

IMPACT OF GEOTECHNICAL PROPERTIES ON BANK FAILURE MECHANISM AT DAULATDIA FERRY GHAT OF PADMA RIVER OF BANGLADESH

U. Saha^{1*}, N. C. Ghosh^{2,3}, M. Moniruzzaman^{1,4}, S. Ferdhous¹, F. Rukshana¹, M. D. Bawali¹, B. Roy⁵ and K. R. Karim¹

Abstract

The river bank of Bangladesh is generally established of alluvial deposit which contains sand, silt and clay particles. Char Bahirdia is one of the vulnerable bank sides of the Padma River adjacent to Daulatdia ferry ghat of Goalanda upazilla of Rajbari district. Bank failure mechanism depends on different hydraulic properties of the river and the geotechnical properties of the river bank. The study area is selected for investigation of the geotechnical properties and its impact on the bank failure of Daulatdia ferry ghat of Padma River. The study findings indicate that the cohesive soil strata are soft to hard which are less permeable and challenge surface erosion due to their permeability. This reduces the effects of seepage and piping. However, because of their permeability soil water pressure increases which are subjected to failure during rapid drawdown of water levels as well as soil erosion from toe zone. As a result, the river bank fails as toe failure due to tension crack. On the other hand, the non-cohesive soil strata are very loose to medium dense and dense and there is no bonding between the soil particles as clay particles are almost absent. Pore pressure increases with the increases of saturation and shear strength decreases with the increases of pore pressure. The results show the river bank tends toward the failure disposition. In addition, it is observed that the standard penetration resistance-N values have been changed along all the holes as bored where the soil layers are sometimes very loose and sometime medium dense to dense. As a result, rising of water level intensifies water pressure and increased velocity contributes to the bank failure over there due to liquefaction.

Keywords: Bank failure, Daulatdia ferry ghat, Geotechnical properties, Padma River.

Introduction

Bangladesh is formed on the delta by three major rivers named Brahmaputra, Ganges, and Meghna. These rivers and other rivers of the country originate from outside of the national boundary of the country and make up the Ganges-Brahmaputra-Meghna River system. The sediments carried by the huge discharges of these rivers have built a broad delta over millennia. Eventually the large area of Bangladesh is formed by the sediments and the submerged delta-plain in the Bay of Bengal (Haque, 2023). The 80% soils formation of Bangladesh is the sources of these sediments. The remaining 20% of soils have been formed in Tertiary and Quaternary sediments of hills (12%) and in uplifted Pleistocene terrace (8%) (Banglapedia, 2021). Brammer (1996) expressed that Bangladesh soil contains the different amounts of sand mixed with silt and clay in different areas of the country as the rivers deposit various amounts of these particles in different parts of their floodplains when they flood and over flood the land. He also stated that sandy material is deposited near the river banks and silty material further away from the banks whereas clay to the furthest away from the river. When rivers change their course, 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. Talukdar (2006) defined the causes of erosion are river instability, soil erosion, sediment transport and deposition. Inamul (2010) explains that the river bank can collapse depending on a number of factors predominating the geotechnical characteristics. He expresses that river bank fails when the gravitational forces acting on a bank and exceed the forces hold the sediment together. He also expresses that failure depends on sediment type, layering, and moisture content. Stream bank failure is closely related to the composition of the stream bank material with various categories of materials. It is mentioned here that geotechnical failures occur when the river bank resistance exceeds the forces created by moisture condition of the river bank. It is also explained that human actions are often responsible. It is also mentioned here that

any unnatural destruction of bank vegetation promotes erosion by hydraulic forces (Wikipedia, 2019). Arora (2010) stated that river bank fail due to liquefaction occurs when the soil is cohesion less, loose, saturated and there is a shaking of ground of the required intensity and duration where the undrained conditions develop in the soil due to its permeability. He also expressed that liquefaction could occur in the soil deposit at any depth where these above conditions are satisfied. He stated that liquefaction normally occurs in Indian Standard Classifications type SP where the SPT number N is less than 15. However, sometimes liquefaction occurs in the well graded Sands (SW), Silty Sands (SM) and low plastic Silts (ML) classified soil. He also stated that fine grained soils do not compress under dynamic loadings due to high dynamic pore water pressure. Moreover, they hold the shear strength due to cohesion. Dapporto *et al.* (2003) investigated the riverbanks on the Arno River to identify the main mechanisms of failure and observed that the most common mechanism is the slab-type failure on fine grained banks while cantilever failures prevail on composite banks. They also observed that the role of the river stage and its pore water pressure distributions triggering the main mechanisms of failure. Chiang *et al.* (2010) mentioned with reference to other researchers that bank failure generally occurred particularly during the recession of hydrographs when the riverbank material is under nearly or totally saturated conditions. They recommended that the effect of matric suction has significant impact on riverbank stability and concluded that it should be taken into consideration under lower groundwater level conditions. Nasermoaddeli and Pasche (2010) stated regarding bank failure that when river banks are weakened due to piping of cohesion less soil than capillary action temporarily decreases the angle of repose of the river bank material which is less than existing bank slope. It also stated that when pore pressure increases during rapid drawdown then fluid like failures occur because of liquefaction of fine-grained materials. Nasermoaddeli and Pasche (2010) mentioned that tension cracks are occurred due to shrinking and swelling of clay soils during wetting and

¹ Geotechnical Research Directorate, River Research Institute, Faridpur-7800, Bangladesh.

* Corresponding Author (E-mail: umasaharri@gmail.com)

² Dhaka Laboratory, River Research Institute, Dhaka-1205, Bangladesh.

³ Department of Physics, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh.

⁴ Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh.

⁵ Hydraulic Research Directorate, River Research Institute, Faridpur-7800, Bangladesh.

drying cycles. It also explained that subsurface moisture changes weaken the internal shear strength of the soil mass at the interface of soil types of river bank. In cases of wave action (Nasermoaddeli and Pasche, 2010) expressed that waves directly hits on exposed soil as waves vary with wind speeds and duration, water depth, and the continuous length of water over which winds blow in one direction. Fox *et al.* (2007) synthesized the research on seepage flow and erosion occurring at two stream banks in northern Mississippi and investigated the impact of seepage undercutting on stream bank stability and observed that the loss of supporting material brought by seepage undercutting is a major cause of slope instability. Rinaldi *et al.* (2004) studied on investigating pore pressure changes in response to flow events and their effects on bank stability and observed that positive pore pressures reduced the effective stress. They also observed that destroyed shear strength due to the matric suction and the sudden loss of confining pressure of the river during the initial drawdown were responsible for triggering the mass failure. Watson *et al.* (2006) reviewed on river bank failure factors such as flow properties, bank material composition, bank geometry, bank moisture conditions, channel geometry, vegetation and man-induced factors. They found that these

factors have influenced river bank failure. They expressed that soil which contains large quantities of clay particles creates a higher level of bonding between the particles. They also stated that cohesive soils are more resistant to surface erosion because they are less permeable, and it reduces the effects of seepage and piping. Due to low permeabilities these soils are more susceptible to failure during rapid drawdown of water levels due to the increase in soil water pressure. Terzaghi (1948) stated on the sign of river bank failure and explained that slide is the failure of a soil mass which is located beneath a slope. He stated that it involves a downward and outward movement of the entire soil mass which participates in the failure.

River bank failure is a common phenomenon in Bangladesh. The failure process due to devastating flood and excessive rainfall accelerating the failure process resulting in immense damage of agriculture and infrastructures every year. The people suffered unbearable miseries wherever the river bank failure occurred. Daulatdia ferry ghat of Goalonda upazila in Rajbari district is such a bank failure prone river bank which has been shown in **Fig. 1**.



Fig.1: Daulatdia ferry ghat of Goalonda upazilla in Rajbari district

In this context it is required to pay attention to how to control river bank from erosion through proper planning and design. Under such circumstances, it is needed to identify the mechanism of river bank failure prior the river bank protection. Although there have been many factors influencing the bank failure activities even it is necessary to specify the prioritization of bank failure mechanism. In this regard an attempt has been made to predict the bank failure mechanism of Daulatdia ferry ghat of Padma River in Bangladesh through investigation of influential factors such as bank material composition, bank moisture conditions with the help of a flow property such as water level. From this point of view the location Char Bahirdia of Daulatdia ferry ghat of Goalonda upazilla of Padma River in Rajbari district has been selected.

The main objectives of the study are to investigate the geotechnical properties of Char Bahirdia of Daulatdia ferry Ghat of Padma River of Rajbari district of Bangladesh and its impact on bank failure mechanism.

Methodology

A location of Daulatdia ferry ghat of Padma River in Bangladesh has been considered as a bank failure prone area. The coordinates of the study area have been shown in **Table**

1 as well as **Fig. 2** respectively. The boring is conducted by wash boring method. The boring layout for sub-surface soil collection has been shown in **Fig. 3**. Holes are bored perpendicular to the bank line and the distance first, second and third bore hole were kept 10m, 50m and 300m to 500m respectively from the bank line.

Table 1. Coordinates of the bore holes.

Location	Hole No.	Coordinate	
		Northing	Easting
Char Bahirdia	1	N-2631241	E-784402
	2	N-2631237	E-784349
	3	N-2631205	E-784152

During the boring process samples are collected from each boring hole maintaining a depth of initial of 1.5 m from ground level up to 22 m with count of SPT-N value. After the completion of the boring river, the water level and ground water level had been collected. The locations of the bore holes are BH-1 (N-2631241 & E-784402), BH-2 (N-2631237

& E-784349) & BH-3 (N-2631205 & E-784152) from where soil samples were collected. The laboratory tests were conducted following ASTM procedure for different geotechnical properties. Saturation, pore pressure and shear strength are the most important parameters for evaluating the river bank failure incident. Permeability, which has a relation to grain size of soil particle is also an important parameter for bank failure investigation. Saturation and pore pressure are determined from consolidation test as well as specific gravity consideration and field depth of their respective pressure. Saturation has been considered here 100% as the soils are

submerged. Grain size has been analyzed according to ASTM-D421-58 and D422-63 (Bowles, 1978) and the grain sizes have been accounted from the graph following Unified Soil Classification System.

The grain size analysis is determined by three general procedures such as i) sieve analysis ii) hydrometer analysis iii) combined analysis.

Particle sizes are determined from Grain size distribution curve which has been shown in Fig. 4.

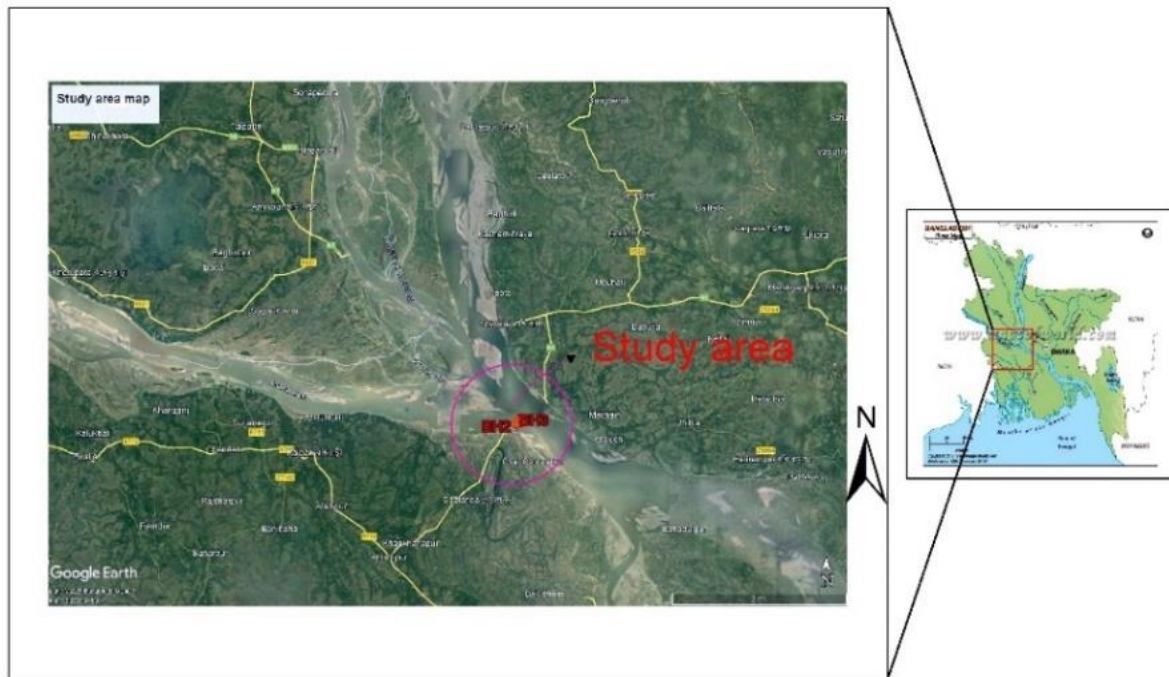


Fig. 2. Study area map.

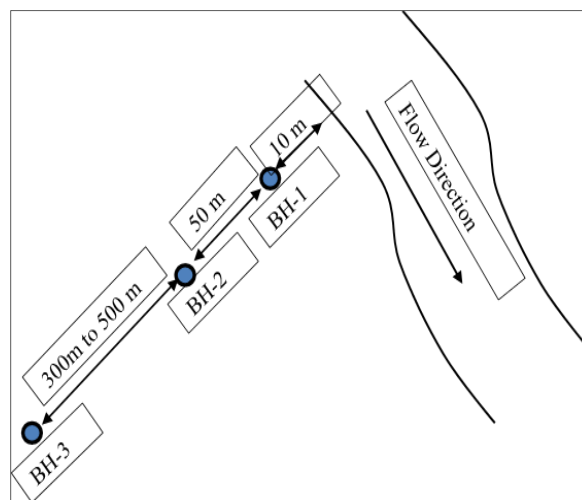


Fig. 3. Boring layout of study area.

Terzaghi & Peck (1948) stated that there is relation of consistency of cohesive soils and density index of non-cohesive soils with number of blows i.e. standard penetration resistance-N value which have been shown in Table 2 & Table 3 respectively.

Arora (2010) explained that coefficient of permeability depends upon the particle size and many other factors. The typical values of the coefficient of permeability have been shown in Table 4.

Table 2. Showing the relation of consistency of clay, number of blows N on sampling spoon and unconfined compressive strength, q_u in tons per ft².

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.m ⁻²)	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 3. Showing the tabular form of 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)

Table 4. Showing the values of the coefficient of permeability in terms of soil type.

Sl. No.	Soil Type	Coefficient of permeability (mm. s ⁻¹)	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

(Source: Arora, 2010)

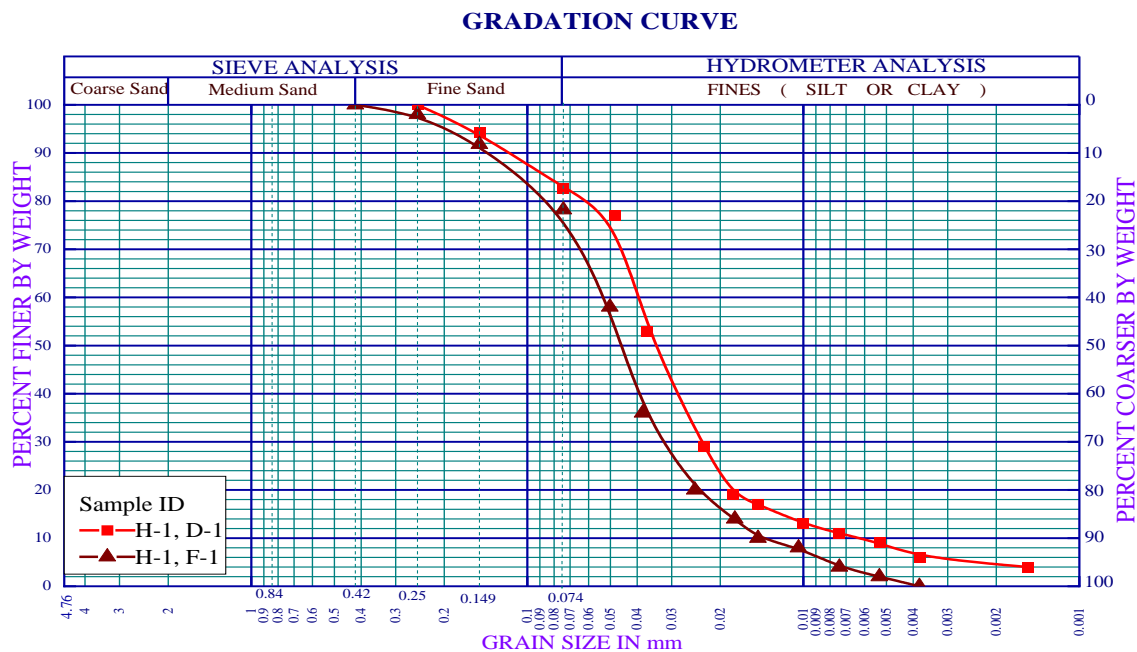


Fig. 4. Showing the grain size distribution curve.

Table 5. Sand, Silt and Clay according to their range

Name of the grain	Range of Values in mm
Gravel	<76.2-4.76>
Sand	<4.76-0.074>
Silt	<0.074-0.002>
Clay	<0.002

(Source: Garg, 2010)

Results and Discussions

Geotechnical properties of Char Bahirdia of Goalonda upazilla of Rajbari district in Bangladesh have been collected from the River Research Institute report (RRI, 2020) and presented in **Table 6**. Geotechnical properties with depth have been presented graphically in **Fig. 5** and **Fig. 6** respectively.

From the graph it has been observed that cohesive soil layer is occasionally observed along the whole 22 m depth of exploration were non-cohesive layer. The SPT values are 3 to 38 for cohesive soils where the SPT values are 3 to 39 for non-cohesive soils. The consistency of cohesive soils varies from soft to hard and the plasticity is medium. The clay particle varies (4 to 9) %, silt particle varies (69 to 88) % and sand particle varies (5 to 27) % for cohesive soils. In the case of non-cohesive soils, it is observed that the clay particle varies (0 to 1) %, silt particle varies (8 to 83) % and sand particle varies (49 to 92) %. It was found that the soil layers were dominating the site through its non-cohesive characters. The density index of non-cohesive soils varied from very loose to dense and the plasticity is non-plastic. The cohesion varies from (3 to 6) kN.m⁻² and the angle of internal friction varies from (5 to 20) degree. The permeability varies from (10⁻⁵ to 10⁻⁴) mm.s⁻¹ for cohesive soils and (10⁻³ to 10⁻²) mm.s⁻¹ for non-cohesive soils. The specific gravity varies from 2.646 to 2.770 for cohesive soils and 2.623 to 2.670 for non-cohesive soils.

Table 6. Showing the geotechnical properties of Char Bahirdia of Goalonda ferry ghat of Padma River.

Name of the parameter	CharBahirdia					
	BH # 01		BH # 02		BH # 03	
	N-2631241 & E-784402		N-2631237 & E-784349		N-2631205 & E-784152	
	Cohesive	Non-cohesive	Cohesive	Non-cohesive	Cohesive	Non-cohesive
N.M.C in %	29-33	24-37	25-40	27-31	31-37	12-36
SPT value	3-38	6-19	2-7	7-39	3	3-27
Unit Weight in kN.m ⁻³	Wet-17.29	Wet-18.62	Wet-18.43-19.37		Wet-17.41	Wet-17.4
	Dry-13.02	Dry-17.29	Dry-14.80-14.81		Dry-13.32	Dry-13.36
Specific Gravity, G _s	2.668-2.707	2.623-2.67	2.66-2.77	2.66	2.646-2.692	2.65-2.67
Cohesion, c in kN.m ⁻²	3-6				4	
Angle of internal friction in degree	5-16				20	
Sand in (%)	11-27	49-92	5-20	49-91	6	50-92
Silt in (%)	69-83	8-50	73-88	45-83	85	8-50
Clay in (%)	4-7	0-1	6-9	0-1	9	0
Permeability in mm.s ⁻¹	10 ⁻⁵ to 10 ⁻⁴	10 ⁻³ to 10 ⁻²	10 ⁻⁵ to 10 ⁻⁴	10 ⁻³ to 10 ⁻²	10 ⁻⁵ to 10 ⁻⁴	10 ⁻³ to 10 ⁻²
Mica in (%)	-	8	-	-	-	10
Colour	Grey		Grey		Grey	

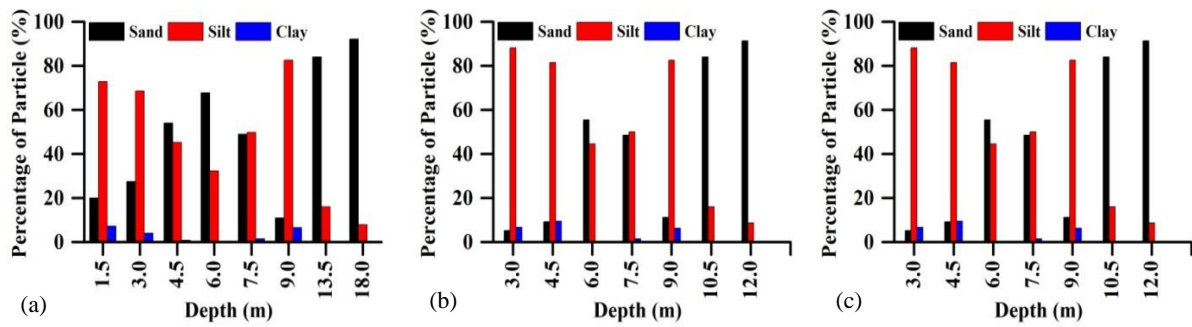


Fig. 5. Percentages of Particle of soil vs. depth graph of a) BH#1 and location (N-2631241 & E-784402), b) BH#2 and location (N-2631237 & E-784349), c) BH#3 and location (N-2631205 & E-784152) of Char Bahirdia at Daulatdia side.

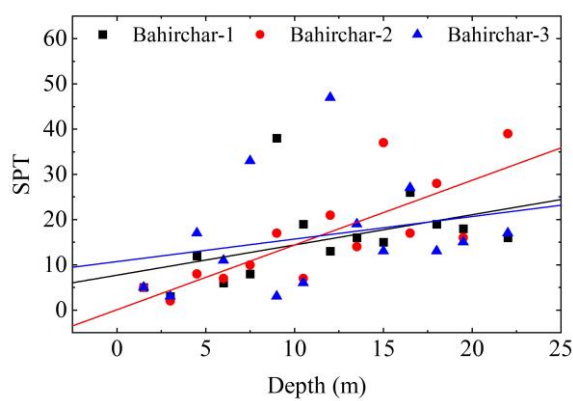


Fig. 6. SPT-N value vs. depth graph for BH#1 to BH#3 of Char Bahirdia at Daulatdia side.

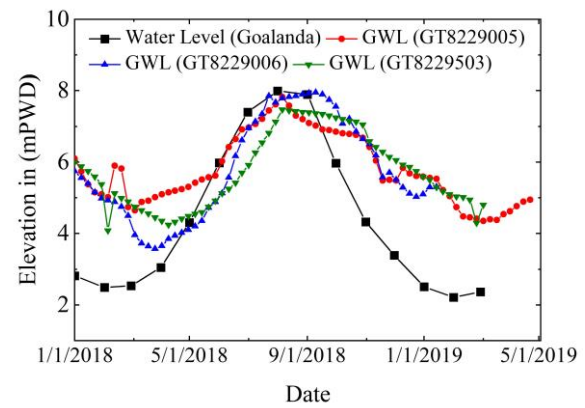


Fig. 7. Graph showing the surface water level (SWL) of Goalanda ghat and ground water level (GWL) of 3 stations of Goalanda ghat, Rajbari with period.

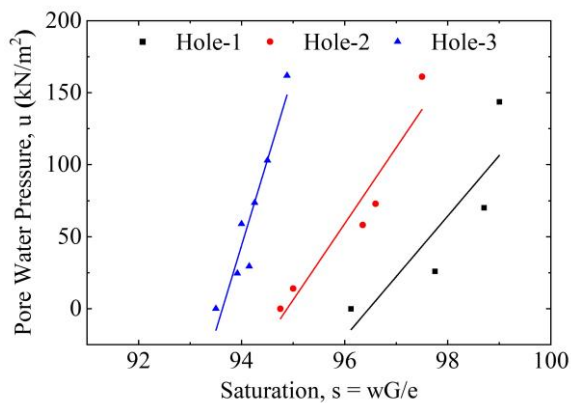


Fig. 8. Graph showing the saturation and pore pressure at Char Bahirdia of Daulatdia side of Padma River.

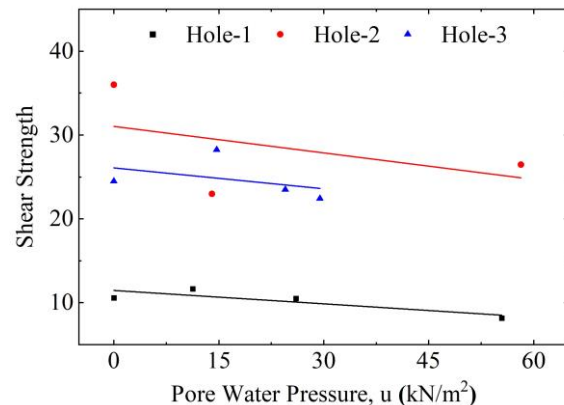


Fig. 9. Graph showing the effect of pore pressure on shear strength at Char Bahirdia of Daulatdia side of Padma River.

Variation of Ground Water Level and Surface Water level at Daulatdia side and their adjust Soil Strata

Ground water level and surface water level of one year period has been shown in Fig. 7.

From Fig. 7 it has been observed that the low flood level at Daulatdia side has generally been varied from 2.5 mPWD to 3.0 mPWD and high flood level varied from 8 mPWD to above in 2018-19. The elevation at Daulatdia side is adjacent to the bank line is 7.0 mPWD, 6.0 mPWD. It would become submerged at monsoon. From the low flood level, the bank

slope height from bank line remains 5.0 mPWD and 4.0 mPWD. In these bank lines, the layering of the bank material is non-cohesive sand mixed with silt particles.

On the other hand, the stratification of the materials from the bank line 5.0 mPWD to the ground surface consists of cohesive layer wherever SILT particles are dominant. The soil strata from the bank line 4.0 mPWD to the ground surface consist of variation of cohesive and non-cohesive soil layer. Where cohesive soil layers dominate SILT particles together with CLAY and SAND particles.

Effect of Saturation on Pore Pressure and effect of Pore Pressure on Shear strength

The pore water pressure has been plotted with its respective saturation in **Fig. 8**. The data have been considered here on the month of February 2018. From the figure it is observed that the pore water pressure has been increased with the increases of saturation. It is mentioned that the data would be 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 here 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 177 kN.m⁻² accordingly. Here the small variation of saturation has occurred due to its soil layers and properties and its ground water level as well as location.

Shear strength has been plotted with corresponding pore pressure in **Fig. 9**. From the graph it is observed that shear strength has been decreased with the increases of pore water pressure in all the holes. The shear strength of the soils of BH#1 is less than that of BH#2 and BH#3. The shear strength of the BH#3 has been varied to 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 varies due to water surface water level. That's why the soil strength is not homogeneous, however, the location was identical. It is also observed that waves are created by ferry, launch and trawler boat traffic near the two bank lines at Daulatdia side.

Conclusion

The stratification of the materials from the bank line to the ground surface consists of non-cohesive layer wherever clay particles are zero except upper and some other layers which are cohesive soil layers. On another bank lines SILT particles together with CLAY and SAND particles make cohesive soils so, according to Watson *et al.* (2006) a medium to poor level of bonding makes among the particles. Consequently, these soils are medium to poor resistant to surface erosion because they are poorly permeable. As a result, seepage and piping have fewer negative impacts. But because these soils have low permeability, they can fail quickly when water levels drop because of the rise in pore water pressure in the soil and soil erosion from the toe zone. As a result, the river bank fails as toe failure due to tension crack. 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 very loose and sometime medium dense to dense. Consequently, rising water level intensifies water pressure resultant the loose layer bank failure due to liquefaction according to Arora (2010). As a result, the river bank as well as the homogeneous soil zone as long liquefies due to water pressure. According to Nasermoaddeli and Pasche (2010) 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.

Recommendations

Geotechnical information is always very important for any type of construction work on it. Therefore, it is very much essential and recommended to investigate the geotechnical properties of the river bank prior to any bank protection works. The soil properties at the study area indicate that soil strengthening is required for bank protection works. The findings of the present study are expected to help a lot to the concerned authorities in undertaking any construction work at the study area. It needs special attention as the water level has become varied in this river. It is also recommended that wave action is to be considered at the design of the ferry ghat protection works.

References

- Arora, K. R. (2010). *Soil Mechanics and Foundation Engineering*. Reprint Edition. Standard Publishers Distributors, Delhi-110006, p-136,442,852.
- Banglapedia (2021). Bangladesh Soil, National Encyclopedia of Bangladesh [online]. https://en.banglapedia.org/index.php/Bangladesh_Soil (Accessed 09 April 2023).
- Chiew, Y. M., Narasimhan, N. & Chu, J. (2010). Effect of Seepage on River bank Stability. School of Civil and Environmental Engineering, Nanyang Technological University, Nanyang Avenue, Singapore 639798, Conference Paper, Published Version, Hydraulic Engineering Repository (HENR). [https://doi.org/10.1061/41147\(392\)34](https://doi.org/10.1061/41147(392)34).
- Dapporto, S., Rinaldi, M., Casagli, N. & Vannocci, P. (2003). Mechanisms of river bank failure along the Arno river. *Earth Surf. Process.* 28(12): 1303-1323. <https://doi.org/10.1002/esp.550>.
- Fox, G., Wilson, G. V., Simon, A., Langendoen, E. J., Akay, O. & Fuchs, J. W. (2007). Measuring stream bank erosion due to ground water seepage: correlation to bank pore water pressure, precipitation and stream stage. *Earth Surf. Process.* 32(10): 1558-1573. <https://doi.org/10.1002/esp.1490>.
- Fox, G. A., Chu-Agor, M. L., & Wilson, G. V. (2007). Seepage Erosion: A Significant Mechanism of Stream Bank Failure. Proceedings of the American Society of Civil Engineers (ASCE) World Environmental and Water Resources Congress, May 15-19, 2007, Tampa, FL, 14 pages (CD-ROM).
- Garg, S. K. (2010). *Soil Mechanics and Foundation Engineering*. First Reprint: 2010, Khanna Publishers, Delhi. Page-17, 53.
- Brammer, H. (1996). The Geography of the soils of Bangladesh. *University Press Limited*. 1996, Page-4.
- Haque, M. I. (2010). Water Resources Management in Bangladesh. *Anushilan publisher*, Chuadanga.
- Haque, C.E. and Jakariya, M. (2023). Bengal Delta, Charland Formation, and Riparian Hazards: Why Is a Flexible Planning Approach Needed for Deltaic Systems?. *Water*, 15(13): 2373. <https://doi.org/10.3390/w15132373>.

Nasermoaddeli, M. H. and Pasche, E. (2010). Modelling of undercutting and failure of non-cohesive river banks. Proceeding of River Flow 2010 International Conference on Fluvial Hydraulic. 1323-1330.

Rinaldi, M., Casagli, N., Dapporto, S. & Gargini, A. (2004). Monitoring and modelling of pore water pressure changes and riverbank stability during flow events. *Earth Surf. Process.* 29(2): 237–254. <https://doi.org/10.1002/esp.1042>.

RRI (2020). Investigation of Geotechnical Reasons for Bank Failure on Daulatdia and Paturia Side of Padma River of Bangladesh. River Research Institute, Faridpur, Bangladesh.

Talukdar, B. (2012). River bank Erosion-A Perspective. Assam Engineering College, Email: bipulaec@gmail.com.

Terzaghi, K., Peck, R. B. & Mesri, G. (1948). Soil Mechanics in Engineering Practice. John Wiley & Sons, Inc. & Chapman & Hall, Ltd.

Watson, A. J. and Basher, L. R. (2006). Stream bank erosion: a review of processes of bank failure, measurement and assessment techniques, and modelling approaches. Motueka ICM Programme Report Series: Bank erosion review, Motueka Integrated Catchment Management Programme Report Series. Landcare ICM Report No. 2005-2006/0.