International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

2010 - Fifth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

27 May 2010, 4:30 pm - 6:20 pm

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Recommended Citation

Koner, Radhakanta and Chakravarty, Debashish, "Evaluation of Seismic Response of External Mine Overburden Dumps" (2010). *International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*. 17.
https://scholarsmine.mst.edu/icrageesd/05icrageesd/session04b/17

Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

EVALUATION OF SEISMIC RESPONSE OF EXTERNAL MINE OVERBURDEN DUMPS

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ABSTRACT

The stability of mines external overburden dump slope experiencing an earthquake is controlled by deformations; consequently a stability analysis that predicts slope displacements is desirable.

The amount of displacement, deformation occur at the crest of the overburden dumps is an important factor for the seismic loading response of the dumps for the field personnel at the mine site for designing the dump slope geometry. The state of effective stress and seismic intensity significantly affects the stability range.

In this paper, a simplified approach is presented for the seismic response of overburden dumps, and the role played by relevant parameters such as soil shear strength, dump height, slope angle, damping scheme, periods of seismic load and peak acceleration at excitation time is addressed.

INTRODUCTION

Opencast coal mining has contributing major share of coal production at Indian mining scenario. The opencast method of mining is remove top overburden (OB) layer and exploits the coal. The waste OB to coal ratio is increase with the increased depth of mining operation. In this situation the OB dumps are heightened to cope with restricted land availability (Koner et. al., 2008).

Various environmental and stability concern has been raised in recent times due to collapse of the existing OB dumps (Koner and Chakravarty, 2008) and subsequent fatality. In this works a seismic stability study of the OB dumps has been undertaken. Mining structures are experience various seismic event. The earthquake and blast vibration are major source of seismic instability parameters.

The Indian coal mining rules, regulation, and acts are silent about the permissible permanent displacement of mine structures at the seismic impacts. The Director General of Mines Safety (DGMS), issued time to time circulars according to the needs of the safe mine operation. One circular, DGMS (Tech) (S&T) Circular No.7 of 1997 Dhanbad, dated the 29th August, 1997, issued some notes of warning regarding damaged due to blasting in near by areas. The Specific notes on permissible level of deformation / displacement are not present here also.

According to the international community also, very little literature have been found in this directions. In civil engineering the Newmark's approach used, to calculate permanent displacement of slope mass with seismic loads have significant impact on the safety of the large scale slope. The following few literatures may light some ray of hope for the researcher to take decision regarding the design and modeling of the large scale dump slope. The parameter, 'critical displacement' found in the following literature;

(1) Hynes-Griffin and Franklin (1984), suggest displacement up to 100 cm may be acceptable for well constructed earth dams.
(2) While investigating and designing landslide hazards maps of San Mateo County, California Wieczorek et al. (1985), used 5 cm as critical parameters.
(3) In Southern California Keefer and Wilson (1989) used 10 cm for coherent slides.
(4) In Mississippi valley, 5-10 cm range for landslide are used by Jibson and Keefer (1993).
(5) The criteria if the Newmark's displacement is less than 15 cm the slope is acceptable, developed by the State of California (2008). While greater than 30 cm Newmark's displacement at slope will be considered unsafe. The displacement between 15-30 cm are left with the engineers, the assessment and judgment of the particular complexity, in particular context, whether to accept or reject.

It is very difficult at this time to define single value of critical permanent displacement that can be used to evaluate the performance of a dumps slope during earthquake. According to Jibson (1993), that field engineers are in better position to decide on critical, or acceptable, value of the permanent displacement to degree of the problem dimensions and the behaviours of slope mass materials. Thus the ductile, plastic materials at the slope may sustain larger displacement than those of brittle, sensitive material at slopes. The following statement made by Houston et al. (1987) appear in the discussion of Newmark's methods, may suggest best solution: "It probably should be viewed as a tool to assist the engineer in deciding whether the probable slope movement is: (1) a fraction of inch, or (2) a few inches, or (3) a few feet. This level of distinction is usually adequate to enable an engineering or management decision."

In this context a study has been undertaken to assess the OB dumps stability in response to earthquake vibration. This study principally focuses the analysis on the effects of OB dumps parameter and OB strength characteristics to stability of OB dump in response to earthquake excitation. Numerical methods are applied to solve dynamic equation of motion.

EARTHQUAKE FAILURE

The possibility of the occurrence of a slide where a overburden (OB) dumps slope is subject to earthquake loading, depends on numerous factors which include the geometry of the OB dumps, the geology of the dumping area, the OB dumps material engineering properties, the ground water condition, the presence of pre-existing shear zones at dumps space etc. It is not uncommon for an OB dumps slope to survive stronger earthquake shaking and fail under lower earthquake shaking because some of the above factors were more favourable for the second case.

In the case of disrupted slides and falls, the OB dumps material in the slide is sheared and distorted in a nearly random manner. The dumps slopes involved are usually steep and failures take place very suddenly. The damages and loss of life from such slides in developed areas may be devastating. This phenomenon is very rare in the mining dumps failure.

Coherent slides generally occur at deeper failure surfaces in moderate to steeply sloping ground and they involve rotational and translational failures of coherent OB dumps loose soil and fragmented rock mixture. They develop at slow to rapid velocities.

Evaluation of dumps slope stability

The evaluation of OB dumps stability is a process that requires the collection of information on the geology, topography and hydrology of the site, the material engineering properties etc. One typical OB dumps is shown in fig 1. OB dumps stability analysis can yield sufficiently accurate results, only if the above factors are evaluated carefully and the appropriate input parameters are used in stability calculation.

Fig. 1. External OB dumps at Western Coalfields.

Static slope stability

OB dumps became unstable when the shear stresses on a potential failure surface exceed the shearing resistance of the OB material. In the case of OB dumps where stresses on the potential failure surface are high the additional earthquake induced stresses needed to trigger failure are low. One dumps slide is shown in fig 2. In this sense the seismic slope stability is dependent on the static slope stability. The most commonly used methods of slope stability analysis are the limit equilibrium methods. Stress-deformation analysis, using finite element, finite difference method, are performed nowadays.

Limit equilibrium methods

The limit equilibrium methods have been used extensively for many years for the analysis of natural and manmade slopes. They have been calibrated against actual slope failures and with careful selection of appropriate input parameters these methods can yield sufficiently accurate results. With these methods the force or moment equilibrium of a mass of OB material above a potential failure surface is considered. Shearing is assumed to take place on the potential failure surface with the OB material above assumed to be rigid. The soil on the potential failure surface is assumed to be rigid-perfectly plastic and its shear strength is mobilized concurrently on all points on the failure surface. Since the states of stress and mobilized strength are the same for all elements of OB material on the failure surface, the factor of safety is constant over the entire failure surface. In real slopes however the factor of safety for each element of OB on the failure surface is not constant.

The possibility of a progressive failure mechanism is needs to be given proper attention in slope stability estimation. The various limit equilibrium methods treat the soil as a rigid-perfectly plastic material but in reality many soils exhibit brittle, strain-softening stress-strain behaviour.

This means that the peak shear strength of the soil may not be mobilized simultaneously at all points on the failure surface and with this kind of mechanism it is possible to have a failure even if the factor of safety based on peak shear strength is above 1.0. Kramer (1996) suggests that the stability of strain softening materials is analysed reliably only by using residual shear strengths.

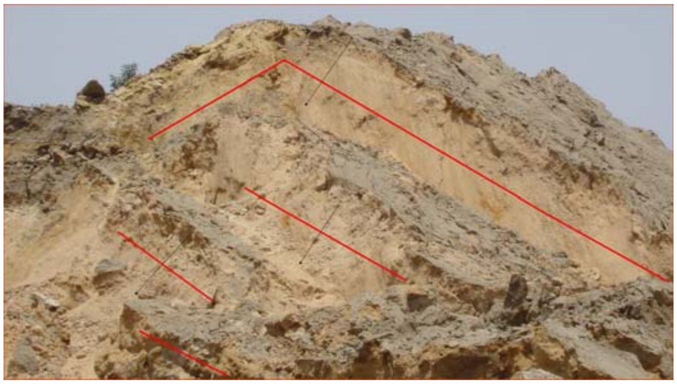

Fig.2. OB dumps failure at Sasti mines at Western Coalfields (black arrow showing direction of slide).

Stress-deformation analyses

Stress-deformation analyses can be performed mainly with finite element and finite difference models which allow the simulation of the complicated stress-strain behaviour of OB dumps material. These methods is powerful tool which can cope with irregular geometries, complex boundary conditions and pore water pressure regimes and can simulate complicated phase dumping sequence.

The method can predict stresses, movements and pore water pressures due to continuous dumping at the running dumps and also predict the most critically stressed zones within the dumps slope. In this way the most likely mode of failure can be identified and deformations up to and sometimes beyond the point of failure can be calculated.

SEISMIC SLOPE STABILITY

Seismic slope stability analyses are further complicated by two additional factors:

i) The dynamic stresses induced by earthquake shaking and
ii) The effect of dynamic stresses on the stress strain behaviour and strength of slope materials.

Depending on the behaviour of the OB during seismic shaking, seismic instabilities may be grouped into two categories:
(i) Inertial instabilities and
(ii) Weakening instabilities

In the case of inertial instabilities the strength of the OB remains relatively unaffected by the earthquake shaking and any permanent deformations are produced when the strength of the OB is exceeded during small intervals of time by the dynamic stresses. In the case of weakening instabilities the earthquake shaking produces a substantial loss of strength which gives rise to very large displacements and instability. The most common causes of weakening instability are flow liquefaction and cyclic mobility. There are numerous analytical techniques that deal with the above two categories and these are either based on limit equilibrium or stress-deformation analyses.

Analysis of inertial instability

When the dynamic normal and shear stresses on a potential failure surface are superimposed upon the corresponding static stresses, these may produce inertial instability of the slope if the shear stresses exceed the shear strength of the soil. The problem is approached by performing a pseudostatic analysis that produces a factor of safety against slope failure.

Pseudostatic Analysis

The pseudostatic approach has been used by engineers to analyse the seismic stability of earth structures since the 1920´s. This method of analysis involves the computation of the minimum factor of safety against sliding by including in the analysis static horizontal and vertical forces of some magnitude.

These horizontal and vertical forces are usually expressed as a product of horizontal or vertical seismic coefficients and the weight of the potential sliding mass. The horizontal pseudostatic force decreases the factor of safety by reducing the resisting force and increasing the driving force. The vertical pseudostatic force typically has less influence on the factor of safety since it affects positively (or negatively) both the driving and resisting forces and for this reason this is ignored by many engineers.

The factor of safety of a slope critically depends on the value of seismic coefficient. In the mid 60´s when pseudostatic analyses were widely used, one of the biggest problems facing the engineer was that of selecting a value of the seismic coefficient to be used for design purposes. At the time the selection of values was mostly empirical.

Permanent deformation analyses

Newmark (1963) first proposed the important concept that the effects of earthquakes on embankment stability should be assessed in terms of the deformations they produced rather than the minimum factor of safety. The method assumes rigid-plastic materials and presumes knowledge of the time history of the acceleration acting on the embankment during the earthquake. Newmark made an analogy between the soil in a potentially unstable slope and a rigid block resting on an inclined plane, as illustrated in fig 3. In the Newmark analysis, the mass of soil located above the critical failure surface is represented as a rigid block. As the rigid block is subjected to dynamic motion, it will slide down the inclined slope if the block is not in equilibrium.

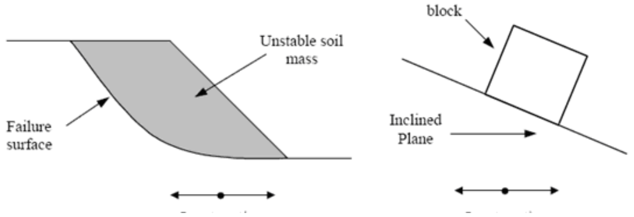

Fig. 3. Analogy between potential landslide and block resting on inclined plane.

The total relative displacement at time is given by

$$d_{rel}(t_1) = \frac{1}{2}\left(A - a_y\right)\Delta t^2 \frac{A}{a_y} \qquad (1)$$

where, A is the amplitude, a_y is the acceleration of the block relative to the plane, and Δt is the duration of the pulse acting on the plane.

For a single acceleration pulse, displacement is related to the amplitude and duration of the pulse. Since in the case of an actual earthquake there will be several occurrences where the earthquake induced acceleration exceeds the yield acceleration producing a number of increments of displacement. It is logical to expect that the total displacement will depend on

(i) Strong motion duration
(ii) Amplitude and
(iii) Frequency content

Assumptions

The accuracy of the Newmark analysis in predicting permanent deformations depends on how well the slope fits the assumptions of the method. By representing the potentially unstable soil mass as a rigid block, it is assumed that the soil above the failure surface does not deform internally. This assumption of material rigidity implies that the shear strength of the soil is equally mobilized along the critical failure plane. It is also assumed that the interface between the block and inclined plane exhibits rigid-perfectly plastic stress-displacement behavior.

By analyzing the conditions under which the block would be in equilibrium, Newmark showed that permanent displacements would occur when a certain level of acceleration is exceeded. The concept of this acceleration level, termed the yield acceleration, is discussed in the following section.

Yield Acceleration

The first step of the Newmark analysis procedure is to determine the yield acceleration of the rigid block. The yield acceleration, a_y, is commonly based on pseudostatic slope stability analysis, is the minimum pseudostatic acceleration required to produce instability in the assembly.

MATERIALS AND METHODOLOGY

The OB dumps slope selected in this study have isotropic material behaviour and uniform material property through out the mass.

Finite Difference Modelling

A two-dimensional nonlinear model of the OB dumps, including base site was developed using FLAC (2005). The OB is modeled using 2-D nonlinear material, rectangular grid elements. The OB domain is analysed under the assumption of plane strain condition. The lateral and base boundary conditions for the computation OB domain are modeled using a modified transmitting/absorbing boundary.

Lysmer-Kuhlemeyer transmitting/absorbing boundary

Numerical methods relying on the discretization of a finite region of space require that appropriate conditions be enforced at the artificial numerical boundaries. In static analyses, fixed or elastic boundaries (e.g., represented by boundary-element techniques) can be realistically placed at some distance from the region of interest. In dynamic problems, however, such boundary conditions cause the reflection of outward propagating waves back into the model and do not allow the necessary energy radiation. The use of a larger model can minimize the problem, since material damping will absorb most of the energy in the waves reflected from distant boundaries. However, this solution leads to a large computational burden. The alternative is to use quiet (or absorbing) boundaries. Several formulations have been proposed. The viscous boundary developed by Lysmer and Kuhlemeyer (1969) is used in FLAC.

Seismic input

To analyze the dynamic behaviour of the OB dumps, the accelerogram was used recorded in Imperial Valley on the occasion of the 19th May 1940 earthquake, which had a magnitude of 6.95 on the Richter scale and in Kobe on the occasion of the 16th January 1995 earthquake, which had a magnitude of 6.9 on the Richter scale. The El Centro seismic wave propagated in a N-S direction, the seismic signal lasted 31s and a peak ground surface acceleration of 0.215g after 11.49s. The total 40 seconds of accelerogram data were used for the dynamic analysis simulation (fig 3). The Kobe seismic wave propagated along Takarazuka, the seismic signal lasted 20s and a peak ground surface acceleration of 0.694g after 6.02s. Total 40.94 second of accelerogram data used for the dynamic analysis simulation (fig 4).

Geometry

The OB dumps in Indian mining scenario ranges from 100m to 1000m in length, and width varies according to space availability and average range is 200m. These dumps are piled at the no-mineral zone with in the mine lease hold area. Average 30 to 60m space is kept for safe mining operation from any major mining structures and transport roads from the OB dumps bottom point. Normally these OB dumps does not affect the opencast coal benches as it is located far from the working district of the mine. So the boundary region of the numerical analysis is kept 50m away from the toe of the OB dumps. Because more the region of analysis more the time and memory required to solve the problem, so to balance the operation above mentioned boundary are selected for the analysis. The geometry of the numerical models is varied in height and slope angle. The height of the OB dumps varied from 15m to 40m at 5m interval. The angle of dumps slopes are following 25deg, 28.5deg, 30deg, and 35deg.

Grid discretization

Kuhlemeyer and Lysmer (1973) shows that for accurate representation of the wave transmission through a model, the spatial element size, Δl must be smaller than approximately one-tenth to one-eight of the wavelength of the input wave (dynamic load). This requirement is expressed in the following relation:

$$\Delta l \leq \frac{\lambda}{10} \tag{2}$$

where, λ is the wavelength associated with the highest frequency component that contains appreciable energy.

The multiplier history contains very high frequency component and, therefore, would lead to a very fine element size in order not to violate the element size requirement in equation 2. Using small element sizes would lead in turn to a small dynamic time step and prohibitively long computation time. It is possible to adjust the input by recognizing that most of the power for the input is contained in the lower frequency components. A frequency analysis was performed on the dynamic load multiplier using a Fast Fourier Transformation technique. After filtering an element size of approximately 1 m was selected.

Damping

Natural dynamic systems show some degree of damping when subjected to dynamic loading. In OB material, damping is mainly due to energy loss as a result of internal friction in the material. The damping in a numerical calculation should ideally reproduce the energy losses in the natural system when subjected to dynamic loading. In OB material natural damping is mainly hysteretic (i.e., independent of frequency), but this type of damping is difficult to reproduce numerically (Cundall, 1976).

There are two means of supplying damping to a FLAC simulation: (1) by use of damping schemes such as Rayleigh dampingn or local damping and (2) by use of plasticity constitutive models can dissipate a considerable amount of energy. Rayleigh damping is used in combination with plasticity models in this work.

Material models

Mohr-Coulomb material model was used in this investigation. The Mohr-Coulomb model has a shear yield surface that is defined by the strength parameters cohesion and friction angle.

The OB dumps material collected from field studies and tested have the following geotechnical properties (table1).

Table 1. Material property

Density (kg/m3)	Cohesion (KPa)	Internal friction angle (deg.)
2300	50	30

RESULT AND DISCUSSION

The OB dumps stability study consist of

Influence of Dump slope Parameters on Permanent Displacements

The parametric analyses investigated the influence of dumps slope height, dumps slope angle, and OB strength, on permanent displacements of the dumps. The magnitudes of the dumps case parameters were increased and decreased up to 30% to create a range of observed behavior. The acceleration and displacement time history for each cases are presented, as well as a plot illustrating the effect of each property on the permanent displacements. The acceleration time history is provided to correlate to displacement time history.

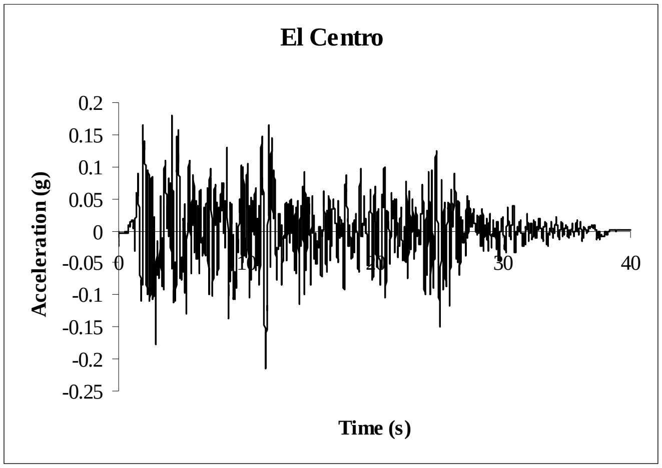

Fig. 4. El Centro accelerogram

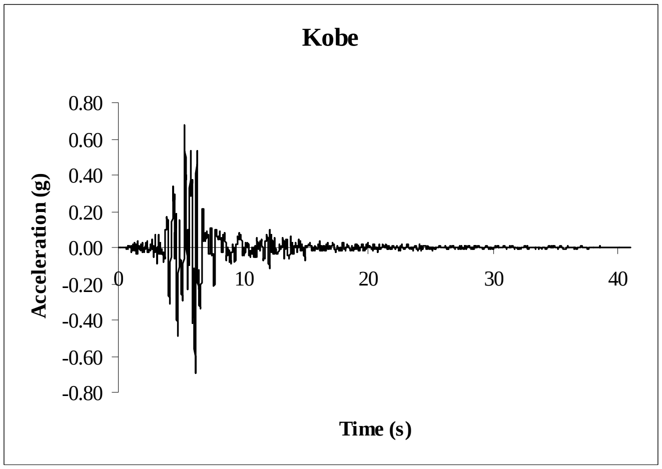

Fig. 5. Kobe accelerogram

Effect of dumps height

The height of the dumps was observed to influence the magnitude of permanent displacements (fig 8). The rate of displacement appears to increase with the dumps height. It is intuitive that taller dumps will typically experience larger deformations with all other properties constant.

Effect of dumps angle

The slope angle of the dumps was observed to influence the magnitude of permanent displacements (fig 9). The rate of displacement appears to increase with the dumps slope gradient. Steeper dumps will experience larger deformations with all other properties constant.

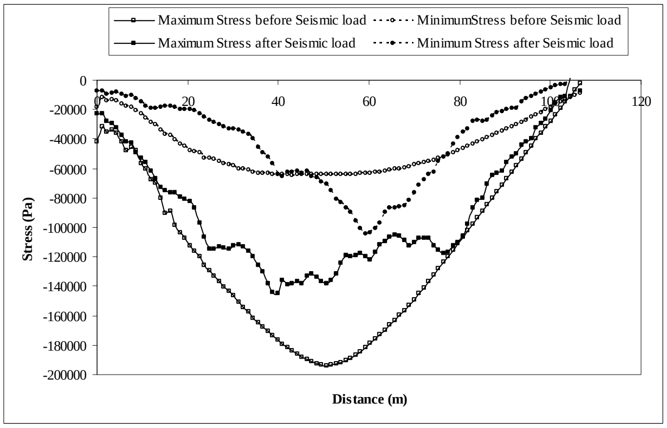

Fig. 6. Principal stress along the OB dumps mass from toe to the right boundary.

Effect of OB dumps material Strength

The value of the internal friction angle reflects the strength of the material. An increase in OB material strength increases the amount of resistance to permanent displacements. The considerable effect of the friction angle on permanent displacements has been shown in fig 19. It has been observed that 10% decrease in friction angle greatly increases the amount of permanent displacements.

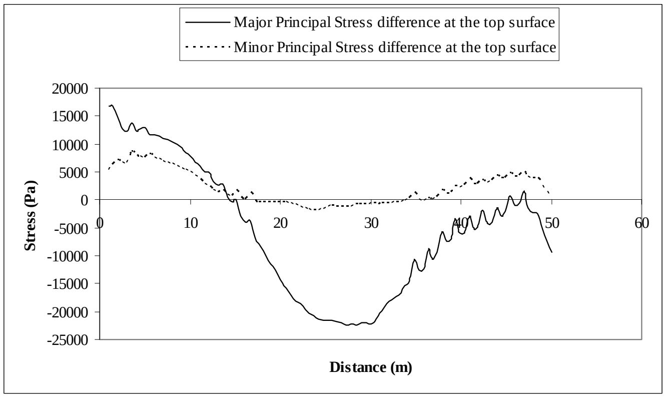

Fig. 7. The Principal stress difference before and after seiamic load at the top surface.

The results show how the principal stress state changed after OB dumps experiencing earthquake. It has been observed that stress reorientation some time reduced compressive stress due to deformation already occur and plasticity involve with damping scheme (fig 6 and 7).

Another interesting observation found in fig 10, after negative displacement it shifted positive. There have strong chance of crack development at the top surface. This is some times developed at the OB dumps slope.

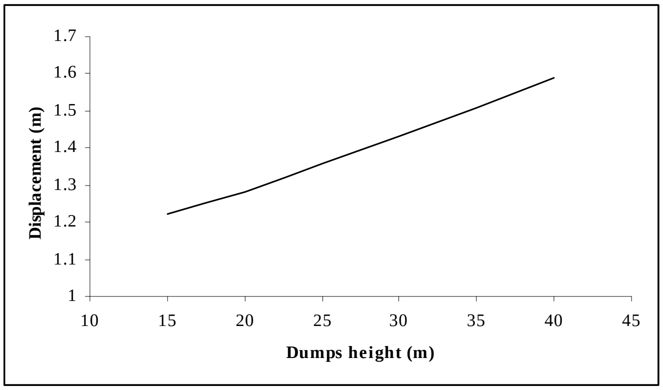

Fig.8. Displacement vs. dump height plots.

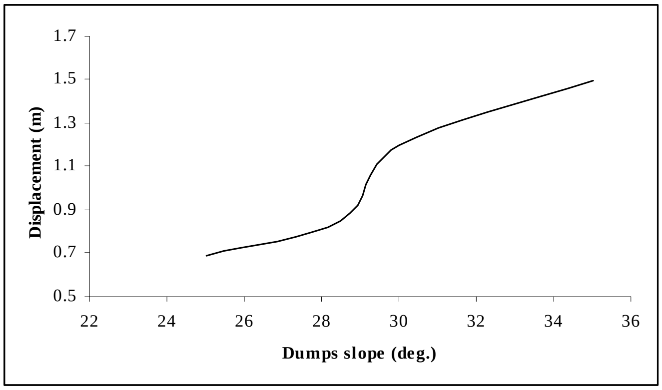

Fig.9. Displacement vs. dump slope angle plots.

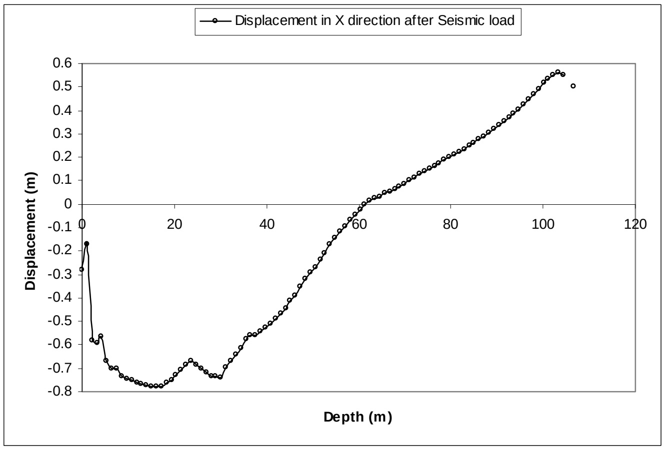

Fig. 10. Displacement along OB dumps mass from toe to the right boundary after seismic load.

The displacement patterns observed have developed ripples at the dumps slope (fig 11). This may be due to the uneven interaction of OB and base material at the dumping schedule.

Displacement difference has been observed the crest side shown in fig 12. Shear strain and volumetric strain also developed due the plasticity consideration at the analysis shown at fig 13 and 14 respectively.

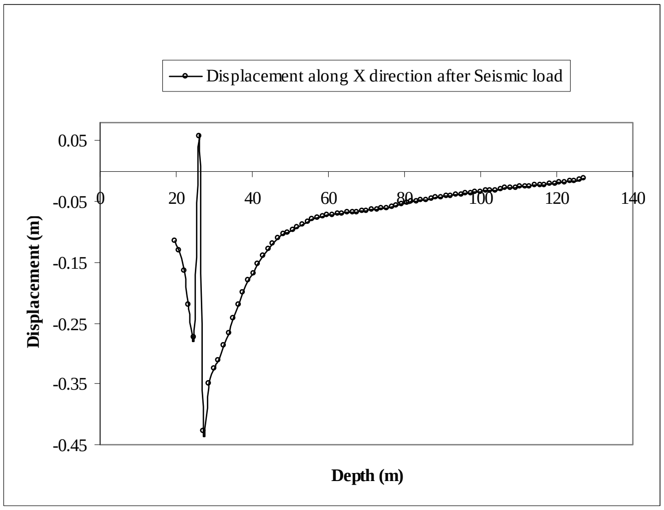

Fig.11. Displacement along OB dumps bottom surface from the toe after seismic load applied.

Influence of Input Accelerations on Permanent Displacements

The effect of the input motion on permanent displacement was investigated. The El Centro and Kobe recorded earthquake motions of varying durations, amplitude and frequency (with four different sub category of frequency contents applied at the filtering scheme) were selected for the analyses

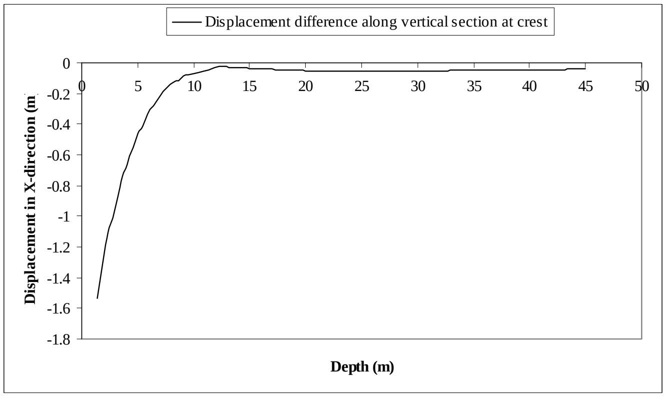

Fig. 12. Displacement difference at vertical section from crest between before and after earthquake.

The seismic acceleration response shown at few monitoring points has increased amplitude shown in fig 15, 16 and 17. That means greater vibration experiences at the structure. The amplitude is die down after 30s.

Plasticity has been developed at the dumps with 40deg slope angle (shown in fig 18) at the sliding side of the OB dumps, indicating potential failure mass in future.

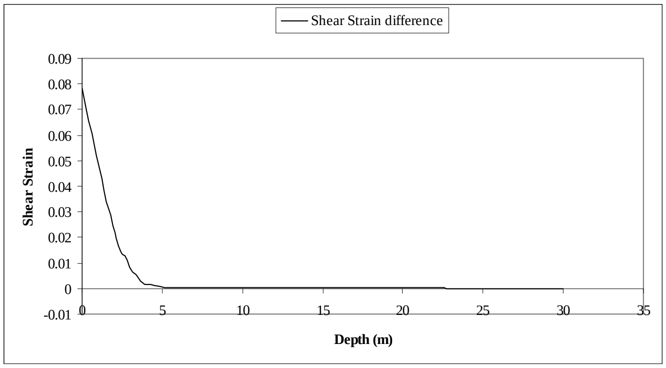

Fig.13. Vertical sections along toe to the 30m depth shear strain profile.

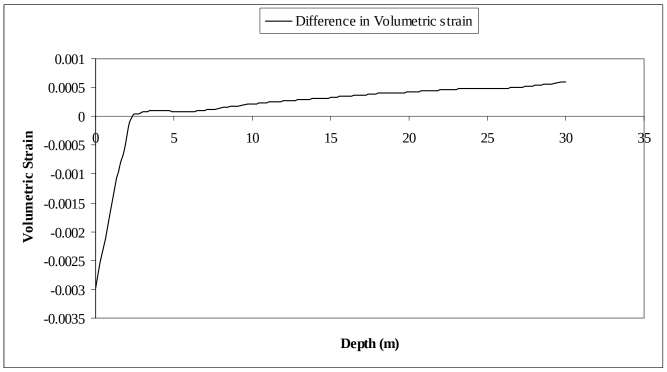

Fig. 14. Vertical sections along toe to the 30m depth volumetric strain profile.

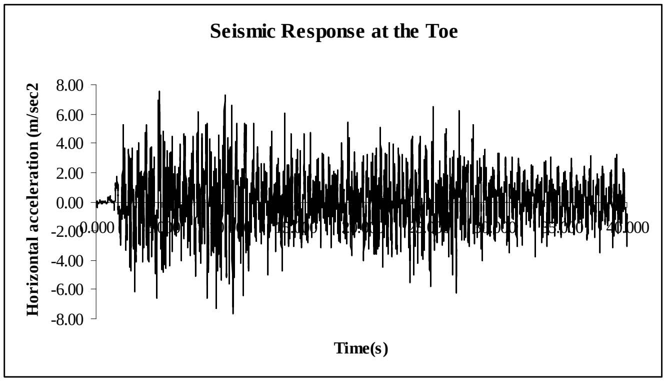

Fig. 15. Seismic excitation acceleration history at the toe of the OB dumps.

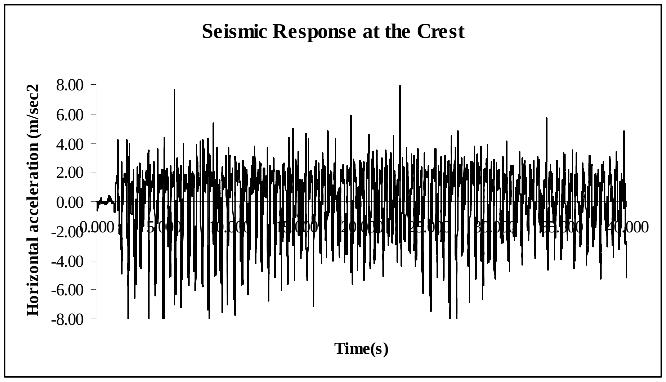

Fig. 16. Seismic excitation acceleration history at the crest of the OB dumps.

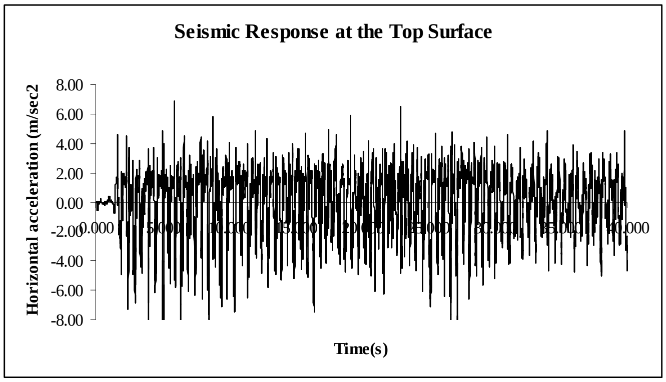

Fig. 17. Seismic excitation acceleration history at the top surface of OB dumps.

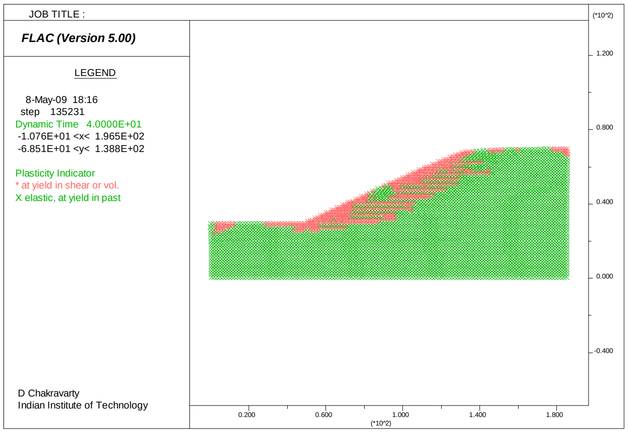

Fig. 18. Plasticity developed along the OB dumps surface.

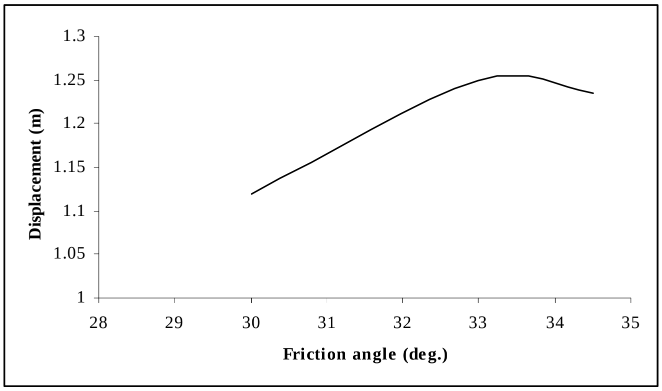

Fig.19. Internal friction angle vs. displacement plots.

CONCLUSION

The study concludes the following:

1) OB dumps behaviour could be simulated via numerical methods in earthquake excitation.
2) The displacement profile showing steeper gradient at slope angle change compare to height of the dump.
3) The greater amplitude of the Kobe excitation always vibrates OB mass more to El Centro.
4) Crack developed could be explained via tension zone at the top surface after two side of the dumps experiences different directional displacement (positive and negative).
5) This prior information will help the mining engineering to strengthen OB dumps to sustain at the similar earthquake and reduce geo hazards at the mine site.

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