

Relationship Between Fluid of Reservoir and Dynamic Settlement of Embankment During Earthquake

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Abstract. Due to interaction between water and embankment during earthquake, one of the main problems is to control structural damage from water overtopping, seepage and cracks. Review study indicated that maximum displacement during earthquake is related to crest cracks and water structure interaction between embankment and reservoir. Numerical transient analysis to estimate relationships between height of water and dynamic settlement in medium size embankment is performed. Analyses of models using plane strain and finite element methods are implemented by ANSYS13 software. Nagan earthquake record with 5.02 seconds and peak ground acceleration equal to $PGA=0.65g$ for input data is used. Comparison of results in the first few models indicated that dynamic settlement with minimum value of displacement in the vertical and horizontal axes as well as the maximum shear stress in the foundation, must follow ratio, $\alpha = H_w/H$. It was found that when the ratio, α , is more than 0.90, the damage due to differential settlement is at critical state, however, when $\alpha=0.80$ the settlement level is in safe condition. In addition, numerical analysis performed, had a good agreement with results from the literature review. Further research to investigate the best value of α ratio for large embankment is suggested in the future.

Keywords: dynamic settlement, interaction, embankment, α ratio, reservoir

1. Introduction

Due to behavior of interaction between embankment and reservoir during dynamic loading control of differential settlement is required because, there are some damages like to cracks that caused to piping or overtopping and failure. According to literature review since the beginning of 1920s and up to 1960s 'Pseudo-static method' of analysis was well-known. But this method was very simple and it was not take into account the nature of the slope-forming material or the foundation material. In the year 1965, based on deformation characteristics, Newmark [1] proposed 'Sliding block method'. Among other methods, 'Shear beam model' analysis was quite popular. This method was presented by Mononobe [2]. Gazetas [3] proposed an improved 'Inhomogeneous shear beam model' which can take care of the fact that the shear modulus in earth or rock-fill dams is not constant but increases with $2/3$ power of depth from the crest. Clough and Chopra [4] performed the finite element method for two-dimensional plane-strain analysis to estimate of the dynamic response of an embankment assuming that it consists of linearly elastic, homogeneous, isotropic materials. Later on, Chopra [5] represented hydrodynamic pressure on dams during earthquake and Hung et al [6] considered non

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linear hydrodynamic pressures on dams during earthquake too. several other researchers developed the finite element and finite difference method for non-linear, inelastic, non homogeneous, anisotropic behavior of materials under seismic loads and interaction between water and dam during earthquake. Zeghal and Abdel-Ghaffar [7] proposed a local-global finite element method of analysis for determination of the non-linear seismic behavior of earth dams. Ming and Li [8] conducted a fully coupled finite element analysis of failure of Lower San Fernando dam and tested the possible reason of the dam failure. Quick development of computer programs had an useful data of earthquake engineering research. For instance, several computer programs like [9-13] were used widely for the intensive seismic analysis of embankment. Namdar et al[14] investigated seismic evaluation of embankment shaking table test and finite element method so represented that there are good agreements between results of finite element and experimental physical modeling. Zhu et al [15] and Brinkgreve et al[16] have evaluated a two-dimensional seismic stability for a levee embankment using finite element based program PLAXIS. Coupled solid-fluid with finite element method of embankment is considered [17] currently. Shortly, literature review indicated that the maximum displacement during dynamic loading is conducted to the crest and interaction between dam and foundation is cased to it. This paper considered effect of height water behind of the unsaturate medium embankment on dynamic settlement with the end of construction and supply reservoir to control dynamic settlement during earthquake.

2. Modeling Process

Numerical dynamic analysis were considered step by step. Ansys software was comprehensive by finite element method with 100000 coadline. But, it was leaded to Computer Aided Engineering (CAE) and very strong to connecte with another softwares. Also, it was universal and popular in the most of finite element softwares. Moreover, Solid42 element for material of structures (embankment and foundation) and Fluid79 element for water behind of the earth dam to model with plane strain 2D method according to recommended by ANSYS help menu were used. Also, to evaluate of dynamic analaysis in models, Nagan earthquake is applied with acceleration-time and it was converted to displacement-time by SISMOSOFT3 software. After that, total displacement of the horizontal axis shown 0.43 meter in the end of dynamic load. So far, most of the famous records in the literature had a half value of the horizontal PGA for vertical axis. Therefore, value of the vertical total displacement equal to 0.2 meter is performed. Also, vertical displacement in the horizontal boundary (Bed rock) was zero and input data of NAGAN record is used for horizontal displacement of boundary. In add, both of the lines of verticals boundary had a vertical total displacement equal to 0.2 meter and 0.01 meter for horizontal displacement so it was related to transient property in the model to equilibrium elasticity conditions of waves.

2.1 Parameter of models and mesh

Table1 presented the parametric dimensional models for different level of water behind of saturate body. Also, (α) ratio is presented by: $\alpha = H_w/H$

Table1. Dimension of models.

H=40 m	L=145.56m	Hw =38.00m	$\alpha=0.95$	Z=20.00m	Y=15.00m	S=7.00m	$\phi=30$	Model1
H=40 m	L=145.56m	Hw =36.00m	$\alpha=0.90$	Z=20.00m	Y=15.00m	S=7.00m	$\phi=30$	Model2
H=40 m	L=145.56m	Hw =34.00m	$\alpha=0.85$	Z=20.00m	Y=15.00m	S=7.00m	$\phi=30$	Model3
H=40 m	L=145.56m	Hw =32.00m	$\alpha=0.80$	Z=20.00m	Y=15.00m	S=7.00m	$\phi=30$	Model4

Also, parametric dimensional of models with five main points to evaluate dynamic results illustrated in Figure1. Figure2 illustrated that plane mesh is performed with regular method

for effect of intraction and node to node meshing was used.

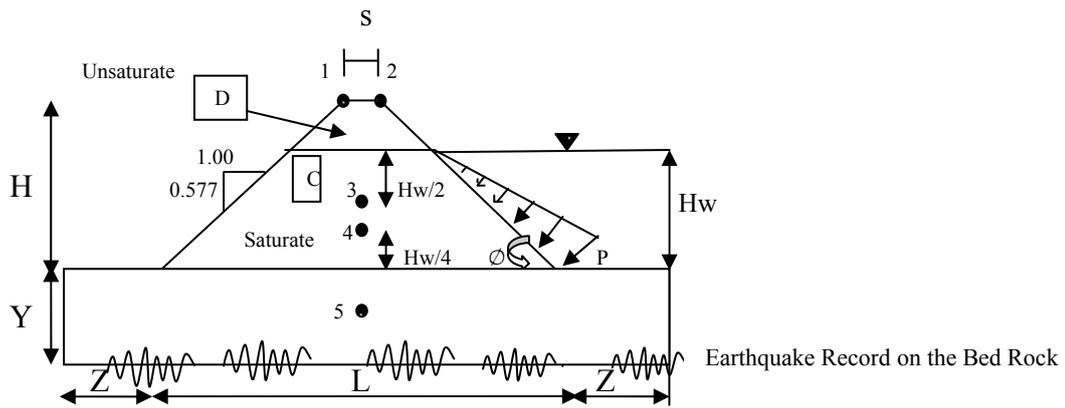


Figure 1. Dimension of models according to Table1 for plane strain(2D)analysis and main points (1-5) to evaluate exist data.

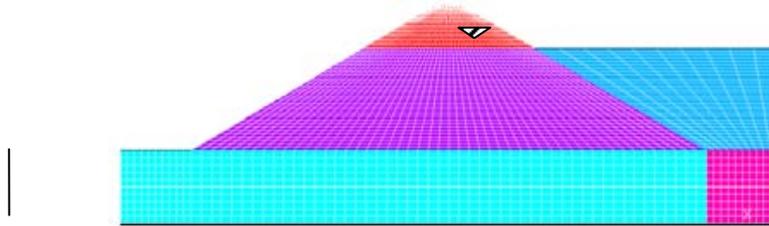


Figure 2: This figure illustrated that mesh of model with regular method .

2.2 Material Properties and Dynamic Load

This part introduced three section of material properties for water, foundation and embankment. Saturate clay body with isotropic property and foundation soft soil saturate (lose sand) were used. Also, ANSYS LIQUID suggested that incompressible water according to Table 2. Moreover, Table 2 introduced material property in each zone so behavior of solid material according to hardening isotropic bilinear and friction coefficient were leaded to contact model for effect of interaction. In addition, to chose of value for soil properties is referenced by [18].

Table 2. Material Properties .

Zone	Relative density (Kg/m ³)	Elasticity Modulus (Kg/m ²)	Poisson's Ratio	Yield stress (Kg/m ²)	Tangent Modulus	Friction coefficient
A-Foundation (lose- sand saturate)	800	3*10 ⁶	0.25	1.20*10 ⁴	0.01	0.30
B- Foundation (lose-sand.saturate)	800	3*10 ⁶	0.25	1.20*10 ⁴	0.01	0.001
C-Embankment (Clay saturation)	900	2*10 ⁶	0.45	8.00*10 ³	0.01	0.001
D-Embankment (un saturation)	1900	4*10 ⁵	0.30	1.60*10 ³	0.01	0.001
Water	1000	1*10 ¹²	0.001	-----	-----	-----

This research included non-linear behavior of soil and some items such as density, Yang modulus and Poisson's ratio, Yield stress with tangent modulus for bilinear isotropic hardening of solid material were used so huge elasticity modulus for non compressure behavior of water according to suggestion of the help menu of ANSYS was used. Moreover, Figure 3 represented non linear behavior of soil to evaluate analysis and explained behavior of materials in Table 2. This figure had performed two parts such as line (a) for elastic and line (b) to present of elasto-plastic and plastic conditions. All models were evaluated by NAGAN record. This record had an acceleration-time with PGA=0.65g and 5.02 second for time. Moreover, record is converted to displacement-time for input data in ANSYS13 by SISMOSOFT3 software. Figure4 illustrated that NAGAN record with time displacement and indicated that maximum and minimum displacement were 16.5 mm and 11 mm respectively. All of

sub steps were 0.02 second and record was 5.02 second only with PGA=0.65g so PGA was peak ground acceleration.

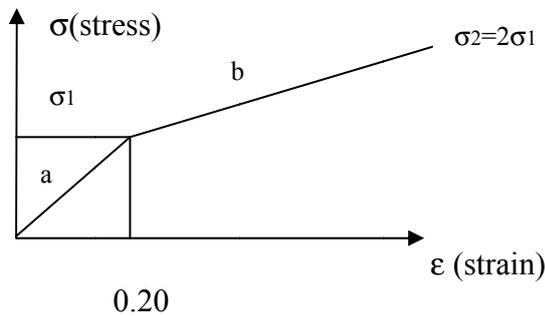


Figure 3. Non-Linear hardening behavior of soil .

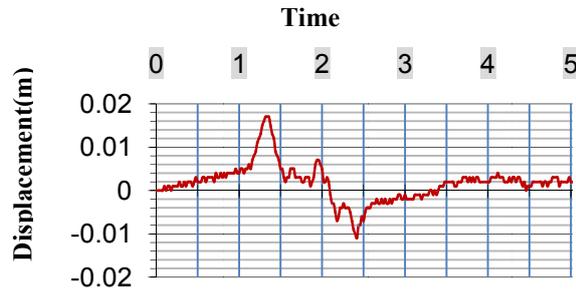


Figure 4. NAGAN earthquake record (PGA=0.65g).

2.3 Chart of numerical modeling

This chart introduced process of numerical modeling and Figure5 illustrated that it included five steps such as input data, transient analysis , exist data, results and conclusion.

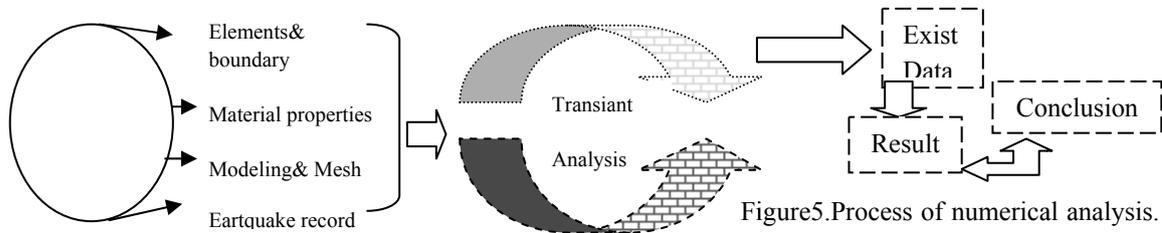


Figure5.Process of numerical analysis.

3. Results and Analysis

Numerical analysis in models were performed by Nagan record with displacement-time. Also, Figures 6 and 7 illustrated non-linear behavior of material during dynamic load for XY shear stress in point5 and vertical displacement in point3 respectively.

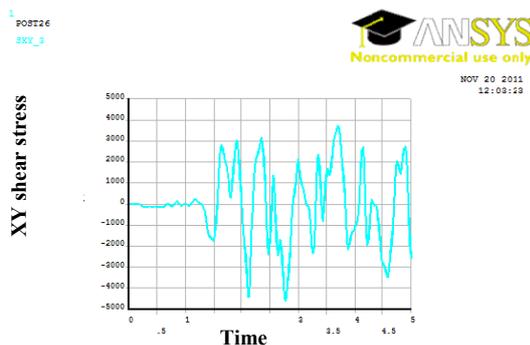


Figure 6.XYshear stress(Kg/m²) in the model4- point 5.

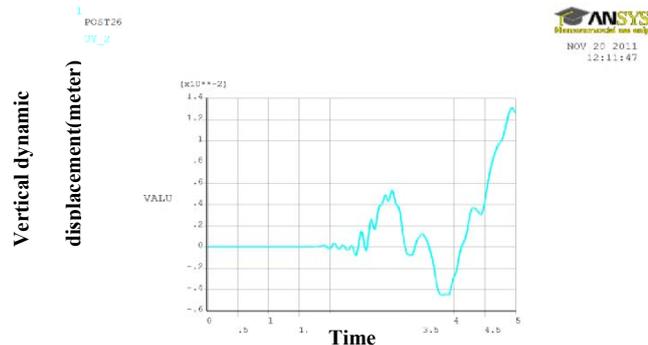


Figure7. Vertical displacement(m) in the Model4- point 3.

Both of figures presented value in each sub step of dynamic load and indicated that some of values were positive or negative and it was related to non-linear behavior of analysis during earthquake. All of the nodes had a same and regular process. Also, this function was very great to analysis by ANSYS. According to Figures 8-11 so maximum horizontal displacement was in the crest and increase of α ratio cased to increase of it and maximum settlement or vertical displacement was in the crest . Differential settlement in model2 was more than another models and model 2 was critical so differential settlement was cased to generate cracks at crest and after earthquake cased to development and increase of piping and failure. It was so important to control design and model4 was the less

differential settlement in the crest. Moreover, maximum shear stress is related to foundation(point5) for all models and more value of α ratio cased to increase of shear stress in the crest specially. Furthermore, values of shear stress and shear strain had a good similarity of value in the models for all main points except of the crest in the model1 so it was critical for both of them. To validate of results, Figure12 indicated that differential settlement in embankment during earthquake was cased to generate cracks in the crest and results had a good agreement with literature review.

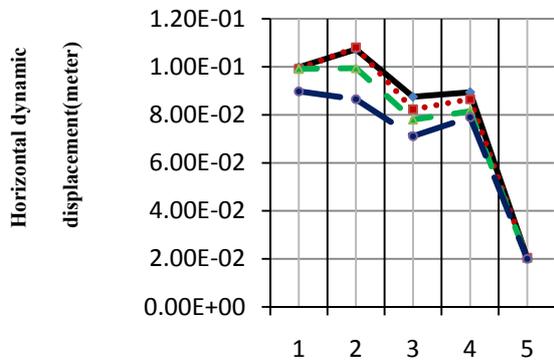


Figure 8. Horizontal displacement(m)-Main points(1-5).

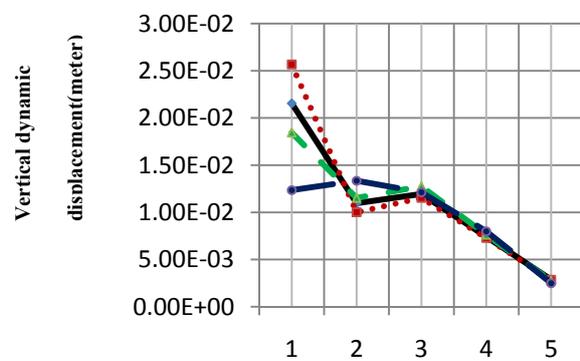


Figure 9. Vertical displacement (m)- Main points(1-5).

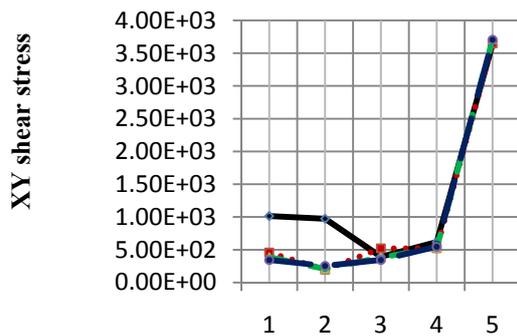


Figure 10. XY Shear stress (Kg/m^2)-Main points(1-5).

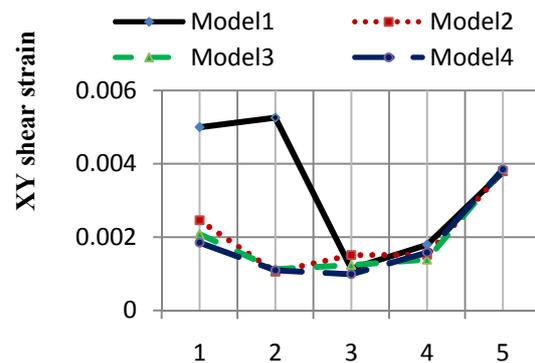


Figure 11. XY Shear strain- Main points(1-5) .



Figure 12. Cracking and inelastic deformations of the crest embankment was caused by the 2001 Bhuj earthquake in India. The prediction of cracks and damage requires nonlinear dynamic analyses and modelling of dam materials. Sort by[19].

4. Conclusion

Dynamic analysis of medium size embankment with saturated material properties in the dam and soft soil foundation under the earthquake of $\text{PGA} = 0.65\text{g}$ is considered. Displacement, XY shear stress and XY shear strain depend on the α ratio which is conducted in reference to the height of fluid(water) level in the reservoir. Comparison of results in the five reference points of plane strain(2D) dynamic analysis indicated that there are cracks in crest and settlement in foundation when the α ratio reaches critical values of within 0.90 to 0.95. It was found that the best ratio ($\alpha = H_w/H$) to prevent of damages is equal to 0.80 which satisfy all the safety conditions. Numerical analysis which has good agreement with results from the literature review also shows that obvious differential vertical displacements in the reference points at crest has occurred and this condition can lead to crack

generation. Research to evaluate the best value of α ratio for large embankment is suggested in the future.

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