Safety Evaluations of Rajshahi City Protection Embankment, Rajshahi, Bangladesh

Younus Ahmed Khan*

Abstract

Stability analyses using different slope stability methods including finite element method at three different locations along the Rajshahi City Protection Embankment (RCPE) revealed the embankment to be safe against sliding, but the presence of cracks, toe erosion and significant rise of water level in River Padma may cause failure. The factor of safety at Talaimari, Shashanghat and Dargahpara areas ranges from 1.5 to 1.8 with river water below the danger level (<18.5m). Reduction in strength parameters or softening phenomena can reduce the factor of safety significantly at these locations. The analyses considering softening phenomenon showed that the embankment could fail with a 50% - 80% reduction in the shear strength of material. A method of Progressive failure analysis, PgFan, Finite element method developed by Griffiths and Lane (1999) and Bishop (1955) method were used for the analysis. A number of cracks near the top of the embankment at Talaimari and Shasanghat and several erosional cavities at the toe at Talaimari and Dargahpara developed during 2002-2004 rainy seasons, were considered critical to the stability of the embankment. The study suggests immediate repairs to the embankment, in the areas of Shasanghat, Dargahpara and specially Talamari parts of the RCPE.

Introduction

Rajshahi City Protection Embankment (RCPE) is situated on the southern boundary of Rajshahi City of Bangladesh (Fig. 1). The 15 km long costly embankment structure on the river Ganges serves as an important infrastructural protection to this city of 1 million population. The embankment material consists of fine-grained sands with silt and clay. Weathering, soil erosion and man-made activities in and around the embankment have been noticeably intense in recent years. The heavy monsoonal rainfalls on the upstream catchment, sometimes increases the river water level above the danger level. In 1988 and 1998 the situation was worst when seepage at a number of points/ locations developed on the city side slope of the embankment. The recent earthquake of 5th July 2008 caused damages to several buildings, scared the inhabitants of this city. The weathering, erosional interactions and seepages can drastically reduce the shear strength of soil materials and cause damage to the embankment,. Moreover, earthquake generated horizontal acceleration may reduce the shear strength considerably. The lowering of shear strength or softening of soil material eventually induces failure along a critical failure surface of the embankment slope. In such a situation, embankment safety in terms of slope failure should be rechecked. Stability analysis for such type of embankment needs careful and rigorous analytical techniques.

The safety analyses for the river embankments have been carried out ever since the development of modern slope stability analysis methods, like limit equilibrium method (Bishop, 1955; Spencer, 1967; Sarma, 1979), Finite Element method (Griffiths, 1999), Yamagami et al., 1999 and Progressive failure method (Khan et. al, 2002a).

*Department of Geology and Mining, The University of Rajshahi, Rajshahi 6205, Bangladesh.
e-mail: younus@ru.ac.bd

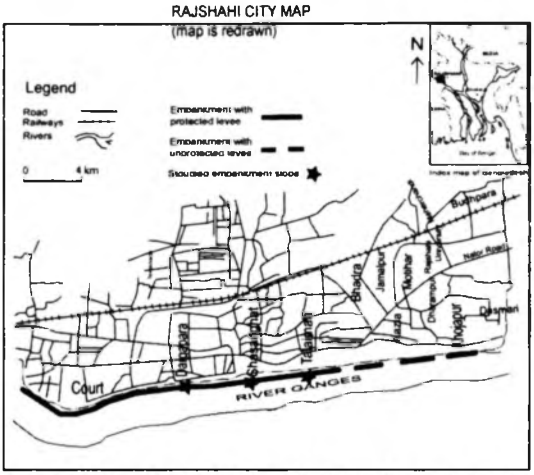

Fig. 1: Map of the Rajshahi City showing slope locations along the embankment.

Fig. 2: a. Toe erosion of the embankment slope and b. Embankment with full river water.

In 1988, Rahman, predicted some average values of safety factors for the embankment slope as a whole without mentioning any specific slip surface. According to Rahman (1988) the average safety factor of RCPE is 1.26 with the Fellinius method and 1.38 with the Bishop method. In Rahman's analysis no water level was considered which seems to be the most critical factor for any embankment slope analysis. Monir and Khan (2004) worked on seepage problems of the Rajshahi City Protection Embankment and concluded that some parts were vulnerable to seepage. They recommended for regular repair and maintenance work for the safety of this embankment. A rigorous stability analysis was performed at Khojapur location of the embankment using progressive failure analysis method and found that the embankment at Khojapur location was safe (Factor of Safety, 1.419) in its peak strength, but safety is questionable with a 50% reduction of shearing strength (Khan, et. al 2002b). Such rigorous analysis can be very important in other locations of this 15 km long embankment. The detail stability analyses at different locations of the embankment will certainly depict the real situation of safety under softening of soil material.

The paper embodies the results of an attempt on the stability evaluations of RCPE at four different locations using rigorous methods of slope stability analysis.

Geo-environmental Conditions of The Embankment

The RCPE is an earth-fill embankment comprised of medium to fine sand with clayey silt. The adjacent Rajshahi city area comprised of Recent flood plain deposits. Three slope locations were selected where the embankment has faced considerable damages due to the interaction of weathering and soil erosion. The embankment at Talaimari, Shasanghat and Dargapara areas developed several cracks on the top at Talaimari and Shasanghat and several erosional cavities at the toe level at Talaimari (Fig. 2), Dargahpara and other areas during the 2002-2004 rainy seasons. These damages were locally repaired during later years.

Methods of Analysis

The field data related to the slope geometry, river water levels and soil samples from the four selected slopes were collected. The geometry of the embankment slope at selected areas was developed with a field survey with clinometer and measuring tapes and then plotted on the graph. Direct shear tests on soil samples were conducted and soil unit weight using the standard procedure, was determined. Three different methods of slope stability analysis were used to determine the factor of safety for the specified slopes of the embankment. The details of the analysis methods of slope stability are discussed in the following sections.

Strength and Water Level Parameters of the Embankment Slope

Three different sections at Talaimari, Shasanghat and Dargapara locations of the embankment were selected for the stability analysis. The slopes at these three locations seemed to be most vulnerable due to severe weathering and erosion activities.

Undrained Direct shear test (using ASTM standard) was adopted for the determination of shear strength parameters. The related description of the shear box apparatus and the test procedures are found elsewhere (e.g. Cernica, 1995). The samples were subjected to a shear force and subsequent rupture by increasing the horizontal force until failure was induced. This was repeated for several values of normal force. The normal and shear stresses were dtermined by dividing the applied normal and shear forces, respectively, by the cross sectional area of the shear box. A failure envelope was obtained by plotting the normal stresses and the respective shear stresses at failure. The angle of shearing resistance (f°) and the cohesion (c) were obtained from the plotted Mohr circle. The unit weight of the representative samples were obtained with the water replacement method described by Cernica (1995).

The phreatic surface inside the embankment was obtained by plotting the water levels, from shallow tube wells installed near the toe of the slope, and the river water level on the up-stream.

Methods Used For Factor of Safety Calculations

Factor of safety is defined as the ratio between available shear strength and induced shear stress along a specified shear plane. There must be a single shear plane where the factor of safety is the lowest among many other shear planes, which is known as the critical shear plane. Three computer-programs namely XSTABL (Sharma, 1994), Progressive Failure anlysis 'ProgFan' (Khan et, al., 2002) and FE method developed by Griffiths and Lane (1999) were used for a factor of safety analysis.

The 'XSTABL' includes several established and conventional methods of slope stability analysis including Bishop Method (1955). With 'XSTABL' one can handle searching techniques for determining the critical failure plane. Bishop (1955) method of slices was used to determine the critical shear planes only. Then a rigorous method namely, the method of Progressive failure analysis-ProgFan (Khan,et.al, 2002) was used to determine the factor of safety of the critical shear plane for the selected slopes.

'ProgFan' a computer program can analyze progressive failure along a shear plane using non-vertical slices within the limit equilibrium framework. ProgFan calculates local factors of safety as well as overall factor of safety along any failure plane of a slope. In ProgFan, softening effects along shear plane are approximately taken into consideration in terms of peak and residual strengths. During the calculation procedures, ProgFan uses peak and residual strength parameters (i.e. f_p, f_r and c_p, c_r) simultaneously. Generally peak cohesive strength (c) of the soil reduces suddenly to a residual level due to the softening effect. The other strength parameter, friction angle is not normally so sensitive to softening. Therefore, to evaluate the softening effects only the residual cohesive strength was used along with the peak cohesion and peak friction angle in the progressive failure analysis.

The XSTABL was used for finding a constant overall factor of safety and on the other hand ProgFan was used for determining the variable local factor of safety as well as the overall factor of safety along the critical failure plane of the studied slope of RCPE.

The Finite Element method (FEM) developed by Griffiths and Lane (1999) was used for an assessment of the overall stress-strain situation as well as factor of safety. The FE method uses strength reduction factor as a means of factor of safety. The FEM model considers material strength properties, Poisson's ratio, Young's modulus and soil unit weight for the analysis. The Poisson's ratio and the Young's modulus were taken as 0.3 and 1.05 respectively.

The analyses were conducted considering the river water level to be below the danger limit (<18.5m).

Results and Discussion

The Table-1 shows the results of the slope stability analyses using 3 different methods. All the three slope sections are apparently stable at full tank/ Reservoir level (FTL/FRL). The results from progressive failure analysis indicate that the slopes may fail with softening of strength. There are several examples (e.g. Selset slide in UK) where slopes have failed even with a factor of safety (FoS) much higher than 1.0 because of softening effects. Skempton and Brown (1961) suggested residual strength effect for the Selset failure. Again Skempton and Coats (1985) reported another similar failure in Carsington dam failure in UK. Sudden decrease in shear strength eventually led to failure of the embankment slope, in such a case the conventional slope stability methods can not predict the actual factor of safety because these methods do not consider peak and residual shear strength simultaneously.

In Talaimari slope section, the soil is facing erosion due to the action of dying roots and human activities. The factor of safety, using the Bishop method, progressive failure method and FEM are 1.63, 1.567 and 1.60 respectively with water level was about 0.84H using peak strength analysis. Here H is the height of the slope. If, for example peak

Table 1: Slope parameters and results of stability analysis

Slope locations and conditions	Strength and other parameters	Factor of safety		
		Bishop method (1955) XSTABL (Sarma, 1984)	Finite element method (Griffiths and Lane,1999)	Progressive failure method (Khan et al. 2002)
Talaimari Toe erosion and dying trees on embankment, erosion present, human interaction and repair works going on.	ϕ_p =15.5°; c_p =18.0 kN/m^2; γ=19.20 kN/m^3 Height=11.48m Width=9.0m Water Level=0.84H	1.636	1.609	1.297 with c_r = 0.5c_p at failure 1.004 with c_r = 0.3c_p
Shashanghat Human settlements, soil erosion and weathering	ϕ_p =18.20°; c_p =14.90 kPa; γ=19.30 kN/m^3 Height=7.65m Width=3.5m Water Level=0.56H	1.791	1.703	1.242 with c_r = 0.5c_p at failure 1.08 with c_r = 0.36c_p
Dargahpara Human settlements, undercutting slope materials, soil erosion on slope top.	ϕ_p =18.00°; c_p =14.00 kPa γ=19.50 kN/m^3 Height=7.0m Width=3.4m Water Level=0.60H	1.667	1.620	1.220 with c_r = 0.5c_p at failure 1.02 with c_r = 0.40c_p

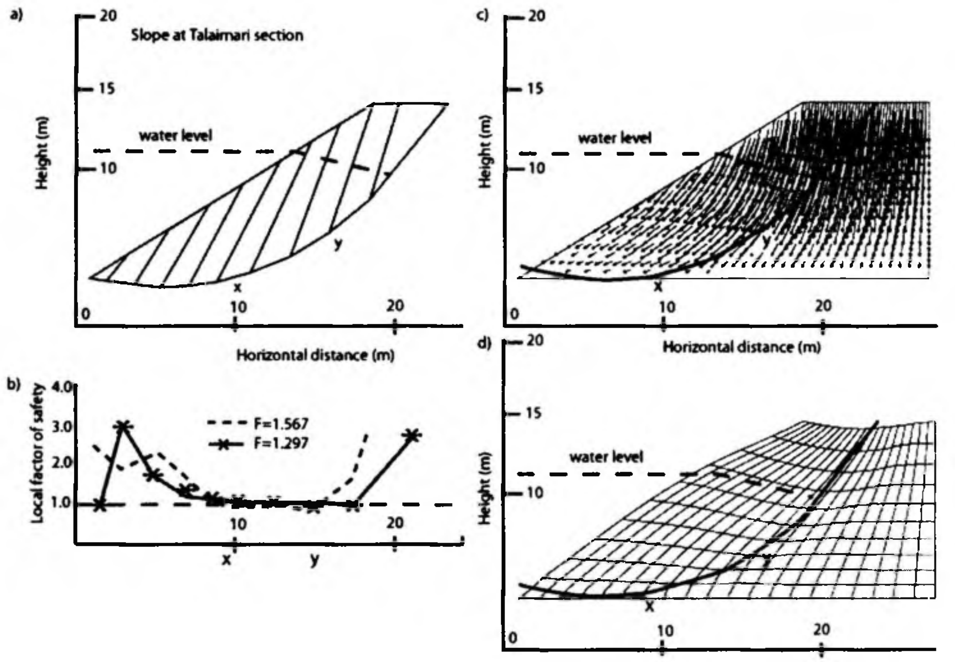

Fig. 3: Talaimari section a. Slope geometry and b. local factor of safety of progressive failure analysis; c. displacement vectors and deformed mesh from FE method sections

strength lowers to a residual value of $0.5c_p$, the same shear surface results much lower factor of safety in progressive failure analysis. The local factor of safety for several locations along the slip surface reduces to a failure situation; even the F remains greater than 1.0 (Fig. 3). The strength softening may occur in those locations (marked xy in Fig. 3) to cause failure of the slope as a whole and the factor of safety may reduce to unity (1.00). In the figure 3c and 3d, displacement vectors and deformed mesh of the slope shows the strain developed at failure. These displacement vectors and deformed mesh also indicate failure state in a part of xy of the shear plane which matched with the local factor of safety shown in figure 3b. The same results also found in other two slope (Fig. 4 and 5). All the slope sections analyzed were found to be stable at water level below the danger level of the embankment. They may attain failure situation if strength softening occurs.

Softening or sudden decrease in shear strength may occur due to drawdown of the river water or with application of external loading. Earthquake generated horizontal acceleration can cause softening in the embankment soil materials.

Conclusion

Stability analyses at three different locations along the Rajshahi City Protection Embankment concluded that the embankment is safe against sliding. The presence of cracks, toe erosion and significant rise of water level at River Padma may cause failure due to the residual strength effect. The factor of safety at Talaimari, Shashanghat and Dargahpara areas ranges from 1.5 to 1.8 with river water below the danger level (<18.5m). Softening phenomena at these locations of the embankment can reduce the factor of safety significantly. The analyses considering softening phenomenon showed that the embankment could be failed if 50%-80% reduction of shear strength occurred.

A number of cracks near the top of the embankment at Talaimari and Shasanghat and several toe erosion cavities at Talaimari

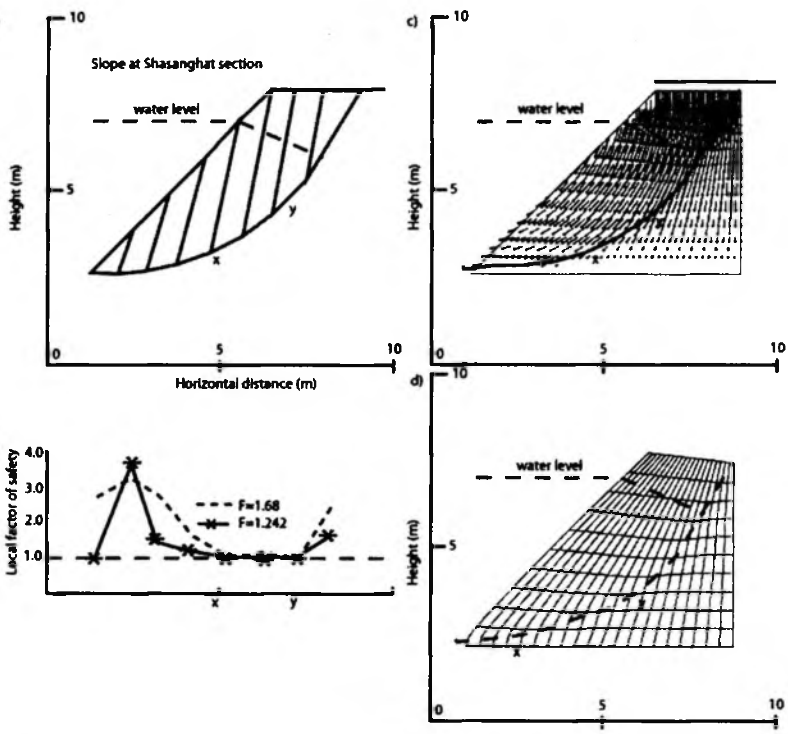

Fig. 4: Shashanghat section: a. Slope geometry and b. local factor of safety of progressive failure analysis; c. displacement vectors and deformed mesh from FE method.

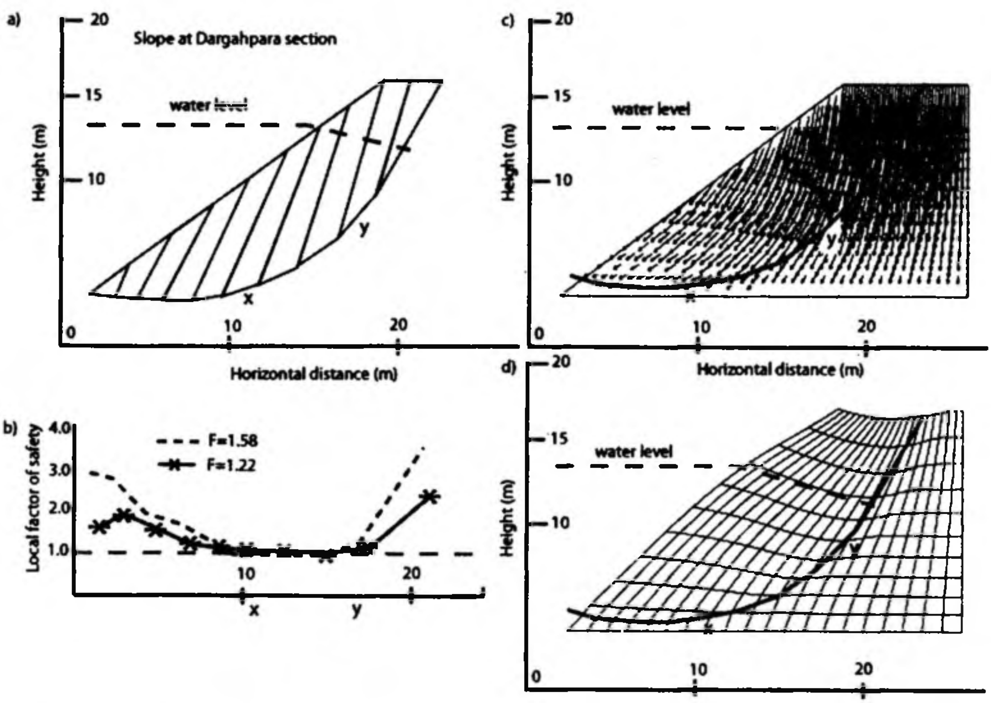

Fig. 5: Dargahpara section: a. Slope geometry and b. local factor of safety of progressive failure analysis; c. displacement vectors and deformed mesh from FE method.

and Dargahpara were critically developed during 2002-2004 rainy seasons.

The study suggests repair works have to be undertaken in the Shasanghat, Dargahpara and specially Talamari areas of the embankment.

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