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Modeling the deformation of Earth Dam during an Earthquake

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Abstract— Embankments or earth dams are of important structures which have considerable application in the vast area of geotechnical engineering. The control of different geotechnical phenomena such sliding, and overturning and settlement of the clayey dams has high research priority from which a strong controlling tool obtains for engineers and managers. In this article, the dynamic or seismic deformation of embankments is investigated by finite element modeling in ANSYS software. The Young modules ratio of models was defined as the crest elasticity modules relative to the soft soil elasticity modules of the foundation. It is indicated that the higher value of elasticity ratio yields the lower amount of dynamic horizontal displacement and higher dynamic vertical displacement. Comparing the results with the literature indicated a good agreement in aspect of dynamic displacements. Finally dams with better seismic performance are introduced.

Keywords— earth dam, seismic behavior, hydrodynamic pressures, ANSYS.

INTRODUCTION

Despite the progress are made in understanding the behavior of embankment erected on soft clay ground in recent years, the optimal design of such embankment stay difficult and complex (Hird et al.1995) [1]. The failure of earth structures such as natural slopes or earth embankments and dams has resulted in heavy loss of life and property in communities' world wide, where the understanding of the mechanism of slope failure and its analysis have generally been in sufficient to prevent accidents which occurred. At present, this problem stay incompletely resolved (Espinoza et al.1994) [2]. Slope stability analyses have received a great deal of studies by various researchers and a wide variety of analytical procedures have been developed over the years.

The reconnaissance reports of several recent earthquakes document numerous cases of significant damage to bridge foundations and abutments from liquefaction-induced ground failures. Additional documentation on the damage to highways, bridges, and embankments from liquefaction of loose, saturated, cohesionless soils clearly points out the need to develop improved criteria to identify the damage potential of both new and existing highway structures. The experience of the Niigata earthquake developed an awareness of the following types of damage and behavior due to liquefaction.

1- Settlement, tilting, and toppling of bridge foundation elements due to a reduction in ground bearing capacity.
2- Tilting, rotation or collapse of retaining walls, abutments and quay walls as a result of increased earth pressure and reduction in soil shear strength.
3- Failure of earth structures, such as embankments, due to decreases in the strengths of sandy soil materials.

Dynamic analysis of concrete dams have been considered in the last decade. Gazetaset al. (1992) investigate on Seismic analysis and design of rockfill dams. Theoretical methods for estimating the dynamic response and predicting th performance of modern rockfill dams subjected to strong earthquake shaking are reviewed. The focus is on methods accounting for nonlinear material behavior, for 3-dimensional canyon geometry, and asynchronous base excitation. It is shown that both strong nonlinearities and lack of coherence in the seismic excitation tend to reduce the magnitude of the deleterious 'whip-lash' effect computed for tall dams built in rigid narrow canyons. Particular emphasis is accorded to Concrete- Faced-Rockfill dams and a case study involving an actually designed dam in a narrow canyon points to potential problems and suggests desirable modifications [3].

Franklin (1983) survey on seismic stability of embankment structures. He discuss on the guidelines and criteria used by the U.S. Corps of Engineers for seismic analysis and design of dams, and the procedures used by the Waterways Experiment Station to evaluate the seismic stability of earth and rock-fill dams [4].

Noorzad et al. (2010) were investigate on Seismic displacement analysis of embankment dams with reinforced cohesive shell. They refer to this subject, that Suitable materials for use as shell of embankment dams are clean coarse-grained soils or natural rockfill. In some sites these materials may not be available at an economic distance from the dam axis. The use of in-situ cohesive soils reinforced with geotextiles as the shell is suggested in this study for such cases. Dynamic behavior of reinforced embankment dam is evaluated through fully coupled nonlinear effective stress dynamic analysis. A practical pore generation model has been employed to incorporate pore pressure build up during cyclic loading. Parametric analyses have been performed to study the effect of reinforcements on the seismic behavior of the reinforced dam. Results showed that reinforcements placed within the embankment reduce horizontal and vertical displacements of the dam as well as crest settlements. Maximum shear strains within the embankment also decreased as a result of reinforcing. Furthermore, it was observed that reinforcements cause amplification in maximum horizontal crest acceleration [5].

Okamura et al. (2013) were investigate on Seismic stability of embankments subjected to pre-deformation due to foundation consolidation. It has been reported that the major cause of earthquake damage to embankments on level ground surfaces is liquefaction of foundation soil. A few case histories, however, suggest that river levees resting on non-liquefiable foundation soil have been severely damaged if the foundation soil is highly compressible, such as thick soft clay and peat deposits. A large number of such river levees were severely damaged by the 2011 off the Pacific coast of Tohoku earthquake. A detailed inspection of the dissected damaged levees revealed that the base of the levees subsided in a bowl shape due to foundation consolidation. The liquefaction of a saturated zone, formed at the embankment base, is considered the prime cause of the damage. The deformation of the levees, due to the foundation consolidation which may have resulted in a reduction in stress and the degradation of soil density, is surmised to have contributed as an underlying mechanism. In this study, a series of centrifuge tests is conducted to experimentally verify the effects of the thickness of the saturated zone in embankments and of the foundation consolidation on the seismic damage to embankments. It is found that the thickness of the saturated zone in embankments and the drainage boundary conditions of the zone have a significant effect on the deformation of the embankments during shaking. For an embankment on a soft clay deposit, horizontal tensile strain as high as 6% was observed at the zone above the embankment base and horizontal stress was approximately half that of the embankment on stiff foundation soil. Crest settlement and the deformation of the embankment during shaking were larger for the embankment subjected to deformation due to foundation consolidation [6].

INTRODUCTION OF FORCES AND MODELING BY SOFTWARE

The momentum equations for two dimensional flows in a vertical plane (Fig.1), integrated over a control volume are written as (Demirel, 2012) [7]:

$$\frac{\partial}{\partial t}\int_{CV} u d\forall + \int_{CS} u\vec{V}d\vec{A} = -\frac{1}{\rho}\int_{CV}\frac{\partial p}{\partial x}d\forall + \theta\int_{CS}\vec{\nabla}u d\vec{A} - \int_{CV} a_x d\forall \quad (1)$$

$$\frac{\partial}{\partial t}\int_{CV} w d\forall + \int_{CS} w\vec{V}d\vec{A} = -\frac{1}{\rho}\int_{CV}\frac{\partial p}{\partial z}d\forall + \theta\int_{CS}\vec{\nabla}w d\vec{A} - \int_{CV} g d\forall \quad (2)$$

where *x* and *z* are coordinate axes in horizontal and verticaldirections respectively, *ax* is horizontal ground acceleration,*u* and *w* are velocity components, $\vec{V}$ is velocity vector relative to the moving ground, *p* is pressure, *t*is time, *g* is gravitational acceleration, ν is kinematic viscosity, *ρ* is fluid density, ∇ is the del operator, *CV* indicates control volume, *CS* indicates control surface and d$\vec{A}$ is the area element normal to the control surface pointing out of the control volume. Horizontal ground acceleration is included to represent earthquake excitations (Demirel, 2012) [7].

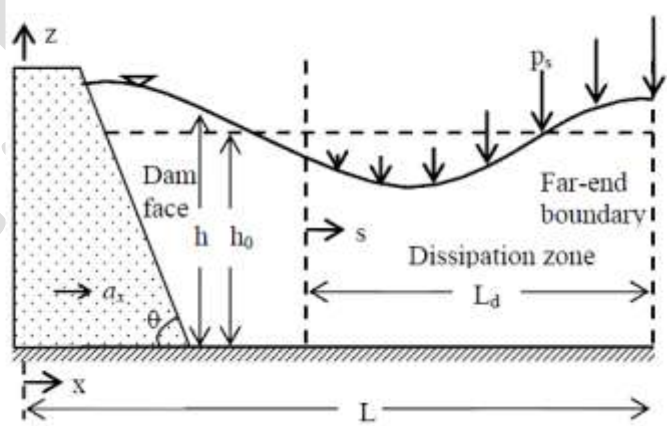


Figure 1. Definition sketch of dam-reservoir system subjected to earthquake

Chopra presented ananalytical expression for the variation of hydrodynamicpressures on a vertical dam face during arbitrary groundmotion (Chopra, 1990) [8]:

$$p^x(0,z,t) = \frac{4\rho a}{\pi}\sum_{n-1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\cos\lambda_n z\int_0^t a_x(\tau)J0\{\lambda_n c(t-\tau)\}d\tau \qquad (3)$$

where$J0$=the Bessel function of the first kind of zero. The determination of hydrodynamic response of a vertical dam face to prescribe earthquake motion involves the numerical evaluation of Eq. (3).

NUMERICAL ANALYSIS

In this article, the dynamic or seismic deformation of embankments is investigated by finite element modeling in ANSYS software. Like other systems of analysis, in thisanalytical system, that is composed fromdam and its surrounding soil. Initially the Mohr–Coulomb failure criterion and drained behavior was considered for all the materials. Material properties that have been adopted in this study are presented in table 1.That this work is done in part of Engineering Data from software.

TABLE 1- MATERIAL PROPERTIES

Layer of dam	γ (kg/^3)	E (pa)	ν	G (pa)
Foundation	800	3E+07	0.25	1.2E+07
Saturated layer	900	2E+07	0.45	6.866E+06
Saturated layer1	1900	4E+06	0.3	1.538E+07
Saturated layer2	1900	6E+06	0.3	2.307E+06
Saturated layer3	1900	6E+06	0.48	2.027E+06

The first step for the analysis of Dam system and its interaction with soil and the surrounding fluid, is creating geometry. For this purpose, from existing tools in Ansys software were used. Fig. 2 shows the geometry of dam and foundation.

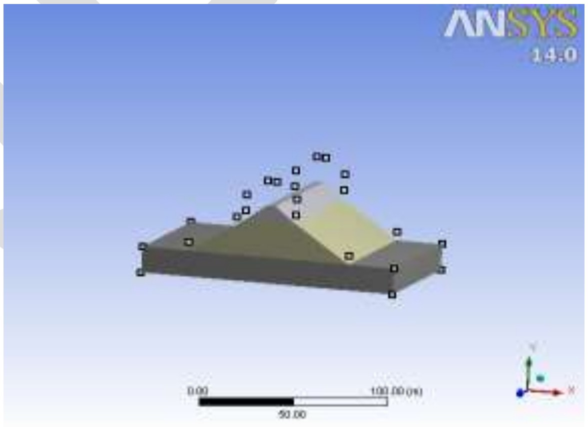


Figure 2.geometry of dam and foundation

The modeling of damshave adimension, that are shown in Fig. 3.

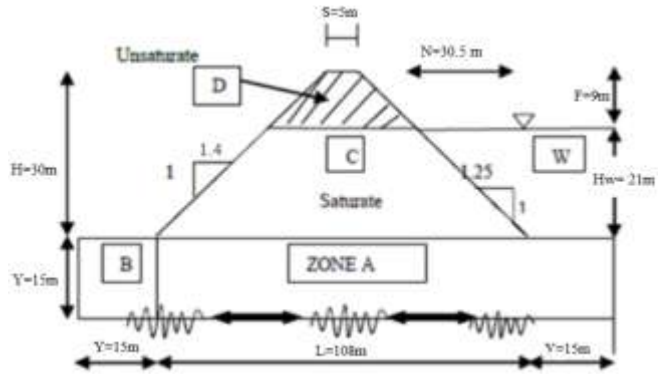


Figure 3.the geometrical dimensions ofDam

After thegeometry of themodel, shouldcreate the appropriatemesh. Typical adopted mesh is shown in Fig. 4.

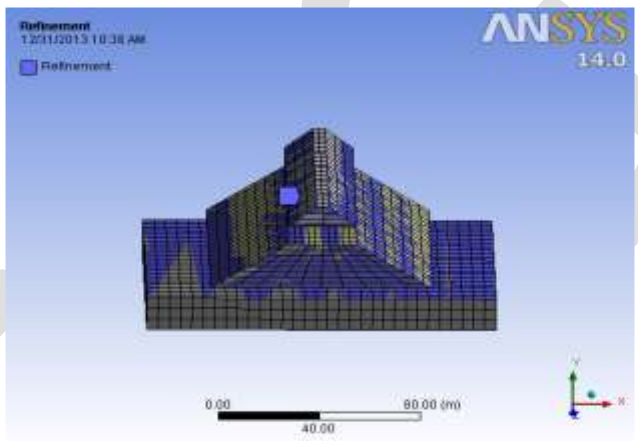


Figure 4.used Mesh for model

Figures5to7 shows thehorizontal displacementofdams. The purpose of thisstudy and threedifferentdamsis Comparison ofhorizontal displacementand dynamicssettlementunderseismicloads.

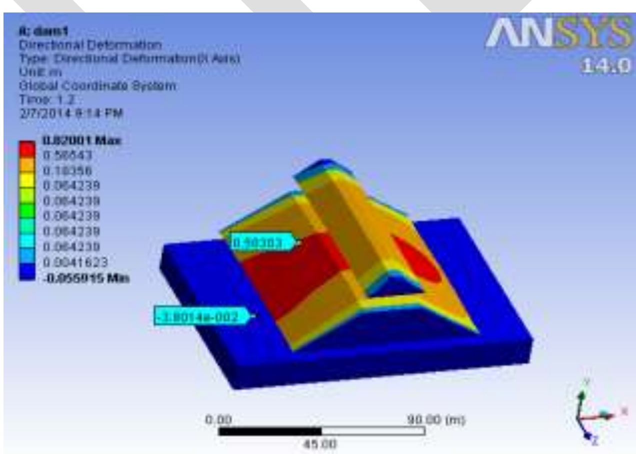


Figure 5 . Minimum and maximum of dynamic horizontal displacement of Dam 1

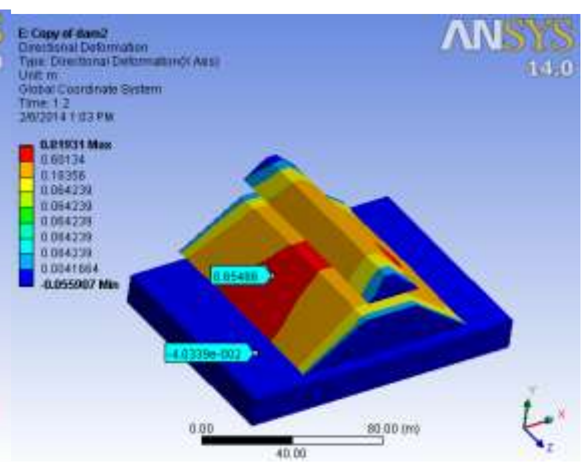


Figure 6. Minimum and maximum of dynamic

horizontal displacement of Dam 2

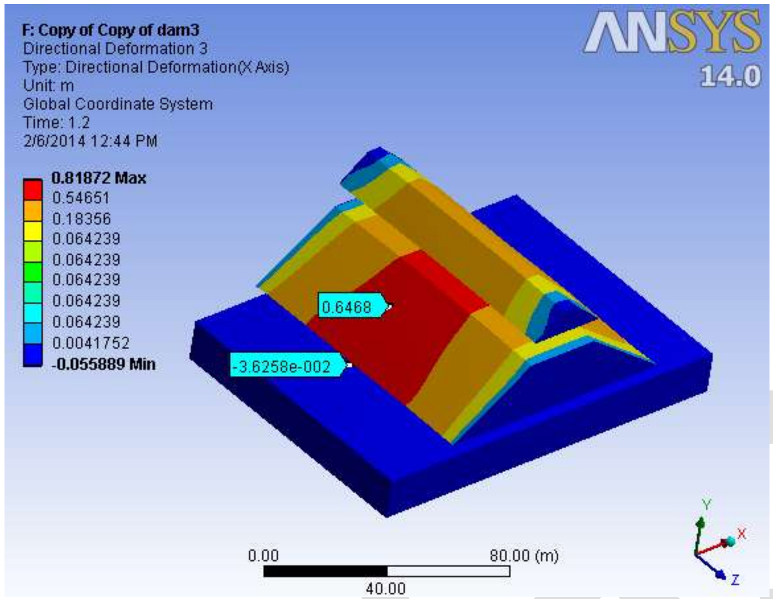
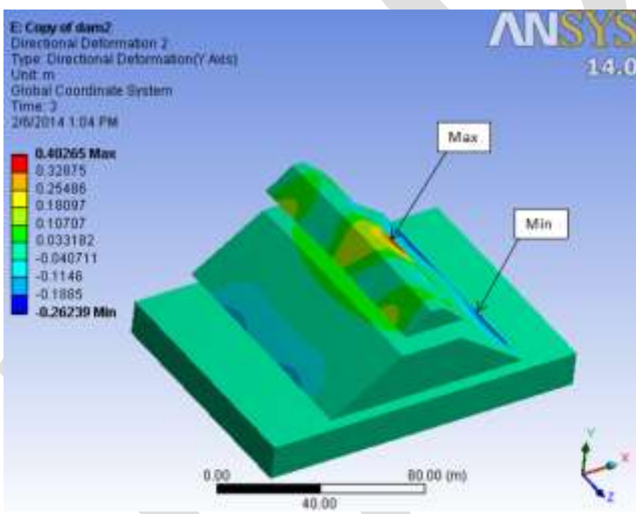


Figure 7. Minimum and maximum of dynamic horizontal displacement of Dam 3

Also, figures8to10show theminimumandmaximum ofdynamicverticaldisplacement(settlement) inthe earthquake.



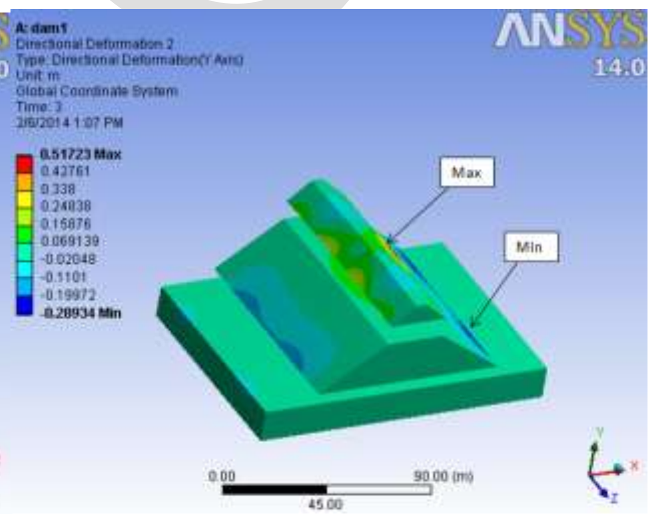


Figure 8 . Minimum and maximum of dynamic vertical displacement of Dam 1

Figure 9. Minimum and maximum of dynamic vertical displacement of Dam 2

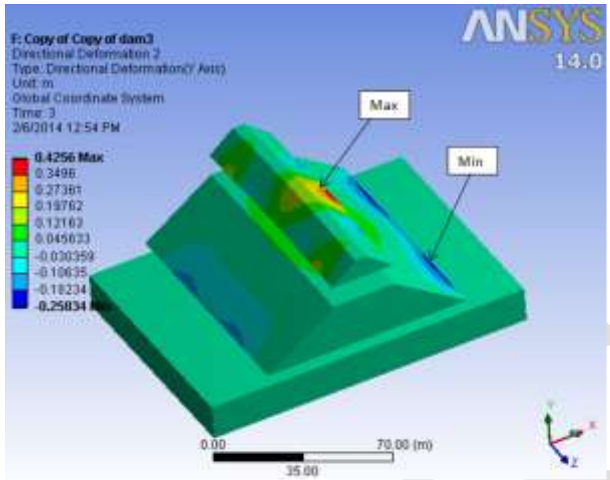


Figure 10. Minimum and maximum of dynamic verticaldisplacement of Dam 3

Considering the above figures, The Young modules ratio of models was defined as the crest elasticity modules relative to the soft soil elasticity modules of the foundation. It is indicated that the higher value of elasticity ratio yields the lower amount of dynamic horizontal displacement and higher dynamic vertical displacement. Comparing the results with the literature indicated a good agreement in aspect of dynamic displacements. Finally dams with better seismic performance are introduce

CONCLUSION

In this study, dynamic or seismic behavior dams were studied. Three types of Dam, with different geotechnical characteristics in different layers under the influence of earthquake with maximum acceleration of 0.5g were placed. The results indicate that values of seismic displacement (both of horizontal and vertical), are a function of the modulus of elasticity ratio of the dam crest on its foundation.

Also, as can be seen, Increase in Poisson's ratio models like the results that obtained in this study lead to a reduction in dynamic Settlement of points.

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