SEISMIC SLOPE STABILITY ANALYSIS OF KASWATI EARTH DAM

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ABSTRACT
The behavior of embankment dams, as one of the most important structures, under earthquake loading has attracted the attention of many researchers and dam designers. A large number of water-retaining earthen dams were affected by the earthquake. This paper examines static and dynamic slope stability analysis of “Kaswati Dam” located in Bhuj region by using of geo-studio 2007. Static analysis include Static slope stability method include Limit equilibrium analysis and stress deformation analysis. Limit equilibrium analysis consider force and/or moment equilibrium of a mass of soil above a potential failure surface. Static slope stability analysis is done by Bishop’s simplified method and Dynamic slope stability analysis is done by time history method. The consequences of these problems were the dams performed reasonably in spite of being shaken by free-field horizontal peak ground acceleration (PGA) as high as 0.28g. A Magnitude (MW) 7.6 earthquakes occurred in Bhuj, India on January 26, 2001 Slope stability usually expressed in terms of an index, most commonly the factor of safety.

KEYWORDS: Static analysis, Dynamic analysis, Time history method, Kaswati dam, Bishop’s method, Factor of safety

I. INTRODUCTION
A Magnitude 7.6 (Mw 7.6) earthquake occurred in Gujarat state, India on 26 January 2001. The epicenter of the main shock of the event was near Bachau at 23.36°N and 70.34°E with a focal depth of about 23.6 km. The event, commonly referred to as the Bhuj Earthquake, was among the most destructive earthquakes that affected India. A large number of small- to moderate-size earthen dams and reservoirs, constructed to fulfill the water demand of the area, were affected by Bhuj Earthquake. Most of these dams are embankment dams constructed across discontinuous ephemeral streams. Although many of these dams were within 150 km of the epicenter (Figure 1), the consequences of the damage caused by the earthquake to these facilities were relatively light primarily because the reservoirs were nearly empty during the earthquake.

![Figure 1: Location of Kaswati Dam](image)

Kaswati Dam, constructed in 1973, is an earth dam with a maximum height of 8.8 m and crest length of 1455 m. The dam is underlain by loose to medium-dense, alluvial, silt-sand mixtures. Limited amount of subsurface exploration data indicate that the site is underlain by 2 to 5 m thick granular soils characterized with an SPT blow count between 13 and 19, below which relatively dense granular soils with an SPT blow count typically above 25 is found (Krinitzsky and Hynes 2002). Like the other impoundments, Kaswati Reservoir was nearly empty during Bhuj Earthquake. However the alluvium soils underneath the upstream portion of the dam was saturated during the earthquake. Bhuj Earthquake triggered shallow sliding near the bottom portion of upstream slope, and bulging of ground surface near the upstream toe. Such distress may have been due to localized liquefaction near the upstream toe of the dam. EERI also report relatively narrow, longitudinal cracks along the crest of the dam running the length of the dam over which the lower portion of the upstream slope exhibited distress. It appears that the problem of development of longitudinal cracks along the crest was indirectly due to localized liquefaction of upstream foundation soils. The downstream slope, on the other hand, remained largely unaffected.

STATIC SLOPE STABILITY ANALYSIS
Slope became unstable when the shear stresses required to maintain equilibrium reach or exceed the available shearing resistance on some potential failure surface. For slopes in which the shear stresses required to maintain equilibrium under static gravitational loading are high, the additional dynamic stresses needed to produce instability may be low. Hence the seismic stability of a slope is strongly influenced by its static stability. Because of this and fact the most commonly used methods of seismic stability analysis rely on static stability analysis. The procedures for analysis of slope stability under static conditions are well established. An excellent, concise review of the static analysis was presented by Ducan (1992). Detailed descriptions of specific methods of analysis can be found in standard references such as National Research Council (1976), Chowdhury (1978) and Huang(1983). Currently, the most commonly used methods of static slope stability analysis are limit equilibrium analysis and stress deformation analysis.

LIMIT EQUILIBRIUM ANALYSIS
Limit equilibrium analysis consider force and/or moment equilibrium of a mass of soil above a potential failure surface. The soil above the potential failure surface is assumed to be rigid (i.e. shearing can occur only on the potential failure surface). The available shear strength is assumed to be mobilized at the same rate at all points on the potential failure

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surface. As a result, the factor of safety is constant over entire failure surface. Because the soil on the potential failure surface is rigid-perfectly plastic, limit equilibrium analysis provide no information on slope deformation.

Slope stability usually expressed in terms of an index, most commonly the factor of safety, which is usually defined as

\[ FS = \frac{\text{available shear strength}}{\text{shear stress required to maintain equilibrium}} \]

Bishop (1955) devised a scheme that included interslice normal forces, but ignored the interslice shear forces. Again, Bishop’s Simplified method satisfies only moment equilibrium. Of interest and significance with this method is the fact that by including the normal interslice forces, the factor of safety equation became nonlinear and an iterative procedure was required to calculate the factor of safety.

A simple form of the Bishop’s Simplified factor of safety equation is:

\[ F_s = \frac{\sum \frac{1}{m_{\alpha}} \left[ c'b + (W-u_b) \tan \theta' \right]}{\sum W \sin \alpha} \]

Where \( m_{\alpha} = \left( 1 + \tan \theta' \tan \alpha / F_s \right) \cos \alpha \)

### Table 1: Soil property of kaswati dam

<table>
<thead>
<tr>
<th>FERTICULAR</th>
<th>M.D. D</th>
<th>O.M. C</th>
<th>COMESSION KG/M</th>
<th>( \theta )</th>
<th>TAN ( \theta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEMI. PEROUS</td>
<td>1780</td>
<td>10.20</td>
<td>0.0</td>
<td>34°</td>
<td>0.674</td>
</tr>
<tr>
<td>IMPEROUS</td>
<td>1640</td>
<td>20.00</td>
<td>0.2</td>
<td>20°</td>
<td>0.364</td>
</tr>
<tr>
<td>FOUNDATION</td>
<td>1950</td>
<td>12.00</td>
<td>0.0</td>
<td>30°</td>
<td>0.674</td>
</tr>
</tbody>
</table>

### BASIS OF ANALYSIS

The system is assumed to be two-dimensional. It is assumed that the coulomb equation for shear strength is applicable and strength parameter \( c \) and \( \theta \) are known. Seepage condition and water level are known and pore-water pressure can be estimated. The condition of plastic failure are assumed to be satisfied along the sleep surface. Depending upon the method of analysis, some additional assumptions are made regarding the magnitude distribution of forces along various planes.
The cyclic stress-stain behavior of the materials within the body of the dam or embankment and that of foundation soils. Potential instability of an earth dam or an embankment during an earthquake may be due to the inertial effects or due to cyclic softening of soils. Techniques ranging from very approximate to very elaborate are available for seismic stability analysis of dam and embankment. In the order of increasing complexity, these methods include:

- Equivalent-static Stability Analysis
- Sliding Block Method
- Dynamic Analysis (Simplified or Rigorous)

**New mark Sliding Block Analysis**

The pseudo static method of analysis, like all limit equilibrium methods, provide the factor of safety but no information on deformations associate with slope failure. This method involves evaluation of permanent deformation during an earthquake and comparing it with what is the acceptable deformation. This is usually carried out by the New mark’s sliding block analysis wherein the potential failure mass is treated as a rigid body on a rigid base with the contact in between as rigid plastic. The acceleration time history of the rigid body is assumed to correspond to the average acceleration time history of the failure mass.

**Dynamic analysis**

Dynamic analysis is recommended for important dams and embankments, failure of which may lead to high levels of risk, and dams located over active fault zone. Small to intermediate size dams found to be unsafe by simplified analyses described to dynamic analysis if adequate data and expertise are available for undertaking such an exercise.

Dynamic analysis essentially involves estimation of the deformation behavior of an earth dam or an embankment using the finite element or finite difference method. A complete and detailed dynamic analysis is a major undertaking that requires extensive database and specialized skills. The results of such analyses are sensitive to the input seismologic parameters and engineering properties. As a result, a pre-requisite for using these procedures is a thorough seismotectonic assessment and a detailed site and material characterization.

Dynamic analysis employing a non-linear stress strain relationship provides a rational framework for estimation of deformation of an earth dam or an embankment. The biggest difficulty in employing these models is to obtain soil stress strain models that are representative of the soil in situ behavior. This approach requires an accurate characterization of the stress-strain behavior of the materials within the body of the earth dam or embankment and foundation. Dynamic analysis of earth dams and embankments also require a suitable earthquake time histories representing design earthquakes.

**Dynamic response**

History Points can be defined at selected points to get a complete picture of the dynamic response; that is, data is saved for each time-step integration point. Figure shows the response at the crest of the Dam. There is not much difference between this record and the input record in Figure. The peak at the crest is slightly less than the 0.28g peak in the base record. In other words, there is no significant amplification or unrealistic damping.
CONCLUSION

Damaging effects of Bhuj Earthquake on embankment dams have been considered in this paper. This paper presents Static slope stability analysis by Bishop’s simplified method and dynamic slope stability analysis by Time History Method of “Kaswati earth dam”. In static upstream slope stability analysis that can achieve minimum factor of safety is 2.922 and Dynamic upstream slope stability analysis that can achieve minimum factor of safety is 1.137. In static downstream slope stability analysis that can achieve minimum factor of safety is 2.109 and Dynamic downstream slope stability analysis that can achieve minimum factor of safety is 1.095. In dynamic analysis of upstream slope 38% factor of safety decreases with compare to static analysis. In dynamic analysis of downstream slope 50% factor of safety decreases with compare to static analysis.

REFERENCES


Table 3  Factor of  safety of  D/S slope

<table>
<thead>
<tr>
<th>STATIC CONDITION</th>
<th>DYNAMIC CONDITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius</td>
<td>Factor of safety</td>
</tr>
<tr>
<td>71.808</td>
<td>2.159</td>
</tr>
<tr>
<td>35.785</td>
<td>3.190</td>
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<tr>
<td>35.689</td>
<td>3.802</td>
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<tr>
<td>35.687</td>
<td>3.940</td>
</tr>
<tr>
<td>32.797</td>
<td>4.486</td>
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Fig9- Graph  Factor o safety vs Time (D/S slope)