%.
- Natural Moisture content of cohesive soil varies from (26.30-41.53)%.
- Natural Moisture content of non-cohesive soil varies from (21.48-30.33)%
- Wet unit weight varies from 14.66kN/m^3 to 25.81kN/m^3
- Dry unit weight varies from 11.81kN/m^3 to 19.14kN/m^3
- Specific gravity varies from 2.599 to 2.715
- Saturation varies from 88% to 100%
- Permeability varies from 1.08×10^{-4}cm/sec to 8.27×10^{-2}cm/sec.
- Pore pressure varies from -24 to 140 kN/m^2
- pH varies from 7.72 to 8.04
- Ground level varies from 6.667mPWD to 9.492mPWD
- Water level varies from 2mPWD to 9mPWD around all the year from dry to monsoon
- Ground water level varies from 3.048m to 3.9624m

5.3 Geotechnical reasons for bank failure at Paturia Side

From the investigation it is found that the main geotechnical reasons of bank failure at the Paturia side are-

- Variation of particle sizes of soil
- Variation of natural moisture content of soil
- Increasing trend of saturation of soil
- Increasing trend of pore pressure of soil
- Decreasing trend of shear strength
- Variation of density of soil
- Variation of permeability of soil layer
- Ground water fluctuation at the study area shows various gradient causing seepage failures during dry season.
- Waves are created by ferry and launch traffic near the bank line at Paturia side. As wave action is the impact of waves hitting directly on exposed soil as well as trafficking ferry and launch. So, it follows the bank failure action in addition with the remaining pore water pressures of cohesive soil at the Paturia side.
- Due to overpressure on the bank of traffic loading and unloading causes bank failure

5.4 Geotechnical parameters at the bank of Daulatdia Side

From the field and laboratory investigation the following geotechnical parameters are found out:

- Cohesive soil layers are observed up to (0-12.5)m. Especially, cohesive soil layers are observed up to (0-2)m
- SPT-N values of cohesive soils varies from 2 to 7
- Cohesive soils contain sand-(5-27)%, silt-(68-72)%, clay-(0-11)%
- A number of amount of non-cohesive soil layers are presented
- Non-cohesive soil layers are dominant after that depth
- SPT-N values of non-cohesive soils varies from 3 to 50
- Non-cohesive soils contain sand-(48-97)%, silt-(3-49)%, clay-(0-2)%
- Mica Content varies from 6% to 10% in which Muscovite-(1-5)% ,Biotite-(2-5)% and Chlorite-(1-2)%
- Natural moisture content of cohesive soil varies from 24% to 44%
- Natural Moisture content of non-cohesive soil varies from 7% to 34%
- Wet unit weight varies from 15.86kN/m^3 to 19.37kN/m^3
- Dry unit weight varies from 12.95kN/m^3 to 15.56kN/m^3
- Specific gravity varies from 2.646 to 2.81
- Saturation varies from 87% to 98%
- Permeability varies from 3.37×10^{-5}cm/sec to 8.27×10^{-2}cm/sec
- Pore pressure varies from -48 to 177kN/m^2
- pH varies from 7.71 to 8.70
- Ground level varies from 6.753mPWD to 9.526mPWD
- Water level varies from 2mPWD to 9.5mPWD around all the year from dry to monsoon
- Ground water level varies from 2.7432m to 6.4008m

5.5 Geotechnical reasons for bank failure of Daulatdia Side

From the investigation it is found that the main geotechnical reasons of bank failure at the Daulatdia side are-

- Variation of particle sizes of soil
- Variation of natural moisture content of soil
- Increasing trend of saturation of soil
- Increasing trend of pore pressure of soil
- Decreasing trend of shear strength
- Variation of density of soil
- Variation of permeability of soil layer
- Due to overpressure on the bank of traffic loading and unloading causes bank failure
- Seepage is more as there are permeable soil layer
- Seepage line effect the bank. Seepage is significant as there are maximum permeable soil layer
- At the beginning of monsoon, failure occurs during the raising period of surface water causes mass failure as the gravitational force is less than soil mass.
- At monsoon, failure occurs for high stream causes liquefaction of soil as there are several non-cohesive layers whose SPT values are less than 15 especially at Afsarsheikher Para.
- At recession period, failure occurs as ground water level does not fall as surface water level due to various sizes soil and types of layers as well as their properties
- At recession period, failure occurs as there is no confining pressure and slope is not sufficient as much as need i,e. bank is very steep(1:0.5 -1:1)
- Hydraulic condition mainly flow concentration and increased velocity is also an important factor for bank erosion at the Daulatdia site.
- Ground water fluctuation at the study area shows various gradient causing seepage failures during dry season.
- Waves are created by ferry and launch traffic near the bank line at Daulatdia side. As wave action is the impact of waves hitting directly on exposed soil as well as trafficking ferry and launch. So, it follows the bank failure action in addition with the remaining pore water pressures of cohesive soil at the Daulatdia side.

5.5 Bank failure mechanism at Paturia side of Padma River

The low flood level at Paturia side generally varies from 1.8m to 2.0m and high flood level varies from 7m to 9m. The elevation at Paturia side adjacent to the bank line is 6.667m to 6.935m. It becomes submerge at monsoon. From the low flood level the bank height is 4.867m to 4.935m. In this bank line, the layering of the bank material is FINE SAND mixed with some silt and trace mica. On the other hand, the stratification of the materials from the bank line to the ground surface consists of cohesive layer wherever the high flood level varies from 7m to 9m. In this layer, about 30% of clay particles are presented over this layer which has been observed. Due to presence of such amounts of clay particles create a higher level of bonding between the particles. Consequently, these soils are more resistant to surface erosion because they are less permeable.

This reduces the effects of seepage, piping. However, because of low permeability, these soils are more susceptible to failure during rapid drawdown of water levels due to the increase in soil pore water pressures. Here it is mentioned that the maximum bank height with respect to bank full height is more. That's why the bank failure tendency is low.

It is noticed that waves are created by ferry and launch traffic near the bank line at Paturia side. Waves vary with wind speeds and duration, water depth, and the continuous length of water over which winds blow in one direction. As wave action is the impact of waves hitting directly on exposed soil as well as trafficking ferry and launch. So, it follows the bank failure action in addition with the remaining pore water pressures of cohesive soil at the Paturia side.

5.6 Bank Failure mechanism at Daulatdia side of Padma River

The low flood level at Daulatdia side generally varies from 2m to 2.5m and high flood level varies from 8m to 9.5m. The elevation at Daulatdia side adjacent to the bank line is 7.219m, 6.753m and 7.914m. It would become submerge at monsoon. From the low flood level the bank height remains 5.219m, 4.753m and 5.914m to 4.719m, 4.253m and 5.414m. In these bank lines, the layering of the bank material is FINE SAND mixed with some silt and trace mica.

On the other hand, the stratification of the materials from the bank line 5.219m to the ground surface consists of cohesive layer wherever SILT particles are dominant. The soil strata from the bank line 4.753m to the ground surface consists of alternate layer of cohesive and non-cohesive soil layer. The cohesive soil layers dominate SILT particles together with CLAY particles in comparison with the presence of SAND particles. The stratification of the materials from the bank line 5.219m to the ground surface consists of non-cohesive layer wherever clay particles are zero except upper 1.5m layer which is cohesive soil layer. At Daulatdia side, high flood level varies from 8m to 9.5m.

On the two bank lines 7.219m and 6.753m, as SILT particles together with CLAY particles make cohesive soils so a medium level of bonding between the particles. Consequently, these soils are moderately resistant to surface erosion because they are moderate permeable. This reduces the moderately effects of seepage, piping. However, because of moderate permeability, these soils are as susceptible to failure during rapid drawdown of water levels due to the increase in soil pore water pressures as well as soil erosion from toe zone. As a result, the river bank fails as base failure due to water pressure.

In measurement of bank slope, it is observed that the bank is very steep as toe soils are eroded due to soil characteristics. On the other hand, the maximum bank height with respect to bank full height is so small. That's why the bank failure tendency is high.

It is observed that waves are created by ferry, launch and trawler boat traffic near the two bank lines at Daulatdia side. Waves vary with wind speeds and duration, water depth, and the continuous length of water over which winds blow in one direction. As wave action is the impact of waves hitting directly on exposed soil as well as trafficking ferry and launch. So, it expedites the bank failure action in addition with the remaining pore water pressures of cohesive soil at the Daulatdia side.

On the bank line 7.914m, the low flood level is 5.914m and high flood level is 8m. In the low flood level soil layer contains SAND particles together with little amount of silt particles make non-cohesive soils layer. So, there is no bonding between the particles as CLAY particles are absent. The standard penetration resistance–N values have been altered which make the soil layers sometime loose and sometime dense. Consequently, rising water level intensify water pressure resultant the loose layer bank failure due to liquefaction. As a result, the river bank as well as the homogeneous soil zone as long liquefies due to water pressure.

Chapter 6

Recommendations

Geotechnical information is always very important for any type of construction works on it. Therefore it is very much essential to investigate the soil character of the river bank prior any bank stabilization and protection works. In particular severe erodible and bank erosion prone area needs to focus on investigation through proper testing of different soil parameters. The findings of the present research work are expected to help a lot to the concerned authorities for undertaking any construction work at the study area. The following recommendations are proposed from the research work.

Geotechnical investigation in depth at the study area to adopt any stabilization/bank protection works

Geotechnical investigation needs to any of the earth retaining and earth structures. As geotechnical investigation includes site investigation, design and construction of foundations, retaining structures, stability of slopes, underground structures, pavement design, earth dam and other problems related with soil such as soil heave, soil subsidence, frost heave, shrinkage and swelling of soils.

Every stabilization and river bank protection works are the components of the soil which tends to move it downward causes instability. Geotechnical investigation provides the way for proving the in stabilization and river bank protection works.

Wave action needs to be considered during the design of the ferry ghat protection works

Bangladesh is occupied by 80% of the alluvial soils. The study areas are in the alluvial soils reason and public route for ferry. The wave action deposits the sediment as well as detaches the coarse sediment. Having the soils are new alluvium and water seeping below the body of the hydraulic structures which endangers the stability of the structure and may cause its failure either by piping or by direct uplift.

Here hydraulic instability is caused by scour at the toe of a marginally stable bank, flood propagation and flood recession, debris and vegetation, removal of bank vegetation, detachment of coarse sediment by wave action, secondary current etc.

Wave action is the impact of waves hitting directly on exposed soil. Waves vary with wind speeds and duration, water depth, and the continuous length of water over which winds blow in one direction. Wave heights can be calculated when these properties are known. Choosing and designing a shoreline stabilization method requires knowing the maximum height of waves affecting the property. Waves can also be created by heavy boat traffic near shorelines. So, Wave action needs to be considered during the design of the ferry ghat protection works.

Soil properties at the study area indicate soil strengthening required for bank protection works.

All the problems of soil engineering are related with the soil properties of the soil. Shear strength is the principal engineering property of soil which controls the stability of a soil mass under loads. It governs the bearing capacity of soils, the stability of slopes in soils, the earth pressure against the retaining structures and many other problems.

The study area is at the river bank and the soil strata are very loose to dense in condition. At monsoon, the soil is submerged and become full of saturation indeed. In that condition, the increasing trend of pore pressure decreases the soil strength. As a result the river bank tends toward the failure. So, an engineer needs to required soil strengthening opportunities in this regard.

Sand drain should be implemented up to low water level

Sand drain is used mainly to increase the rate of drainage in the embankment. The horizontal drainage occurs due to because of sand drains. The sand drain accelerates the process of dissipation of excess pore water created by surcharge. The geotechnical engineers design foundation and other structures on the ground after investigation of the soil, its characteristics and its extent.

River bank slope should be horizontal 3 and vertical 1

A very steep slope may not be stable. The failure of a slope may lead to loss of life and property. It is, therefore, essential to check the stability of proposed slopes with respect to the remaining mass. The failure of a soil mass occurs along a plane or a curved surface when a large mass of soil slides with respect to the remaining mass. A slope failure occurs when the forces causing failure are greater than the shearing resistance developed along a critical surface of failure. The factor which causes an increase in the shear stresses. The stresses are also increased due to steepening of slopes either by excavation or by natural erosion. Another is the factor which causes a decrease in the shear strength of the soil. The loss of shear strength may occur due to increase in water content, increase in pore pressure, shock or cyclic loads, weathering or any other cases.

Water level variation in the river is required special attention

When the water level suddenly goes down pore water cannot drain out so fast. As we know the pore pressure consists of i) downward neutral part of the weight and ii) hydrostatic pressure exerted by water standing against the slope and iii) the resultant water pressure. The downward neutral part of the pore water remains intact and hydrostatic pressure vanishes. In other words, the seepage line inside the slope remains intact and submergence conditions continue. The downward neutral part of the weight causes additional instability in the soil wedge as it cannot mobilize any frictional strength.

The soil needs to be capable of giving additional cohesive resistance for inter-granular forces to resist the sudden drawdown of the water level. Hence, a sudden drawdown case is the worst case for the upstream slopes of levees or earth dam. (S.K.Garg,p-429-430)

Investigation needs for enhancing the knowledge soil profile and its properties

Whenever an engineer likes to plan a structure either it is water control or others it is necessary to know the details of the soil strata, its properties and its other underground conditions of the construction site. The sequence, depths and lateral extent of different soil strata and their properties are required. The position of water table and its fluctuations are also needed for general investigation. However, more detailed investigations are needed to determine the permeability, compressibility, density index, pore pressure etc.

Testing of engineering properties of soil can contribute to find out the precise bank failure reasons

Bank failure phenomena are a common scenario at monsoon in Bangladesh. Almost every year river banks fail and people are facing problems. Devastating flood and excessive rainfall are accelerating the failure process which results in immense damage to river bank, agriculture and infrastructures every year.

The major part of Bangladesh is on the delta formed by three major rivers Brahmaputra, Ganges and Meghna. These rivers and many of the country's other minor rivers originate outside the national boundary of the country and make up the Ganges-Brahmaputra-Meghna river system. Over millennia, the sediments carried by the huge discharges of these rivers have built a broad delta, forming most of the large area of Bangladesh and the submerged delta-plain in the bay of Bengal. The huge sediments are the major sources of formation of 80% soils of the country. The remaining 20% of soils have been formed in Tertiary and Quaternary sediments of hills (12%) and in uplifted Pleistocene terrace (8%).

Riverbank failure occurs both for hydraulic and geotechnical instability. Besides, constructed bridge crossings or other encroachments that involve acceleration and concentration of flood flows tends to cause 'back eddies' or reverse circulation downstream, which can sometimes erode river banks. Hydraulic instability is caused by scour at the toe of a marginally stable bank, flood propagation and flood recession, debris and vegetation, removal of bank vegetation, detachment of coarse sediment by wave action, secondary current etc. Geotechnical instability is the major causes of the geotechnical unstable materials, improper method of construction, seepage and sliding etc. among many reasons.

Under such circumstances, continuous research needs to find out precise bank failure reasons.

Chapter 7

Recommendations for new structures

- Many times the protective work along the bank of the river follows only the conventional technique. However, they need vast geotechnical investigation for appropriate design of protective works. The research may recommend implementing the result to the design of those structures of the protective work -
- If the protective works are at the same area of the study area of the research
- If the protective works are at the same soil strata

Chapter 8

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Annexure

Table-1: Soil parameters of hole no.-1 of Daskandi location of Paturia side

Name of the parameter	Location									
	Daskandi									
	Hole No. 1									
	D1	U1	D2	U2	D3	D4	D5	D6	D7	D10
Depth in m	1.5	2.5	3	3.5	4.5	6	7.5	9	10.5	15
Natural Moisture Content, NMC in %	29.52	20.93	36.27	30.31	37.48	29.23	26.3	36.89	26.25	26.3
Wet Unit Weight, γw in kN/m3		25.78		18.43						
Dry Unit Weight γd in kN/m3		21.32		14.14						
Specific Gravity, Gs	2.599	2.685	2.690	2.70			2.695	2.690	2.65	
Compression index, Cc		0.146								
Permeability k in mm/sec	1.20E-03	7.68E-02	5.88E-02					5.29E-03	8.27E-02	7.80E-02
Unconfined compressive Strength, qu in kN/m2		30.78 at 2% strain								
Cohesion c in kN/m2				30						
Angle of internal friction ϕ in degree				18						
Sand in %	13.2	16.04	7.77		4.34		85.71	19.19	92.64	92.4
Silt in %	79.65	77.38	84.02		64.27		14.29	79.38	7.36	7.6
Clay in %	7.15	6.58	8.21		31.39		0	1.43	0	0
SPT value	4		3		4	11	17	9	32	24
Color	Light Brown	Grey								

Table-2: Soil parameters of hole no.-2 of Daskandi location of Paturia side

Name of the parameter	Location									
	Daskandi									
	Hole No.2									
	D1	U1	D2	U2	D3	D4	D5	D6	D7	D12
Depth in m	1.5	2.5	3	3.5	4.5	6	7.5	9	10.5	18
Natural Moisture Content, in %	40.3	34.88	41.53	30.6	38.54	34.43	26.7	39.33	24.53	26.57
Wet Unit Weight,γw in kN/m3		25.81		18.43						
Dry Unit Weight γd in kN/m3		19.14		14.14						
Specific Gravity,Gs	2.67	2.709	2.709	2.626	2.603				2.65	2.66
Compression index, Cc		0.18 at 91.03% sat.		0.21 at 89.73% sat.						
Permeability,k in mm/sec	5.88E-04	1.08E-04		8.75E-03		5.88E-04		1.08E-04	8.27E-02	6.57E-02
Unconfined compressive Strength, qu in kN/m2		71.45 at 9% strain								
Cohesion c in kN/m2		0		40						
Angle of internal friction ϕ in degree		21		12						
Sand in %	4.91	8.06		16.32	6.33	25.17		8.34	92.67	89.5
Silt in %	87.11	82.53		57.4	60.56	69.4		82.25	7.33	10.5
Clay in %	7.98	9.41		26.28	33.11	5.43		9.41	0	0
SPT value	2		2		3	12	16	8	41	25
Colour	Brownish grey	Grey								
pH	7.72									

Table-3: Soil parameters of hole no.-3 of Daskandi location of Paturia side

Name of the parameter	Location									
	Daskandi									
	Hole No.3									
	D1	U1	D2	U2	D3	D4	D5	D6	D7	D12
Depth in m	1.5	2.5	3	3.5	4.5	6	7.5	9	10.5	15
Natural Moisture Content, in %	32.02	30.54	31.98	32.52	36.88	9.55	31.72			
Wet Unit Weight, γw in kN/m3		17.24		19.04						
Dry Unit Weight γd in kN/m3		13.44		14.37						
Specific Gravity, Gs	2.68	2.672		2.715	2.70	2.66	2.69			2.69
Compression index, Cc		0.20 at 90.93% sat.		0.12 at 92.72% sat.						
Permeability k in mm/sec		6.22E-04	3.88E-03	8.75E-03						
Unconfined compressive Strength, qu in kN/m2		69.01 at 7.5% strain								
Cohesion c in kN/m2		76		22						
Angle of internal friction ϕ in degree		13		21						
Sand in %	7.78	4.55	28.04	15.65	0					
Silt in %	73.98	92.9	70.25	84.35	62.79					
Clay in %	18.24	2.55	1.71	0	37.21					
SPT value	6		5		9	7	11			27
Colour	L. Brown	Grey	L. Brown	Grey						
pH	7.87									

Table-4: Soil parameters of hole no.-1 of Baruria location of Paturia side

Name of the parameter	Location													
	Baruria													
	Hole No.1													
	D1	U1	D2	U2	D3	D4	D5	U3	D6	D7	D10	D12	D13	D14
Depth in m	1.5	2.5	3	3.5	4.5	6	7.5	9	10.5	15				
Natural Moisture Content, in %	34.56	32.82	39.76	42.53	31.7	31.92	31.32	28.85	22.51	26.45	23.85	26.17	23.35	20.6
Wet Unit Weight, γw in kN/m3		17.97		19.02				19.54						
Dry Unit Weight γd in kN/m3		13.53		13.34				15.16						
Specific Gravity, Gs	2.66	2.693		2.677		2.66		2.686	2.60		2.66			
Permeability k in mm/sec	1.08E-02	5.88E-04			5.88E-04		4.32E-04							
Unconfined compressive Strength, qu in kN/m2		16.85 at 2.5% strain		13.58 at 17% strain										
Sand in %	68.19	12.33	4.63		22.06		26.78	83.71/20.16	90.75	86.18				
Silt in %	31.81	84.24	64.82		76.51		69.23	16.29/73.26	9.25	13.82				
Clay in %	0	3.43	30.55		1.43		3.99	0/6.58	0	0				
SPT value	4		4		13	13	14		12	27	46	33	43	55
Color	Grey													

Table-5: Soil parameters of hole no.-2 of Baruria location of Paturia side

Name of the parameter	Location													
	Baruria													
	Hole No.2													
	D1	U1	D2	U2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D14
Depth in m	1.5	2.5	3	3.5	4.5	6	7.5	9	10.5	15				
Natural Moisture Content, NMC in %	32.18	31.26	31.87	24.17	25.73	30.46	28.57	33.63	30.33	32	23.13	25.6	22.21	24.27
Wet Unit Weight, γw in kN/m3		16.35		14.66										
Dry Unit Weight, γd in kN/m3		12.45		11.81										
Specific Gravity,Gs	2.72	2.605	2.65			2.68	2.69		2.66	2.65				2.65
Compression index,Cc		0.215 at 90.25% sat.												
Permeability k in mm/sec			2.54E-02	1.82E-03				1.92E-04		6.93E-02				6.68E-02
Unconfined compressive Strength, qu in kN/m2		27.17 at 7% strain		61.67 at 6.5% strain										
Sand in %	7.78	15.58	71.44	32.73		37.46		11.07	80.65	91.05				90.14
Silt in %	70.24	73.75	28.56	65.56		60.83		83.23	19.35	8.95				9.86
Clay in %	21.98	10.67	0	1.71		1.71		5.7	0	0				0
Mica(Total) Content in %			8.5											
Muscovite in %			2											
Biotite in %			5											
Chlorite in %			1.5											
SPT value	4		5		3	14	6	6	25	19	26	29	39	30
Colour	Grey		L. Brown	Grey										
pH	7.9	8.04												

Table-6: Soil parameters of hole no.-3 of Baruria location of Paturia side

Name of the parameter	Location													
	Baruria													
	Hole No.3													
	D1	U1	D2	D3	D4	U2	D5	D6	D7	D8	D9	D10	D12	D14
Depth in m	1.5	2.5	3	4.5	6	6.5	7.5	9	10.5	15	13.5	15	18	22
Natural Moisture Content,NMC in %	32.63	30.25	33.75	36.66	31.59	35.65	23.02	28.31	26.76	31.44	25.88	25.85	26.79	26.2
Wet Unit Weight,γw in kN/m3		19.1				17.92								
Dry Unit Weight γd in kN/m3		14.66				13.26								
Specific Gravity,Gs	2.69	2.661	2.66	2.66	2.69	2.55								
Compression index,Cc		0.1775 at 93.83%				0.24 at 96.22%								
Permeability, k in mm/sec			1.56E-04		2.65E-02									
Unconfined compressive Strength, qu in kN/m2		151.16 at 15% strain				70.92 at 14% strain								
Cohesion c in kN/m2		5				1/9								
Angle of internal friction ϕ in degree		18				15								
Sand in %	6.06		19.19	67.02	2.91	3.19								
Silt in %	77.67		74.23	32.98	69.08	56.84								
Clay in %	16.27		6.58	0	28.01	39.97								
SPT value	4		3	7	13		27	18	27	11	45	33	35	50
Colour	L. Brown	Grey												

Table-7: Soil parameters of hole no.-1 of Char Bahirdia location of Daulatdia side

Name of the parameter	Location												
	Char Bahirdia												
	Hole No.1												
	D1	U1	D2	U2	D3	D4	D5	D6	D7	D9	D10	D12	D14
Depth in m	1.5	2.5	3	3.5	4.5	6	7.5	9	10.5	13.5	15	18	22
Natural Moisture Content, NMC in %	28.74	30.04	33.44	32.75	30.22	31.73	26.55	25.73	24.13	26.65	29.09	36.84	26.07
Wet Unit Weight, γw in kN/m3		18.62		17.29									
Dry Unit Weight γd in kN/m3		17.29		13.02									
Specific Gravity,Gs	2.668	2.623		2.707		2.67			2.66				2.65
Compression index, Cc				0.1825 at 96.12% sat									
Permeability, k in mm/sec	1.67E-02		1.92E-04		5.92E-03	8.75E-03	4.34E-03	2.32E-04				7.87E-02	
Unconfined compressive Strength, qu in kN/m2				52.35 at 14% strain									
Cohesion c in kN/m2		3		6									
Angle of internal friction ϕ in degree		16		5									
Sand in %	20.06		27.48		54.01	67.73	48.9	10.89		83.99		92.15	
Silt in %	72.8		68.53		45.15	32.27	49.67	82.53		16.01		7.85	
Clay in %	7.14		3.99		0.84	0	1.43	6.58		0		0	
Mica(Total) Content in %		8											
Muscovite in %		2											
Biotite in %		5											
Chlorite in %		1											
SPT value	5		3		12	6	8	38	19	16	15	19	16
Color	Grey												

Table-8: Soil parameters of hole no.-2 of Char Bahirdia location of Daulatdia side

Name of the parameter	Location										
	Char Bahirdia										
	Hole No.2										
	D1	U1	D2	D3	U2	D4	D5	D7	D8	D12	D14	
Depth in m	1.5	2.5	3	4.5	5	6	7.5	10.5	10.5	12	18	
Natural Moisture Content, NMC in %	32.82	24.48	31.32	32.15	30.84	27.59	31.09	39.63	27.74	27.45	29.22	
Wet Unit Weight, γw in kN/m3		18.43			19.37							
Dry Unit Weight γd in kN/m3		14.81			14.8							
Specific Gravity, Gs	2.682	2.706		2.66	2.77			2.736	2.66		2.66	
Compression index, Cc					0.115 at 95% strain							
Permeability k in mm/sec			1.70E-04	8.70E-05		5.29E-03	4.34E-03	2.32E-04		6.68E-02		
Unconfined compressive Strength, qu in kN/m2		43.58 at 7.5% strain			18.36 at 6.5% strain							
Sand in %			5.19	9.18		55.45	48.59	11.19	83.99	91.37		
Silt in %			88.19	81.41		44.55	49.98	82.55	16.01	8.63		
Clay in %			6.62	9.41		0	1.43	6.26	0	0		
SPT value	5		2	8		7	10	7	21	28	39	
Colour	Grey											

Table-9: Soil parameters of hole no.-3 of Char Bahirdia location of Daulatdia side

Name of the parameter	Location										
	CharBahirdia										
	Hole No.3										
	D1	D2	D3	U1	D4	D6	U2	D7	D9	D11	D13
Depth in m	1.5	2.5	3	3.5	4.5	6	7.5	9	10.5	15	
Natural Moisture Content, NMC in %	12.31	35.5	27.56	30.27	25.99	36.51	30.75	24.7	23.1	26.86	23.79
Wet Unit Weight,γw in kN/m3				17.4			17.41				
Dry Unit Weight γd in kN/m3				13.36			13.32				
Specific Gravity,Gs	2.65	2.66	2.67	2.7		2.646	2.692		2.68	2.66	2.67
Compression index, Cc				0.1575 at 93.92% sat			0.17 at 94.25% sat				
Permeability k in mm/sec	7.50E-03					7.50E-05		3.37E-05			7.49E-02
Unconfined compressive Strength, qu in kN/m2				70.28 at 11% strain			103.06 at 15% strain				
Cohesion c in kN/m2							4				
Angle of internal friction ϕ in degree							20				
Sand in %	84.19	50.3	84.64		87.62	5.61		74.59	89.6		92.46
Silt in %	15.81	49.7	15.36		12.38	84.98		25.41	10.4		7.54
Clay in %	0	0	0		0	9.41		0	0		0
Mica(Total) Content in %	10										
Muscovite in %	3										
Biotite in %	5										
Chlorite in %	2										
SPT value	5	3	17		11	3		6	19	27	13
Colour	Grey										
pH	8.57										

Table-10: Soil parameters of hole no.-1 of Launchghat location of Daulatdia side

Name of the parameter	Location											
	Launchghat											
	Hole No.1											
	D1	U1	D2	D3	U2	D5	D8	D9	D10	D11	D12	D13
Depth in m	1.5	2.5	3	4.5	5	7.5	7.5	9	10.5	15		
Natural Moisture Content, NMC in %	34.54	36.35	44.06		38.64			18.59	26.89	27.58	28.43	26.95
Wet Unit Weight, γw in kN/m3		19.09			19.02							
Dry Unit Weight γd in kN/m3		14			13.73							
Specific Gravity, Gs	2.69	2.66	2.70		2.70			2.67				2.66
Permeability k in mm/sec			7.12E-02									8.27E-02
Unconfined compressive Strength, qu in kN/m2		30.63 at 2.5% strain			69.10 at 14% strain							
Cohesion c in kN/m2		2			10							
Angle of internal friction ϕ in degree		18			4							
Sand in %	10.33			93.21		86.08	81.86			86.25	81.2	92.9
Silt in %	78.82			6.79		13.92	18.14			13.75	18.8	7.1
Clay in %	10.85			0		0	0			0	0	0
Mica (Total) Content in %												
Muscovite in %												
Biotite in %												
Chlorite in %												
SPT value	4		2	12		13	13	12	13	22	17	21
Colour	Grey											
pH				8.7								

Table-11: Soil parameters of hole no.-2 of Launchghat location of Daulatdia side

Name of the parameter	Location									
	Launchghat									
	Hole No.2									
	D1	U1	D2	U2	D7	D8	D9	D10	D12	D13
Depth in m	1.5	2.5	3	5	10.5	12	13.5	15	18	19.5
Natural Moisture Content,NMC in %	32.56	25.02	16.01	26.81	25.76	36.84	25.06	24.62	20.26	23.62
Wet Unit Weight,γw in kN/m3		16.85		19.04						
Dry Unit Weight γd in kN/m3		13.48		15.01						
Specific Gravity,Gs	2.68	2.66		2.69		2.70			2.66	
Liquid Limit,LL in %	45					47				
Plasticity Index,PI in %	21					23				
Unconfined compressive Strength, qu in kN/m2		147.69 at 19% strain		33.96 at 6% strain						
Cohesion c in kN/m2				1						
Angle of internal friction ϕ in degree				27						
Sand in %	6		30	55.2	88.4	4.8		84.4	88.4	85.2
Silt in %	80		70	44.8	11.6	78.8		15.6	11.6	14.8
Clay in %	14		0	0	0	16.4		0	0	0
Mica(Total) Content in %	8									
Muscovite in %	4									
Biotite in %	2									
Chlorite in %	2									
SPT value	4		10		24	4	16	18	36	18
Colour	Grey									
pH			8.46							

Table-12: Soil parameters of hole no.-3 of Launchghat location of Daulatdia side

Name of the parameter	Location										
	Launchghat										
	Hole No.3										
	D1	U1	D2	U2	D3	D4	D6	D7	D8	D10	D14
Depth in m	1.5	2.5	3	3.5	4.5	6	9	10.5	12	15	22
Natural Moisture Content, NMC in %	40.25	24.7	31.72	22.52	39.73	32.48	31.65	31.53	31.59	27.34	24.52
Wet Unit Weight, γw in kN/m3		18.22		15.86							
Dry Unit Weight γd in kN/m3		14.61		12.95							
Specific Gravity, Gs	2.66	2.66	2.67	2.70	2.68			2.66		2.67	2.66
Liquid Limit, LL in %						40					
Plasticity Index, PI in %						13					
Unconfined compressive Strength, qu in kN/m2		52.78 at 4% strain									
Cohesion c in kN/m2		1		25							
Angle of internal friction ϕ in degree		31		10							
Sand in %	46.8	34.8	30	20	1.6	23.2		90		93.6	90
Silt in %	53.2	65.2	67.6	73.6	82	66.8		10		6.4	10
Clay in %	0	0	2.4	6.4	16.4	10		0		0	0
Mica(Total) Content in %		10									
Muscovite in %		5									
Biotite in %		3									
Chlorite in %		2									
SPT value	3		2		3	14	6	4	12	11	24
Colour	Grey										
pH	7.71										

Table-13: Soil parameters of hole no.-1 of Afsarsheikher Para location of Daulatdia side

Name of the parameter	Location												
	Afsarsheikher Para												
	Hole No.1												
	D1	U1	D2	D3	U2	D4	D5	D6	D7	D9	D11	D13	D14
Depth in m	1.5	2.5	3	4.5	5	6	7.5	9	10.5	13.5	16.5	19.5	22
Natural Moisture Content,NMC in %	24.24	8.87	7.08	8.5	20.76				22.68	24.85	19.24	23.18	23.83
Wet Unit Weight,γw in kN/m3		15.91			18.76								
Dry Unit Weight γd in kN/m3		14.61			15.53								
Specific Gravity,Gs	2.674	2.663			2.66	2.669	2.666		2.67		2.666		2.65
Permeability k in mm/sec		3.17E-02									2.22E-02		
Cohesion c in kN/m2					6								
Angle of internal friction ϕ in degree					17								
Sand in %	15.54	86.8	84.24		71.51	81.55	89.86			82	72.67		85.7
Silt in %	66.26	13.2	15.76		27.69	18.45	10.04			18	26.84		14.3
Clay in %	18.2	0	0		0.8	0	0			0	0.49		0
Liquid Limit, LL in %	39												
Plastic Limit, PL in %	22												
Plasticity index, PI in %	17												
Mica(Total) Content in %		6											
Muscovite in %		1											
Biotite in %		3											
Chlorite in %		2											
SPT value	3		9	10		8	12	13	50	30	17	25	15
Colour	L. Brown	Grey											
pH	8.42												

Table-14: Soil parameters of hole no.-2 of Afsarsheikher Para location of Daulatdia side

Name of the parameter	Location									
	Afsarsheikher Para									
	Hole No.2									
	D1	U1	D2	D3	U2	D4	D5	D6	D9	D13
Depth in m	1.5	2.5	3	4.5	5	6	7.5	9	13.5	19.5
Natural Moisture Content,NMC in %	26.33	12.93	7.25		23.08	33.54	22.52		21.94	26.78
Wet Unit Weight,γw in kN/m3		16.84			16.1					
Dry Unit Weight γd in kN/m3		14.91			13.08					
Specific Gravity,Gs	2.672	2.65		2.66	2.68	2.66			2.66	2.66
Permeability k in mm/sec	7.14E-05	1.08E-02			4.45E-02					8.07E-02
Cohesion c in kN/m2		0			2					
Angle of internal friction ϕ in degree		23			19					
Sand in %	6.37	80.6	82.08		71.86	76.4	88		89.06	96.98
Silt in %	83.94	19.4	17.92		27.02	23.6	12		10.94	3.02
Clay in %	9.69	0	0		1.12	0	0		0	0
Liquid Limit,LL in %	34									
Plastic Limit,PL in %	25									
Plasticity index,PI in %	9									
Mica(Total) Content in %					12					
Muscovite in %					3					
Biotite in %					5.5					
Chlorite in %					1.5					
SPT value	7		10	10		5	19	16	32	23
Colour	Grey									
pH			8.3							

Table-15: Soil parameters of hole no.-3 of Afsarsheikher Para location of Daulatdia side

Name of the parameter	Location													
	Afsarsheikher Para													
	Hole No.3													
	D1	U1	D2	D3	U2	D4	D5	D7	D8	D9	D10	D11	D12	D13
Depth in m	1.5	2.5	3	4.5	5	6	7.5	10.5	12	13.5	15	16.5	18	19.5
Natural Moisture Content, NMC in %	34.63	11.39	9.31	26.7	33.93	33.98	28.96				26.7		26	25.01
Wet Unit Weight,γw in kN/m3		17.33			18.83									
Dry Unit Weight γd in kN/m3		15.56			14.06									
Specific Gravity,Gs	2.721	2.65			2.67	2.67	2.66				2.66			2.66
Permeability k in mm/sec		T-2.28E-03/B-3.50E-02			1.15E-02	1.38E-02							5.80E-03	
Cohesion c in kN/m2		2			5									
Angle of internal friction ϕ in degree		24			21									
Sand in %	4.94	72.07			50.06	54.05	87.9				81.6		23.38	87.1
Silt in %	79.1	27.93			49.7	45.95	12.1				18.4		76.62	12.9
Clay in %	15.96	0			0	0	0				0		0	0
Liquid Limit, LL in %	38													
Plastic Limit, PL in %	23													
Plasticity index, PI in %	15													
Mica(Total) Content in %		9			10									
Muscovite in %		5			3									
Biotite in %		3			5.5									
Chlorite in %		1			1.5									
SPT value	4		16	5		8	11	26	12	21	27	50	14	50
Color	Grey													

Table-16: Soil Profile at, Hole-1, Daskandi, Paturia

Sample ID	Depth (m)	Soil Description	SPT (N-values)	Clay (%)	Silt (%)	Sand (%)	GWL
				Grain Size Analysis			
D-1	1.5	SILT, little fine sand	4	7.15	79.65	13.2	3.3528 m
UD-1	2.5	SILT, little fine sand		6.58	77.38	16.04	
D-2	3.0	SILT, trace fine sand	3	8.21	84.02	7.77	
UD-2	3.5	CLAY, trace fine sand					
D-3	4.5	CLAY, trace fine sand	4	31.39	64.27	4.34	
D-4	6.0	CLAY, trace fine sand	11				
D-5	7.5	CLAY	17	0.00	14.29	85.71	
D-6	9.0	SILT, little fine sand	9	1.43	79.38	19.19	
D-7	10.5	FINE SAND, trace silt, trace mica	32	0.00	7.36	92.64	
D-8	12.0	FINE SAND, trace silt, trace mica	31				
D-9	13.5	FINE SAND, trace silt, trace mica	45				
D-10	15.0	FINE SAND, trace silt, trace mica	24	0.00	7.60	92.40	
D-11	16.5	FINE SAND, trace silt, trace mica	22				
D-12	18.0	FINE SAND, trace silt, trace mica	34				
D-13	19.5	FINE SAND, trace silt, trace mica	28				
D-14	21.0	FINE SAND, trace silt, trace mica	25				

Table-17: Soil Profile at, Hole-2, Daskandi, Paturia

Sample ID	Depth (m)	Description	SPT (N-values)	Clay (%)	Silt (%)	Sand (%)	GWL
				Grain Size Analysis			
D-1	1.5	SILT, little fine sand	2	7.98	87.11	4.91	3.9624 m
UD-1	2.5	SILT, little fine sand		9.41	82.53	8.06	
D-2	3.0	SILT, trace fine sand	2				
UD-2	3.5	CLAY, little fine sand		26.28	57.40	16.32	
D-3	4.5	CLAY, trace fine sand	3	33.11	60.56	6.33	
D-4	6.0	SILT, some fine sand	12	5.43	69.40	25.17	
D-5	7.5	FINE SAND, little silt, trace mica	16				
D-6	9.0	SILT, trace fine sand	8	9.41	82.25	8.34	
D-7	10.5	FINE SAND, trace silt, trace mica	41	0.00	7.33	92.67	
D-8	12.0	FINE SAND, trace silt, trace mica	21				
D-9	13.5	FINE SAND, trace silt, trace mica	29				
D-10	15.0	FINE SAND, trace silt, trace mica	19				
D-11	16.5	FINE SAND, trace silt, trace mica	22				
D-12	18.0	FINE SAND, little silt, trace mica	25	0.00	10.50	89.50	
D-13	19.5	FINE SAND, little silt, trace mica	35				
D-14	21.0	FINE SAND, little silt, trace mica	31				

Table-18: Soil Profile at, Hole-3, Daskandi, Paturia

Sample ID	Depth (m)	Soil Description	SPT (N-values)	Clay (%)	Silt (%)	Sand (%)	GWL
				Grain Size Analysis			
D-1	1.5	CLAY, trace fine sand	6	18.24	73.98	7.78	3.3528 m
UD-1	2.5	SILT, trace fine sand		2.55	92.90	4.55	
D-2	3	SILT. some fine sand	5	1.71	70.25	28.04	
UD-2	3.5	SILT, little fine sand		0.00	84.35	15.65	
D-3	4.5	CLAY, trace fine sand	9	37.21	62.79	0.00	
D-4	6	SILT, some fine sand	7				
D-5	7.5	FINE SAND, trace silt, trace mica	11				
D-6	9	FINE SAND, trace silt, trace mica	12				
D-7	10.5	FINE SAND, trace silt, trace mica	35				
	12.0	FINE SAND, trace silt, trace mica	30				
D-9	13.5	FINE SAND, trace silt, trace mica	31				
D-10	15.0	FINE SAND, trace silt, trace mica	26				
D-11	16.5	FINE SAND, trace silt, trace mica	50				
D-12	18.0	FINE SAND, little silt, trace mica	27				
D-13	19.5	FINE SAND, little silt, trace mica	31				
D-14	21.0	FINE SAND, little silt, trace mica	27				

Table-19: Soil Profile at, Hole-1, Baruria, Paturia

Sample ID	Depth (m)	Soil Description	SPT (N-values)	Grain Size Analysis Clay (%)	Silt (%)	Sand (%)	GWL
D-1	1.5	FINE SAND, some silt, trace mica	4	0.00	31.81	68.19	3.3528 m
UD-1	2.5	SILT, little fine sand		3.43	84.24	12.33	
D-2	3	CLAY, trace fine sand	4	30.55	64.82	4.63	
UD-2	3.5	SILT, little fine sand					
D-3	4.5	SILT, some fine sand	13	1.43	76.51	22.06	
D-4	6	FINE SAND, some silt, trace mica	13				
D-5	7.5	SILT, some fine sand	14	3.99	69.23	26.78	
UD-3	8.0	FINE SAND, little silt, trace mica		0.00	16.29	83.71	
D-6	9.0	FINE SAND, trace silt, trace mica	12	0.00	9.25	90.75	
D-7	10.5	FINE SAND, little silt, trace mica	27	0	13.82	86.18	
D-8	12.0	FINE SAND, little silt, trace mica	20				
D-9	13.5	FINE SAND, little silt, trace mica	22				
D-10	15.0	FINE SAND, little silt, trace mica	46				
D-11	16.5	FINE SAND, little silt, trace mica	49				
D-12	18.0	FINE SAND, little silt, trace mica	33				
D-13	19.5	FINE SAND, little silt, trace mica	43				
D-14	21.0	FINE SAND, little silt, trace mica	55				

Table-20: Soil Profile at, Hole-2, Baruria, Paturia

Sample ID	Depth (m)	Soil Description	SPT (N-values)	Grain Size Analysis: Clay (%)	Silt (%)	Sand (%)	GWL
D-1	1.5	CLAY, trace fine sand	4	21.98	70.24	7.78	3.048 m
UD-1	2.5	SILT, little fine sand		10.67	73.75	15.58	
D-2	3	FINE SAND, some silt, trace mica	5	0.00	28.56	71.44	
UD-2	3.5	SILT, some fine sand		1.71	65.56	32.73	
D-3	4.5	FINE SAND, some silt, trace mica	3				
D-4	6	SILT. some fine sand	14	1.71	60.83	37.46	
D-5	7.5	SILT. some fine sand	6				
D-6	9	SILT, little fine sand	6	5.7	83.23	11.07	
D-7	10.5	FINE SAND, little silt, trace mica	25	0	19.35	80.65	
D-8	12.0	FINE SAND, trace silt, trace mica	19	0	8.95	91.05	
D-9	13.5	FINE SAND, trace silt, trace mica	26				
D-10	15.0	FINE SAND, trace silt, trace mica	29				
D-11	16.5	FINE SAND, trace silt, trace mica	39				
D-12	18.0	FINE SAND, trace silt, trace mica	41				
D-13	19.5	FINE SAND, trace silt, trace mica	29				
D-14	21.0	FINE SAND, trace silt, trace mica	30	0.00	9.86	90.14	

Table-21: Soil Profile at, Hole-3, Baruria, Paturia

Sample ID	Depth (m)	Soil Description	SPT (N-values)	Grain Size Analysis: Clay (%)	Grain Size Analysis: Silt (%)	Grain Size Analysis: Sand (%)	GWL
D-1	1.5	CLAY, trace fine sand	4	16.27	77.67	6.06	3.6576 m
UD-1	2.5	CLAY, little fine sand					
D-2	3	SILT, little fine sand	3	6.58	74.23	19.19	
D-3	4.5	FINE SAND, some silt, trace mica	7	0.00	32.98	67.02	
D-4	6.0	CLAY, trace fine sand	13	28.01	69.08	2.91	
UD-2	7.0	CLAY, trace fine sand		39.97	56.84	3.19	
D-5	7.5	FINE SAND, trace silt, trace mica	27				
D-6	9.0	FINE SAND, trace silt, trace mica	18				
D-7	10.5	FINE SAND, trace silt, trace mica	27				
D-8	12.0	FINE SAND, trace silt, trace mica	11				
D-9	13.5	FINE SAND, trace silt, trace mica	45				
D-10	15.0	FINE SAND, trace silt, trace mica	33				
D-11	16.5	FINE SAND, trace silt, trace mica	34				
D-12	18.0	FINE SAND, trace silt, trace mica	35				
D-13	19.5	FINE SAND, trace silt, trace mica	32				
D-14	21.0	FINE SAND, trace silt, trace mica	50				

Table-22: Soil Profile at, Hole-1,CharBahirdia, Daulatdia

Sample ID	Depth (m)	Soil Description	SPT (N-values)	Grain Size Analysis Clay (%)	Silt (%)	Sand (%)	GWL
D-1	1.5	SILT, little fine sand	5	7.14	72.80	20.06	3.3528 m
UD-1	2.5	FINE SAND, little silt, trace mica					
D-2	3.0	SILT, some fine sand	3	3.99	68.53	27.48	
UD-2	3.5	FINE SAND AND SILT					
D-3	4.5	FINE SAND AND SILT	12	0.84	45.15	54.01	
D-4	6	SILT, some fine sand	6	0.00	32.27	67.73	
D-5	7.5	FINE SAND, some silt, trace mica	8	1.43	49.67	48.90	
D-6	9	FINE SAND, little silt, trace mica	38	6.58	82.53	10.89	
D-7	10.5	FINE SAND, little silt, trace mica	19				
D-8	12.0	FINE SAND, little silt, trace mica	13				
D-9	13.5	FINE SAND, trace silt, trace mica	16	0.00	16.01	83.99	
D-10	15.0	FINE SAND, trace silt, trace mica	15				
D-11	16.5	FINE SAND, trace silt, trace mica	26				
D-12	18.0	FINE SAND, trace silt, trace mica	19	0.00	7.85	92.15	
D-13	19.5	FINE SAND, trace silt, trace mica	18				
D-14	21.0	FINE SAND, trace silt, trace mica	16				

Table-23: Soil Profile at, Hole-2, CharBahirdia, Daulatdia

Sample ID	Depth (m)	Soil Description	SPT (N-values)	Grain Size Analysis: Clay (%)	Silt (%)	Sand (%)	GWL
D-1	1.5	SILT, trace fine sand	5	7.14	72.80	20.06	4.5720 m
UD-1	2.5	SILT, little fine sand					
D-2	3.0	SILT, trace fine sand	2	6.62	88.19	5.19	
D-3	4.5	SILT, trace fine sand	8	9.41	81.41	9.18	
UD-2	5.0	SILT, little fine sand					
D-4	6	FINE SAND AND SILT	7	0.00	44.55	55.45	
D-5	7.5	FINE SAND AND SILT	10	1.43	49.98	48.59	
D-6	9.0	FINE SAND AND SILT	17				
D-7	10.5	SILT, little fine sand	7	6.26	82.55	11.19	
D-8	12.0	FINE SAND, little silt, trace mica	21	0	16.01	83.99	
D-9	13.5	FINE SAND, little silt, trace mica	14	0.00	16.01	83.99	
D-10	15.0	FINE SAND, little silt, trace mica	37				
D-11	16.5	FINE SAND, little silt, trace mica	17				
D-12	18.0	FINE SAND, trace silt, trace mica	28	0.00	8.63	91.37	
D-13	19.5	FINE SAND, trace silt, trace mica	16				
D-14	21.0	FINE SAND, trace silt, trace mica	39				

Table-24: Soil Profile at, Hole-3, CharBahirdia, Daulatdia

Sample ID	Depth (m)	Soil description	SPT (N- values)	Grain Size Analysis: Clay (%)	Silt (%)	Sand (%)	GWL
D-1	1.5	FINE SAND, trace silt, trace mica	5	0.00	15.81	84.19	3.048 m
D-2	3.0	FINE SAND AND SILT, trace mica	3	0.00	49.70	50.30	
D-3	4.5	FINE SAND, little silt, trace mica	17	0.00	15.36	84.64	
UD-1	5.0	SILT, little fine sand					
D-4	6	FINE SAND, little silt, trace mica	11	0.00	12.38	87.62	
D-5	7.5	FINE SAND, little silt, trace mica	33				
D-6	9.0	SILT, little fine sand	3	9.41	84.98	5.61	
UD-2	9.5	SILT, little fine sand					
D-7	10.5	FINE SAND, some silt, trace mica	6	0.00	25.41	74.59	
D-8	12.0	FINE SAND, some silt, trace mica	47				
D-9	13.5	FINE SAND, little silt, trace mica	19	0.00	10.40	89.60	
D-10	15.0	FINE SAND, little silt, trace mica	13				
D-11	16.5	FINE SAND, some silt, trace mica	27				
D-12	18.0	FINE SAND, some silt, trace mica	13				
D-13	19.5	FINE SAND, trace silt, trace mica	15	0.00	7.54	92.46	
D-14	21.0	FINE SAND, trace silt, trace mica	17				

Table-25: Soil Profile at, Hole-1, Launchghat, Daulatdia

Sample ID	Depth (m)	Soil Description	SPT (N-values)	Grain Size Analysis: Clay (%)	Silt (%)	Sand (%)	GWL
D-1	1.5	SILT, little fine sand	4	10.85	78.82	10.33	4.4196 m
UD-1	2.5	FINE SAND. little silt. trace mica					
D-2	3	CLAY. trace fine sand	2				
D-3	4.5	FINE SAND, trace silt, trace mica		0.00	6.79	93.21	
UD-2	5.0	CLAY, trace fine sand	12				
D-4	6	FINE SAND, trace silt, trace mica	23				
D-5	7.5	FINE SAND, little silt, trace mica	13	0.00	13.92	86.08	
D-6	9	FINE SAND, little silt, trace mica	7				
D-7	10.5	FINE SAND, little silt, trace mica	9				
D-8	12.0	FINE SAND, little silt, trace mica	13	0.00	18.14	81.86	
D-9	13.5	FINE SAND, little silt, trace mica	12				
D-10	15.0	FINE SAND, little silt, trace mica	13				
D-11	16.5	FINE SAND, little silt, trace mica	22	0.00	13.75	86.25	
D-12	18.0	FINE SAND, little silt, trace mica	17	0.00	18.80	81.20	
D-13	19.5	FINE SAND, trace silt, trace mica	21	0.00	7.10	92.90	
D-14	21.0	FINE SAND, little silt, trace mica	39				

Table-26: Soil Profile at, Hole-2, Launchghat, Daulatdia

				Grain Size Analysis		
Sample ID	**Depth (m)**		**SPT (N-values)**	**Clay (%)**	**Silt (%)**	**Sand (%)**
D-1	1.5	CLAY, little fine sand	4	12.5	79.2	8.3
UD-1	2.5	FINE SAND, little silt, trace mica				
D-2	3	FINE SAND, some silt, trace mica	10	0	64	36
D-3	4.5	FINE SAND, some silt, trace mica				
UD-2	5.0	FINE SAND, some silt, trace mica	22			
D-4	6	FINE SAND, some silt, trace mica	8			
D-5	7.5	FINE SAND, some silt, trace mica	19			
D-6	9	FINE SAND, some silt, trace mica	16			
D-7	10.5	FINE SAND, little silt, trace mica	24	0	81.4	18.6
D-8	12.0	CLAY, trace fine sand	4	18.3	75.7	6
D-9	13.5	FINE SAND, trace silt, trace mica	16	0	81.6	18.4
D-10	15.0	FINE SAND, little silt, trace mica	18	0	12	88
D-11	16.5	FINE SAND, little silt, trace mica	22			
D-12	18.0	FINE SAND, little silt, trace mica	36	0	11	89
D-13	19.5	FINE SAND, little silt, trace mica	18	0	16	84
D-14	21.0	FINE SAND, little silt, trace mica	14			

GWL: 5.7912 m

Table-27: Soil Profile at, Hole-3, Launchghat, Daulatdia

Sample ID	Depth (m)	Soil Description	SPT (N-values)	Grain Size Analysis: Clay (%)	Grain Size Analysis: Silt (%)	Grain Size Analysis: Sand (%)
D-1	1.5	FINE SAND AND SILT	3	0	88	12
UD-1	2.5	SILT, some fine sand		2	68	30
D-2	3	SILT, some fine sand	2	0	47	53
UD-2	3.5	SILT, some fine sand				
D-3	4.5	CLAY, trace fine sand	3	17.5	80.5	2.0
D-4	6	SILT, some fine sand	14	10	56	34
D-5	7.5	SILT, some fine sand	4			
D-6	9	SILT, some fine sand	6			
D-7	10.5	SILT, some fine sand	4			
D-8	12.0	FINE SAND, little silt, trace mica	12	0	10	90
D-9	13.5	FINE SAND, little silt, trace mica	10	0	7.8	92.2
D-10	15.0	FINE SAND, trace silt, trace mica	11	0	10	90
D-11	16.5	FINE SAND, trace silt, trace mica	18			
D-12	18.0	FINE SAND, trace silt, trace mica	15			
D-13	19.5	FINE SAND, little silt, trace mica	33			
D-14	21.0	FINE SAND, little silt, trace mica	24			

GWL: 2.7432 m

Table-28: Soil Profile at, Hole-1, Afsar Sheiker Para, Daulatdia

Sample ID	Depth (m)	Soil Description	SPT (N-values)	Grain Size Analysis Clay (%)	Grain Size Analysis Silt (%)	Grain Size Analysis Sand (%)
D-1	1.5	CLAY, little fine sand	3	18.20	66.26	15.54
UD-1	2.5	FINE SAND, little silt, trace mica		0.00	13.20	86.80
D-2	3.0	FINE SAND, little silt, trace mica	9	0.00	15.76	84.24
D-3	4.5	FINE SAND, little silt, trace mica				
UD-2	5.0	FINE SAND, little silt, trace mica	10	0.80	27.69	71.51
D-4	6.0	FINE SAND, some silt, trace mica	8	0	18.45	81.55
D-5	7.5	FINE SAND, little silt, trace mica	12	0.00	10.14	89.86
D-6	9.0	FINE SAND, little silt, trace mica	13			
D-7	10.5	FINE SAND, little silt, trace mica	50			
D-8	12.0	FINE SAND, little silt, trace mica	11			
D-9	13.5	FINE SAND, little silt, trace mica	30	0.00	18.00	82.00
D-10	15.0	FINE SAND, little silt, trace mica	27			
D-11	16.5	FINE SAND, some silt, trace mica	17	0.49	26.84	72.67
D-12	18.0	FINE SAND, little silt, trace mica	30			
D-13	19.5	FINE SAND, little silt, trace mica	25			
D-14	21.0	FINE SAND, little silt, trace mica	15	0.00	14.30	85.70

GWL: 6.4008 m

Table-29: Soil Profile at, Hole-2, Afsar Sheiker Para, Daulatdia

Sample ID	Depth (m)	Soil description	SPT (N-values)	Grain Size Analysis: Clay (%)	Silt (%)	Sand (%)
D-1	1.5	CLAY, little fine sand	7	9.69	83.94	6.37
UD-1	2.5	FINE SAND, little silt, trace mica		0.00	19.40	80.60
D-2	3.0	FINE SAND, little silt, trace mica	10	0.00	17.92	82.08
D-3	4.5	FINE SAND, little silt, trace mica				
UD-2	5.0	FINE SAND, little silt, trace mica	10	1.12	27.02	71.86
D-4	6.0	FINE SAND, some silt, trace mica	5	0.00	23.60	76.40
D-5	7.5	FINE SAND, little silt, trace mica	19	0.00	12.00	88.00
D-6	9.0	FINE SAND, little silt, trace mica	16			
D-7	10.5	FINE SAND, little silt, trace mica	16			
D-8	12.0	FINE SAND, little silt, trace mica	21			
D-9	13.5	FINE SAND, little silt, trace mica	32	0.00	10.94	89.06
D-10	15.0	FINE SAND, little silt, trace mica	25			
D-11	16.5	FINE SAND, little silt, trace mica	15			
D-12	18.0	FINE SAND, little silt, trace mica	34			
D-13	19.5	FINE SAND, trace silt, trace mica	23	0.00	3.02	96.98
D-14	21.0	FINE SAND, trace silt, trace mica	14			

GWL: 6.096 m

Table-30: Soil Profile at, Hole-3, Afsar Sheiker Para, Daulatdia

GWL: 4.2672 m

Sample ID	Depth (m)	Soil Description	SPT (N-values)	Grain Size Analysis Clay (%)	Silt (%)	Sand (%)
D-1	1.5	CLAY, little fine sand	4	15.96	79.10	4.94
UD-1	2.5	FINE SAND, some silt, trace mica		0.00	27.93	72.07
D-2	3.0	FINE SAND, some silt, trace mica	16			
D-3	4.5	FINE SAND, some silt, trace mica				
UD-2	5.0	FINE SAND AND SILT, some silt, trace	5	0.24	49.70	50.06
D-4	6.0	FINE SAND AND SILT, some silt, trace	8	0.00	45.95	54.05
D-5	7.5	FINE SAND. little silt. trace mica	11	0.00	12.10	87.90
D-6	9.0	FINE SAND. little silt. trace mica	21			
D-7	10.5	FINE SAND, little silt, trace mica	26			
D-8	12.0	FINE SAND, little silt, trace mica	12			
D-9	13.5	FINE SAND, little silt, trace mica	21			
D-10	15.0	FINE SAND, little silt, trace mica	27	0.00	18.40	81.60
D-11	16.5	FINE SAND, little silt, trace mica	50			
D-12	18.0	FINE SAND, little silt, trace mica	14	0.00	76.62	23.38
D-13	19.5	FINE SAND, little silt, trace mica	50	0.00	12.90	87.10
D-14	21.0	FINE SAND, little silt, trace mica	47			

A brief on visual inspection of disturbed soil samples

Undisturbed soil samples removed from Shelvy-tube.

Sectioning of Undisturbed Soil samples for difeerent tests

Setting soil speciman for consolidation test

Apparatus arrangement for Specific Gravity test

Conducting Liquid Limit test

Discussion meeting with BIWTA officials

Research Team with Dr. Jiban Kumar Sarker at Daskandi Site

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