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River Embankment and Bank Failure in Bangladesh: A Study on Geotechnical Characteristics and Stability Analysis

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***Abstract*— This paper aimed to investigate the geotechnical properties of failed Jamuna river embankment material and Padma riverbank material of Bangladesh. Study results reveal that the soil of Jamuna river embankment is not well graded sand and the permeability is found moderately high which increases rapidly in submerge condition. The maximum strength is found low as embankment material. Moreover, the slope is not well protected that makes the embankment vulnerable to erosion. In case of riverbank failure, the permeability and strength of bank material both decreases rapidly with the increase of water content which associates the bank failure process. Nevertheless, the tension crack behind the bank face and toe erosion also accelerate the mass failure mechanism of the riverbank. The design methodology of embankment was evaluated by a case study. The study found that the factor of safety (FS) is over estimated of about 22-24% if seepage analysis is not considered in designing embankment.**

INTRODUCTION

The failure of embankments and riverbank erosion are common problem in Bangladesh. 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 [1]. But, earthen embankments in Bangladesh are facing problems like erosion, breaching in every year. In this study, embankment failure and riverbank erosion problems in Bangladesh have been looked with respect to the stability and geotechnical properties. The present study aimed (i) To investigate the physical and mechanical properties of the embankment material of Jamuna river located at Sirajganj district of Bangladesh, (ii) To determine the geotechnical properties of Padma riverbank material and clarify the bank-failure mechanism in Charghat area located in Rajshahi district of Bangladesh, (iii) To evaluate the existing design methodology for embankment stability analysis through a case study.

COLLECTION AND TESTING OF MATERIALS

The soil samples were collected directly from the broken part of the right bank embankment of Jamuna river (Fig. 1) in Shirajganj district and from the eroded bank of Padma River located in Rajshahi district. The laboratory tests were conducted in the Laboratory of Mie University. The testing procedures were in accordance with Japanese Industrial Standard (JIS) and Japanese Geotechnical Standard (JGS). The tests include particle size analysis (JIS A 1204), particledensity (JIS A 1202), liquid limit & plastic limit (JIS A1205), compaction characteristics (JIS A 1210), consolidation, permeability (JIS A 1218), direct shear test (JGS 0560 & 0561) and unconfined compressive strength tests (JIS A 1216). On the basis of the test results, the soil was also classified by JGS engineering classification. The falling head method was followed to determine the coefficient of permeability. The unconfined compressive strength test was done with samples having different water content.

Figure 1: Study Areas

RESULTS AND DISCUSSION

Physical properties

The parameters of basic physical properties are shown in Table 1. The significant difference is found between the plastic and liquid limits of soils. Plastic limit of embankment soil refers to non plastic (NP) where that of riverbank soil is 27%. From grain size distribution analysis, maximum grain size and effective size (D_{10}) of embankment soil were 425μm and 7.6μm respectively (Fig. 2). The fine grain (<75μm) content in embankment soil is found 49% (silt=41%, clay=8%) and the coarse grain (≧ 75μm) is 51%. Accordingly, the soil has been classified into SF (Fine sand) group using JGS engineering classification. Similarly, the riverbank soil was classified as

Table 1 Physical properties of soils

Properties	Embankment soil	Riverbank soil
Particle density	$2.747 g.cm^{-3}$	$2.676 g.cm^{-3}$
Liquid limit	25.8%	32%
Plastic limit	NP	27%
Maximum size	425μm	850μm
Sand(	51%	6%
Silt (5μm -75μm)	41%	69%
Clay (< 5μm)	8%	25%
Soil type	SF	ML

silty soil with lower liquid limit (ML) which contents silt and clay of 69% and 25%, respectively.

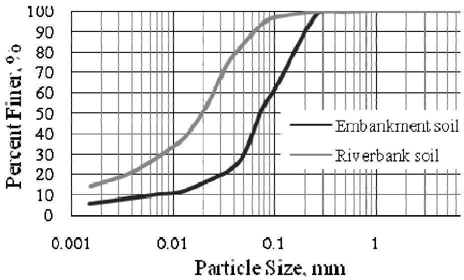

Fig. 2 Particle size distribution curves

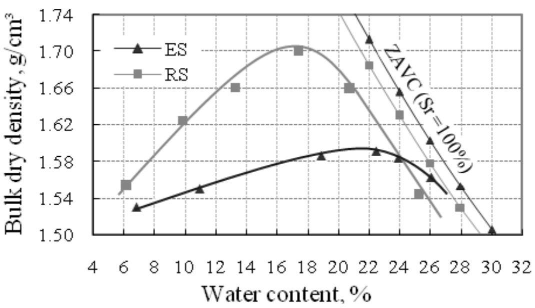

Fig. 3 Compaction curves of ES and RS

Geotechnical properties

From compaction tests result, the maximum dry densities of embankment soil (ES) and riverbank soil (RS) are found 1.59g/cm^3 and 1.72gm/cm^3 at optimum water content (w_{opt}) of 21.2% and 16.5%, respectively (Fig.3). The changes in permeability and strength values of ES with the increase of water content are plotted in Fig. 4. The minimum value of permeability coefficient is calculated as 1.29×10^{-5}cm/s at 24% water content which is beyond the optimum water content and near to liquid limit (w = 25.8%). The change in the coefficient of permeability was observed almost one order larger value from the smallest coefficient of permeability for unit change of water content on dry side. It is also predicted that the permeability is increased rapidly in submerge condition of the soil. From uniaxial compression test, the maximum value of compressive strength (q_u) was reported as 51.8kPa at 19.6% water content which is below the optimum water level. It was also clear that the uniaxial compressive strength of the soil largely varied with the small change in water content.

So, the embankment constructed with this material needs lot of care to control water content and the strength level. As embankment material; it has got a very low strength and thus, very vulnerable to slope failure and erosion process. Hence, the slope surface needs to be protected from erosion caused by the rainfall, run off and the strong wave during high flow of river. However, the slope of the embankment of Jamuna river is found not well protected. In some places of the embankment, sandbags have been used but not worked well due to inefficient placement and lack of maintenance (Fig.5).

Moreover, the sandbags are placed only in the emergency situation of flood. But, it is equally important to protect the slope surface during other times to protect from wash-off the fine particles by rainfall as well as run off. Some other places, precast concrete blocks are being used as a riprap. But, these are very expensive and so it is limited to some extent only. Bangladesh doesn`t have large abundant quantities of rock. Sand is the cheapest and only readily accessible material throughout the construction season. So, the sandbag application could be the practical way of protecting embankment dam in Bangladesh. Besides sandbag; thin layer of cement composites can be used as a measure of slope protection. But, a comprehensive study of its impact on the slope stability condition is required to find out an effective and sustainable system of slope protection.

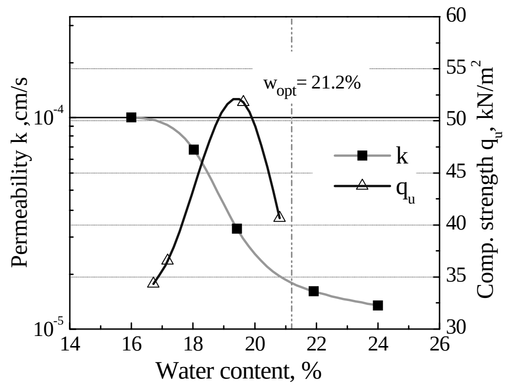

Fig. 4 Permeability and strength of embankment soil with water content

Fig. 5 Sandbags on embankment slope

The effect of water content on the geotechnical properties of riverbank soil is shown Fig. 6. The value of permeability is found to be 3.5×10^{-7}cm/s at over 90% saturation. From direct shear test, the shear strength parameters, cohesion (c) and internal frictional angle (ø) were obtained as 153kPa and 22°, respectively.

The maximum compressive strength was found to be 280kPa at 12.8% water content which is below the optimum water content (16.45%). But, the strength decreases rapidly with the increase of water content and reaches to about 150kPa at 22% water content. It is also observed that the strength reduces 46% with the increase of water content by 10% after the peak value.

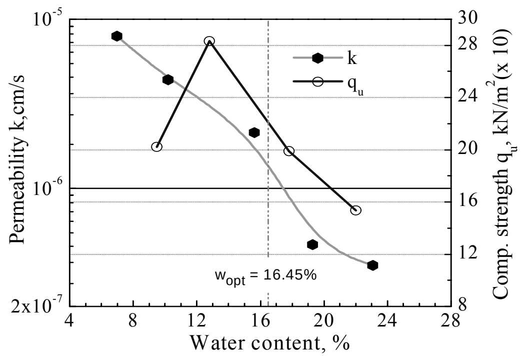

Fig. 6 Change of strength and permeability with water content of riverbank soil

Bank failure mechanism

The bank-failure mechanism of Padma river in the study area was identified based on the field observations, discussion with the local community and the test results of the sample materials. The failure is associated with the formation of tension cracks few feet behind the bank line (Fig. 7). It is also reported that the severe bank failure occurs during the recession of flood water when the velocity of river flow seems to be very high. This type of failure can be described as slab-type rotational failure that includes both mechanisms such as planar failure with tension crack and toppling involving failing blocks with the same geometry. From geotechnical point of view, it is understood that the strength of bank soil decreases rapidly with the increase of water content. The permeability also becomes very low (<1×10^{-6}cm/s) at the same time (Fig. 6) which ultimately increases the weight of material and triggers mass failure of bank.

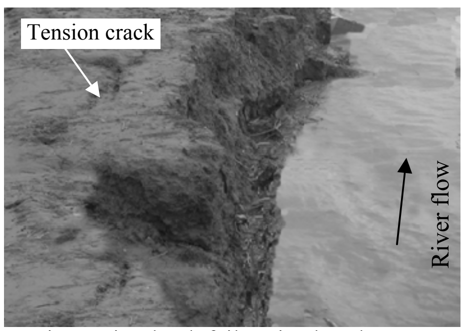

Fig. 7 Riverbank failure in charghat area

In addition, during drawdown of river water at the end of flood, groundwater level in the bank decreases at a lower rate than the level of surface water due to low permeability of the bank material. This phenomenon causes an imbalance of force of water pressure in the riverbank and the confining pressure of surface water on the slope which also causes sudden mass failure of the bank. In this circumstance, it is very much necessary to find out the limiting value of the critical bank slope and height in order to take necessary measure for the protection of riverbank in the study area. A limit equilibrium method of bank stability analysis can be followed as proposed by Darby and Thorne [2]. This is a new approach for riverbank stability analysis which can be applicable for the steep, cohesive, non-layered riverbank that fails along planar failure surface. In this method, pore-water and hydrostatic confining pressure are also included where the failure plane is not constrained to pass through the toe of the bank.

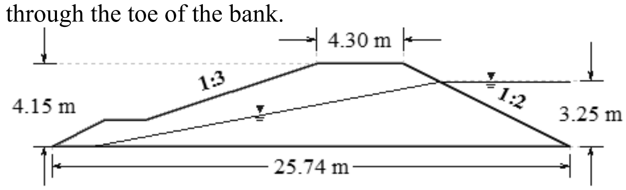

Fig. 8 Section of Manu river embankment

Case study

A case study was conducted on the Manu river embankment which is located in Moulvibazar district of Bangladesh. The embankment was designed (Fig. 8) considering the free surface in embankment as an assumed saturation line which is decided on soil type according to design manual of Bangladesh Water Development Board (BWDB). In this study, the free surface is reasonably determined by conducting seepage analysis using Finite Element Method (FEM). The slope stability analysis was performed by limit equilibrium methods and the results were compared with the existing values.

The hydraulic model for seepage analysis was the Van Genuchten–Mualem [3] model which is the most widely used model in simulation of unsaturated flow processes. Therefore, it has been used in this study for representing the relationship between the hydraulic conductivity and the pressure head as shown in (1).

$$k_h = k_s\sqrt{S_e}\left\{1-\left[1-S_e^{(n/(n-1))}\right]^{1-1/n}\right\}^2 \qquad (1)$$

Where,

k_h is the coefficient of permeability at any pressure head h,

k_s is the saturated coefficient of permeability,

$$S_e = \left[\frac{1}{1+(\alpha h)^n}\right]^m$$

$$m = 1 - \frac{1}{n}$$

h is the soil-water pressure head in meter

α (1/m) and *n* are curve shape parameters

These hydraulic parameters (k_s, α and *n*) was obtained by using a database program ROSETTA [4] that used soil texture data for predicting the parameter values.

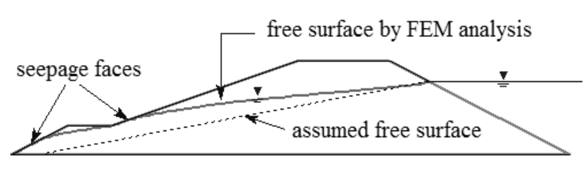

Fig. 9 Location of free surface and seepage faces

Slope stability analysis

Stability of the Manu river embankment was checked in terms of Factor of Safety (FS) values. Followed by FEM seepage analysis, limit equilibrium slope stability analysis was conducted both for assumed saturation line (1:5.45) and free surface predicted by FEM seepage analysis (Fig. 12).

The saturated and unsaturated unit weight of soil was taken as 120 pcf (18.8KN/m^3) and 115 pcf (18.1KN/m^3), respectively. The Mohr-Coulomb strength criterion was used with the shear strength parameters of cohesion, c = 100psf (4.78 kPa) and friction angle, φ = 18°. Random technique for generating circular surfaces has been used to find a critical failure surface from 100 trial surfaces. The lower and upper angle limit of each failure surface at toe was set as -5° and -45°, respectively (-ve for anticlockwise direction). Table 2 shows the summary of limit equilibrium analysis.

Table 2 Results of slope stability analysis

Methods	**Minimum Factor of Safety (FS)**		**Deviation (%)**
	Assumed saturation line	Predicted free surface	
Bishop simplified	2.011	1.622	23.98
Janbu simplified	1.880	1.541	21.99
Spencer	2.012	1.622	24.04
Crop of eng#1	2.043	1.648	23.96
Morganstern-price	2.011	1.622	23.98

The results show that the factor of safety is over estimated about 22-24% in case of assumed saturation line. Moreover, the assumed saturation line does not satisfy the Laplace equation for two-dimensional flow through a homogeneous, isotropic medium. Hence, seepage analysis is necessary to solve the seepage problem as well as to get the reliable factor of safety value and safe design of embankment.

CONCLUSION

The following conclusions can be drawn from the present study:

- The soil which was used for constructing Jamuna river embankment has been found poorly graded sand with higher silt content. The permeability of the soil is high with the lower strength properties. There is no protective measure on the slope and easy to be washed off by rain and wave action.
- In contrast, the Padma riverbank soil contains mostly the silt particles with 25% of clay content. Eexcessive pore water pressure affects the shear strength of bank material which leads to the mass failure of the bank.
- In the study area, bank failure mechanism is associated with the formation of tension crack behind the bank face. The type of failure is categorized as slab-type rotational failure mechanism.
- In slope stability analysis of embankment, the factor of safety is found to be overestimated for assumed saturation line.

RECOMMENDATIONS

The geotechnical properties of embankment material need to be improved by using additives or reinforcing materials like soil-cement, natural or geosynthetic fiber etc. It is also necessary to protect the slope by facing materials using geo-bags, cement composites with reinforcement etc. It is also recommended to locate the free surface inside the embankment by conducting seepage analysis prior to conduct slope stability analysis to obtain more reliable factor of safety in designing stable embankment.

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