STABILITY EVALUATION OF RAJSHAHI CITY PROTECTION EMBANKMENT AT KHOJAPUR AREA, RAJSHAHI, BANGLADESH

Younus Ahmed Khan¹, Takuo Yamagami² and Jing-Cai Jiang³

Abstract

Stability analyses and evaluations of a slope of Rajshahi City Protection Embankment (RCPE) at Khojapur area indicate some sort of potential failure possibilities due to critical horizontal earthquake accelerations (a_c) and softening effects of soil materials. Safety analyses were done in two different computer programs. First, the four different conventional slope stability analysis methods are used for factor of safety and then a progressive failure analysis program is applied to the specified critical failure surface. The RCPE has factor of safety of 1.421 to 1.408 at the high water level. Analyses relating to softening effects of the embankment show significant reduction of factor of safety. Considering the earthquake occurrence possibilities, the safety factors have been calculated with the different horizontal earthquake acceleration (a) at same water level. The calculated results (Factor of safety=1.003 to 1.012 with corresponding a_c=0.235g to 0.190g) show potential threats to the safety of the embankment at Khojapur area. The RCPE at Khojapur may fail at the horizontal earthquake acceleration of 0.19g.

This finding strongly recommends a detail investigation of seismic stability and softening phenomena of the RCPE

Introduction

The studied embankment is situated on the southern boundary of Rajshahi City in the Northern Bangladesh (Fig. 1). About 15 km long Rajshahi City Protection Embankment (RCPE) on the river Ganges is an important and costly engineering structure that provide an overall infra-structural protection to about 1 million city dwellers. The safety analysis for such type of embankments always needs careful and rigorous analytical techniques. This is an earthfill embankment consists fine-grained sands with silts and clays. Weathering and Soil erosion have been noticeably intense in recent years specially, after massive plantation on the embankment. The heavy monsoonal rainfall in the upstream sometimes increases the river water above the danger level. Such type of situation can threaten the embankment. In 1998 and 1988 the situation were worst where a number of water seepage had been developed along the city side slope of the embankment. Due to these weathering-erosion interaction and seepage action, there may develop strain softening of soil of the embankment. Strain softening drastically reduces the shear strength of soil materials from peak to residual value. Moreover, earthquake generates horizontal acceleration, which may reduce the shear strength considerably. The reduction of shear strength eventually induces failure along a critical failure surface of the slope. The Safety analyses of the river embankments have been

¹ Asstt. Prof. Dept. of Geology and Mining, Rajshahi University, Rajshahi, Bangladesh,
² Prof., ³ Asstt. Prof., Dept. of Civil Engineering, University of Tokushima, Japan
pursued since the development of modern limit equilibrium technique (Fellinious, 1936; Bishop, 1955; Spencer, 1967; Junbu, 1954; Morgenstern and Price, 1965; Sarma, 1979).

Figure 1. Rajshahi City map showing the studied slope location.

Any failed slope generally exhibits the behavior of progressive failure which states that local yielding or failure initiated at some points gradually develops and finally leads to overall failure of the slope along a slip surface. Such type of progressive failure is usually common in the river bank embankment and is rarely understandable with the above mentioned conventional methods of slope stability analysis. Recently, effective methods have been developed for the analyses of progressive failure (Yamagami and Taki, 1997; Yamagami et al. 1999, Khan et al. 2002). One of these methods of progressive failure analysis is used here along with other conventional methods.

There has been no significant published report on safety analysis of RCPE. Rahman (1988) performed some safety analysis on this embankment and predicted 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 Fellinious method and 1.38 with the Bishop method. In his analysis no water level was considered which seems to be the most critical factor for any embankment analysis. Apparently the embankment is safe without any external forces, but it may fail under softening effects and or possible earthquake's shaking conditions. The real situation of safety under different softening levels and possible horizontal earthquake acceleration is of prime importance of any stability analysis for such important embankment.

Therefore, this paper attempts the stability evaluation of RCPE at Khojapur area with the effects of softening of soil materials and horizontal earthquake acceleration.

Methods of analysis

Location and selected cross sections of RCPE

The Court-Talaimari part of the RCPE has recently been rejuvenated, but the Talaimari-Khojapur part is lying almost unprotected. The embankment part at Khojapur area is seems to be most vulnerable. The field observations along the embankment from Court
area to Khojapur area during the last two flood year indicate that Khojapur part of the embankment is more prone to soil erosion which deserves to be analyzed carefully. The geometry of the embankment slope at Khojapur area was traced out with clinometer and measuring tapes and then plotted on graph paper accordingly.

**Determining the strength parameters and water level**

In order to analyze the safety of the RCPE, several samples were collected from the specified cross sections. The samples were used in the laboratory to determine the strength properties. Undrained Direct shear test (using ASTM standard) was adopted for the shear strength parameters. The detail description of the shear box apparatus and the test procedures are found elsewhere (e.g. Punmia, 1985). 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 found by dividing the normal forces and shear forces, respectively, by the cross section of the shear box. Then, a failure envelope (Fig.2) was obtained by plotting the normal stresses and the respective shear stresses. Mohr circles were constructed on the plot and the angle of shearing resistance ($\phi'$) and the cohesion, $c$ were obtained correspondingly. The unit weight of the representative samples were obtained with the water replacement method described by Punmia, 1985. The average
The unit weight of soil was 1.959 t/m³. The average values of angle of shearing resistance and cohesion were determined as 28.5° and 1.838 t/m².

Within the studied slope, the water level was obtained from two boreholes that were used for installation of tube wells and one shallow borehole was dug near the toe of slope. With these data water level across the slope was approximated accordingly.

**Factor of Safety calculations**

**Computer programs: XSTABL and ProgFan**

In order to analyze the embankment’s safety, five conventional limit equilibrium methods of slope stability analysis and one progressive failure analysis method have been chosen. Two computer programs namely XSTABL (Sharma, 1994) and ProgFan (Progressive Failure Analysis of slopes using Non-vertical slices) (Khan et al., 2002), were used for safety analysis. XSTABL, well-known computers program, consisting a group of slope stability analysis methods. XSTABL can handle searching techniques for determining the critical failure surface. The XSTABL includes several established and conventional methods of slope stability analysis among which Bishop method (1955), Spencer method (1967), General Limit Equilibrium (GLE) method and Janbu simplified method (1954) was used in the analyses. ProgFan another computer program that can analyze progressive failure along a shear surface using the non-vertical slices within the limit equilibrium framework. ProgFan calculates local factors of safety as well as overall factor of safety along any failure surface of a slope.

In ProgFan, softening effects along failure surface 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. ϕ and c) simultaneously. Later in the texts, the subscripts, p and r will be used for peak and residual strength parameters of soil respectively. Both the programs can take into consideration of αₑ, but the softening effects with progressive failure only can be used in ProgFan.

Therefore, XSTABL was used here for finding 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.

**Table 1. Calculated factor of safety with no horizontal earthquake acceleration αₑ=0.0g**

<table>
<thead>
<tr>
<th>Methods</th>
<th>Factor of safety</th>
<th>Methods</th>
<th>Factor of safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bishop method</td>
<td>1.408</td>
<td>GLE with f(x)</td>
<td>1.413</td>
</tr>
<tr>
<td>Spencer method</td>
<td>1.415</td>
<td>GLE with half sine</td>
<td>1.412</td>
</tr>
<tr>
<td>Janbu simplified method</td>
<td>1.421</td>
<td>ProgFan</td>
<td>1.419</td>
</tr>
</tbody>
</table>

Technical Journal, RRI, December, 2002
Calculated results and discussions

The above mentioned two computer programs were used for the calculations of factors of safety of specified slope of RCPE. Using Bishop method in XSTABL program the critical failure surface was determined with the minimum factor of safety and is shown in figure 3.

The searched critical failure surface is in circular shape. Along this critical failure surface, other methods in XSTABL programs were used in order to find the factor of safety for individual method. The local factors of safety and the overall factor of safety for this same failure surface were determined with ProgFan. The calculated local factors of safety and the overall factor of safety are shown in the figure 4b. The factors of safety calculated from different slope stability methods using the XSTABL and ProgFan programs are shown in the Table 1.

It is noted here that the local factors of safety clearly indicate the possible failure zone along the shear surface.

Effects of softening on the safety of RCPE

Figure 5 shows the analytical results of several cases where the peak (\( \phi_b \) & \( c_b \)) and residual (\( \phi_r \) & \( c_r \)) strength parameters were treated differently. If we consider the shear strength of the soil materials of the embankment became reduced to a 80% of the peak value (case 2), the local failure zone will extend further and the overall factor of safety will reduce drastically (\( F_{\text{overall}}=1.33 \)). Similarly for the case 3, where the residual strength become 50% of the peak strength, local failure zone dominates over the entire slip surface and the resulted overall factor of safety become close to 1.18 (Table 2).

Noticeably, such type of softening effects on the factor of safety is not possible to consider in the conventional slope stability methods. This exhibits a unique advantage of the method of progressive failure analysis.

Pseudo-static analysis of RCPE

The pseudo-static analysis for the embankment safety was done considering the horizontal earthquake acceleration (a) in terms of g (gravitational constant). First, the analysis was performed with XSTABL program and the results showed (Table 3) that the critical earthquake acceleration (a_c) for the mentioned section of the embankment ranges from 0.195g to 0.235g depending on different methods. It may be noted here that the horizontal earthquake acceleration which causes failure (i.e, \( F=1.0 \)) in a slope is considered as critical horizontal earthquake acceleration

According to the results with ProgFan program, the slope may fail in response to a horizontal earthquake acceleration of 0.19g. At the critical value of acceleration (a_c) the local failure zone extends to almost entire shear surface and the failure is eminent.

In all the pseudo-static analysis the strength parameters was the same as shown in figure 6.

According to Newmark (1965) the critical acceleration of a potential failure mass is a simple function of the static factor of safety and the slope geometry and expressed as
\[ a_c = (F_{s} - 1) g \sin \alpha \]

where, \( F_s \) = static factor of safety; \( \alpha \) = angle of slope.

Table 2. Values of overall factor of safety from progressive failure analysis (ProgFan) in three different cases of softening

<table>
<thead>
<tr>
<th>Cases</th>
<th>Softening condition</th>
<th>Soil parameters</th>
<th>Foverall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>No softening</td>
<td>( \phi = \phi_p ) ( c = c_p )</td>
<td>( \phi_r = 28.5^\circ; c_r = 1.836 \text{ t/m}^2 )</td>
</tr>
<tr>
<td>Case 2</td>
<td>( \phi = 0.8 \phi_p ) ( c = 0.8 c_p )</td>
<td>( \phi_r = 28.5^\circ; c_r = 1.465 \text{ t/m}^2 )</td>
<td>1.336</td>
</tr>
<tr>
<td>Case 3</td>
<td>( \phi = 0.5 \phi_p ) ( c = 0.5 c_p )</td>
<td>( \phi_r = 14.25^\circ; c_r = 0.918 \text{ t/m}^2 )</td>
<td>1.185</td>
</tr>
</tbody>
</table>

Table 3. Values of \( a_c \) for Khojapur section of RCPE from different methods of XSTABL and proposed method.

<table>
<thead>
<tr>
<th>Methods</th>
<th>Acceleration, ( a_c )</th>
<th>( F_{overall} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bishop method (1955)</td>
<td>0.22g</td>
<td>1.006</td>
</tr>
<tr>
<td>Simplified Janbu method (1954)</td>
<td>0.195g</td>
<td>1.003</td>
</tr>
<tr>
<td>Spencer method (1973)</td>
<td>0.235g</td>
<td>1.008</td>
</tr>
<tr>
<td>General Limit Equilibrium (GLE) method</td>
<td>0.235g</td>
<td>1.003</td>
</tr>
<tr>
<td>ProgFan</td>
<td>0.190g</td>
<td>1.012</td>
</tr>
</tbody>
</table>

Figure 4. ProgFan analysis: (a) Slope geometry with inclined slices, strength properties and (b) distribution of local factor of safety of RCPE at Khojapur area.
Newmark (1965) pseudo-static above equation for critical acceleration was also considered in the present analysis. According to the equation 1, the critical horizontal earthquake acceleration determined for this case was 0.263g.

The value determined from the progressive failure analysis method (ProgFan) and those of the other methods differ a little. The value of $a_e$ is less than the other methods, this means that the embankment slope of RCPE is supposed to fail at lower acceleration level and which is about 0.19g. Moreover local factors of safety are found so that local failure zone is evident in the ProgFan analysis. Again, the Newmark's equation shows higher acceleration than that of ProgFan. Therefore, the use of the progressive failure analysis with pseudo-static consideration is comparatively safer in the redesign works of the RCPE.

Conclusion and Recommendation

Stability evaluation of Rajshahi City Protection Embankment (RCPE) at Khojapur area using two programs of stability analyses (XSTABL and ProgFan) significantly indicate failure threats of the embankment slope due to softening effects and horizontal earthquake acceleration. Several conventional limit equilibrium methods and a progressive failure analysis method were used for the safety analyses. Constant overall factor of safety of the embankment slope was determined using the conventional methods and variable local factors of safety along critical failure surface were also calculated with a method of progressive failure analysis. Local failure zone along the slip surface was also evident at the studied slope. This embankment slope may fail due to
strength reduction of soil with softening phenomena. Again, failure can occur at the earthquake’s effects with critical horizontal acceleration ranges from 0.19g to 0.235g.

This value of critical horizontal earthquake acceleration can be included in redesigning work of the embankment. However, water table information used in this study was not adequate for design purposes, it recommends detail water level investigation within the embankment slope.

The present paper strongly recommends detail investigation in redesigning the embankment slope of Talaimari-Khojapur part of RCPE.

References


