Analysis of a Road Embankment with Pond Ash in an Active Seismic Region

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SUMMARY:
Huge quantities of ash is being produced annually by thermal power plants as a by-product. Bulk utilization of this ash produced is possible in geotechnical engineering applications, like construction of highway embankments, raising of ash dykes and filling of low lying areas. However, design and construction of such geotechnical structures particularly in active seismic regions requires thorough understanding of dynamic response of these structures. In this article, dynamic response of a highway road embankment is studied under various possible static and seismic loading conditions. Influence of various earthquake ground motion characteristics (e.g. amplitude, duration and frequency content) on the dynamic response of the embankment is assessed. Effects of water stagnation on the stability of the road ash embankment is also examined. Based on the study, it is found that response of highway embankments constructed with ash is satisfactory under various static and seismic loading` conditions.

Keywords: Pond ash, Road embankment, Seismic slope stability

1. INTRODUCTION

Use of coal for generation of power results in production of huge quantity of ash. In India alone, annual production of ash is over 100 million tons (Dhadse et al. 2008). Efforts are needed to utilize this ash not only from environmental considerations, but also to avoid land usage for ash dumping. Coal ash which is one of the major air, water and soil pollutant, disrupter of ecological cycles can be minimized by utilizing in large earthworks for geotechnical applications like highway embankments construction and filling low lying areas. However construction of highway embankments in high seismic regions requires knowledge of dynamic behaviour of the coal-ash, which can be different from soils due to its high porosity, low unit weight, and interlocking behaviour. Dynamic response of the embankment is very often studied in terms of change in factor of safety of slope due to additional loading from earthquake. To analyze these slope instability problems under earthquake conditions, several methods have been used by the researchers (Ambraseys& Srbulov, 1995; Ashford& Sitar, 2002; Bijan& Nicholas, 2000; Jakka et al., 2011; New-mark, 1965; Seed, 1966; Seed et al., 1975).

In the present study, the numerical analyses of model slopes have been carried out based on finite element procedure using the Geo-Studio software. The effects of ground motion parameters such as amplitude and frequency of vibrations in the range of 0.1g to 0.3g and 1Hz to 5Hz respectively have been studied. An embankment of height 10m is initially designed as per the Indian Standard Code (IS) code of practice considering loading conditions appropriate to the seismic zone IV, India. Ash from Badarpur ash pond is considered in the construction of the embankment. Embankment so designed is used to study and analyze the road ash embankment under various dynamic loading conditions to identify various critical components/parameters in the design and the performance of the ash embankments.

2. MATERIALS PROPERTIES

Ash collected from Badapur ash pond, New Delhi, India is considered in the construction of the embankments. Material properties of the Badarpur pond ash are compiled from the published literature (Jakka et al., 2010& 2011). Table 2.1 provides the general and geotechnical properties of the Badarpur pond ash, while dynamic properties and strength characteristics are provided in Table 2.2. Modulus reduction and damping ratio curves of the materials are shown in the Fig.2.1 &2.2.For analysis of submerged slopes, liquefaction behaviour of the ash is very important. The required curves are shown in Fig.2.3 &2.4.

Table2.1 Geotechnical properties of materials used (Jakka et al., 2010b)

Material	Specific gravity	State	Void ratio	Dry unit weight (kN/m^3)	Coeff. of permeability K (m/s)	Compressibility characteristics	
						Compression index, C_c	Recompression index, C_r
BP-F	2.18	Dense	0.97	10.84	9.4E-07	0.089	0.018

BP-F: Badarpur Pond ash from outflow point

Table 2.2 Dynamic properties and shear strength characteristics of material used (Jakka et al., 2011)

Material	State	Shear modulus G_{max} (kPa)	Peak strength parameters		Residual strength parameters	
			Cohesion, C (kPa)	Angle of friction ϕ(deg)	Cohesion, C (kPa)	Angle of friction ϕ(deg)
BP-F	Dense	24862	0	37	0	33.7

BP-F: Badarpur Pond ash from outflow point

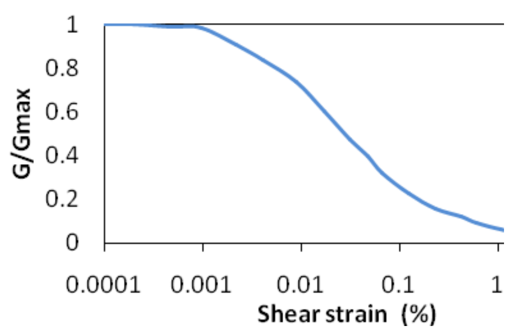

Figure 2.1. Modulus reduction curve for ash used in the embankment (Jakka et al., 2011)

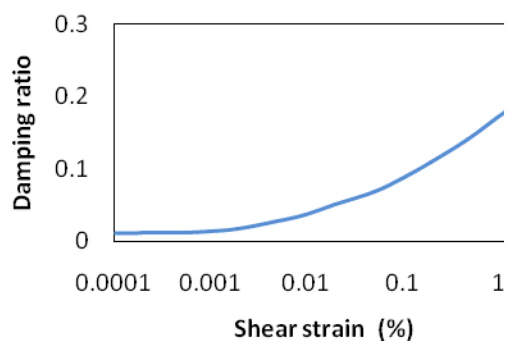

Figure 2.2. Damping ratio curve for ash used in the embankment (Jakka et al., 2011)

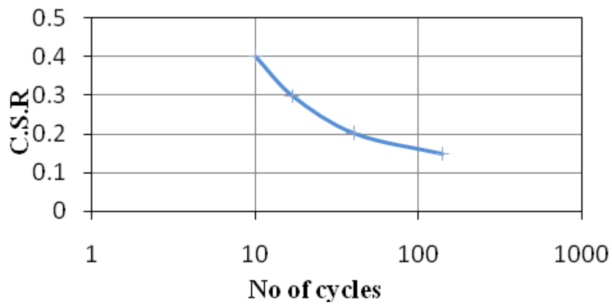

Figure 2.3. Cycle strength curves for pond ash from inflow and out flow points (Jakka et al., 2010a)

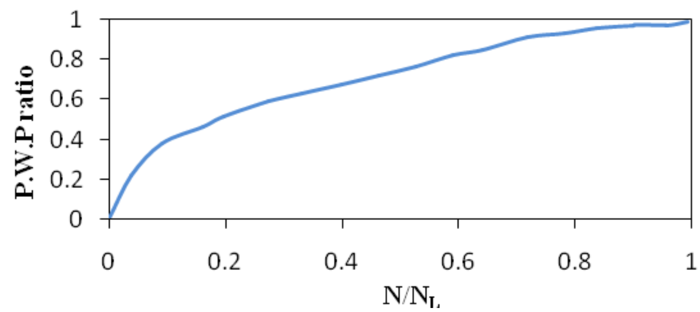

Figure 2.4. Pore water pressure function for the pond ash in dense state (Jakka et al., 2010a)

3. CONFIGURATION OF THE ASH EMBANKMENT

Initially, a trial Embankment is to be assumed with fly ash material. Properties of ash in dense condition appropriate to road embankment are considered. For the assumed section, static slope stability analysis is carried out to access the factor of safety of slope under static loading conditions. If factor of safety is found to be unsatisfactory, the above procedure is repeated again with new section. After satisfactory design of embankments, they are checked for that stability under earthquake conditions. Pseudo-static approach, as suggested in IS code of procedure is used. Seismic coefficient required to convert earthquake loading in to equivalent static load is taken from IS 1893-2002 appropriate to seismic zone IV. After replacing earthquake loading into appropriate equivalent static load, rest of procedure is same. At the end of analysis if factor of safety is not satisfactory, the above procedure is repeated for new embankment section. Following above procedure, road ash embankment slopes are fixed. The trail configuration of the cross section is shown in the Fig. 3.1.

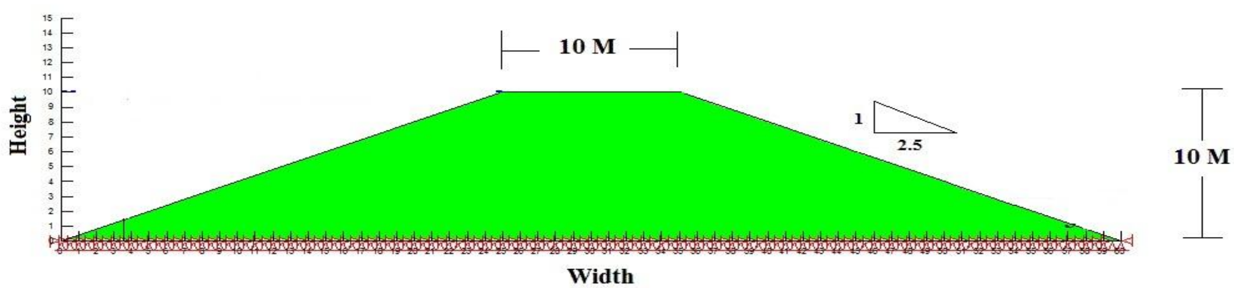

Figure 3.1. Configuration of the embankment

4. DYNAMIC ANALYSIS OF ASH EMBANKMENT

Numerical analyses of the embankments in static and dynamic conditions were carried out using finite element procedure employing computer program Geo Studio2004. The analyses of the both the models were carried out based on Mohr Coulomb yield criteria. The embankments were discredited by iso-parametric elements. In the static condition, gravity analysis was performed and the stresses are allowed to reach equilibrium state under self weight by applying appropriate boundary conditions. The boundary at the bottom of the embankment was fixed. Dynamic analyses of the embankments were carried out using QUAKE/W. In dynamic analysis, the two vertical side boundaries were made free to allow deformations and fixed at the base in order to simulate the field condition. The vertically propagating seismic waves from base of the embankment that reaches the crest of the embankment induce the displacements. QUAKE/W provides the stress variations within the embankment at different time steps during the ground excitation. Using these stresses, further analysis is carried out to analyze the safety factor of the embankment slope and its variation during the ground excitation using SLOPE/W.

The designed ash embankment of height 10m with side slopes of 1:2.5 is analysed for studying influence of amplitudes, frequency, duration and other conditions. Details of input motions used and the response obtained are discussed in the following subsections.

4.1 Ground Motion Input Parameters

Input motion characteristics significantly influence the response of the embankment. Amplitude, frequency and duration are the three important characteristics of ground motion. Slope stability of the embankment is influenced by the magnitude of stresses induced by the propagation of waves. Magnitude of stresses induced is further influenced by maximum embankment response. Maximum response is influenced by the combination of frequency & amplitude content of the earthquake motion and material. Each earthquake motion is unique and will have different waves of amplitudes at different frequencies, which makes difficult to use any specific earthquake motion to analyse and identify the critical parameters in the design. To avoid this limitation, controlled motions are synthesized and used in this study. Here 0.1g to 0.3g amplitude and 1 Hz to 5 Hz frequency sinusoidal motions have used as an input ground motion with duration of 10 sec. A typical sinusoidal motion used in the study with amplitude of 0.2g at 1 Hz with duration of 10s is shown in Fig.4.1

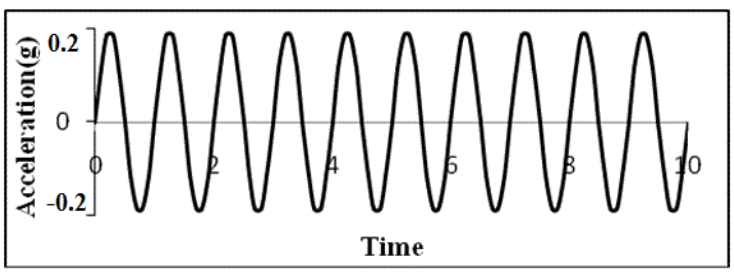

Figure 4.1. Typical sinusoidal motion used in the study with 0.2g amplitude and 1Hz frequency

4.2 Effect of Frequency and Amplitude

Frequency is the one of the important ground analysis response parameter, which plays a major role during earthquakes. Every structure has its own natural frequency. If external excitation matches with this frequency, structure will be subjected to very high amplitudes of shaking. Natural frequency (f_o) of a level ground surface with un-damped soil can be estimated using,

$$f_o=V_s/4H \qquad (4.1)$$

Where, V_s = Shear wave velocity

H = Height of embankment

In the present study, we considered 10 m road ash embankment with side slopes of 1:2.5.Ash stiffness is not constant with increase in strains as discussed earlier. Moreover, ash exhibited increase in the damping with increase in the shear strains as shown in Fig.2.2. For such cases, it is very difficult to accurately estimate the predominant output frequency and its amplitude. These values are influenced by both input frequency and its amplitude. To tackle this problem, controlled ground motions are used as discussed earlier. Sinusoidal motions of frequencies 1 to 5 Hz and amplitudes 0.1g to 0.3 g are used as input excitations and then response of embankment is analysed for each case. Response of the road embankment with Badarpur pond ash from out flow point (BP-F), expressed in terms of horizontal displacement is shown in Fig.4.2.

From these graphs, it can be seen that as frequency of input motion is changing, the response of embankment is also changing even though amplitude of shaking is same. This is clearly indicating influence of structure frequency over the input excitation. Similar results can be observed at all other amplitudes. However the peak response is not occurring at the same frequency. To understand this, another set of analysis is carried out, considered linear elastic approach to eliminate the influence of soil nonlinear behaviour. Results are shown in Fig.4.3. Here we can clearly seen, no shift of peak response is obtained for all input amplitudes of shaking.

It is clearly establishing the fact that the shift observed in previous case is related to non linear behaviour of ash. As amplification of shaking increasing, the stiffness of ash is reducing significantly. As stiffness reduces, its natural frequency will also reduce as per Eqn4.1. This is causing amplification at lower frequencies.

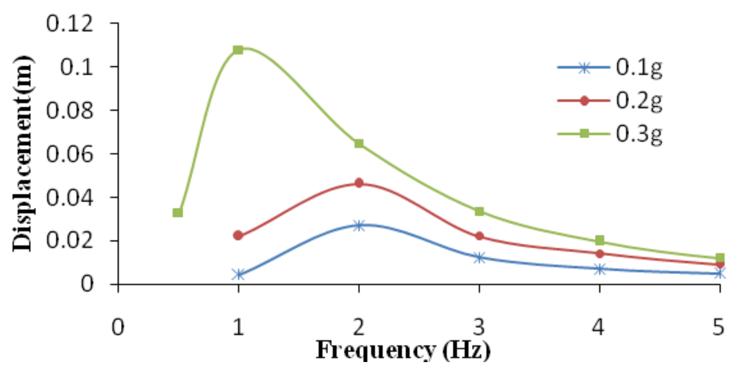

Figure 4.2. Variation of the horizontal displacement of the embankment with respect to different frequencies of shaking.

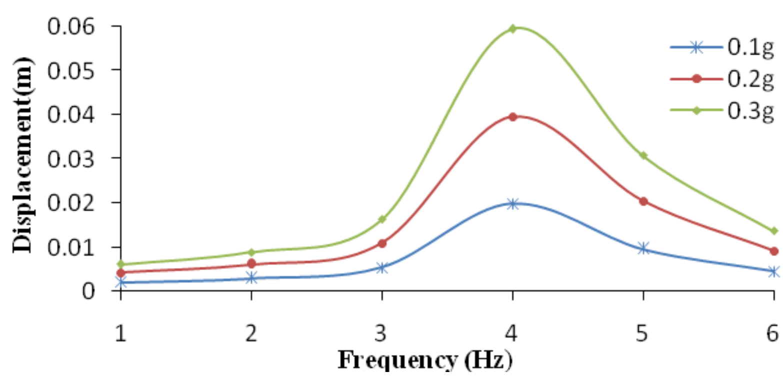

Figure 4.3. Variation of the horizontal displacement of the embankment with respect to different frequencies of shaking.

Amplitude is another important ground analysis response parameter, which plays a major role during earthquakes. Response of the embankment with increasing amplitude of shaking is shown in Fig.4.4 for different frequencies of excitations. As amplitude of excitation is increasing, the response of the embankment is increasing in all the cases. Increasing in amplitude of excitation has linear effect for 1 Hz frequency. System (embankment) response is nonlinear at 1 Hz frequency.

It is observed that as frequency of excitation increases, embankment response decreases between 2Hz to 5Hz response. When frequency of excitation reduces below 1Hz, mixed response is observed. At low amplitudes of excitation embankment responds is found to be less. However as amplitudes of shaking increasing beyond 0.2g, an opposite trend is observed. This is due to change of natural frequency of system at higher amplitudes as discussed in the early sections.

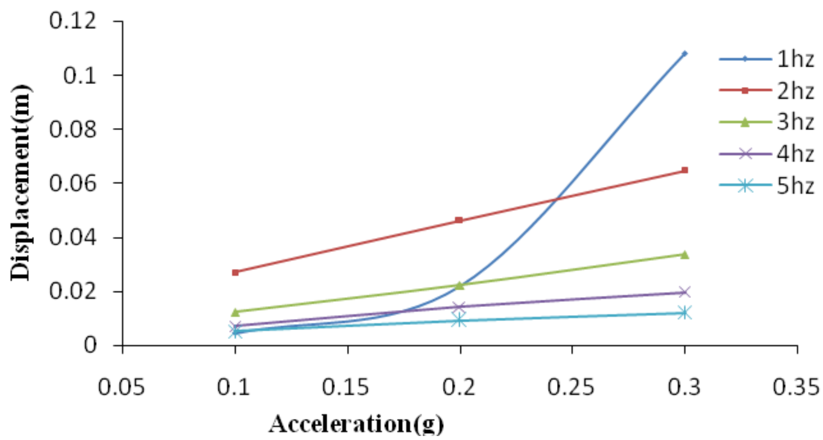

Figure 4.4. Variation of the horizontal displacement of the embankment with respect to different amplitudes of shaking.

4.3 Performance of the Embankment under Recorded Motion

After studying the dynamic behaviour of ash embankment under different earthquake loading condition, they are subjected to real earthquake excitations, Bhuj 2001 earthquake motion recorded in ahmadbad an active seismic region is considered as input motion. The input motion used in analysis and its response spectrum are shown respectively in Fig.4.5 &Fig.4.6.The embankment showed amplification to the recorded motion, as shown in the Fig.4.7. Further post seismic slope stability is carried out for end of earthquake condition. Fig.4.8 shows the variation of factor of safety during earthquake. As factor of safety is not falling below 1.0, no permanent deformations are expected in this case.

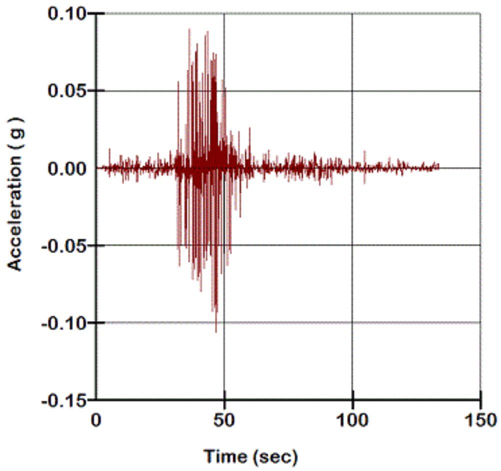

Figure 4.5. Acceleration time history of the input ground motion

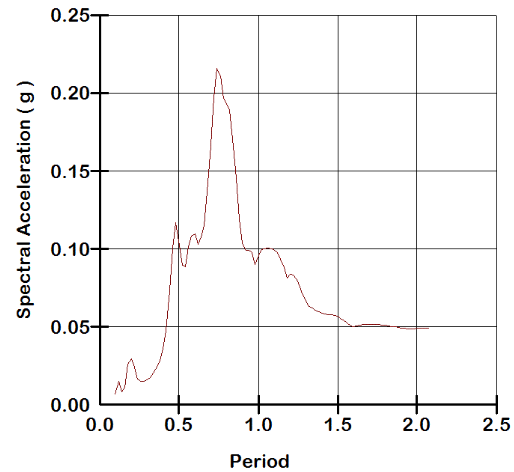

Figure 4.7. Response spectrum of crest motion of the embankment

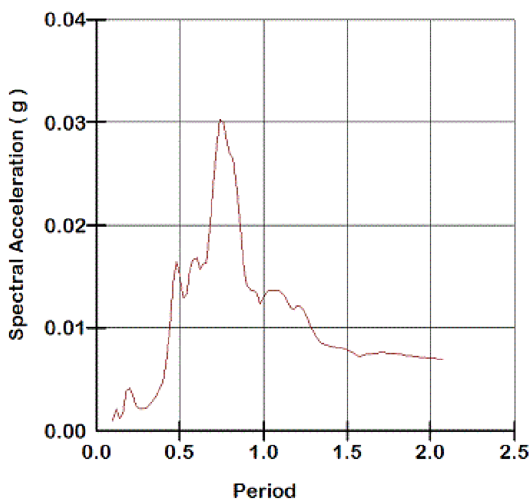

Figure 4.6. Response spectrum of input motion

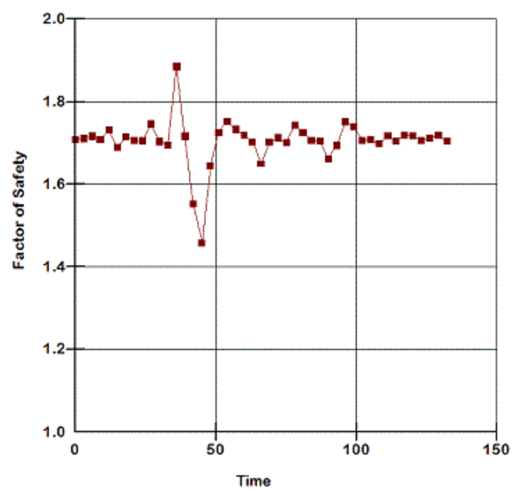

Figure 4.8. Variation of factor of safety of road ash embankment in dry condition, during the earthquake ground shaking

4.4 Effect of Saturation/flooding

Road embankments constructed in low lying areas in high rainfall regions, can be submerged, as discussed in introduction, if saturated mass is subjected to ground shaking, the pore water pressure develops which can lead to slope instability. This effect has been studied by considering free standing water at one side as shown in Fig.4.9

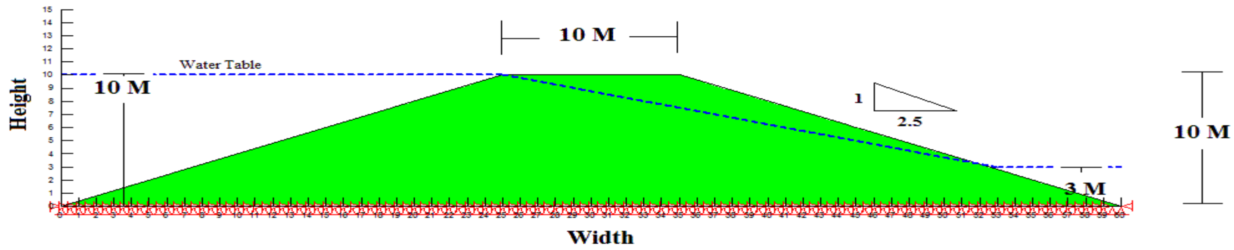

Figure 4.9. Road ash embankment under submerged conditions.

Same Bhuj 2001 input motion is considered for the analysis. The response of embankment using recorded motion is observed to be same as observed in the previous case (i.e. response of embankment in dry condition). As Quake/W doesn't consider effect of pore water pressure on the response directly, both with and without water table yielded same response. Post earthquake slope stability analysis is carried out and results are shown in Fig.4.10. It can be seen that factor of safety is reduced significantly compared to dry case this is due to increase in pore pressure with in saturated mass of ash.

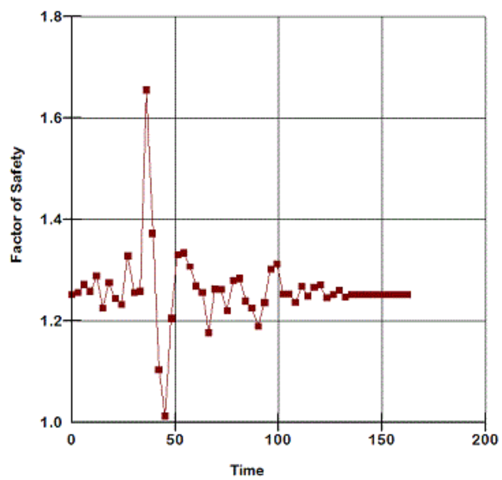

Figure 4.10. Variation of factor of safety of saturated road ash embankment during the earthquake ground shaking

5. DISCUSSIONS AND CONCLUSIONS

Bulk utilization of ash produced is possible in large geotechnical earth works such as construction of highway embankments, raising of ash dykes and filling of low lying areas. However, design and construction of such geotechnical structures particularly in active seismic regions requires thorough understanding of their dynamic response. In this article, dynamic response of a highway road embankment constructed with pond ash is analysed under various possible static and seismic loading conditions. In the present study, the numerical analyses of model slopes have been carried out based on finite element procedure using the Geo-Studio software.

An ash road embankment of height 10m designed as per the IS code of practice considering loading conditions appropriate to the seismic zone IV, India are used in the studies. Synthetic ground motions are prepared for carrying out controlled studies. The effects of ground motion parameters such as amplitude and frequency of vibrations in the range of 0.1g to 0.3g and 1Hz to 5Hz respectively have been studied.
The following conclusions are drawn from this study:

- It is observed that maximum crest responses occur at different frequencies for different amplitudes of shaking.
- It is also observed that as amplitude of the shaking increases there is a clear shift of maximum response towards lower frequencies. Whereas no such shifting is observed in case of linear elastic method. This implied that non-linear behaviour of the ash materials influencing the amplitude and frequency of excitations of the embankments.
- Shift of maximum response towards lower frequencies under higher amplitudes of shaking is due to reduction in the shear modulus of the ash under higher magnitude of shaking. As magnitude of shaking increases, strains are increasing which cause reduction in shear modulus. As shear modulus reduces, its shear wave velocity also decreases, which further reduces the natural frequencies of the embankment and causing amplifications at low frequencies.
- It can be observed that as frequency of excitation is varying, the response of the embankment is also changing. Maximum response is occurring when frequency of external excitation is matching with natural frequency of the structure due to resonance.
- Due to nonlinear behaviour of pond ash, the natural frequency of the embankment is not constant and it is reducing with increased amplitude levels of shaking.
- Road ash embankment analysed in dry condition under recorded ground motion, showed post earthquake safety factor more than one. It doesn't also show any permanent deformations during the ground excitations.
- Road ash embankment analysed in saturated condition under the same recorded ground motion, showed lower post earthquake safety factor compared to dry condition. This is due to development of positive excess pore water pressures in the embankment. Even though safety factor is considerably reduced compared to dry condition, no permanent deformations are observed even for this case.
- Overall, road ash embankment considered in this study is found to perform satisfactory under the considered site specific earthquake ground motion.

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