Seismic Slope Stability Analysis of Tailings Earthen Dam Using TALREN 4

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ABSTRACT

Several tailings earthen dams have failed during past earthquakes. Due to the failure of tailings dam, the stored tailings waste releases into the surrounding locality causing a disaster for mankind. To reduce such phenomenon, both static and seismic analyses should be conducted for tailings earthen dam. In this paper the static and seismic slope stability analyses are presented for a typical section of 28 m high tailings earthen dam constructed by the downstream method in two phases. The analyses are performed using geotechnical software TALREN 4. Both 1st and 2nd phase of tailing earthen dams are analyzed for different upstream conditions of reservoir like empty, partially filled up and fully filled up cases with compacted and non-compacted dumped waste materials in both slurry and clean water conditions. Seismic analyses are performed using different input seismic motions considering both horizontal and vertical seismic accelerations.

1. INTRODUCTION

A large number of tailings earthen dams have failed historically because of earthquake. The failure of tailings earthen dam can be life threatening for the mankind of that locality because of the presence corrosive and toxic elements in the tailings waste deposit. To reduce such phenomenon, both the static and seismic analyses must be conducted for tailings earthen dam.

Available literature indicates that upto 1960s, pseudo-static method was very popular for the seismic analysis of earthen dam. But the pseudo-static approach is too much simple to consider the dynamics of the earthquake phenomenon and it dose not take into account the nature of the slope-forming material or the foundation material. Klohn et al. (1978) have modified the pseudo-static method and proposed a methodology which couples a conventional pseudo-static method of dynamic analysis with an evaluation of the seismically induced pore pressures. Based on deformation characteristics, Newmark (1965) proposed ‘sliding block method’ using pseudo-static approach. But this method considers the rigid-plastic behaviour of the embankment only. This method has been further developed by other researchers. Hatanaka (1952) performed two-dimensional ‘shear beam’ analysis for dam in rectangular canyon and developed rational design procedure with use of response spectrum. Keightly (1966) used the lumped-mass ‘shear beam’ model to understand results of full-scale tests.

Clough and Chopra (1966) first introduced the Finite Element Method for two-dimensional plane-strain analysis for evaluating the dynamic response of an embankment assuming that it consists of linearly elastic, homogeneous, isotropic materials. Later on, several other researchers have developed the Finite Element Method (FEM) and Finite Difference Method (FDM) for non-linear, inelastic, non-homogeneous, anisotropic behaviour of materials under seismic conditions.

Zeghal and Abdel-Ghaffar (1992) presented a local-global finite element method of analysis for determination of the non-linear seismic behaviour of earth dams. Ming and Li (2003) carried out a fully coupled FEM analysis of failure of Lower San Fernando dam and tried to investigate the possible causes of the dam failure.


In this paper the static and seismic slope stability analyses are presented for a typical section of 28 m high actual tailings earthen dam constructed by the downstream method in two phases. The tailings earthen dam located at a site in eastern part of India comes under seismic zone II as per IS: 1893 (2002). The analyses are performed using geotechnical software TALREN 4 (2007). The objective of this analysis is to check the stability of the dam slope during earthquake events.

2. MODEL GENERATION AND ANALYSIS

Static and seismic slope stability analyses are performed for a typical section of actual tailings earthen dam constructed in two phases by the downstream method.

In the 1\textsuperscript{st} phase of the project, the height of the dam is raised up to 10 m above the existing ground level and in the 2\textsuperscript{nd} phase, the final height of the dam is 28 m and the length is about 350 m. Freeboard is kept as 1.5 m. Figure 1 shows the details of the complete tailings dam section. Table 1 presents the properties of various components of the tailings dam. With its different components, the tailings earthen dam is modeled in geotechnical software TALREN 4 (2007) and the material properties of various components of the dam is assigned. The tailings dam is analyzed for five different reservoir conditions. Such as:

Case-1: Water level is at 3 m below the existing ground level with Compacted and Pond tailings in solid form.

Case-2: Water level is up to the top surface of the Pond tailings portion with Compacted and Pond tailings in solid form.

Case-3: In presence of stored water above Compacted tailings portion,

Case-4: Pond tailings portion is filled with slurry and below that there is Compacted tailings, and

Case-5: Reservoir is filled with slurry only.

The water table is considered at a depth of 3.0 m from the existing ground level. In presence of water or slurry in the reservoir, the seepage analysis is performed using FLAC\textsuperscript{3D} (2006) and the generated phreatic surface is used for TALREN 4 (2007) analyses.

The Bishop’s method of analysis is chosen for the slope stability analysis and the circular failure surface is considered.

For the design seismic zone II as per IS: 1893 – Part 1 (2002), the value of Horizontal Seismic Coefficient = $k_h = 0.1$ and the value of Vertical Seismic Coefficient = $k_v = \frac{1}{2} k_h = 0.05$ [as per IS: 1893-1984 (Reaffirmed 2003)] are considered. Additionally the value of $k_h = 0.15$ and the value of $k_v = \frac{1}{2} k_h = 0.075$ are also considered for the present seismic slope stability analysis.

![Fig. 1: Model of the Entire Tailings of the Dam Section](image-url)
The value of the yield acceleration (i.e., the acceleration at which the slope moves below the factor of safety value of 1.0) for the 1st phase and 2nd phase of the tailings earthen dam is also determined using TALREN 4 (2007).

3. RESULTS AND DISCUSSIONS

Table 2 presents the Factor of safety (FS) values for static and seismic slope stability analysis and the Yield Acceleration (YA) for 1st phase dam. Figure 2 shows the FS value for the static slope stability analysis for Case-2 and Case-3 and Figure 3 shows the FS value for the seismic slope stability analysis for Case-4 and Case-5 with $k_h = 0.1$ and $k_v = 0.05$ for the 1st phase dam.

Table 2. Factor of Safety (FS) Values for Static and Seismic Slope Stability Analysis and the Yield Acceleration (YA) for 1st Phase Dam

<table>
<thead>
<tr>
<th>Tailings Dam</th>
<th>Static FS</th>
<th>Seismic FS</th>
<th>YA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditions</td>
<td>For $k_h=0.1$, $k_v=0.05$</td>
<td>For $k_h=0.15$, $k_v=0.075$</td>
<td></td>
</tr>
<tr>
<td>Case-1</td>
<td>3.98</td>
<td>2.84</td>
<td>2.50</td>
</tr>
<tr>
<td>Case-2 &amp; Case-3</td>
<td>3.92</td>
<td>2.77</td>
<td>2.39</td>
</tr>
<tr>
<td>Case-4 &amp; Case-5</td>
<td>3.90</td>
<td>2.72</td>
<td>2.28</td>
</tr>
</tbody>
</table>

Seismic FS value for the 1st phase dam is observed as 2.5 when water table is at 3 m below the existing ground level and 2.39 when the water level is up to the top surface of the pond tailings portion for $k_h$ and $k_v$ value of 0.15 and 0.075 respectively. For the same conditions of water level the FS value for the 2nd phase dam is decreased by 30% and 33.9% respectively. When the slurry is up to the top surface of the Pond Tailings portion for the 1st phase dam the FS value is obtained as 2.28 for $k_h = 0.15$ and $k_v = 0.075$. For this condition the FS value is decreased by 35.9% for 2nd phase dam. It can also be observed that the minimum value of YA for the 1st phase dam is 0.47g. But, for the 2nd phase dam the minimum YA value is decreased by 42.5% as compared to the minimum value of YA for 1st phase dam.

Table 3: Percentage Decrease in Factor of Safety (FS) and the Yield Acceleration (YA) for 2nd Phase Dam as Compared to 1st Phase Dam

<table>
<thead>
<tr>
<th>Tailings Dam</th>
<th>Static FS</th>
<th>Seismic FS</th>
<th>YA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditions</td>
<td>% Decrease</td>
<td>% Decrease</td>
<td>% Decrease</td>
</tr>
<tr>
<td>Case-1</td>
<td>32.9</td>
<td>30.6</td>
<td>30.0</td>
</tr>
<tr>
<td>Case-2 &amp; Case-3</td>
<td>32.9</td>
<td>32.5</td>
<td>33.9</td>
</tr>
<tr>
<td>Case-4 &amp; Case-5</td>
<td>32.8</td>
<td>34.9</td>
<td>35.9</td>
</tr>
</tbody>
</table>

Table 3 presents the percentage decrease in Factor of safety (FS) and the Yield Acceleration (YA) for 2nd phase dam as compared to 1st phase dam. Figure 4 shows the FS value for the static slope stability analysis for Case-2 and Case-3 and Figure 5 shows the FS value for the seismic slope stability analysis for Case-4 and Case-5 with $k_h = 0.1$ and $k_v = 0.05$ for the 2nd phase dam.

It can be noted from Table 2 and 3 that for the 1st phase dam the lowest value of static FS against slope failure is 3.92 and for the 2nd phase dam this value is decreased by 32.9% as compared to 1st phase dam when the water level is up to the top surface of the pond tailings portion. But when there is slurry of tailings materials present in the reservoir the lowest value of FS against slope failure for the 1st phase dam is obtained as 3.90 and for the 2nd phase dam it is decreased further by 32.8%.

Fig. 2: Static Slope Stability Analysis for 1st Phase Dam for Case-2 and Case-3

Fig. 3: Seismic Slope Stability Analysis for 1st Phase Dam for Case-4 and Case-5 with $k_h = 0.1$ and $k_v = 0.05$

Fig. 4: Static Slope Stability Analysis for 2nd Phase Dam for Case-2 and Case-3
4. CONCLUSIONS

It can be observed that due to the presence of adequate drainage provisions in the dam, the seepage problem almost does not affect the free sloping surface of the dam. Under both the conditions of seepage or without seepage the factor of safety values remains almost same. From the results it can be stated that, with increase in height of the dam the FS and YA value decrease significantly as expected.

Finally, after static and seismic slope stability analyses, it can be concluded that the proposed tailings earthen dam section is quite safe against slope failure.

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REFERENCES


