

GEOTECHNICAL HAZARD ANALYSIS OF RIVER EMBANKMENT OF BANGLADESH AND ITS PROTECTABILITY

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ABSTRACT: Bangladesh has a long artificial river embankment, developed mainly for the protection of its inhabitants and resources from disastrous flash floods, tidal water, cyclone surges, river currents and others. This process increases erosion of embankments and water turbidity which bring the concerned sediments from alluvial land to the inland sides and river bed that further increase vertical soil accommodation and decrease the water depth. In this research geotechnical hazard analysis has been conducted based on the statistical riverine data and flood occurrence information, obtained from various recognized institutions and secondary literatures and scientific investigation of soil structural failures from field survey. The soil characteristics and existing conditions of the embankments of the three big rivers of Bangladesh - the Ganges, the Meghna, and the Brahmaputra-Jamuna, have been investigated. The research also includes the reasons behind the failure of different embankments that were happened in last decades. A design methodology has been proposed to make these embankments more durable and to improve the strength using a pre-designed methodological case study.

Keywords: Embankment, Soil detachment, River discharge, Vetiver, Reinforcing material

1. INTRODUCTION

Despite being a small country, Bangladesh faces the highest number of natural calamities due to its unique geological feature which presents the country has its largest delta in the world, formed by the Ganges, the Brahmaputra and the Meghna (GBM) river system. The Bengal delta is characterized by flat terrain interlaced with an intricate network of about 700 rivers, canals and streams with a total length of approximately 22,115 km which create estuaries, tidal inlets and tidal creeks [13]. The combined catchment basin of the GBM river system measures to 1,758,000 square km, which is more than 12 times the size of Bangladesh. The amount of sediment carried annually by the rivers of the Bengal delta is about 2 billion tons. Over 92 percent of the annual runoff generated in the GBM area which flows through Bangladesh, which is only about 7 percent of the total catchment area [13]. During the rainy seasons (June to September), more than 85% rainfall occurs that brings huge amount of silts from the origin of rivers that started from the slope of Himalaya. Therefore, within a period of 4 months, nearly a trillion cubic meter of water carrying about two billion tons of silt passes through the Bengal delta. Riverine floods occur when the amount of runoff originating in a watershed exceeds the carrying capacity of natural and constructed drainage system. A total of 5695 km of embankments including 3433 km in coastal areas, 1695 flood control/regulating structures and 4310 km of drainage canals have been constructed by

BWDB. Bangladesh has steady economic growth and is self-sufficient in food. So, protection is needed against the recurring flooding to make this growth sustainable.

Due to the socio-economic condition of Bangladesh most of the embankments are simply constructed with earthen materials. These earthen embankments are vulnerable to rain splash and the flow of flood water; hence they cannot solve the flood problem effectively and permanently [2]. Recent studies and news outlets has pointed out many instances of embankment failures and breaches in the past several decades. These earthen embankments are prone to breach due to their faulty design and wrong construction. For the repair and reconstruction of these existing embankments, the government has been spending a lot of money annually. So, embankments along the sea, estuaries and rivers and their associated drainage channels and systems need to be upgraded to offer greater protection from tidal activity, storm surges and water level rise. In this study the embankment failure and riverbank erosion have been investigated with respect to rainfall and flood occurrence and soil properties. Thus the study is mainly aimed to: (i) to investigate the present condition of embankments of the major rivers of Bangladesh by field observation and discussion with local community, (ii) to determine the effect of flood and rainfall on embankment and their subsequent structural collapse (iii) to provide suggestions for designing sustainable embankment (i.e. slope, factor of safety, alternate construction materials justified by

present socio-economy) using pre-designed methodological case study.

2. METHODOLOGY

2.1 Study Area

For the Ganges basin we have selected Lohajang Upazila (23.46670N to 90.34170E, with an area of 130.12 km²) of Munshiganj district, for the Brahmaputra-Jamuna basin the selection was Kazipur Upazila (24.64170N to 89.65000E, with an area of 368.63 km²) of Sirajganj district respectively. For Lohajang Upazilla, the average annual rainfall is 2102 mm, and for Kazipur Upazila, the average annual rainfall is 1649 mm [12]. In this study, a comparison of physical and geotechnical properties is carried out by field observation with the help of available previous research paper, data from government institutions, and national newspapers.

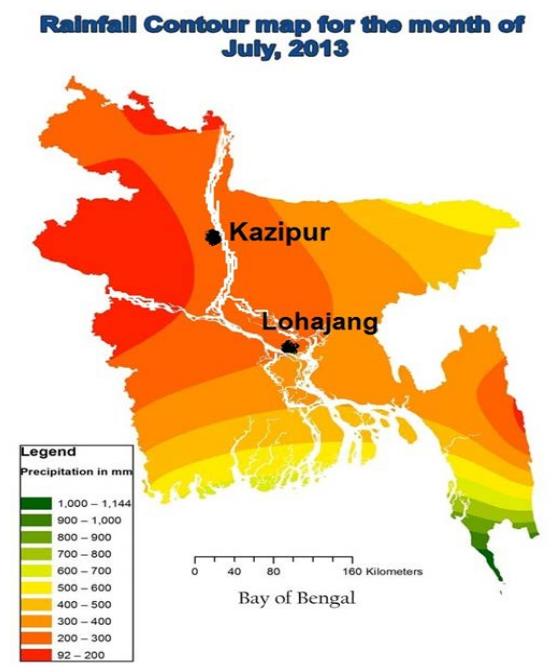


Fig.1 Study areas

2.2 Material Collection

In this study, embankment material isn't experimental rather a comparison of physical and geotechnical properties is shown with the help of available previous research paper, data from government institutions, national newspapers and by field observation.

3. PRESENT SCENARIOS OF EROSION AND EMBANKMENTS IN BANGLADESH

An average 256.1 ha and 622.2 ha of total land area of Gaibandha and Sirajganj respectively were eroded including embankments per year during the period of 1973-2009 [4]. During this period, the study areas i.e. Lohajang and Kazipur observed 3.82 ha and 6.89 ha erosion per year respectively [6]. Throughout June 2015, major bank erosions were estimated to take place at 48 places along a 210 km stretch of the Brahmaputra-Jamuna, Ganges and Meghna riverbank [6]. The government has built 1,209 km of embankments and has repaired 15,358 km of embankments in the 2014-15 fiscal year (April to March). Recent breaching of embankments at different location with their subsequent damages and date of breaching are shown in table 2.

Table 1 Embankment soil characteristics at study

Location	Lohajang, Munshiganj	Kazipur, Sirajganj
Soil sample	Ganges sandy soil	Brahmaputra's alluvial soil
Texture	Sandy loam	Loam
OM (%)	1.37	0.8
Type	Non-calcareous grey	Non-calcareous alluvium
Sand (%)	0	27
Alluvium (%)	17	72
Clay (%)	83	1
Percolation rate	Poor	Medium

location [12], [13].

4. CAUSES OF EMBANKMENT FAILURE

Since most of the embankments of Bangladesh are made of earth only without any surface protection, so the top soil easily washed away with the rain splash and current or flow of water. Also scouring at the toe of embankments decreases the length of slope and subsequently weakens the slope [1].

4.1 Natural Forces

- Wave action (daily/periodic and created by constant wind):
 - The impact of tidal waves are much

- greater on the embankments located at the vicinity of the sea.
- Cyclonic storms in the coastal zone (occurring repeatedly) act upon the water surface, which in turn moves it towards the shore with enormous hydraulic loads.
- ii. Rainfall impact (from both the regular monsoon rains and torrential rains): The heaviest rainfall occurs in July and ranges from 350 mm to over 875 mm accordingly (Bangladesh Meteorological Department, 2015). The main features of rainfall impact are:
- Surface runoff caused by rainfall results in sheet erosion.
 - Flooding (monsoon/periodic floods and those created by storms/cyclones).
 - Monsoon rainfall causes flooding which gives rise to serious washing of embankment top soil.
- iii. Turbulent water currents (mainly in rivers and at coastlines):
- The high flow rate of water makes the water current turbulent which is accompanied by vortex motion in rivers and estuaries often cause erosion of the banks.
 - At the originating point of a branch river or canal, especially in the surroundings of hydraulic structures, the turbulent water current erodes the banks and subsequently the embankments.
- iv. Wind action: The slow and steady action of wind in the relatively sparse fields and coastlines blows away the topsoil of the embankments where it is sandy or a mixture of silt and sand.

4.2 Human Interference

- i. Homestead and agricultural practices: Embankments often become the privileged sites for the construction of villages and isolated homesteads. Also agricultural practices on embankments are encouraged by a high demographic pressure on the available land and accordingly a shortage of land for the rural population.
- ii. Cattle pasture: Cattle, mainly belonging to people living on the embankment, cause erosion by uncontrolled pasture. When the embankment is over pastured, plant species and the vegetative cover, especially the grasses, exhibits reduced growth, weaken and cannot provide adequate protection of the embankment.
- iii. Public cuts: Public cuts and tubes linking a river or seaside with the country side of its embankment are seen at most establishments. These have a negative effect on the strength of embankments, which makes them vulnerable to slow but continual erosive forces. During flood or cyclonic surges, collapse or major erosion occurs at those locations.
- iv. Unplanned afforestation of embankment slope: Afforestation without appropriate planning and management techniques destroys the undergrowth grass cover and becomes ineffective for erosion protection.
- v. Improper design and construction technique: In many cases the embankments are designed with insufficient setback, resulting in increased exposure to waves and current action. This may be due to the high costs involved in land acquisition.

Table 2 Recent embankments breach in Bangladesh.

Region/District	River	Name of embankments	Date of breach	Damages
Faridpur	Padma	Faridpur city protection embankment	May 18, 2015	20 meter bolder collapsed
Sirajganj, Dhekuria	Jamuna	Dhekuria embankment	March 29, 2015	10 houses destroyed
Bogra; Jamalpur; Sirajganj;	Jamuna	Flood protection embankments	August 30, 2014	150 villages flooded in Bogura; 20 villages flooded in jamalpur; 600 families shelter less in sirajganj
Rajshahi	Padma	Rajshahi city protection	August 07, 2014	Soil moved and damaged
Feni, Fulgaji	Muhuri	Muhuri river embankment	June 22, 2014	30 villages flooded
Pabna, Sathiya	Ichamoti	Ichamoti river embankment	May 20, 2014	Crops and fisheries worth 2 crore damaged

- vi. Deforestation in upstream region: Deforestation of steep slopes is assumed to lead to accelerated soil erosion and landslides during monsoon rainfall, which contributes to floods of biblical proportion in the downstream regions like that of Bangladesh.
- vii. Other natural and man-made reasons behind embankments collapse are- soil erosion, seepage and sliding, insufficient supervision during construction, insufficient or no clod breaking, inadequate compaction and or no insufficient laying of topsoil layers, use of inferior materials, inadequate , river migration maintenance etc.

5. TYPES OF EXISTING EMBANKMENTS IN BANGLADESH

5.1 Earthen Embankments

Most of the embankments are constructed by fill embankments or earthen embankments due to it are relatively cheaper and have a low initial cost.

5.2 Concrete Embankments

A very few embankments are constructed using concrete or reinforced earth methods. They have a comparatively higher cost of construction. The DND embankment which protect Dhaka, Narayanganj, and Demra from the adjoining Buriganga and Shitalkhya rivers, Brahmaputra right hand embankment which protect from Brahmaputra-Jamuna river channel are some of the examples [2].

5.3 City Protection Embankments

Almost all of the cities of Bangladesh are situated on the banks of either one or more rivers. To protect the cities from flooding, city protection embankments are constructed. The slope of the city protection embankments are often covered with concrete blocks (sometimes sand bags are also used). The Meghna-Dhonagoda embankment and others that have been constructed to protect cities and towns like Rajshahi, Shirajganj, Chandpur, Khulna and Barisal are belonging to this category [2]. These embankments let the river water remain confined only to their channels and pass directly to the sea.

6. DESIGN APPROACH OF EMBANKMENT

6.1 Design Methodology Followed By BWDB

According to design manual, return period is to be taken 20 years for full flood control embankment where agricultural damage is predominant. The material to be used for the construction of embankment is classified as sandy-clay type soil. The country side slope (c/s) of embankment was determined on the basis of the saturation gradient line slope which is based on the type of soil.

Table 3 Saturation gradient line slope for different soils (standard design manual, BWDB, vol.1).

Soil type	Saturation gradient line slope (V:H)
Clay	1:4
Clayey loam	1:6
Loam	1:8
Sand	1:15

BWDB= Bangladesh Water Development Board

6.2 Slope Stability Analysis

Stability of the Jamuna and Padma river embankment was checked in terms of Factor of Safety (FS) values.

Table 4 Slope stability analyses for the failed sections of Jamuna and Padma flood control embankment [2].

Embankment failed	Jamuna		Padma	
Type of analyses	Effective stress analysis		Effective stress analysis	
Water storage condition	Without water storage	With water storage	Without water storage	With water storage
Factor of safety	1.45	1.27	1.55	1.35
Deviation (%)	14.17		14.8	
Recommended F.S. (without EQ)	1.5	1.5	1.5	1.5

The results show that the factor of safety is over estimated about 14-15% in case without water storage. Moreover, without water storage condition does not satisfy the recommended factor of safety.

Hence, seepage analysis is necessary to solve the seepage problem as well as to get the reliable factor of safety value and safe design of embankment.

6.3 Parameters That Need To Be Considered In Design of Embankment

In Bangladesh, a very few things are considered while designing embankments i.e. slope stability of soil, type of soil, water level, cost etc. But considering parameters like river current, rain splash and effect of wind could give the embankments more resistivity against breaching so frequently.

6.3.1 Relationship between soil detachment rates and flow discharges

In the design of embankments, Bangladesh Water Development Board (BWDB) usually doesn't consider river inflow or peak discharge. But it is an important parameter that is responsible for embankment breaching. So, taking peak discharge for a fixed return period could give maximum soil detachment rate (i.e. soil erosion). Considering this data in design of embankments would make the structure more durable and strong.

Multi-variable, non-linear regression analyses between average detachment rates, average flow discharges, and slope gradient produced the relationship is as follows [7].

$$D_c = 5.43 \times 10^6 q^{2.04} S^{1.27} R^2 \quad (1)$$

Where,

D_c = soil detachment rate (kg s⁻¹m⁻²),

q = flow discharge (m³s⁻¹),

S = slope gradient (%),

R = Correlation factor.

The effect of slope on detachment rate increases as slope gradient becomes greater [7]. R^2 was taken as 0.97 for different soil characters of major rivers of Bangladesh [7].

Brahmaputra-Jamuna is the most erosion prone river basin in Bangladesh. Soil erosion rate is higher in Brahmaputra river basin than in Ganges and Meghna basin (Fig.2). Greater incoming wave energy causes toe scouring, which tends to weaken the embankment and fastens the structural collapse in sloping dikes (Fig.3). So, embankments in Brahmaputra basin need to be stronger than the other two as there severity of detachment of soil is larger. Naturally the steeper the slope of a field, the greater the amount of soil loss from erosion by water.

Table 5 Monthly average discharge (BWDB, 2015) and predicted soil detachment rate (using eq.1) at major rivers in 2014.

Month	Slope of bed (%)	Brahmaputra		Ganges		Meghna	
		0.008		0.003		0.003	
		Flow rate (m ³ /s)	Predicted detachment rate (10 ¹³ kg s ⁻¹ m ⁻²)	Flow rate (m ³ /s)	Predicted detachment rate (10 ¹³ kg s ⁻¹ m ⁻²)	Flow rate (m ³ /s)	Predicted detachment rate (10 ¹³ kg s ⁻¹ m ⁻²)
April	Stations taken for Brahmaputra, Ganges and Meghna are Bahadurabad, Hardinge bridge, Meghna-Padma confluence resp.	11323	0.213	1102	0.00053	-	-
May		17772	0.535	1479	0.00096	-	-
June		36835	2.36	2605	0.00306	44170	0.99
July		79533	11.4	26583	0.35	82445	3.52
August		40819	2.92	32725	0.53	71805	2.66
September		36250	2.29	25304	0.316	60720	1.89
October		33995	2	18606	0.169	43949	0.975
November		13606	0.31	6040	0.017	-	-
December		8242	0.111	3126	0.0044	-	-
January		7181	0.0842	1629	0.00117	-	-
February		7019	0.08	1316	0.00076	-	-
March		8820	0.128	947	0.00039	-	-

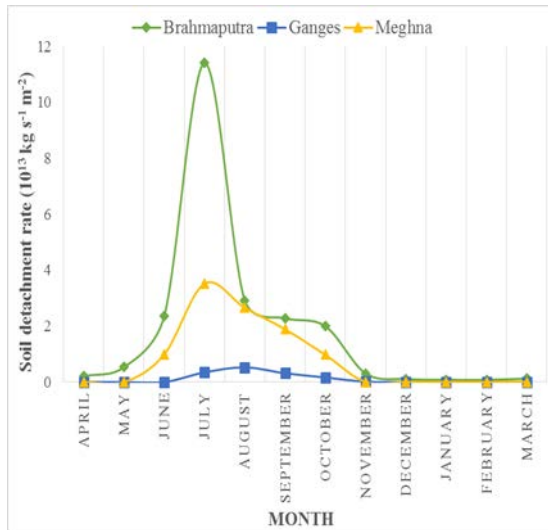


Fig.2 Predicted soil detachment rate in 2014.

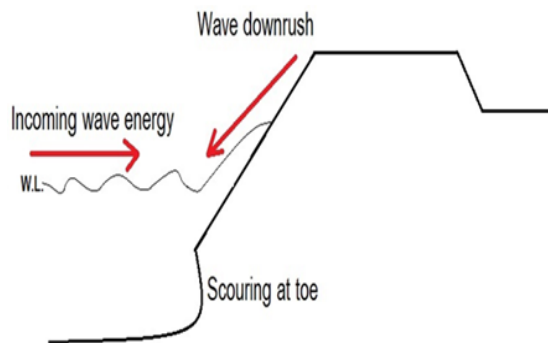


Fig.3 Cross section of an embankment showing toe scouring.

6.3.2 Change of river course

The major rivers of Bangladesh such as the Ganges, the Brahmaputra-Jamuna and the Meghna have a tendency to change their courses over alluvial plain. While they're en route to course change, hydraulic structures are merely adequate to restrict the rivers. There is a strong geologic possibility based on historic river course changes like that of Brahmaputra from its old Brahmaputra to present Jamuna or that of old Ganges from Bhagirathi to present Padma [8]. Although such epochal shifts are very rare instances of occurring. But, they can't be ignored also. River experts consider the Brahmaputra as one of the earth's most turbulent and dynamic rivers. They fear that the position of Brahmaputra on a fan of its own silt on the northern part of Bangladesh is tell of another possible natural shift of river change. So, it is prudent to construct and design the embankment

geographically modeling the river first based on its possibility of course change, shifting and alignment with nearby river channels.

7. ALTERNATIVE EMBANKMENT REINFORCING MATERIALS

Based on the socio-economic conditions of Bangladesh, a very cheaper yet effective method to protect the surface of existing earthen embankments would be the plantation of Vetiver (*Chrysopogon zizanioides*) grass along with the application of Jute Geo Textiles (JGT) [3]. Vetiver not only serves the purpose of slope protection but also adds environment reducing pollution. The in-situ shear test reveals that, the shear strength and effective soil cohesion of vetiver rooted soil matrix are respectively 2.0 times and 2.1 times higher than that of bared soil [5].



Fig.4 (a) Just after planting the vetiver grass along with Jute Geo-Textile (JGT).

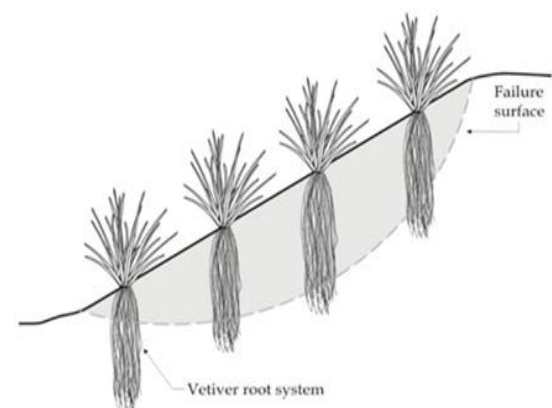


Fig.4 (b) Cross section of vetiver grass on embankment showing large root depth.

During the time of vetiver root growth, the soil protection can be attained by using geo-jute. While the geo-jute degrades with time, simultaneously

vetiver roots grow and take over to support the soil instead of the geo-jutes. Also to increase the solidarity of the embankment, other steps can be taken such as use of additives or reinforcing materials like soil-cement, natural or geo-synthetic fibers, geo-tubes, pressure berms etc. Pressure berms have been found quite effective in stabilizing earth retaining structures. A research project lead by the Norwegian Public Road Administration (NPRA) is presently investigating the possible use of Granulated Foamed Glass (cellular glass) as a lightweight material for road construction applications [9]. Granulated foamed glass (cellular glass) is produced by recirculating waste glass. In Bangladesh, every year huge quantity of wastes is generated which contains a significant amount of waste glass. They can be put to a good use by recycling them into granulated foamed glass.

8. CONCLUSIONS

The following points can be concluded from this research.

- i. The soil of Ganges tidal floodplain (Lohajang, Munshiganj) has poor percolation rate indicating less water intrusion in pore spaces of soil which substantiates with lesser occurrences of soil erosion and embankment breach in the subsequent area. The soil of active Brahmaputra-Jamuna floodplain (Kazipur, Sirajganj) has medium percolation rate indicating moderate water intrusion on pore spaces of soil which substantiates with higher occurrences of soil erosion and embankment breach in the subsequent area.
- ii. The failure of soil mostly depends on the factor of safety. The more the safety factor the more would be the assurance of soil strength along with the less chance of failure possibility. From table 4, we can recommend Factor of Safety of 1.5.
- iii. While searching for alternative material to increase the solidarity of embankment, it is found that planting of Vetiver grass along with the application of Jute Geo-Textile (JGT) in the slopes of embankments as the most suitable practice in light of Bangladesh's present socio-economic aspects. Also adding pressure berms in the design, the durability of embankment can be improved.
- iv. Proper designing of embankments, effect of river water discharge is very much required to obtain more reliability in designing stable embankment.

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