Slope stability analysis of Buriganga river bank

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Abstract. *The paper aims to evaluate the stability of a particular section of the Buriganga River embankment, which is an economically significant river in Bangladesh. The study involved collecting soil samples from the embankment to determine its index properties, grain size distribution, organic matter content, and shear strength parameters. Laboratory tests, including direct shear and consolidated drained shear tests, were conducted with varying water content and normal load to determine the cohesion and angle of internal friction for both disturbed and undisturbed soil samples. Using XSTABL software, slope stability analysis was performed with a 1:1.5 slope based on the soil investigation results. The maximum factor of safety was found to be 1.548 for the undisturbed soil sample and 0.82 for the disturbed soil sample. The study showed that increasing soil cohesion significantly increases stability.*

Keywords

Buriganga river, Slope stability analysis, Factor of safety, XSTABL.

1. Introduction

Geotechnical engineers are typically responsible for conducting slope stability analysis, which involves various factors such as budget, method, structural shape, and materials used. Improper design methodology and construction procedures are the main causes of embankment failure, so engineers take into account different factors during their analysis. As a result, slope stability analysis is a significant area of research for geotechnical engineers. River embankments present an even more interesting case for slope stability analysis, as the wide variation of soil properties in small areas can make analysis challenging.

Numerous studies have been conducted in the past to analyze slope stability, with scientists, researchers, and engineers working to make the process easier. Geotechnical engineers are frequently required to stabilize river banks, as many cities around the world are built near rivers. The Buriganga river runs alongside Dhaka, the capital of Bangladesh, and is of great economic value, as it provides water for various purposes such as groundwater recharge, recreation, fisheries, sanitation, and agriculture. However, there is a lack of extensive research on the Buriganga river, which motivated this study. The aim of this research is to examine the soil properties and evaluate the factor of safety for the Buriganga river embankment. XSTABL software was used to determine the critical surface and analyze the factor of safety [1–22].

2. Methodology

The research process started with a field study and reconnaissance survey. Based on the field data, soil samples were taken from the Buriganga river bank. The necessary geotechnical data was gathered through an intricate experimental program. XSTABL software was used to calculate the factor of safety.

2.1. Overview of sample collection

Soil samples were collected from the unprotected river bank. The place for soil collection is situated at 23^o 43' 23" latitude and 90^o 21'35" longitudes (Fig. 1).

A reconnaissance survey was done to know about the length of protected and unprotected riverbank. Survey was made on the field for getting information about river bank condition at different places. Data from Bangladesh Water Development Board was helpful to get information about the history of river bank, type of erosion etc. This survey was helpful in making a choice on study area. The site was selected based on the following points:

a. Present condition of the river bank.

b. Steepness of the bank slope.

c. Presence of vegetative cover on the slope.

d. Type of soil

e. Local activities along the river bank.

f. Highest flood level

Based on the aforementioned factors, certain collection points were chosen based on their vulnerability. The slope stability in these areas should be lower compared to other sections of the embankment. Consequently, specific analyses were conducted for these locations to determine the minimum factor of safety. From this perspective, it can be inferred that the slopes in other regions of the embankment are relatively more stable in comparison to the areas subjected to the specific analyses.

The task of collecting samples was completed three times. First, a disturbed sample was taken by using a spade and polythene bags. For the Atterberg limit test, organic content test, direct shear test, wash sieve test, sieve analysis, and hydrometer test, a second sampling was carried out. Finally, three samples of undisturbed soil were taken. These undisturbed samples were collected using pipes with a diameter of four inches.

The correct tools, like a core sampler, weren't used when collecting the undisturbed sample. Therefore, care has been made to prevent any disturbance to the sample. To prevent moisture content loss, collected samples were placed in polythene bags and fastened with rope.

The samples were removed from the pipe by a hydraulic jack after being transported to the lab at BUET (Bangladesh University of Engineering and Technology), where they were then preserved in desiccators to ensure that the water content did not change over the course of the testing procedure.

2.2. Laboratory tests

Different laboratory tests were performed to determine the index properties and shear strength properties of the collected soil sample. The tests were performed by maintaining ASTM standard which has shown below in bracket.

a. Specific gravity test (ASTM D854)

b. Atterberg limit test (ASTM D 4318 w)

c. Organic matter content (ASTM D2974)

d. Hydrometer analysis (ASTM D421 and D422)

e. Wash sieve (ASTM D1140)

f. Direct shear test (ASTM D3080)

2.3. XSTABL program

The stability of slopes is examined using the XSTABL program using the limit equilibrium method. This approach determines the factor of

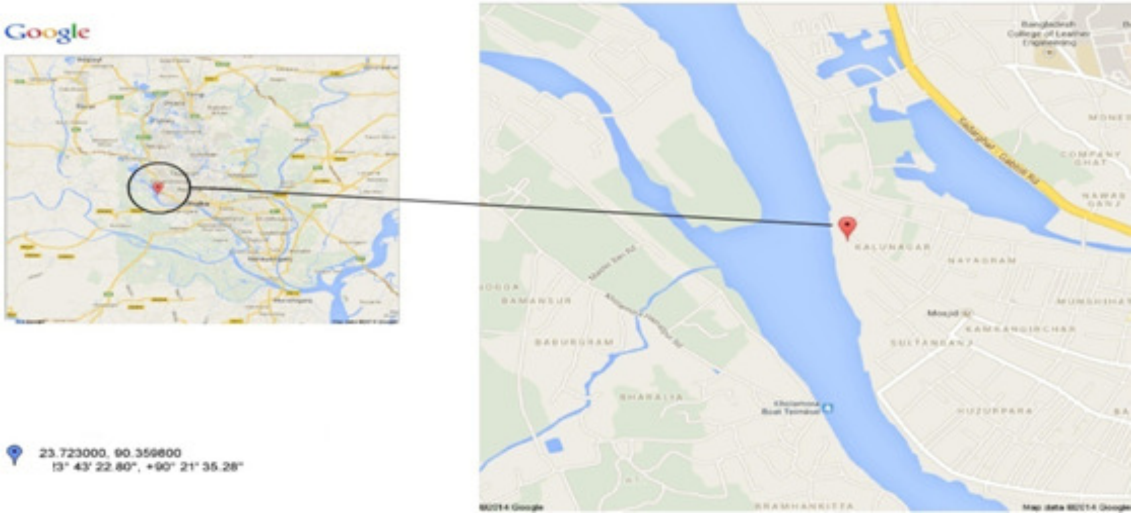


Fig. 1: Location of study area.

safety for various probable failure surfaces on the assumption that the slope will fail along a failure surface. It is calculated as the ratio of driving forces to resisting forces. The slope geometry, soil or rock qualities, and external pressures acting on the slope must be known in order to use the XSTABL program. After determining the factor of safety for various probable failure surfaces, the application produces a graphical output that identifies the critical failure surface.

Due to its user-friendliness and effective factor of safety computation, the XSTABL program was used for the analysis. It saves time and provides reliability. The Janbu approach and the Simplified Bishop's method are the two methods the program provides for determining the critical surface and the minimum Factor of Safety. The latter approach has been used for the study since it is popular and takes inter-slice forces into account, resulting in a reliable result.

After all the essential data for the slope profile, soil parameter, and water surface were input, the slope stability analysis of a specific embankment was found. Total 100 surfaces were generated. The number of most important surfaces and the required level of safety have been determined to be 10.

3. Results and Discussion

Several laboratory tests were performed in order to obtain the texture and other parameters that can illustrate the physical and chemical properties of the soil sample.

3.1. Organic content test

This test was performed to determine the mass and percentage of the organic matter present in the soil sample of Buriganga river bank. The mass of organic matter in soils as a percent generally ranges from 1 to 6% of the total topsoil mass for most upland soils. Soils containing 12-18% organic matter are generally classified as organic soils [Troeh et. al, 2005]. The soil sample tested has 6.19% OM which is closer to the normal range and sample is not organic soil.

3.2. Specific gravity

Soil sample was tested three times to obtain this parameter. Values obtained were 2.6, 2.71 and 2.71. The average value of these three was taken as the specific gravity of the soil specimen and it was 2.67. The specific gravity of soil (except organic soil) ranges from 2.65 to 2.8. Hence, the tested sample has specific gravity within the desired range.

3.3. Atterberg limits

The obtained values of Atterberg limits for the soil sample are given in Table 1 Therefore, the

Tab. 1: Results from Atterberg Limit Test.

Liquid Limit (LL), %	Plastic Limit (PL), %	Plasticity Index (PI), %
52	19	33

soil seemed to be plastic with medium to high dry strength and will be difficult to be crushed (after Atkins, 1997). Again the soil had high swelling potential due to a higher value of plasticity index (Whitlow, 1996).

3.4. Hydrometer analysis

The test showed that, 92.15% of the soil particles are finer than #200 sieve. Therefore, hydrometer analysis was performed on the soil sample instead of ordinary sieve analysis. Fig. 2 shows the results of hydrometer analysis.

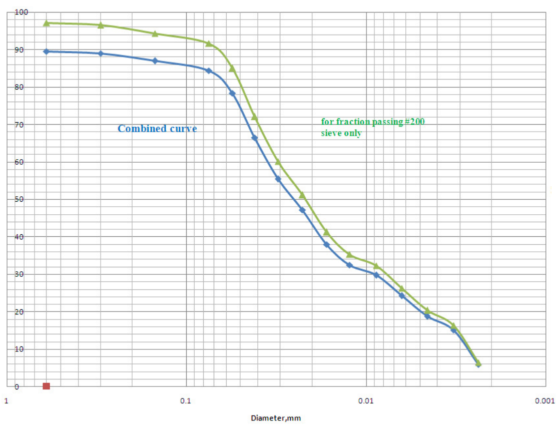


Fig. 2: Hydrometer analysis.

3.5. Soil strength parameter

To determine the strength parameters of soil, cohesion (c) and angle of internal friction (φ) direct shear test was performed. Tests were done on both disturbed and undisturbed soil. For disturbed soil sample, different water content was mixed with soil to observe the change in the strength. Five sets of water content were used with the disturbed sample (Fig. 4-7). They were 10%, 20%, 30% and 40%. Undisturbed samples were tested to see how their strength changes with the change of location along the slope.

(a) Undisturbed sample

Undisturbed samples were tested to see how their strength changes with the change of location along the slope. Samples collected from three different locations were tested. Sample point-1 and point-2 were situated at the upper portion of the slope. Sample point-3 was situated near the river flow. Results are showed in Fig. 3.

b) Disturbed sample

For disturbed soil sample, different water content was mixed with soil to observe the change in shear strength. Five sets of water content 10%, 20%, 30% and 40% were used with the disturbed sample (Fig. 4-7).

Tab. 2: Strength Parameters of Undisturbed Sample.

Location	Cohesion, C (kN/m^2)	Angle of internal friction, $\varphi(^o)$
Collection point-1	7.37	32.15^o
Collection point-2	5.67	34.21^o
Collection point-3	16.55	16.44^o

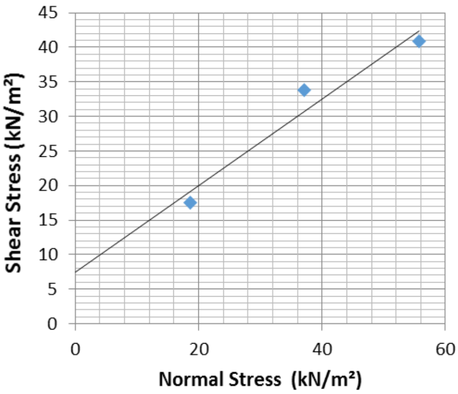
Tab. 3: Strength Parameters of Disturbed Sample.

Water content, %	Cohesion, C (kN/m^2)	Angle of internal friction, $\varphi(^o)$
10%	0.02	34.13^o
20%	8.29	24.16^o
30%	11	26.94^o
40%	6.88	21.80^o

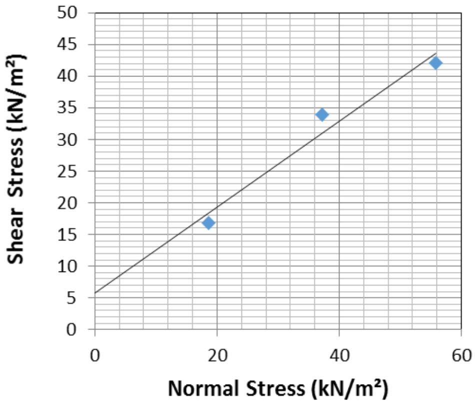
3.6. Factor of safety analysis by program XSTABL

To analyze slope stability by the XSTABL program certain steps have to be followed. The geometry of the slope, soil data for surface and subsurface has been provided. In the program the number of initiation points of circular surfaces is selected as 10. From each initiation point 10 number of surfaces are to be generated and as a result total number of surfaces generated

(a) Sample point-1



(b) Sample point-2



(c) Sample point-3

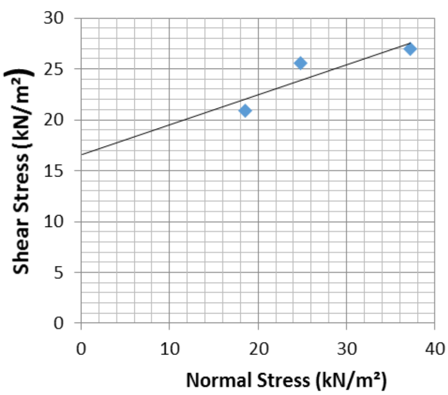


Fig. 3: Hydrometer analysis.

is 10 X 10 = 100. After all the necessary data input for the embankment section of Buriganga total 10 most critical surfaces and the minimum

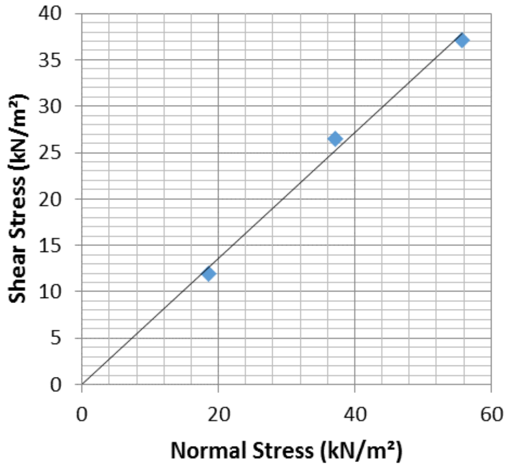


Fig. 4: Disturbed sample with 10% WC.

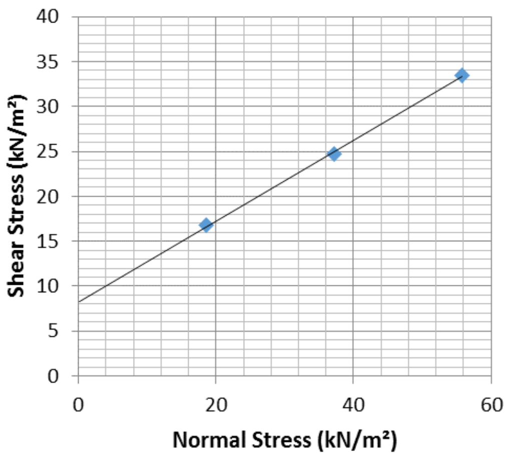


Fig. 5: Disturbed sample with 20% WC.

Factor of Safety have been found and shown in Fig. 8 (only for undisturbed sample - 3).

Factor of safety for other soil sample has been compiled in Table 4. Slope stability has been done maintaining 1:1.5 slope. The maximum factor of safety has been found 1.548 for undisturbed and 0.82 for disturbed soil sample. From this analysis it has been noticed that the soil stability increases with the increase of cohesion of soil.

Different past researches show that with the increase of water in a soil sample, cohesion gradually decreases and angle of friction increases.

Tab. 4: Minimum Bishop factor of safety obtained from XSTABL.

Sl. No	Soil sample	Normal load	C (kN/m^2)	φ (^{o})	Minimum factor of safety from XSTABL
1	Undisturbed sample-1	18	7.37	32.15^o	1.236
2	Undisturbed sample-2	18	5.67	34.21^o	1.138
3	Undisturbed sample-3	6	16.55	16.44^o	1.548
4	Disturbed soil (10% wc)	6	0.02	34.13^o	0.82
5	Disturbed soil (20% wc)	6	8.29	24.16 ^{o}	1.289
6	Disturbed soil (30% wc)	6	11	26.94 ^{o}	1.406
7	Disturbed soil (35% wc)	6	2.85	30.23^o	0.983
8	Disturbed soil (40% wc)	6	6.88	21.80 ^{o}	1.209

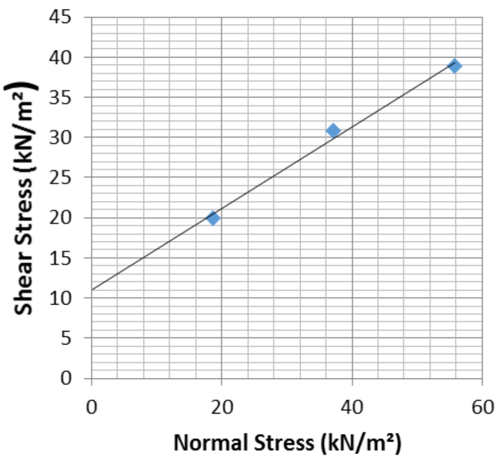


Fig. 6: Disturbed sample with 30% WC.

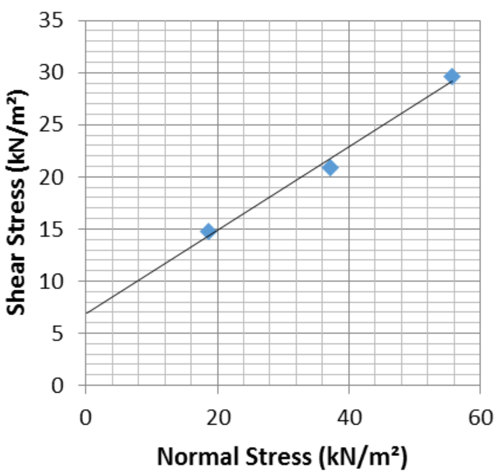


Fig. 7: Disturbed sample with 40% WC.

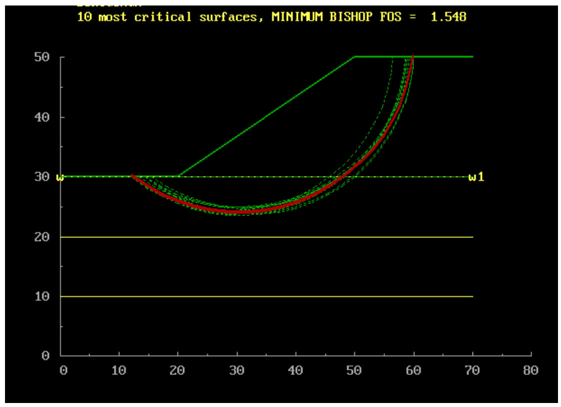


Fig. 8: Display of the 10 most critical surfaces & the minimum factor of safety for Borehole 3 (undisturbed soil).

It happens when experiment is done on a sample collected from a small selected area where change of soil character is negligible. Characteristics of soil are very uncertain and soil characteristics of two soil samples can be totally different from each other even if they are only small distance apart. A large amount of soil was collected from the Buriganga riverbank. Characteristics, structure and texture of those testing samples found different from each other. So, no exact relation can be established among them. So, stabilization is required considering the probable worst case.

On the other hand, there is a significant difference in the factor of safety of disturbed and undisturbed soil sample. In case of river embankment soil can become disturbed mainly due to erosion and water level condition. Rainfall, winds, absence of vegetation cover over slope can cause soil erosion. The loss of the topsoil layer reduces the stability of the remaining soil. The embankment may be disturbed due to different water level throughout the year for example low flood level, high flood level and rapid drawdown.

The stability of the slope is at its peak when the water level in the river rises during a flood. Conversely, the slope stability is at its lowest when there is a rapid reduction in water level. This is due to the diminished stabilizing influence of water on the upstream side and the presence of increased pore water pressure within the embankment during the rapid drawdown phase.

3.7. Methods to increase soil cohesion

Soil stabilization aims at improving soil strength and increasing resistance to softening by water through bonding the soil particles together, water proofing the particles or combination of the two (Sherwood, 1993). Usually, the technology provides an alternative provision structural solution to a practical problem. The simplest stabilization processes are compaction and drainage (if water drains out of wet soil it becomes stronger). The other process is by improving gradation of particle size and further improvement can be achieved by adding binders to the weak soils (Rogers et al, 1996). There are several practical methods to increase soil cohesion, depending on the specific requirements and conditions. Here are a few commonly used techniques:

(a) The cohesion of soil can be enhanced by incorporating binders into it. To improve the strength and stability of soil, substances like cement, lime, fly ash, or other chemical stabilizers are combined with the soil. Selecting the suitable binder for soil stabilization can pose a difficulty. It is vital to mix and apply the binder correctly to ensure even distribution and achieve the best soil stabilization results. It's important to note that the utilization of binders for soil stabilization can have environmental consequences.

(b) The presence of vegetation, particularly plants with deep roots, can contribute to the improvement of soil cohesion. Plant roots play a vital role in binding soil particles together, enhancing its resistance to erosion. Nevertheless, there are various challenges to consider when applying vegetation techniques for this objective. It is essential to carefully select plant species that are suitable for the specific soil and environmental conditions. Ongoing maintenance and management are necessary to ensure the long-term effectiveness of vegetation methods in enhancing soil cohesion.

(c) Enhancing soil cohesion can be achieved by incorporating reinforcement materials. Techniques such as geosynthetics, geotextiles, geogrids, or soil nails can be employed to create a network that strengthens the soil. These materials enhance tensile strength and promote a more uniform distribution of loads, ultimately improving soil cohesion. The selection of the suitable reinforcement material is vital to ensure the effectiveness of soil reinforcement. The material should possess the appropriate tensile strength, durability, and compatibility with the soil.

(d) Certain chemical additives can increase soil cohesion. For instance, soil polymers or soil conditioners can be blended with the soil to improve its bonding characteristics. These additives enhance the soil's ability to resist erosion and contribute to increased stability. However, it is important to ensure that the chemical additives are compatible with the specific soil type and the desired engineering properties.

4. Conclusions

Stabilization of slopes is always a great challenge, especially dealing with river bank slope. Field data and sample were collected to perform required laboratory tests to serve the purpose. The soil sample tested has 6.19% optimum moisture. Hence, sample is not organic soil and its specific gravity was also within desired limits. The plasticity index suggests the soil to be plastic with high swelling potential.

In the determination of shear strength parameters, the obtained results didn't vary in coherence rather erratic values were found in some cases i.e. the value cohesion increased with the water content to a certain value and then it fluctuated with further increase of WC. For undisturbed sample the value of c was found about three times of the other two samples and φ decreased around two times. This might be due to not using proper sample collection tools such as core sampler and the collection of soil samples from adjacent points instead of collecting from one. The slope stability analysis results, obtained by using the shear strength parameters form the direct shear test, referred the slope to be quite stable at that particular section with factor of safety varying from 0.82 to 1.548. However, for steeper slopes the factor of safety was found to 0.82 referring to an unstable condition of the slope of river bank.

Recommendations

The present research suggests the following recommendations for future study:

(a) The analysis conducted in this research focused on specific locations, but it is suggested to carry out similar investigations along the entire embankment.

(b) While this study utilized the XSTABL software and Bishop's simplified method, it is recommended to explore the use of alternative software and methods for analysis.

(c) To further enhance the analysis, different types of stabilizing and soil improvement techniques can be examined, and a comparison among them can be conducted.

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