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Slope Stability Analysis of Embankment of Jamuna River

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Abstract- This research paper deals with analysis of the stability of an embankment which has been carried out considering different slopes. This study was performed with a view to running several simulations and to analyze those to know the pattern of slope failure for certain field conditions. For this purpose embankment soil has been collected from Benotia in Sirajganj near the bank of the river Jamuna. Field bore-logs has been done up to a depth of 30m. The soil was collected in conventional method and brought to Geotechnical Engineering Laboratory of Bangladesh University of Engineering & Technology (BUET) for several tests. These tests were performed in accordance with American Society for Testing and Materials (ASTM). The test results exhibited the soil properties necessary for this analytical study.

To perform the slope stability analysis a computer program named STB2010 has been used. The program works with the Bishop's method of slope stability analysis. The main soil parameters were obtained from the laboratory tests and two more sets of parameters were assumed for parametric studies. Several conditions were run through this program to check the stability pattern by comparing the factors of safety of different field conditions with varying slopes, soil parameters etc. Some unstable conditions were found with low factors of safety (FS) which goes below the desired value of FS 1.2. Hence, the solutions for these conditions were discussed as approaches to prevent the failure of slopes.

Several solution options were discussed and yet the logical solution for this particular case was applying revetment through the portions where the soil tend to fail in a lower factor of safety. Also the other field conditions were taken into account which includes changes of water level, tidal action, wind flow, nearby habitants, riverside activities, naval movement etc. This research was mainly focused to find a solution of the embankment failure of the river Jamuna. Other than this, the research was considered to be successful and effective since a brief solution with the necessary detailing was found.

Keywords- *Slope Stability; Soil Erosion; Riverbank Protection.*

I. INTRODUCTION

Embankment failure and riverbank erosion are common phenomena in a low laying country like Bangladesh. Almost every year earthen embankments and riverbanks are facing serious complications like erosion, breaching or retirements. Among many reasons the major causes are considered due to the use of geotechnically unstable materials, improper method of construction, seepage and sliding. In this study the problem is considered from geotechnical point of view where the geotechnical properties of failed Jamuna river embankment materials were investigated. Moreover, stability analysis technique of embankment has been reviewed through a case study of Jamuna river embankment.

Jamuna is one of the largest rivers in Bangladesh. This river plays an important role in geology & other socio-economic factors like the river side life of natural & human inhabitants. This river has often required earthen embankments at various places to prevent river erosion. Consequent flood and excessive rainfall accelerated the failure process which results immense damage to agriculture and infrastructures every year. Earthen embankments tend to get washed away by heavy rainfall, flood and strong current et cetera reasons. The major causes of failure identified were breach of the embankment cutting by local people, 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. 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.

Being a riverine country the river erosion creates a potential threat to almost every possible aspects of the country including the livelihood, the riverside inhabitants, agriculture, river transportation & most of all the geology of the greater flood plain alongside the river. So, this slow & devastating problem of river erosion & embankment failure has been treated with great importance as well as field investigations were conducted to prevent this problem. Hence, the present article paid attention to investigate the physical as well as mechanical properties of the failed Jamuna river embankment materials at Sirajganj in Bangladesh. Consequently, an appropriate and sustainable method was sought as well to protect the bank of big river embankment like Jamuna in Bangladesh.

Slope stability is a matter of several variables of factors. To determine whether a slope is stable or not, there are various analysis methods. On the other hand the slopes that we find in a river may be natural or manmade. These may be above ground level as embankments or below ground level as in railway cuttings or excavations for construction. The actual slope of an embankment fluctuates widely. A given section attains a certain stability and settlement under a set of conditions but it may reduce or increase. Slopes occur naturally along hills and riversides, in which case they are called natural slopes. In all such cases, the forces of gravity tends to move soil from higher levels to lower levels and the forces that resist this action are on account of the shear strengths of the soil. Presence of water increases weight reduces shear strength and decreases stability.

Slope failure is a common phenomenon in rivers. Weights of manmade structures constructed on or near slopes tend to increase destabilizing forces and hence cause lower 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 [1]. 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.

II. Objectives of Study

The study was aimed to determine the stability and settlement characteristics of Jamuna embankment at selected conditions. In brief followings are the objectives of the study:

- To investigate the physical and mechanical properties of the embankment material of Jamuna river located at Sirajganj district of Bangladesh.
- To evaluate the existing design methodology for embankment stability analyses through a case study.

III. Background

The 2900 km long river Jamuna originating from Himalayas has 240 km inside Bangladesh. This mighty river tends to change its course very frequently and is prone to erosion and widening of the bank. From 1970 to 1990 the Jamuna River widened a very high rate of migration where both banks migrated outward at an average rate of about 70 meter/year. Since the early 1990s, the rate of outward migration of both banks has reduced to 30-50 meter/year [1]. Every year this river undergoes huge river erosion as well as great damage of property and livelihood. Bangladesh Govt. has taken few steps including constructing revetments to prevent the change of direction of this mandarin river but from time to time the soil under the concrete blocks of revetment got washed away due to strong current and other natural reasons causing ultimate revetment failure. To protect bank erosion, more than thirty bank protection structures have been constructed along both banks of the Jamuna River. Almost every year a number of structures encounter different types of failure problems and maintenance of such failure or damaged events are one of the big challenges to Bangladesh Water Development Board (BWDB). This case study was performed on the soil of failed embankment of river Jamuna. Fig.1&2 shows the conditions of the river before and after construction of bank protection structures.

Fig. 1: Jamuna river bank before construction of any bank protection structure [2].

Fig. 2: Jamuna river bank after failure of a bank protection structure.

The study was taken place at a place called Benotia in Sirjagonj district. The site was chosen with a view to finding out the problem regarding embankment failure and to come out with an effective and economic solution. From the preliminary survey the site was found very fragile considering the weak slope stability. The main reason for this problem was soil erosion which occurred due to vulnerable soil properties.

The soil was collected from the weakest point of the riverside, where a lot of failure took place over time. The soil was brought under several laboratory tests. The test results projected a certain picture from which a decision was made that this continuous failure was caused for lack of slope stability due to poor soil properties. From the test result some simulations were run by slope stability software to find out the existing factor of safety of the site. Many of the simulations gave very poor factor of safety some of which were below allowable limit. Hence the simulations were run again after mixing sand with the main sample and as an accompanying solution, a strong revetment design was also proposed for the site.

IV. THEORY

As mentioned before, the program STB2010 uses Bishop's Method. In Bishop's method, the safety factor of a slope is determined by comparing the moment of the weight of a soil wedge about the center of a slip circle, with the resisting moment provided by the shear stresses along the slip surface. The two moments are calculated by subdividing the sliding wedge into a large number of vertical slices. It is assumed that on the vertical side planes of the slices only horizontal (normal) stresses are acting and no shear stresses.

The first basic equation is Coulomb's Equation for the shear stress along the lower part of a slice,

$$t = [c + (s - p) \times \tan(\Phi)] \div F \tag{1}$$

Where,

t is the shear stress,
c is the cohesion,
s is the stress normal to the sliding plane,
p is the pore water pressure,
Φ is the angle of internal friction and
F is the safety factor.

The second basic equation is the equation of vertical equilibrium of a slice,

$$W \times h = s + t \tan \alpha \tag{2}$$

Where,

W is the average unit weight of the slice,
h is its height and
α is slope of the slip surface at the slice considered.

Equilibrium of moment with respect to the center of the circle leads to a formula from which the safety factor can be calculated, iteratively [3].

The program STB2010 contains three refinements of Bishop's method:

- The first refinement is that care is taken that the direction of the shear stress along the slip surface is always opposing the sliding mechanism. This is achieved by cutting of the value of α at a minimum value of $\pi/2 - \pi/4$. This refinement is due to A.W. Koppejan of GeoDelft.
- The second refinement is that the shearing resistance is reduced if the coefficient of neutral horizontal stress is so small that slip would occur along a plane perpendicular to the slip surface, combined with a local rotation, in agreement with a double sliding model, as suggested by G. de Josselin de Jong. The refinement is effective only if the coefficient of neutral horizontal stress is smaller than 1.
- The third refinement is that it is possible to introduce a horizontal body force, away from the slope. This may be used to simulate the stability of the slope during an earthquake. The horizontal forces acting on the slices increases the moment of the weight of the slices with respect to the center of the slip circle, thus reducing the safety factor.

STB2010 is a program for the analysis of the stability of slope. The program uses Bishop's simplified method with some modifications introduced at GeoDelft and the Delft University for the calculation of the factor 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.

This program was created and distributed openly without any limitation except for the case of any modification of the code. So there stands no question of authorization using this program. This analysis was solely performed with the help of STB2010. Although a salient hand calculation was performed with several trials to ensure the precision and reliability of the program. Those calculations matched very closely and then the program was used for all of the analysis of the various conditions.

V. METHODOLOGY

After collecting the soil sample from the site at Benotia in Sirjagonj district the soil was brought to the laboratory at Bangladesh University of Engineering & Technology (BUET) for necessary testing. Sieve analysis was performed immediately to determine the distribution of coarser, larger sized particles and the hydrometer analysis is conducted to determine the distribution of finer particles. The value of D_{10}, D_{40}, D_{50} and D_{90} was found 0.001mm, 0.007mm, 0.008mm and 0.035mm respectively. Atterberg limit indices were obtained from the specified tests and the liquid limit of the soil was found 36%. The soil was classified as clay of low plasticity (CL) according to USCS [6].

Having identified the type of soil dry density test was performed with several moisture contents and the data was plotted to generate dry density vs. moisture content curve.

From the curve the maximum dry density was found 17.5kN/m^3 and respective moisture content was found 15%.

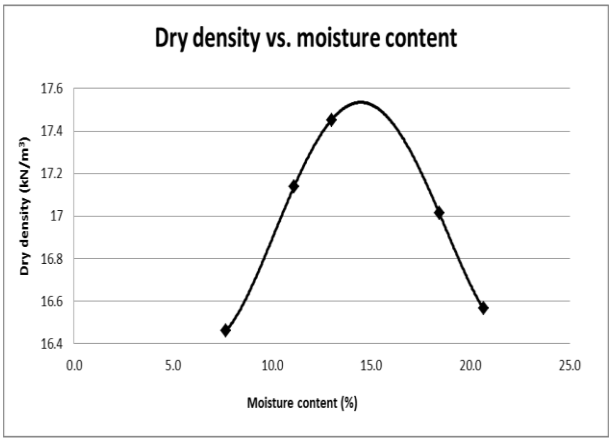

Fig. 3: Dry density vs. Moisture content curve.

This curve shows the interrelation of the sample's dry density with the existing moisture content. This curve was generated from test result and the peak dry density was considered to be 17.5kN/m3 (Fig. 3).

The 95% of maximum dry density (95% of 17.5 is 16.5) was taken for making samples for further compaction test. The value is taken from the west side of the curve. MC for density 16.5kN/m3 is 20%.

Molds were prepared using 20% moisture content for direct shear test. The shear test was performed under consolidated undrained condition. Three different Shear stress vs Shear displacement curves were obtained for 8kg, 16kg & 32kg normal loads (Fig. 5). Laboratory preparation for direct shear test is shown in Fig. 4.

Fig. 4: Laboratory preparation for direct shear test.

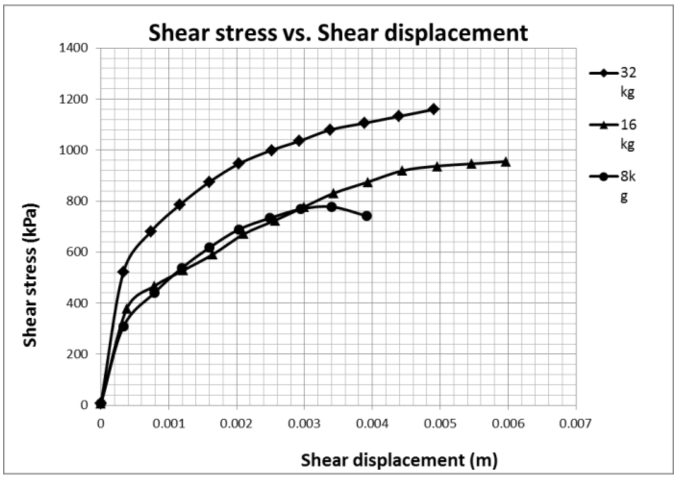

Fig. 5: Shear stress vs Shear displacement curve for 3different lodes (32kg, 16kg & 8kg).

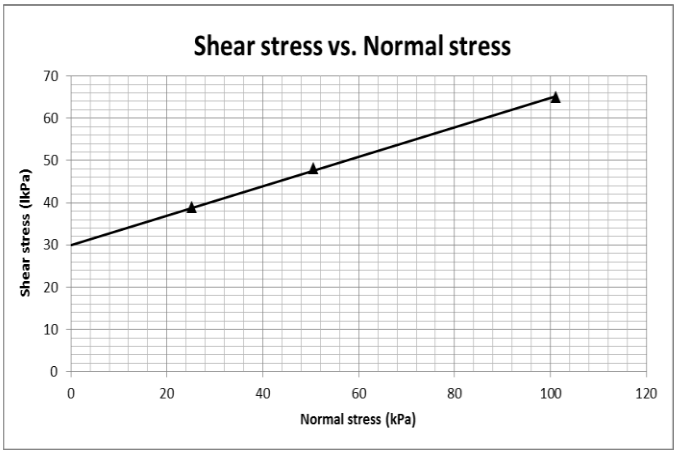

Fig. 6: Shear stress vs Normal stress curve.

Shear stress vs. normal stress curve (Fig. 6) was generated from the Shear stress vs. Shear displacement curve.

From the Shear stress vs. normal stress the value of cohesion 'C' and friction angle Φ were obtained (C = 30kPa, Φ=34°). These values show the main properties of the collected soil sample.

Having the direct shear parameters the values were used to run simulations under three different conditions dry season level, low flood level & high flood level. The simulations were also run for three different slopes 1:1, 1:1.5 & 1:2. In this way 9 simulations were observed and the results were presented in tabular form and the screenshots of the software is shown in fig. 7. From the summarized form of factors of safety obtained from the simulations it is found that the factors were well above the allowable limit (1.2) except for a particular case, which is for 1:1 slope with the high flood level condition. This simulation projects a factor of safety of about 1.4 which is close enough to the allowable limit. So some modifications were done to the main soil sample. Two new samples were made where the main sample was mixed with 5% and 10% →

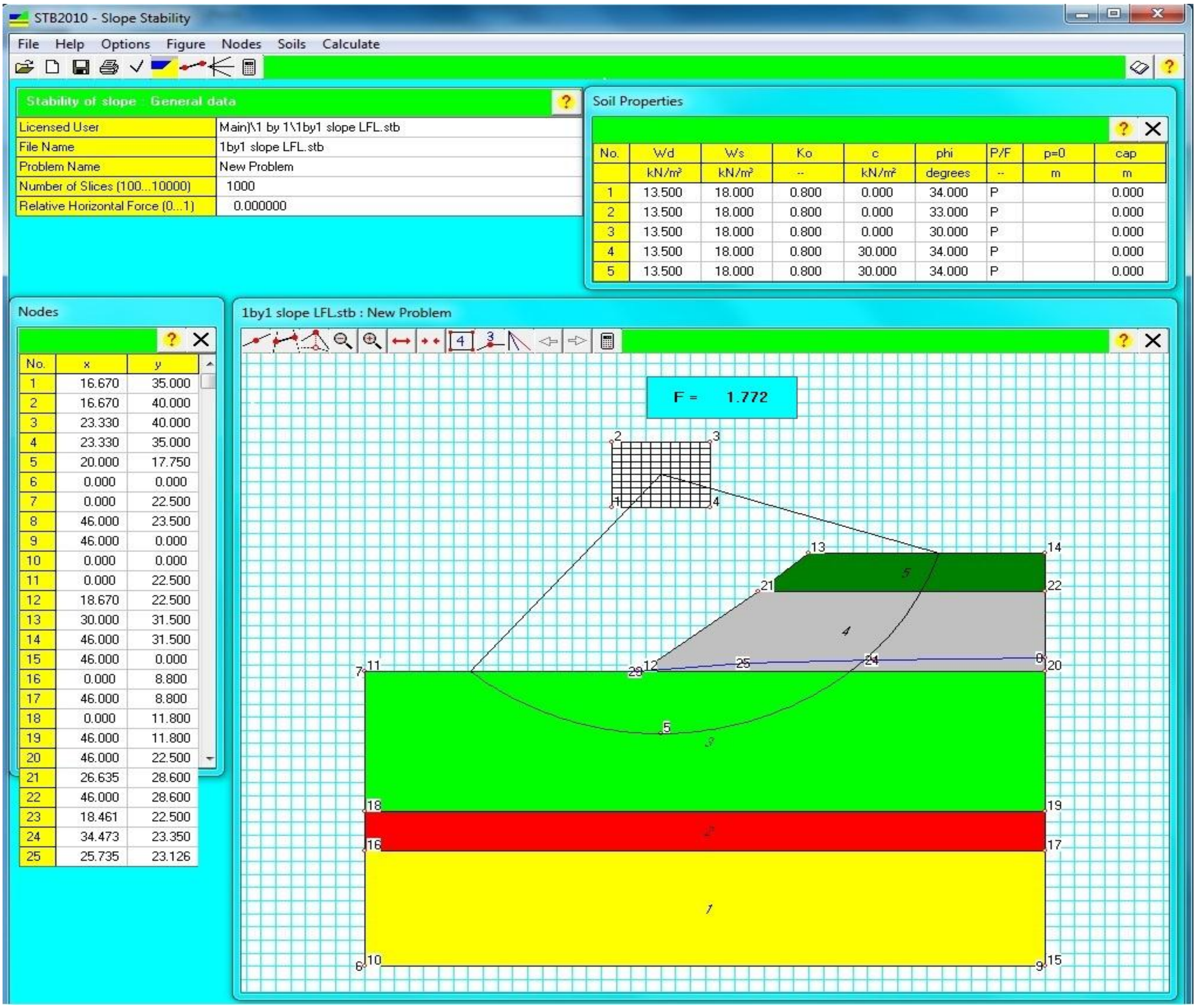

Fig. 7: Slope stability analysis with1:1 slope for a soil of (C = 30 kPa, Φ=34°) in Low water level condition.

sand volumetrically. These two new samples were made to observe the simulations repeatedly. The whole procedure was repeated for two more times and the simulations from STB2010 were obtained. The results projected corresponding factors of safety making a total of 27 conditions. Among these conditions including the two new samples, all of the factors of safety are presented in tabular form for further observations and analysis. Due to shortage of space screenshot from only one calculation by STB2010 is presented (fig. 7).

VI. Material Characteristics

The soil samples were collected directly from the broken part of the right bank embankment of Jamuna River in Shirajganj district. The testing procedures were in accordance with American Society for Testing and Materials (ASTM). The tests include particle size analysis, compaction characteristics, direct shear test and unconfined compressive strength tests. The unconfined compressive strength test was done with samples having different water content. The direct shear test was performed under the specifications of ASTM standard D-3080.

D_{10}, D_{15}, D_{40}, D_{50} and D_{90} of the soil sample were 0.001mm, 0.002mm, 0.007mm, 0.008mm and 0.035mm respectively and liquid limit was 36%.

VII. Results

The factor of safety found form the analysis by STB2010 is presented in a tabular form. Factor of safety was calculated for three different slopes and another three different flood levels.

TABLE I. RESULTS OF STABILITY ANALYSIS OF CLAY (C = 30KPA, Φ = 34°).

Slope	Factor of Safety		
	Dry Condition	**Low flood Level Condition**	**High flood Level Condition**
1 : 1	2.21	1.77	1.37
1 : 1.5	2.48	1.93	1.98
1 : 2	2.56	2.09	2.01

TABLE II. RESULTS OF STABILITY ANALYSIS OF CLAY (C = 15KPA, Φ = 30°).

Slope	Factor of Safety		
	Dry Condition	**Low flood Level Condition**	**High flood Level Condition**
1 : 1	2.00	1.57	1.12[a]
1 : 1.5	2.24	1.72	1.71
1 : 2	2.24	1.77	2.24

a. Bellow allowable limit of Factor of Safety.

TABLE III. RESULTS OF STABILITY ANALYSIS OF CLAY (C = 5KPA, Φ = 25°).

Slope	Factor of Safety		
	Dry Condition	**Low flood Level Condition**	**High flood Level Condition**
1 : 1	2.06	1.40	0.94[b]
1 : 1.5	2.06	1.51	1.48
1 : 2	2.97	1.54	1.48

b. Bellow allowable limit of Factor of Safety.

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 of failure possibility. The initial point of the desired safety factor is nearly 1.2. Hence the lesser value would result in a threat for soil. After analysis, the safety factors for two types of soil at high flood level condition with slope 1:2 are found significantly less than the desired point of the factor (1.12 and 0.94). So it is inevitable to sort out a solution in order to raise the safety factor for the protection of Embankment at Jamuna River.

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.

The main soil collected directly from the site was tested for the mentioned specifications and the results were found satisfactory considering the site condition. The soil was very vulnerable in terms of slope stability. From the test results and the analysis, the factor of safety was found below the allowable limit. This matched with the failure pattern of the site.

In order to enhance the slope stability of the soil two new samples were made with 5% and 10% added Sylhet sand. This sand was chosen considering the availability and cost efficiency.

The two other soil test reports came satisfactory as the factor of safety increased with the greater proportion of mixed sand. The results were compared afterwards. After having some satisfactory factors of safety, the decision was taken to provide sand mixing with the existing soil and an enforced revetment design for more safety and stability of the soil.

VIII. CONCLUDING REMARKS

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. The initial point of the desired safety factor is nearly 1.2. Hence the lesser value would result in a threat for soil. After analysis, the safety factors for two types of soil at high flood level condition with slope 1:2 are found significantly less than the desired point of the factor (1.12 and 0.94). So it is inevitable to sort out a solution in order to raise the safety factor for the protection of Embankment at Jamuna River.

From the above analysis and comparative simulations, it can be said that the highest flood level conditions were the most vulnerable and threatening for the embankment. Since lower factor of safety indicates potential risk at slope stability, it is easy to comprehend that in most of the cases the highest flood level conditions should be given the most importance. Besides, it is also clear that the flatter slopes project less threat to the slope stability. But considering the economic aspects of possible solutions, a slope of 1:1.5 is advised and considered to be a balanced design for embankment slope. More safety and integrity of the embankment is ensured with a proposed revetment design, which is not discussed elaborately in this particular study. But with a reasonably high factor of safety and a strong revetment design, it is considered that the safety measures lie well above the risk level and exhibits a strong resistance against slope failure.

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