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Slope stability analysis of a Jamuna river embankment

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Abstract

A study on Slope Stability Analysis of an embankment has been carried out considering different slopes at different conditions. For this purpose embankment soil has been collected from Basuria in Sirajganj near the bank of Jamuna River. Also field bore logs has been done up to a depth of 30 m. Grain size analysis of the sample reveals that it contains 63% sand, 35% silt and 2% clay, which means the sample, is not pure sandy soil. According to Unified Soil Classification System (USCS) the soil sample is SW – SM. To obtain the shear strength parameters of the collected disturbed sample of the embankment, a remolded sample has been made in the laboratory. For that purpose Standard Compaction Test has been carried out. Consolidated Undrained Shear test has been performed to obtain the shear strength parameters. The cohesion and angle of internal friction are found to be 7 kPa and 21° respectively from shear test. For the parametric study, shear strength parameters have been modified to be 10 kPa; 14° and 20 kPa; 12°. The shear strength parameters of the underlying soils have been obtained using the existing correlation with SPT-N value shown in the bore logs. Based on the results of soil investigations, stability analysis using STB2010 at some conditions (dry, high flood level, low flood level and rapid drawdown with slope 1:1, 1:1.5 and 1:2) of the embankment has been performed. It has been found that the safety factor decreases with steep slope while increasing with flatter one. As the recommended minimum safety factor is 1.2, the strength of soil mostly depends on the factor whether it's protected or not. From the analysis it has been found that except the soil at high flood level with 1:1 slope and rapid drawdown condition with all three slopes, rest of the soils with given condition have satisfied the factor. The maximum safety factor has been found 2.255 for soil at dry condition with a slope 1:2 while the minimum factor is 0.66 at rapid drawdown condition with 1:1 slope. Hence we can realize that the soil having the minimum factor possesses very bad condition which needs to be protected with a conventional design solution. Among all other designs we have chosen Revetment Design as the most appreciable and easily accessible solution for river embankment protection. According to Revetment Design geotextile layer and concrete block layers are placed over the slope to protect failure. It causes a huge cost to place concrete block layer overall the embankment uniformly. Four layers of concrete block have been placed at the bottom through toe up to the middle of the slope while one or two layers are placed from middle up to the top of the embankment for high flood level condition. For rapid drawdown condition, number of layers has been extended to 7 with slope 1:1 but the number has been reduced with flatter slope due to make the design economical. From the design, the soil at critical condition has satisfied the factor of safety.

Keywords: Sands, embankment, shear strength, Slope Stability

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1. Introduction

Earthen embankments in Bangladesh are beset with multi-facetted problems. Devastating flood and excessive rainfall are accelerating the failure process which results immense damage to agriculture and infrastructures every year. Over the last few decades, nearly 13000 km of flood and river embankments have been repaired in Bangladesh (Hossain, M.Z. and Sakai, T., 2011). But, earthen embankments in Bangladesh are facing problems like erosion, breaching in every year. The major causes of failure identified were breach of the embankment cutting by the public, overflow, erosion, seepage and sliding. Furthermore, insufficient supervision during construction results in poor-quality earthworks with the use of inappropriate soil materials, insufficient or no clod breaking, inadequate compaction and or insufficient laying of topsoil layers, the use of inferior materials, inadequate maintenance, river migration and cutting by the public (Hoque and Siddique, 1995). Among many reasons, the improper design methodology and construction procedure is prime and one of the most important causes of embankment failure. The stability of earthen embankments is influenced by seepage occurred during the increase and decrease of the adjacent water level in the river or reservoir (Morii and Kunio, 1993). In Bangladesh, nearly 4,600 km of embankments along the bank of big rivers are flowing across the country. JAMUNA, one of the big rivers is flowing alongside of Sirajganj district of Bangladesh (Figure 1). At 41 locations of its bank, the length of failure occurring is about 160.62km. This is because of the fluctuation of water levels, siltation and scouring and severe wave actions of the river. In addition, devastating flood in almost every year and excessive rainfall are stepping up the early failure of embankments which results immense damage to agriculture and infrastructures. To minimize the impact of natural disasters as well as to achieve the goal of agricultural production, sustainable and cost-effective protection measures of those river embankments are now crucial for Bangladesh. Some of the major causes of these embankment failures are due to the use of geotechnically unstable materials, improper method of construction and insufficient post operative maintenance. So, prior to construction of a stable embankment it is important to evaluate the inherent properties of the construction materials for its safe design as well as to select appropriate protection system.

The concept of stability is one of the most important issues in Civil Engineering field. Stability concept comprises some of the important factors in Civil Engineering namely: force, moment and equilibrium. These factors and concepts form the basis of all Civil Engineering structural analysis and construction work. Overstressing a soil material of an earth slope usually may bring about a sudden rupture with a rapid displacement or sliding of the ruptured soil mass or granular shear strain causing distress to earth structures. Natural slopes, which have been stable for many years, may suddenly fail due one or more of the following causes: External disturbance in the form of cutting or filling of parts of a slope; external disturbance in the form of seismic activity; increase in pore water pressures within a slope; progressive decrease in shear strength of slope materials and weathering can also contribute to failure of slopes. Manmade slope can be categorized into three types, such as, cut slopes, embankment including earth dams and spoil or waste heaps. The factors contributing to the slope stability include: the type of soil, geometry of the cross-section of the slope, weight, loads and load distribution, gravity, increase in moisture content of the soil material, decrease in shear strength of soil, vibrations and earthquakes, due to human action like excavation, undercutting and overloading.

Revetment Design is the most conventional and gratifying solution for river bank protection. Revetments are used to protect banks and shorelines from erosion caused by waves and currents. It is assumed to be easily accessible for Bangladesh. It is composed of a layer of erosion resistant material that covers the erodible material of the river bank and sometimes also the bed of the river. Various materials may be used for this purpose, including grouts and geotextiles. The choice of the most suitable material should be made at an early stage in the project. Armor stone can be directly placed onto the bed or bed to be protected. However generally good practice to place it on an under layer that provides a transition between the coarse armor stone of the cover layer and the fine erodible material of the foundation. The under layer may be made of crushed block or gravel that prevents sub soils from being eroded through the voids of the protection. Geotextiles may be used as a part of the filtering system, either with or instead of the granular filter. The under layer reduces both the risk of foundation material being washed through the armor layer and of the cover layer punching into the subsoil. The level of the revetment toe is determined in relation to the maximum scour expected after completion of the works.

A berm may be required for the construction and maintenance issues. Revetment design using concrete block is considered to be economical rather than using other materials. Articulating concrete blocks (ACBs) are designed to provide stability and erosion control in a wide variety of hydraulic applications. Made on dry cast block machines, the individual units are engineered to capitalize on the weight of concrete, friction between units, and the interconnection of units into flexible mattresses. Flexibility between units is provided to allow the mat to conform to minor deformations in the sub grade. Classes of individual units can be produced at varying thicknesses, providing the designer flexibility in selecting appropriate levels of protection. The range of block classes allows selection of the proper combination of unit weight, surface roughness, and open area for hydraulic stability. For example, an Armor Flex armor unit, shown in Figure 2, is substantially rectangular, having a flat bottom to distribute the weight evenly over the sub grade. The upper sides of the unit are sloped to permit articulation of the armor layer and to accommodate under layer irregularities when the armor units are connected into mats. The units have two vertical openings providing for permeability of the armor layer. This reduces uplift forces on the armor by allowing release of dynamic pressures that occur during wave breaking. The vertical cells also increase surface roughness and allow a flux of water into the under layer, reducing waving run-up.

Weights of manmade structures constructed on or near slopes tend to increase destabilizing forces and slope stability. These slope failures are known as slides. Different sections of an embankment are used in geotechnical engineering to study slope stability, settlement, settlement control and regulation measures, to evaluate the effect of changes made for settlement by conducting pre and post studies. Slope stability is influenced by physical features of the embankment which depend on gradient, roughness, and embankment site developments while settlement is influenced by the compaction of the embankment. Environmental conditions also affect slope stability. Even when considering the slope stability and settlement of various sections of an embankment, there is considerable amount of scatter in the values to be expected. For different types of embankment and embankment geometry many comprehensive studies have been conducted in the developed countries and reported in their research reports (Flate and Preber, 1974; Mesri et al, 1994; Olson 1998). In our country, till now no such extensive investigation was carried out to find the settlement and slope stability of embankment. A comprehensive knowledge on the behavior of embankment can be obtained by studying slope stability and deformation characteristics of Jamuna river embankment.

This paper is aimed to determine the stability and settlement characteristics of Jamuna embankment at selected conditions. It presents a study on the investigation of physical and mechanical properties of Jamuna river embankment materials located at Basuria in Sirajganj district of Bangladesh. Attempt has also been made to evaluate the existing design methodology for embankment stability analysis through a case study.

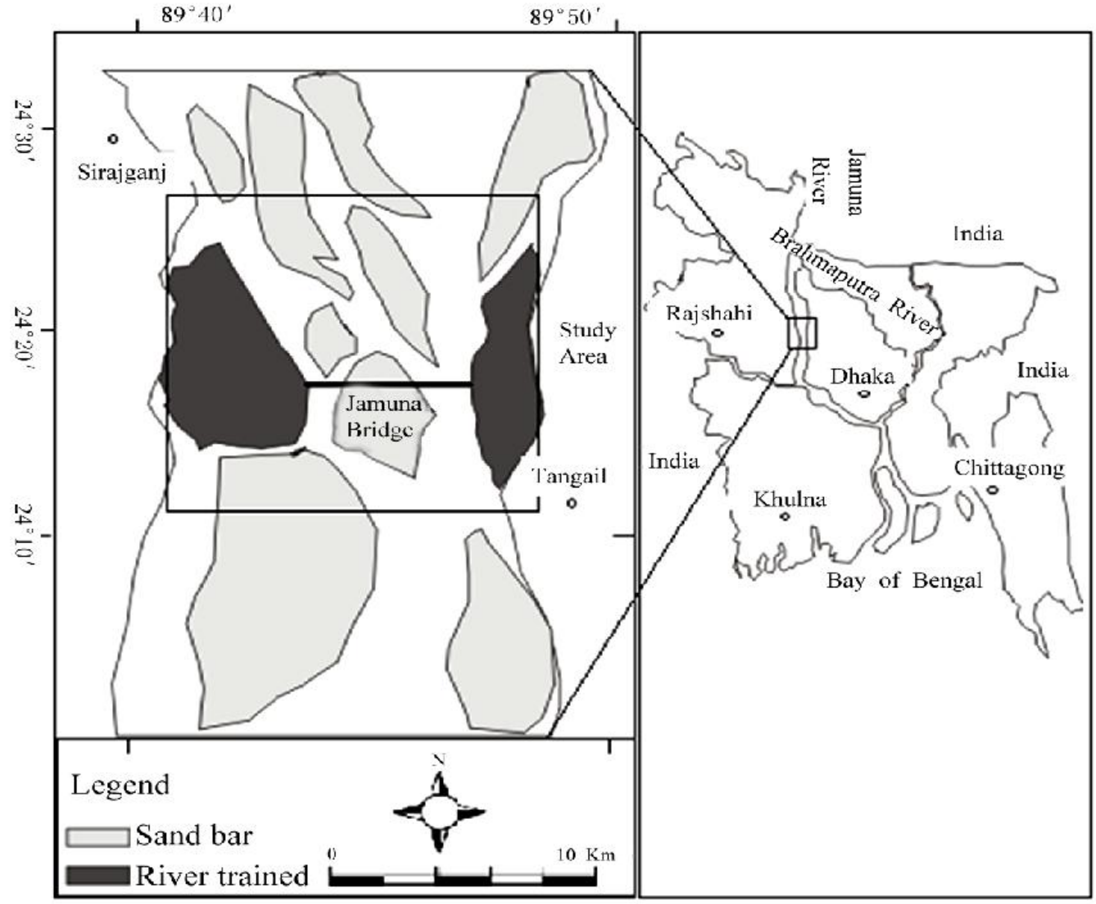

Fig. 1. Location map of the study area

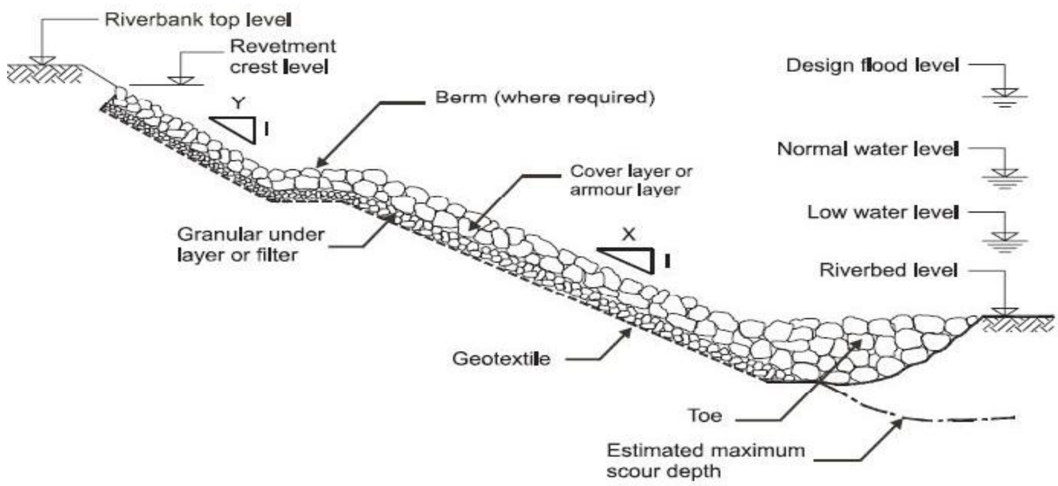

Fig. 2. Components of typical armor stone revetment

2. Geology of The Study Area

The study Jamuna River in 1787 a tectonic movement followed by an abnormal flood led changes in the course of the Brahmaputra and started its flow through a new course known as the Jamuna (Bhuiyan, M.A.H., Rakib, M.A., Takashi, Rahman, M.J.J. and Suzuki, Shigeyuki, 2010). It is the main channel of the Brahmaputra River when it flows out of India into Bangladesh. Jamuna enters in Bangladesh from the North West side of Kurigram district and flows to south, ending its independent existence as it joins the Padma River near Goalundo Ghat. Bounding coordinates of the river area is W: 89.532, E: 89.871, N: 25.228, S: 23.869. The climate of the study area is tropical monsoon. Jamuna Bridge site is located between Tangail and Sirajganj town. It lies within latitude 24022′50″–24026′30″N and longitude 89055′30″–89058′45″E. The river reach is characterized by well defined braiding nature, meta-stable islands, nodes, sandbars, shifting ana-branches and rigorous bank erosion. Geomorphologically, the eastern bank is bounded with the lateral extension of Madhupur Tract and the west bank is the Barind Tract, which is composed of silty clay. During monsoon, the average annual discharge of Jamuna River (JR) at Ba-hadurabad point is about 50000 m3/s. However, the discharge increased to 100000 m^3/s during the 1988 and 1998 flood events. The average water surface slope is approximately 6.5 cm/km for the lower reach. The soil deposits mainly consist of the following types of soils (after Geological Map of Bangladesh, GSB, 1990): ASL – Alluvial Silt – Light to medium – grey, fine sandy to clayey silt. Commonly poorly stratified; average grain size decreases away from main channels. Chiefly deposited in flood basins and inter stream areas. Unit includes small back swamp deposits and varying amounts of thin, inter stratified sand, deposited during episodic or unusually large floods. Illite is the most abundant clay minerals. Most areas are flooded annually. Included in this unit are thin veneers of sand spread by episodic large floods over flood – plain silts. Historic pottery, artifacts and charcoal (radiocarbon dated 500 – 6000 years B.P.) found in upper 4m.

3. Sample Collection and Laboratory Tests

The soil samples were collected directly from the broken part of the right bank embankment of Jamuna River at Basuria in Sirajganj district. The field investigations consisted of drilling of boreholes, identification of subsoil layer, assessment of density and consistency of subsoil layers by carrying out Standard Penetration Test, collection of disturbed and undisturbed tube samples. One borehole was drilled at Basuria site on the bank of Jamuna River. Geologic profile of the subsoil is made from the bore log data at Basuria site. The soil overall the whole depth possess non – plastic behavior. Silt with little clay, brown in color, having very loose density exists near the top of the ground surface extending to about 8 feet depth. The SPT – N value of this type of soil at the given depth is 1. Very fine sand with little silt trace mica is encountered just below the top clay layer having grey in color and non-plasticity behavior. It extends up to the final depth of boring 102 feet (30m) and possibly beyond. The density varies with depth such as loose density up to 28 feet depth, medium density up to 63 feet depth and dense density for the rest. At the layer up to 28 feet depth, the average SPT – N value is 3 while the range of SPT – N value is 15 – 25 up to 63 feet depth. Again SPT – N value up to 73 feet depth is 26 and up to 102 feet the range is 28 – 32 feet. Before analysis, duration of storage of samples is likely to affect some determinations more than others. Certain constituents are subjected to loss by adsorption on the sides of the glass container walls. So polythene bags have been used for the storage of sample for laboratory tests. The laboratory tests have been conducted in the Laboratory of Bangladesh University of Engineering And Technology. The testing procedures are in accordance with American Society for Testing and Materials (ASTM). The tests include particle size analysis, compaction characteristics and consolidated undrained direct shear test. Consolidated undrained direct shear test was done with samples having different water content.

The following tests were conducted in the laboratory in order to access the collected sample:

(i) Grain size analysis
(ii) Compaction test
(iii) Consolidated – Undrained Direct Shear test (CU test)

Grain size analysis is performed to determine the percentage of different grain sizes contained within a soil. Basically two well known laboratory tests for Grain size distribution analysis, they are: Sieve analysis and Hydrometer analysis. The mechanical or sieve analysis is performed to determine the distribution of coarser, larger sized particles and the hydrometer analysis is conducted to determine the distribution of finer particles. The distribution of different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution and it is required in classifying the soil.

Compaction, basically, is the densification of soil by removal of air, which requires mechanical energy. Simplistically, compaction may be defined as the process in which soil particles are enforced to remain closer together with the resultant reduction in air voids. Compaction, measured in terms of dry unit weight, increases the strength characteristics of soils, thereby increasing the bearing capacity of "foundations" constructed over them. Maximum dry density refers to the density at which the volume of air at a specific energy applications kept to a minimum, implying the soil particles are rearranged to give a minimum volume of air at the compaction energy. Soil compaction results in higher strength, reduced settlement and reduced permeability. A remolded sample is developed by compaction test with the corresponding water content of 95% peak value of the dry density at wet side. This remolded sample is used in consolidated undrained direct shear test. From shear test we can conceive the strength of soil which determines the susceptibility to failure.

In all soil stability problems, such as design of foundations, retaining walls and embankments, knowledge of the strength of soil involved is required. The determination of the proper strength to use in a stability problem can be the most difficult question arises in the soil engineering. Hence the test of Strength test enables us to specify the characteristics of soil properly.

4. Laboratory Test Results and Discussion

Four laboratory tests have been performed, they are: Sieve analysis, Standard Proctor compaction test and Consolidated Undrained Direct Shear test. Figure 3 and 4 show grain size distribution of sandy soil and moisture content vs.dry density relationship of sandy soil for Standard Proctor Compaction test respectively. Figure 5 and 6 show Shear stress vs. displacement curve and Shear stress vs. normal stress graph of soil (c = 7 kPa, φ = 21°) for Consolidated undrained direct shear test.

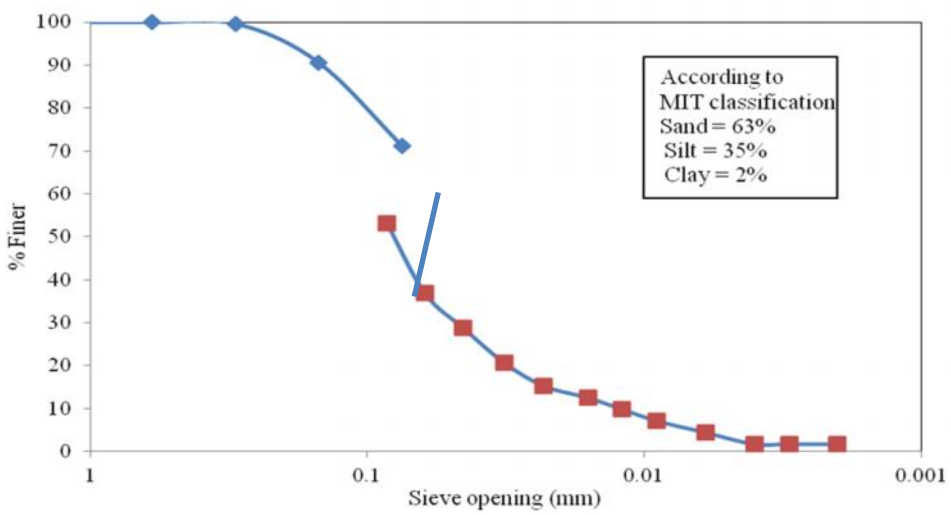

Fig. 3. Grain size distribution of sandy soil

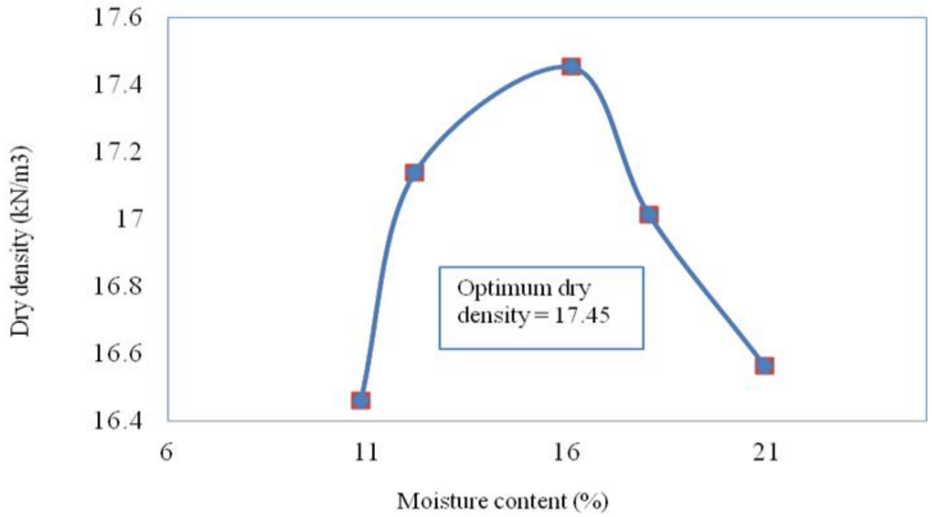

Fig. 4. Moisture content vs.dry density relationship of sandy soil for Standard Proctor Compaction test.

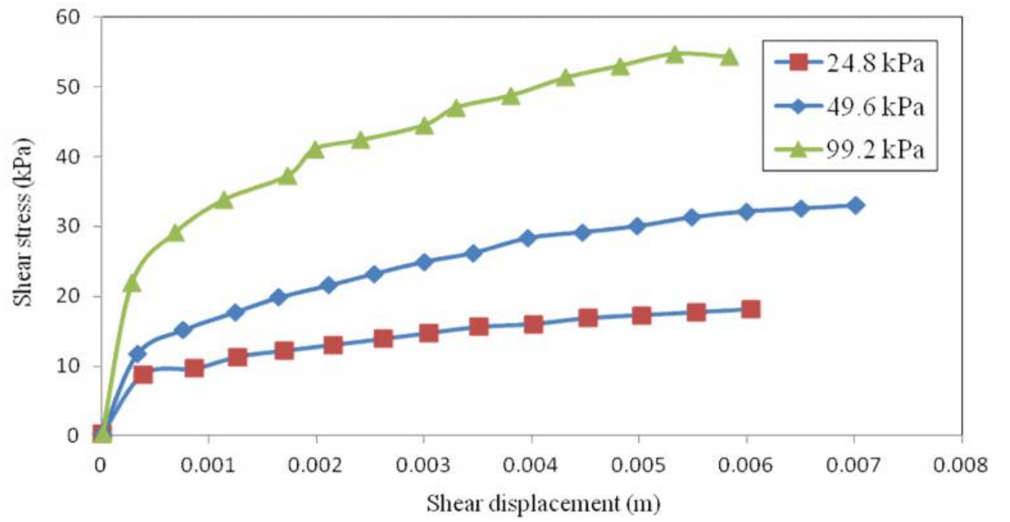

Fig. 5. Shear stress vs. displacement curve for Consolidated undrained direct shear test of soil (c = 7 kPa, φ = 21°).

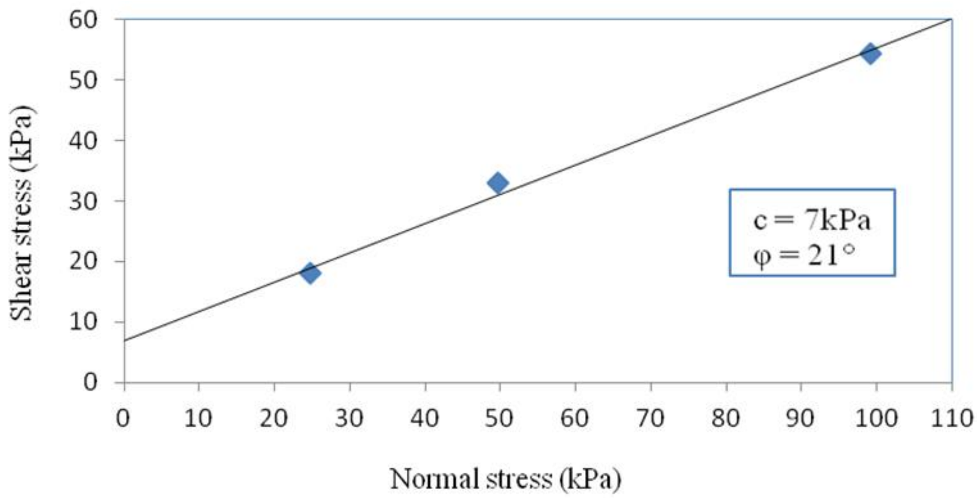

Fig. 6. Shear stress vs. normal stress graph of soil (c = 7 kPa, φ = 21°)

According to MIT classification the percentage of sand, silt and clay at our soil sample have been found 63%, 35% and 2% respectively. Hence it can realize that the sample is not the pure sand. According To Unified Soil Classification system (USCS) the soil sample is SW-SM. It has a portion of silt and clay. The amount of silt portion is quite appreciable while the portion of clay might be negligible. This sandy soil has been used for the compaction test which is necessary to perform consolidated undrained direct shear test further. The motto of the compaction test is to develop a remolded sample for shear test with the corresponding water content of 95% peak value of dry density at wet side. From the shear test the values of cohesion and angle of internal friction have been obtained for sand. For further parametric study, shear strength parameters have been modified. Table 1 shows the values of cohesion and angle of internal friction of three types of soil obtained from Consolidated Undrained direct Shear Test.

Table 1
Results from Consolidated Undrained direct Shear Test

Soil sample	Cohesion, c (kN/m^2)	Angle of internal friction, φ(degree)
Type 1	7	21
Type 2	10	14
Type 3	20	12

From the table 1 we can analyze that cohesion is increasing with the increase of clay while angle of internal friction is decreasing along with it. The more the cohesion the more would be the presence of clay while the reverse case happens for angle of internal friction. The values of cohesion and angle of internal friction have been used in the stability analysis. The shear strength parameters of the underlying soils have been obtained using the existing correlation with SPT-N value shown in the bore logs.

5. Slope Stability Analysis

Civil engineers are often expected to make calculations to check the safety of natural slopes, slopes of excavations, and compacted embankments. This check involves determining the shear stress developed along the most likely rupture surface and comparing it with shear strength of the soil. This process is called slope stability analysis. The most likely rupture surface is the critical surface that has the minimum factor of safety.

The Program STB2010

This is a program for the analysis of the stability of slope (Verruijt, A., Delft University, 2010). The program uses Bishop’s simplified method with some modifications introduced at GeoDelft and the Delft University for the calculation of the facto of safety of circular slip surface, with Koppejan’s correction for very deep circles, and a modification to account for the strength reduction of a double sliding model. The program also allows for a possible horizontal body force, to simulate the effect of an earthquake. The soil properties used in the program are:

- W_d: Dry unit weight (kN/m3).
- W_s: Saturated unit weight (kN/m3).
- K_o: Coefficient of neutral horizontal stress (-).
- c: Cohesion (kN/m^2).
- phi: Angle of internal friction (degrees).
- P/F: Switch for the groundwater condition (-).
- p = 0: Zero level of the pore water pressure (m).
- cap: Thickness of capillary zone, above groundwater table (m).
- The unit weight of water is 10 kN/m^3.

6. Results of Stability Analysis Using STB2010

STB2010 is used for the analysis of stability of slope, using Bishop's method with some conditions. Graphs and other graphics are created here. When the software is started the first form appeared in General, Soil Properties and Nodes chart where all general and sampling related information is given. Figure 7 – 10 show the results of Stability Analysis of soil (c = 7 kPa, φ = 21°) at four conditions (dry, low flood level, high flood level and rapid drawdown respectively) with three slopes (1:1, 1:1.5 and 1:2).

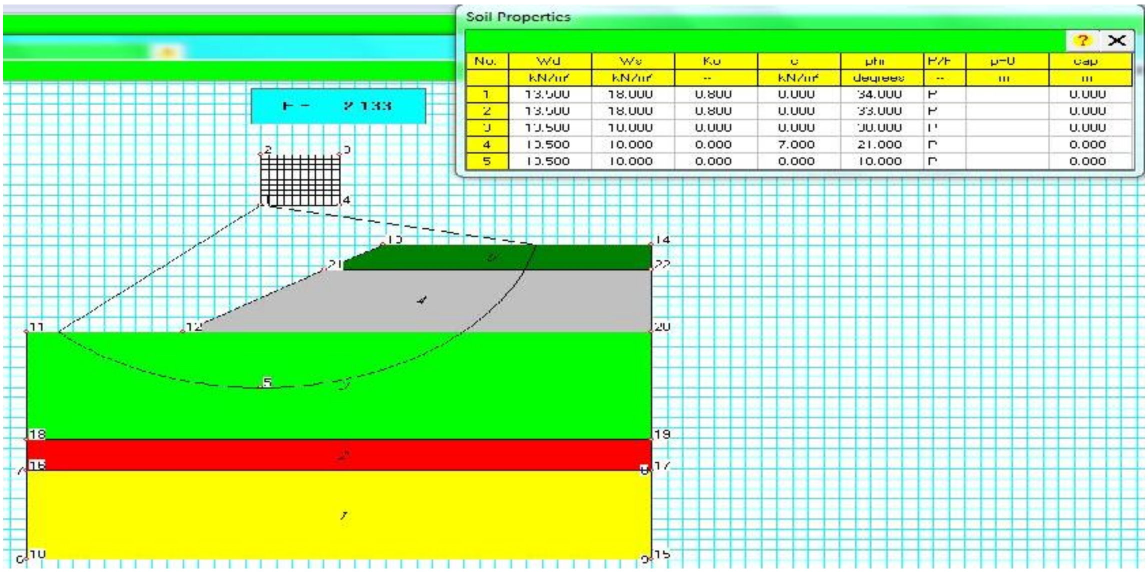

Fig. 7. Result of stability analysis of soil (c = 7 kPa, φ = 21°) at dry condition for slope 1:1.5

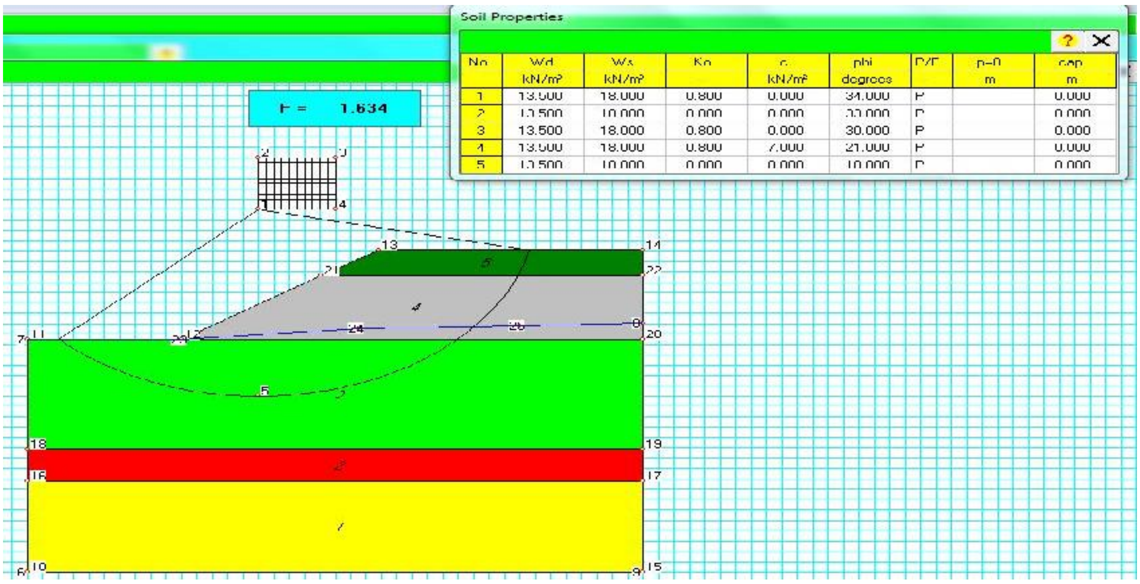

Fig. 8. Result of stability analysis of soil (c = 7 kPa, φ = 21°) at low flood level condition for slope 1:1.5

The results obtained from the analysis using STB2010 are shown in Table 2 to 4. The fluctuation of the safety factor along with four conditions and three slopes for the soils having different parametric characteristics has been shown in Figure 11 to 13. From the figures for all kinds of soil, it has been realized that the safety factor increases with the increase of water

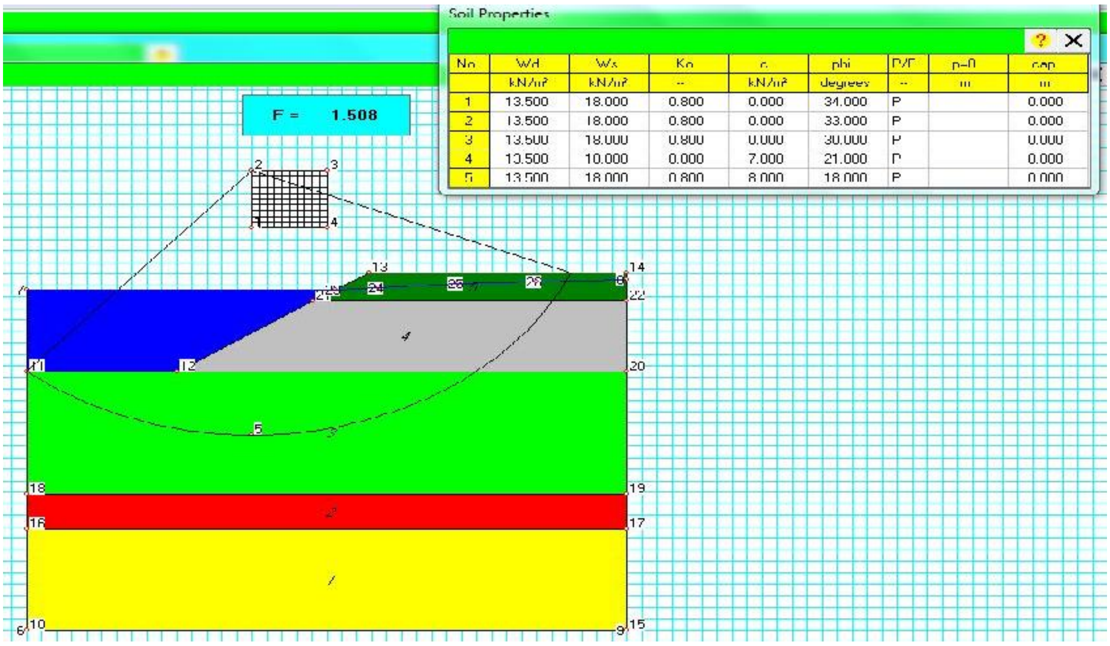

Fig. 9. Result of stability analysis of soil (c = 7 kPa, φ = 21°) at high flood level condition for slope 1:1.5

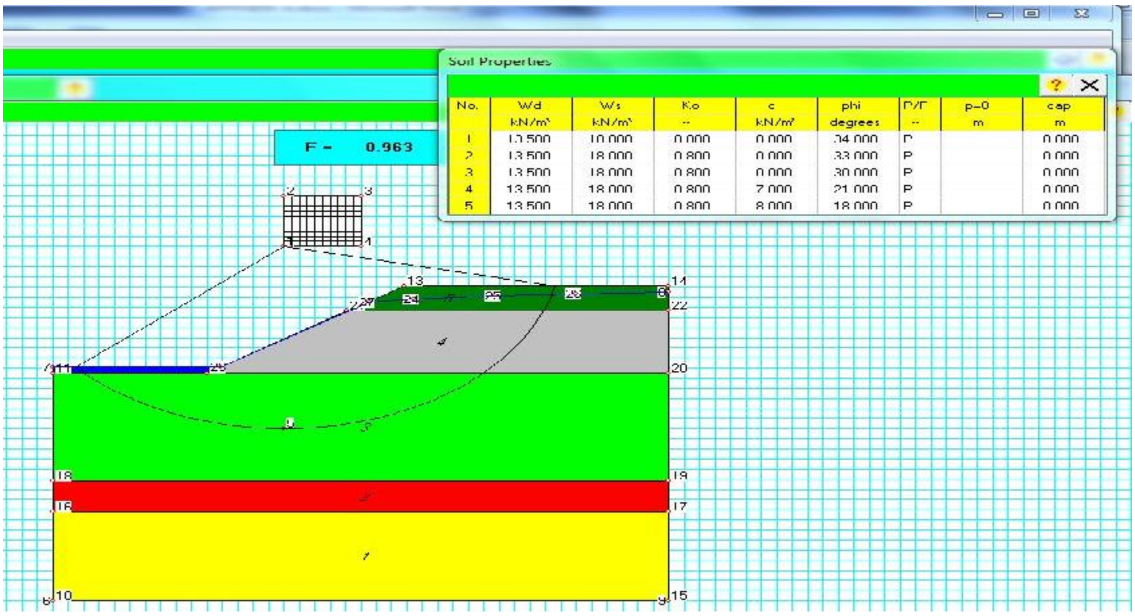

Fig. 10. Result of stability analysis of soil (c = 7 kPa, φ = 21°) at rapid drawdown condition for slope 1:1.5

Table 2
Results of Stability Analysis of Soil Sample Type 1 (c = 7 kPa, φ = 21°)

Slope	Dry Condition	Low flood Level Condition	High flood Level Condition	Rapid drawdown
1:1	1.536	1.244	0.904	0.66
1:1.5	2.133	1.634	1.508	0.963
1:2	2.255	1.669	1.478	0.986

due to seepage into the soil. But at rapid drawdown condition the safety factors have been found to be least among all conditions. It causes due to rapid reduction of external water level. Figure 14 and 15 show the variation of safety factors at high flood level and rapid drawdown condition for different soil condition respectively.

Table 3
Results of Stability Analysis of Soil Sample Type 2 (c = 10 kPa, φ = 14°)

Slope	Dry Condition	Low flood Level Condition	High flood Level Condition	Rapid drawdown
1:1	1.477	1.206	0.916	0.672
1:1.5	2.092	1.594	1.485	0.953
1:2	2.213	1.626	1.461	0.984

Table 4
Results of Stability Analysis of Soil Sample Type 3 (c = 20 kPa, φ = 12°)

Slope	Dry Condition	Low flood Level Condition	High flood Level Condition	Rapid drawdown
1:1	1.581	1.305	0.841	0.6
1:1.5	2.162	1.66	1.576	1.02
1:2	2.284	1.692	1.554	1.054

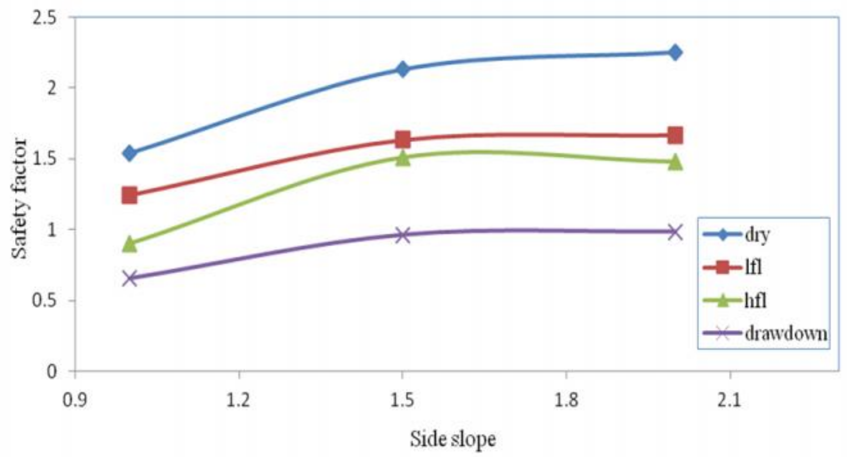

Fig. 11. Comparison on three conditions with three slopes for soil sample Type 1 (c = 7 kPa, φ = 21°)

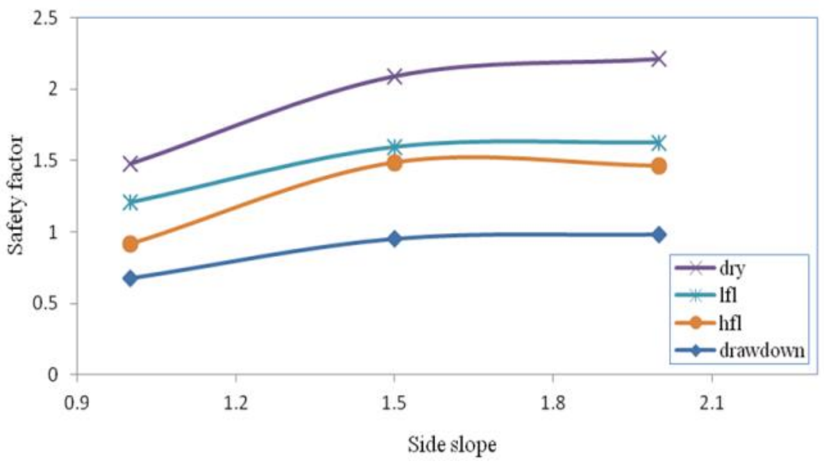

Fig. 12. Comparison on three conditions with three slopes for soil sample type 2 (c = 10 kPa, φ = 14°)

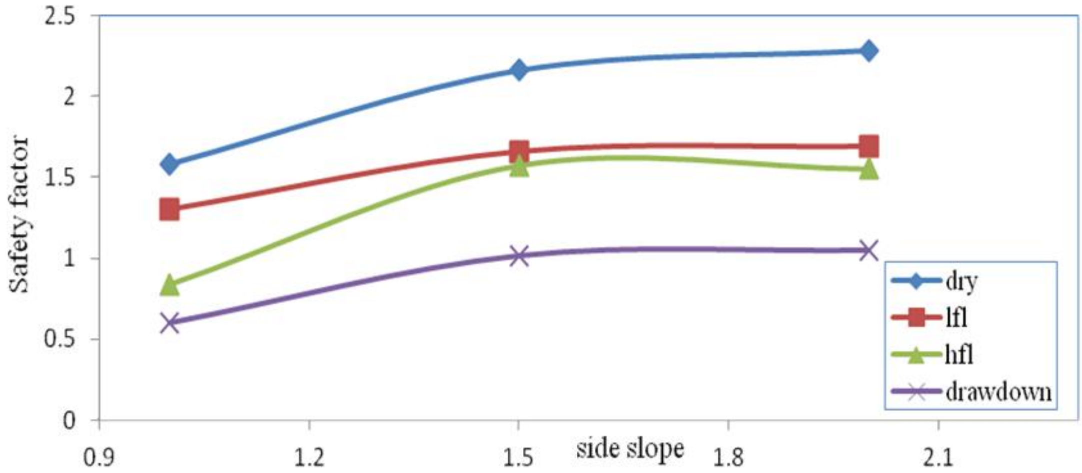

Fig. 13. Comparison on three conditions with three slopes for soil sample Type 3 (c = 20 kPa, φ = 12°)

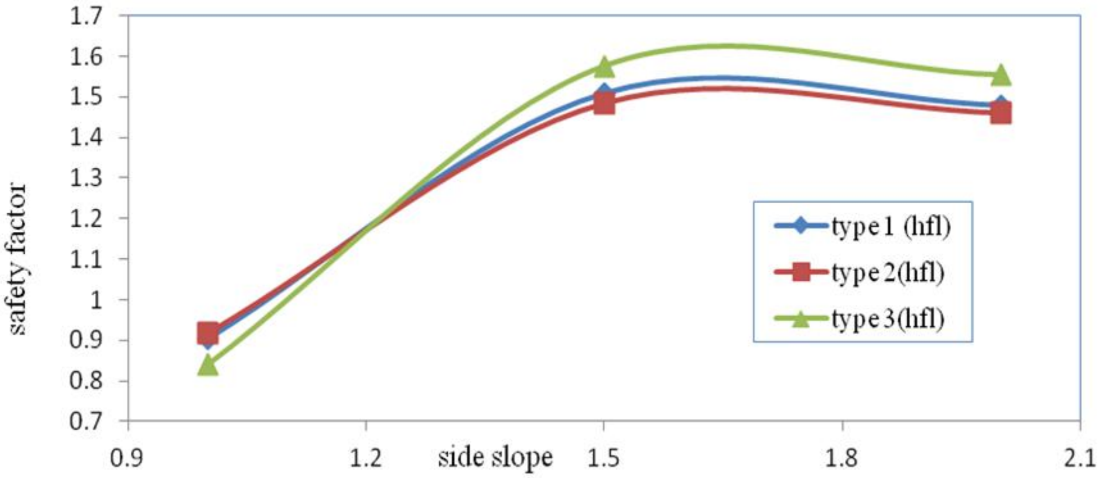

Fig. 14. Variation of safety factor for different soil condition at high flood level condition

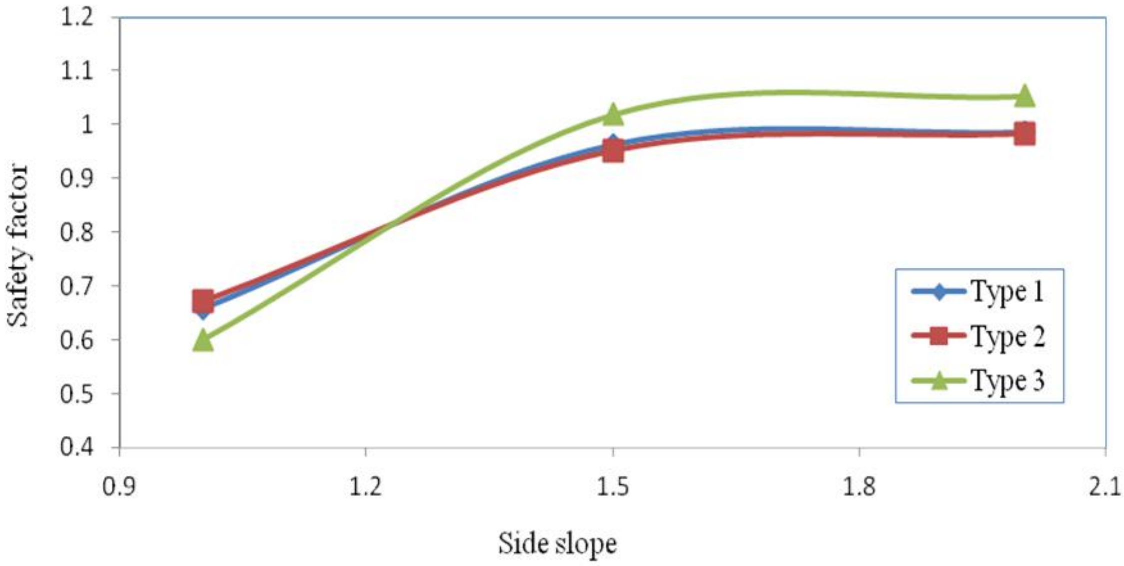

Fig. 15. Variation of safety factor for different soil condition at rapid drawdown condition

After analysis the safety factors for all types of soil at high flood level condition with slope 1:1 and at rapid drawdown for all three slopes have been found to be lower than the minimum recommended factor 1.2. So a typical design is needed to ensure the strength of soil. Revetment design is the most beneficial and affordable solution for Bangladesh. Using concrete block is considered to be efficient for Revetment design.

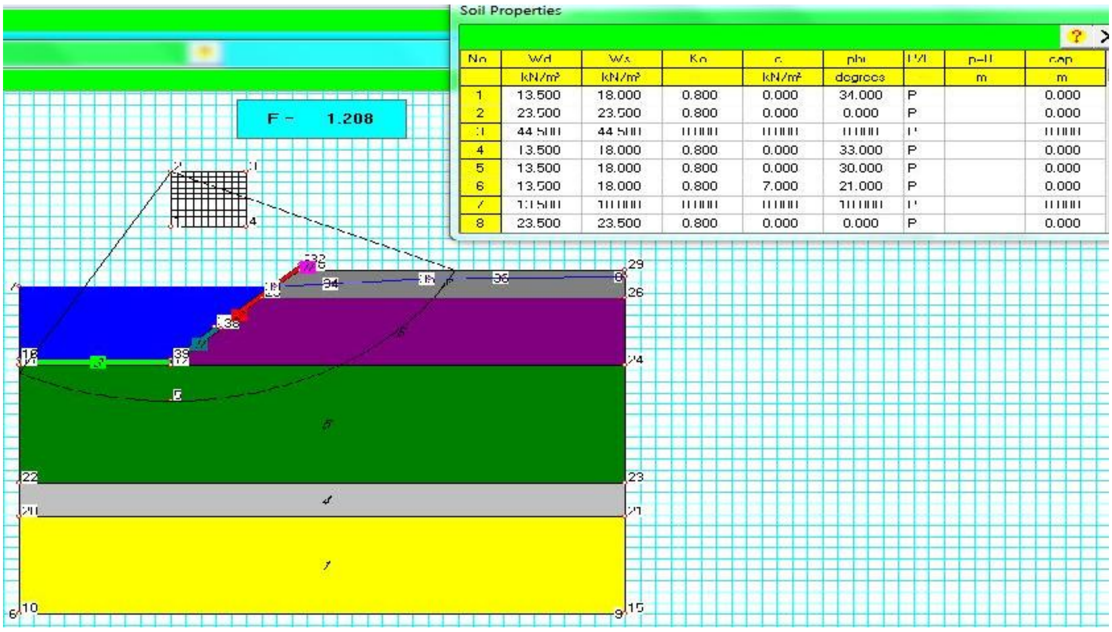

Fig. 16. Revetment Design for soil type 1 (c = 7 kPa, φ = 21°)

In the revetment design, concrete blocks are given in one or two layers, sometimes it extends to three, four or five layers either along with or without geotextile layer. It depends on the range of safety factor that is to be increased. From Stability analysis using STB2010, the safety factors for high flood level condition at slope 1:1 and rapid drawdown with three slopes for all categories of soil have been found to be below the minimum recommended value 1.2. So the revetment design has been performed here to raise the strength of soil. For the design, first a thin layer of geotextile has been given of 15 cm thickness. Then a layer is given with 45 cm * 45 cm * 45 cm concrete block. For the total layer including concrete block and geotextile, the unit weight would be the sum of γ * h of both two materials. If the unit weight of concrete and geotextiles are 23.57 kN/m^3 (150 pcf) and 16 kN/m^3 (102 pcf) respectively then the total unit weight 13 kN/m^2 (γ * h) for 1 m strip would be counted for one layer in the design. When it is of two layers then the unit weight would be 23.5 kN/m^3 by adding extra unit weight of 2nd layer concrete block.

Table 5
Results of Revetment Design at high flood Level condition

Embankment Soil Properties	Factor of safety
c = 7 kPa, φ = 21°	1.208
c = 10 kPa, φ = 14°	1.204
c = 20 kPa, φ = 12°	1.288

The value of unit weight increases with the increase of concrete block layer adding 10.5 for each layer. Again it causes huge cost while increasing block layer one by one. As it costs much to layer the embankment overall with uniform concrete block, we can differ in placing the block layer depending on the satisfaction of safety factor. For sandy soil, four layers of concrete block have been placed at the bottom through toe up to the middle of the slope while two layers have been placed from middle up to the top of the embankment due to make the design economical. Figure 16 shows the result with necessary diagram of stability analysis.

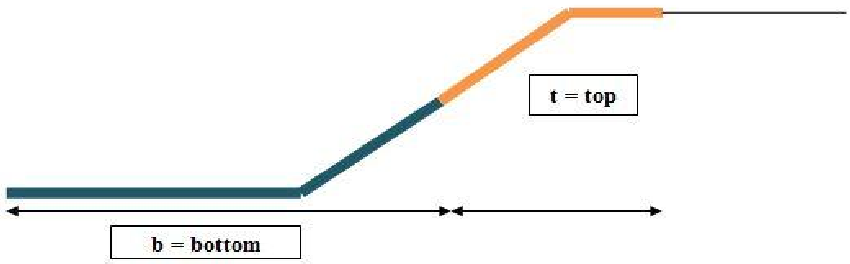

Fig. 17. Slope of an embankment

Table 5 shows the safety factor for different soil conditions at high flood level. For type 1 (c = 7 kPa, φ = 21°), four layers for high flood level condition have been placed at the bottom through toe up to the middle of the slope while two layers have been placed from middle up to the top of the embankment. For type 2 (c = 10 kPa, φ = 14°) four layers have been placed uniformly across the embankment for high flood level condition. For type 3 (c = 20 kPa, φ = 12°), four layers have been placed at the bottom through toe up to the middle of the slope while one layer has been placed from middle up to the top of the embankment for high flood level condition. Again for rapid drawdown condition, the distribution of block layers along with obtained safety factors have been given in table 6. The distribution of block layers is on the basis of making the design economical.

Table 6
Results of Revetment Design at Rapid drawdown condition

slope	c = 7 kPa, φ = 21°	c = 10 kPa, φ = 14°	c = 20 kPa, φ = 12°
1:1	1.201 (7b+1top)	1.200(7b+2top)	1.213 (6b+1top)
1:1.5	1.214 (3b+1top)	1.208 (3b+1top)	1.273(3b+1top)
1:2	1.276 (3b+1top)	1.268 (3b+1top)	1.213(1b+1top)

Table 7
Variation of safety factor of Type1 (c = 7 kPa, φ = 21°) soil

Layer 1	Safety factor	Layer 2	Safety factor	Layer 3	Safety factor	Layer 4	Safety factor
1b + 1t	0.968	2b + 1t	1.043	3b + 1t	1.12	4b + 1t	1.198
1b + 2t	0.981	2b + 2t	1.055	3b + 2t	1.131	4b + 2t	1.208
1b + 3t	0.994	2b + 3t	1.067	3b + 3t	1.141	4b + 3t	1.218
1b + 4t	1.006	2b + 4t	1.078	3b + 4t	1.151	4b + 4t	1.227

Figure 17 shows the slope of an embankment indicating bottom and top. Table 7 shows the variation of safety factor for Type 1(c = 7 kPa, φ = 21°) depending on the distribution of concrete block layers. Safety factor has been found to be 1.198 for placing 4 layers at the bottom through toe up to the middle of the slope and 1 layer from the middle up to the top of the embankment. But it doesn’t satisfy the condition. So 2 layers have been placed instead of 1 layer from the middle up to the top and the safety factor has been found to be 1.208. Table 8 shows the variation of safety factor for Type 2(c = 10 kPa, φ = 14°) depending on the distribution of concrete block layers. Safety factor has been found to be 1.204 for placing 4 layers uniformly across the embankment.

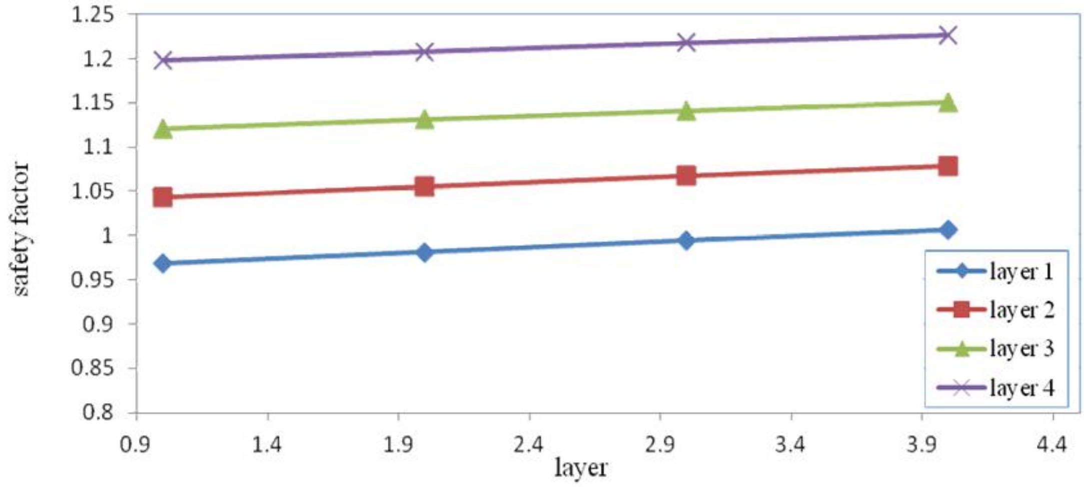

Fig. 18. Safety factor vs. layer graph for Type1(c = 7 kPa, φ = 21°) soil

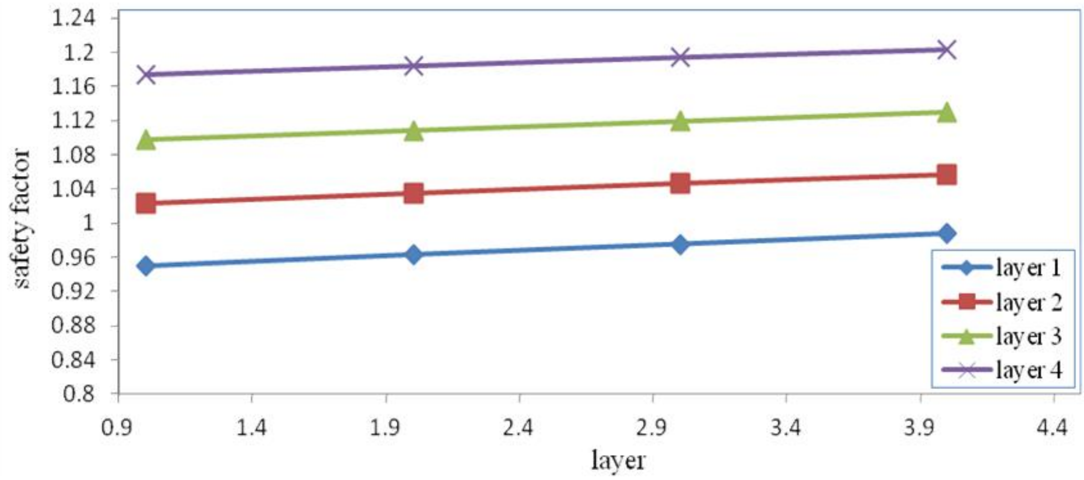

Fig. 19. Safety factor vs. layer graph for Type2 (c = 10 kPa, φ = 14°) soil

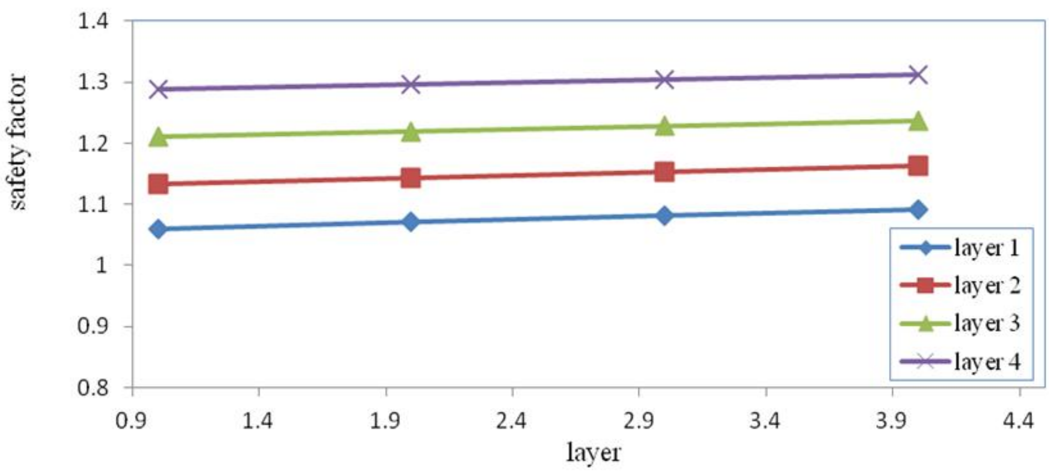

Fig. 20. Safety factor vs. layer graph for Type 3 (c = 20 kPa, φ = 12°) soil

Table 8
Variation of safety factor of Type2(c = 10 kPa, φ = 14°) soil

Layer 1	Safety factor	Layer 2	Safety factor	Layer 3	Safety factor	Layer 4	Safety factor
1b + 1t	0.951	2b + 1t	1.024	3b + 1t	1.098	4b + 1t	1.175
1b + 2t	0.964	2b + 2t	1.036	3b + 2t	1.109	4b + 2t	1.185
1b + 3t	0.976	2b + 3t	1.0477	3b + 3t	1.12	4b + 3t	1.195
1b + 4t	0.988	2b + 4t	1.058	3b + 4t	1.131	4b + 4t	1.204

Table 9
Variation of safety factor of Type3(c = 20 kPa, φ = 12°) soil

Layer 1	Safety factor	Layer 2	Safety factor	Layer 3	Safety factor	Layer 4	Safety factor
1b + 1t	1.059	2b + 1t	1.134	3b + 1t	1.21	4b + 1t	1.288
1b + 2t	1.071	2b + 2t	1.144	3b + 2t	1.219	4b + 2t	1.296
1b + 3t	1.082	2b + 3t	1.154	3b + 3t	1.228	4b + 3t	1.304
1b + 4t	1.092	2b + 4t	1.164	3b + 4t	1.237	4b + 4t	1.312

Table 9 shows the variation of safety factor for Type 3(c = 20 kPa, φ = 12°) depending on the distribution of concrete block layers. Safety factor has been found to be 1.288 for placing 4 layers at the bottom through toe up to the middle of the slope and 1 layer from the middle up to the top of the embankment which satisfies the condition. The variation of safety factor for different parametric soil at high flood level condition has been shown in figure 18 to 20.

After Revetment Design the conditions are satisfied for the soil samples at high flood level and rapid drawdown conditions. For all cases, the safety factors are above the recommended value. These values have ensured the shear strength of soil along with the protection of river embankment. The soil having better safety factors are assumed to be more protective from erosion. After the design, the number of layers at rapid drawdown has been found to be greater in quantity than high flood level condition. But in practice, rarely rapid drawdown condition is considered, so the number of layers used is minimum.

7. Conclusion

Riverbank erosion is often initiated by failure of a riverbank causing high sediment loads or heavy rainfall. This generates high volume and velocity run-off which will concentrate in the lower drainages within the river's catchments area. When the stress applied by these river flows exceeds the resistance of the riverbank material, erosion will occur. As the sediment load increases, fast-flowing rivers will erode their banks downstream. Eventually, the river becomes overloaded or velocity is reduced, leading to the deposition of sediment to further downstream or in dams and reservoirs. The deposition may eventually lead to the river developing a new channel. While all rivers change in the long-term, short-term rates of change vary significantly. With growing demand for protecting people's health and homes, agriculture and city dwellers; the issue of river embankments and flood control embankments in Bangladesh is getting much attention lately. This is because of the construction of river embankments in Bangladesh is the cheapest form to protect flood water in rainy season and store necessary water in the dry season. This research has been carried out to investigate the geotechnical characteristics of the embankment and presented results of more recent soil investigation along the embankment alignment. For this purpose embankment soil has been collected from Basuria in Sirajganj near the bank of Jamuna River. Also field bore logs has been done up to a depth of 30 m. Direct from the broken part of the embankment, the soil samples are collected by which the following laboratory tests: Grain Size Analysis, Compaction Test, Shear Test have been performed. The collected sample contains 63% sand, 35 % silt and 2% clay. According to the Unified Soil Classification System (USCS), the soil sample is SW – SM. With a view to making a remolded sample to obtain the shear strength parameters of the collected disturbed sample of the embankment, a Standard Proctor Compaction test has been conducted in the laboratory. The remolded sample has been made with the corresponding water content of 95% peak value of the dry density at wet side. The optimum dry density has been found to be 17.45 kN/$m^{3.}$ Due to obtain the shear strength parameters, Consolidated Undrained Shear test has been performed in the laboratory. The cohesion and angle of internal friction has been found to be 7 kPa and 21° respectively. For further parametric study, Shear strength parameters has been modified to be 10 kPa; 14° and 20 kPa; 12°. The parameters of the soil sample of the embankment have been found directly from the laboratory tests, while for the underlying soils the shear strength parameters have been obtained from the correlation with SPT – N value shown in the bore logs.

Based on the data of the present investigation, stability analysis of some critical sections of the embankment has been carried out. The stability analysis has been conducted using STB2010. The analysis depends on the soil parameters obtained during the construction of embankment. The analysis has been performed for soils at three conditions; dry, low flood level, high flood level and rapid drawdown with three different slopes; 1:1, 1:1.5 and 1:2. The values of cohesion and angle of internal friction obtained from the shear test have been used in STB2010. The maximum safety factor has been obtained 2.255 for soil at dry condition with a slope 1:2 while the minimum factor is 0.66 at rapid drawdown condition with 1:1 slope. As long as water increases, the soil becomes weakened for steepening slope. But at rapid drawdown condition safety factor has been found to be the least because of rapid reduction of external water level. So the soil would fail at any time as having lower shear strength to protest against erosion. It has been realized that, soil at dry condition has better strength to protect embankment from failure. Again the strength increases with flatter slope rather than steep slope. The main reason of the failure at high water level is considered to be water seepage into the soil while the reason is rapid reduction of external water level for rapid drawdown condition. For this type of soil, a design named Revetment Design with a thin geotextile layer and concrete block layer has been conducted to protect river embankment. This design is affordable and suitable for Bangladesh. To make the design more economical, four layers of concrete block have been placed at the bottom through toe up to the middle of the slope while one or two layers are placed from middle up to the top of the embankment for high flood level but at drawdown condition, number of layers have been increased due to satisfy the recommended value. After Revetment Design a reasonable safety factor has been achieved for the soils at critical condition which ensures the protective strength of soil against failure.

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