

Research Article

Soil Saturated Simulation in Embankment during Strong Earthquake by Effect of Elasticity Modulus

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Received 20 February 2014; Revised 12 June 2014; Accepted 12 June 2014; Published 1 July 2014

Academic Editor: Hongyi Li

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The dynamic analysis process was started after failure in some embankments during an earthquake. In this context, maximum displacement was reported at the crest based on interaction between structure and reservoir. This paper investigates the dynamic behavior of short embankment on soft soil. For this purpose, numerical analysis was carried out using ANSYS13 program based on finite-element method. Simulated models were vibrated by strong earthquake, so the peak ground acceleration (PGA) and duration were 0.65 g and 5.02 seconds, respectively. The comparison results were discussed in key points of plane strain analysis based on modulus ratio between saturated embankment and foundation. As concluded, the modulus ratio between 0.53 and 0.66 led to having a minimum value of horizontal displacement, relative displacement in vertical direction, and shear stress. Consequently, the shear stress was increased while the modulus ratio was decreased. Finally, to avoid more rigidity in the embankment on the soft soil, optimum modulus ratio was recommended at 0.66 in order to reduce the probabilistic of body cracks at the crest with respect to homogeneous behavior during an earthquake.

1. Introduction

Dynamic analysis is one of the main aspects for embankment designing. As a lesson learned, some huge damages such as different types of body cracks were recorded during an earthquake. It seems that a specific attention to complete research in this area is one of the major concerns for geotechnical designers. According to the literature, depth review in this category demonstrated that since the beginning of 1920 until 1960, pseudostatic method was well known. With full respect for this technique, this method was very simple and indicated the weak performance in order to cover some factors such as nature of the slope-forming and foundation material. Based on deformation characteristics, the sliding block method was completely presented by Newmark in 1965 [1]. Among other methods, shear beam method was presented by Mononobe [2]. As stated by Gazetas [3], an improved inhomogeneous shear beam model was investigated and it was concluded that the shear modulus was variable value in earth dams or rock fill dams and increased with $2/3$ power of depth from the crest. To estimate the dynamic response of an embankment,

the finite-element method was successfully presented by Clough et al. [4] using plan-strain analysis (2D). In this study, materials for modeling were consisted of linearly elastic, homogeneous, and isotropic. Later, this study was developed by other researchers using finite-element method and finite-difference method to cover some factors such as nonlinear, inelastic, nonuniform, and anisotropic behavior of materials under dynamic loads. As stated by Zeghal et al. [5], a local-global finite-element method was proposed to determine the nonlinear behavior of earth dams. Ming et al. [6] investigated fully coupled analysis of failure and remediation of lower San Fernando dam. The significant reasons for dam failure were reported in this study. In terms of earthquake engineering research, quick development in the computer programs directly led to the comprehensive analysis. For instance, several programs [7–11] were widely used for dynamic analysis of embankment. As presented by Namdar et al. [12], the assessment of embankment behavior was investigated using shaking table and finite-element method. The good agreement between analytical and physical modeling was obtained in this study. According to study from Wang et al. [13],

TABLE 1: A dimension of models.

$H = 30 \text{ m}$	$K = 15.00 \text{ m}$	$X = 108.92 \text{ m}$	$R = 36.37 \text{ m}$	$H_1 = 21.00 \text{ m}$	$L = 9.00 \text{ m}$	$Z = 15.00 \text{ m}$	$W = 5.00 \text{ m}$	$\theta = 30^\circ$
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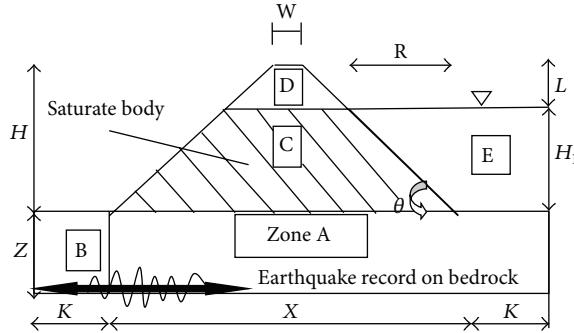


FIGURE 1: A modeling dimension according to Table 1 for plan strain (2D).

the geotextile-reinforced soil in embankment body was studied using centrifuge modeling, and they discussed embankment behavior during an earthquake. According to Zhu et al. [14] and Brinkgreve et al. [15], a two-dimensional seismic stability for a levee embankment was possible using PLAXIS program based on finite-element method. After all, as mentioned, the maximum displacement during earthquake was at the crest, as regards the soil amplification and interaction between dam and reservoir. In terms of dynamic behavior with respect to flexibility, the main role was featured by elasticity modulus. This paper tried to evaluate the effect of material properties based on parametric study in the saturate embankment on dynamic performance in order to find the best modulus ratio between saturated zone and loose sand foundation.

2. Modeling Process

This process includes some phases such as introducing program, element, boundary conditions, parametric dimension, material properties, meshing, key points, and earthquake record which are described below.

2.1. Introduce ANSYS Program and Element. This program is one of the comprehensive software's under finite-element method, and 100000 coed line are available, as related to the computer-aided engineering (CAE). In fact, this program is very famous with strong ability to analyze in different engineering purposes. In the present study, "solid42" element for embankment and foundation was used. In addition, "fluid79" was applied for water element according to help menu. Both elements were recommended for plan strain (2D). In fact, the lateral strain in the simulated models assumed zero.

2.2. Boundary Conditions. In terms of boundary condition for modeling, earthquake record in the horizontal direction of the base of model was used with respect to displacement-time. For this case, NAGAN record with acceleration-time converted to displacement time using SISMOSOFT3 program. Vertical displacement was assumed zero in the

bedrock, and earthquake duration was 5.02 seconds with substep (0.02 second). Both lines of vertical boundary were restricted by zero value in vertical direction, and 0.01 meters for horizontal displacement using trial-error procedure in order to create transient elasticity property for wave during vibration.

2.3. Modeling Parameters. Table 1 presents the dimension of simulated models in the parametric study. As seen, the height of embankment is short, and slope is moderate in order to satisfy slope stability. In addition, the width of the crest is five meters with respect to compaction and the minimum road width.

Figure 1 illustrates the parametric dimension of the simulated models. As shown, the bedrock was coupled by earthquake record. Moreover, based on water level in reservoir, two parts such as saturated zone (C) and unsaturated zone (D) were separated in models. In addition, water tank located in the right side of model, as marked (E).

2.4. Material Properties. Three materials were used for modeling such as water, foundation, and embankment. The structural body was the clay soil with homogeneous characteristics. Foundation material was the soft loose sand saturated. Help menu recommends for modeling the incompressible water; water properties were also presented in Table 2. This table presents the material property in different zone using three properties of the dam body. It is worth noting that the solid material was simulated using hardening isotropic bilinear. In addition, the friction coefficient was used in models in order to establish interface effect between different materials. The amplitude of material properties in different zone of the model for the present parametric study was applied [16]. The nonlinear behavior of soil was utilized using some factors such as density, elasticity modulus, Poisson's ratio, yield stress, and tangent modulus. Table 2 presents the material properties in different zones (A, B, C, D, and E). As can be seen in this table, the huge elasticity modulus was applied for incompressible behavior of water as mentioned earlier.

TABLE 2: Material properties.

Zone	Density (Kg/m ³)	Elasticity modulus (Kg/m ²)	Poisson ratio	Yield stress (Kg/m ²)	Tangent modulus	Friction coefficient
A-foundation (loose-sand saturate)	800	3E6	0.25	1.20E4	0.01	0.30
B-foundation (loose-sand saturate)	800	3E6	0.25	1.20E4	0.01	0.001
C1-embankment (clay saturation)	900	2E6	0.45	8.00E3	0.01	0.001
C2-embankment (clay saturation)	900	16E5	0.45	3.20E3	0.01	0.001
C3-embankment (reinforcement)	900	8E5	0.45	6.40E3	0.01	0.001
D-embankment (unsaturated)	1900	4E5	0.30	1.60E3	0.01	—
E-water	1000	1E12	0.01	—	—	—

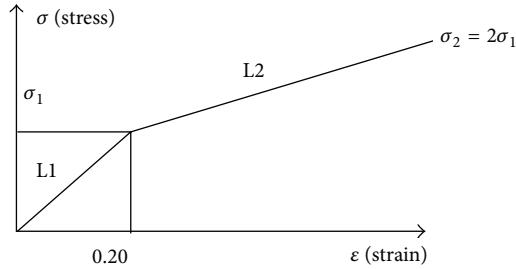


FIGURE 2: Nonlinear property of soil in bilinear method.

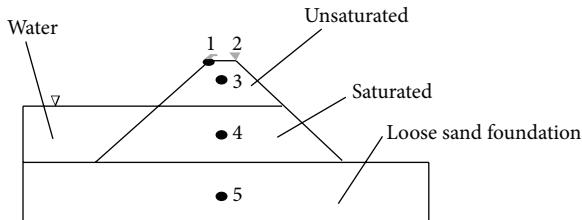


FIGURE 3: Key points (1-5) in models.

Figure 2 shows the nonlinear behavior of soil based on two stages. It can be seen that line L1 for elastic and line L2 to evaluate elastic-plastic and plastic condition, respectively. Line L1 is related to linear performance with respect to elasticity modulus, elastic stress according to 0.2% strain, and Poisson's ratio. Line L2 is related to the nonlinear behavior (elastic-plastic and plastic) with tangent modulus; both lines show bilinear isotropic hardening. It is noted that ultimate stress is double in comparison to elastic stress. In this figure, horizontal and vertical axes are, respectively, strain and stress.

2.5. Meshing and Key Points. According to Figure 3, five key points 1-5 have been selected to evaluate existing data. Both of them are at the crest, and other points are in the middle of zones in D, C, and A. Figure 4 shows the regular meshing in models. This mesh is used in order to interface between both different lines with same nodes.

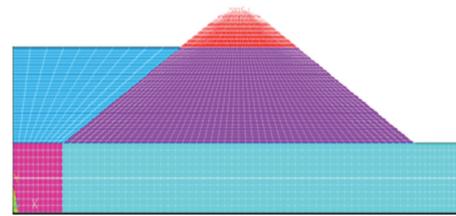


FIGURE 4: Regular meshing method.

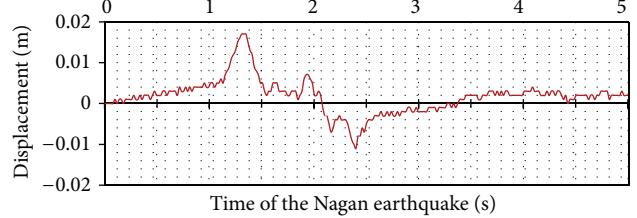


FIGURE 5: Input data from Nagan earthquake record according to displacement in the vertical axis (m) and time in horizontal axis (seconds).

2.6. Earthquake Record. In terms of earthquake vibration, all models were carried out based on time history analysis using Nagan earthquake. For this case, PGA (peak ground acceleration) and duration are, respectively, 0.65 g and 5.02 seconds. In terms of input data for ANSYS, this record was converted to displacement-time. For converting, SISMOSOFT3 program from Berkeley University was used. Figure 5 shows displacement-time for Nagan earthquake after converting.

As shown, the maximum and minimum displacements are 16.5 mm and 11 mm. In this figure, horizontal axis shows the earthquake duration (substep equal to 0.02 seconds). Vertical axis also shows the distribution of displacement based on meter measurement unit.

3. Results and Analysis

Numerical analyses were carried out based on scope of study and research methodology as explained earlier. After analysis

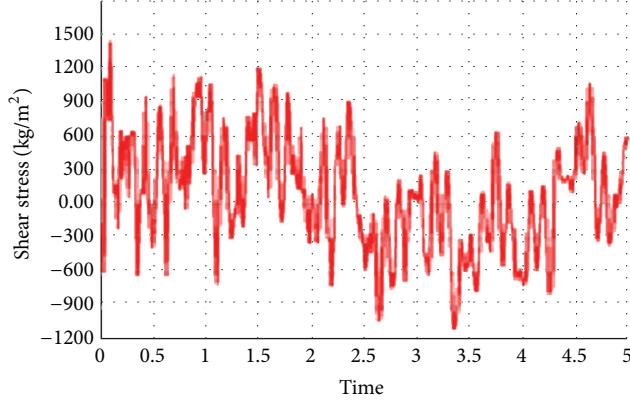


FIGURE 6: Shear stress in point 4 from model 1; vertical axis is value of shear stress, and horizontal axis is time of earthquake.

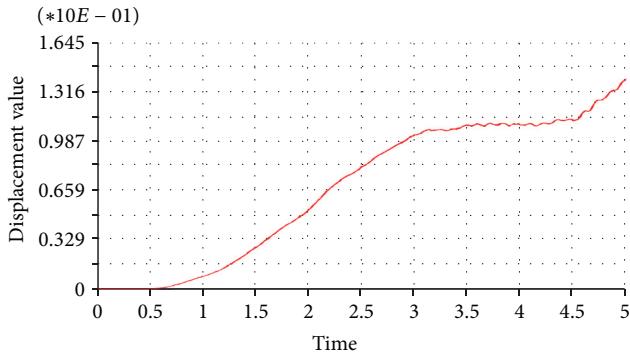


FIGURE 7: Horizontal displacement of point 1 in model 1; vertical axis is value of displacement (meter), and horizontal axis is time of earthquake (seconds).

in order to discuss, some results such as displacement distribution in both directions and shear stress were significantly compared. First of all, Figures 6 and 7 show the nonlinear behavior of material under dynamic load for shear stress and displacement. Figure 8 shows the distribution of shear stress for different models for the same key points. As observed, these factors were changed in each time with positive or negative position. It means that the transient analysis was obviously performed in models. Figures 6 and 7 illustrated the shear stress of point 4 in model 1 and horizontal displacement of point 1 in model 1, respectively.

However, this trend was obtained for structural behavior during an earthquake, as expected. This role was repeated in all key points as introduced earlier. This ability was one of the best engineering earthquake purposes using Ansys program. Due to the results classification, one modulus ratio (λ) was defined according to the following:

$$\lambda = \frac{\text{Elasticity modulus in embankment}}{\text{Elasticity modulus in foundation}}. \quad (1)$$

This ratio was the simple relationship between elasticity modulus in the saturated embankment and soft soil for foundation. Figure 8 shows the distribution of horizontal displacement in models. As seen, displacement in the first model was less than in second model, with respect to increasing elasticity

modulus. This value was dramatically increased in the third model in comparison to other models. In fact, displacement distribution depends on the modulus ratio, and the maximum ratio led to the homogeneous behavior during the strong earthquake. Therefore, horizontal displacement can be decreased while system was limited to the isotropic behavior. The maximum displacement was exposed at key point 4, as located at the middle of saturated embankment. In this case, the influence of water interaction according to the static pressure in the 1/3 of the height was very important. A raise of the modulus ratio led to the increase of horizontal displacement in the middle of foundation zone. However, the minimum horizontal displacement was featured in the key point 5 for all models. Hence, the suitable ratio was obtained in the first model to control horizontal dynamic displacement of the short saturated embankment. Based on the displacement distribution in the vertical direction, the relative displacement for both edges of the crest can play main role for controlling body cracks. Figure 9 shows the vertical displacement in the models. As compared, the maximum and minimum relative displacement were, respectively, found in the second model and first model. As seen, this factor was reduced while the modulus ratio was increased. The reduction of this ratio led to the increased flexibility and settlement. It is worth noting that maximum horizontal displacement occurred at the crest for

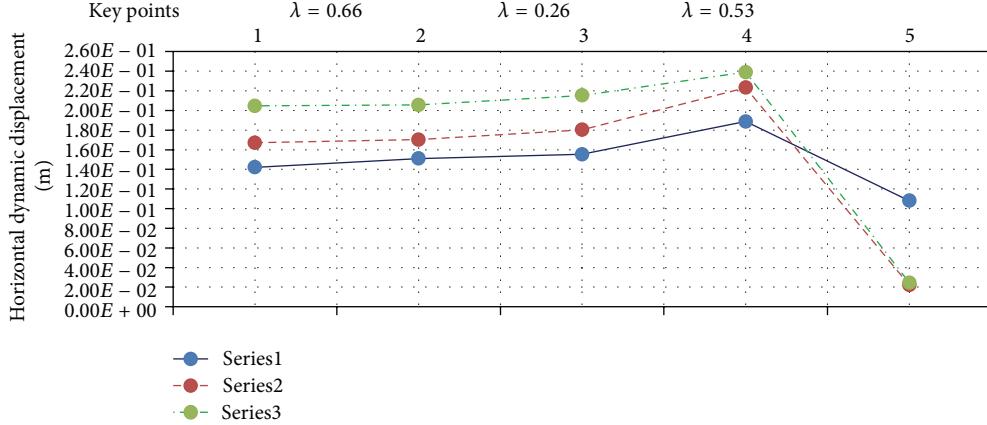


FIGURE 8: Horizontal displacement at the end of earthquake; horizontal and vertical axes are key points and dynamic displacement (meter).

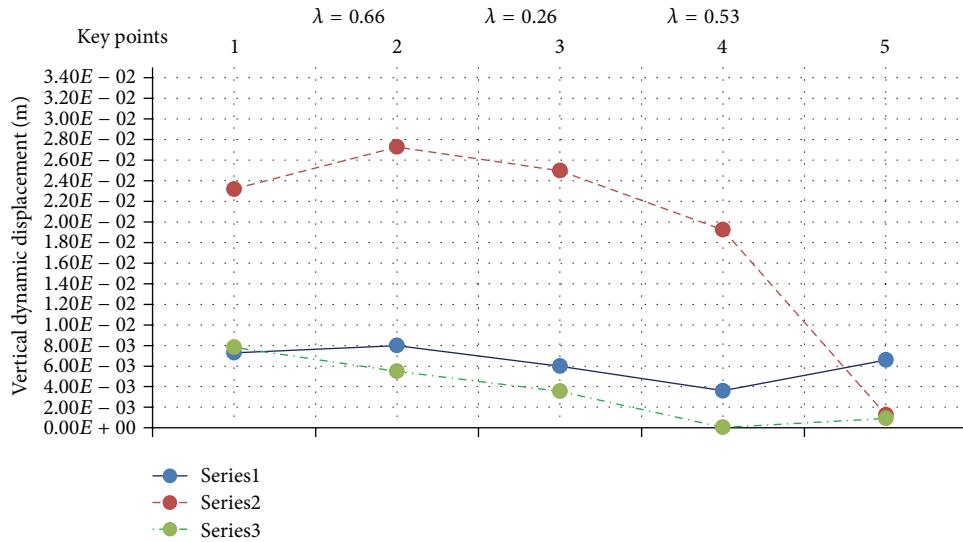


FIGURE 9: Vertical dynamic displacement at the end of earthquake for models, horizontal and vertical axis show key points and vertical displacement (meter), respectively.

all models, and there was good agreement between numerical result and case studies reported in the literature.

Figure 10 illustrates that the body cracks occurred at the crest in terms of relative displacement during vibration [17]. Consequently, the first model represented the appropriate aspects to control vertical dynamic displacement of the short saturated embankment. In addition, the prediction of cracks and damage requires nonlinear dynamic analyses [17]. After the above discussion, the shear stress distribution in models was shown in Figure 11.

The maximum shear stress was placed in the middle of the foundation as expected. Shear stress increased, while modulus ratio decreased. It was revealed that stress on the foundation was four times in the first model in comparison to other models. In brief, the structural behavior indicated the suitable modulus ratio equal to 0.66. As mentioned earlier, the first model also was the best position in order to minimize relative displacement. Finally, modulus ratio that equals 0.66

indicated the flexible behavior when the foundation was placed on the loose soft soil.

4. Conclusion

In this study, the short saturated embankment was evaluated during the strong earthquake while it was coupled by foundation with loose sand. The modulus ratio between saturated embankment and foundation showed the main role to choose the best performance. As a result, based on comparison of the displacement in both direction and shear stress on some key points of the simulated model using ANSYS program, the suitable modulus ratio was 0.66. Finally, the good agreement was revealed between results based on numerical analysis and case studies according to literature. More attempt to find this ratio for tall embankment is the best suggestion to investigate at next.



FIGURE 10: Cracking and inelastic deformations of the crest in an embankment dam caused by the 2001 Buhl earthquake in India.

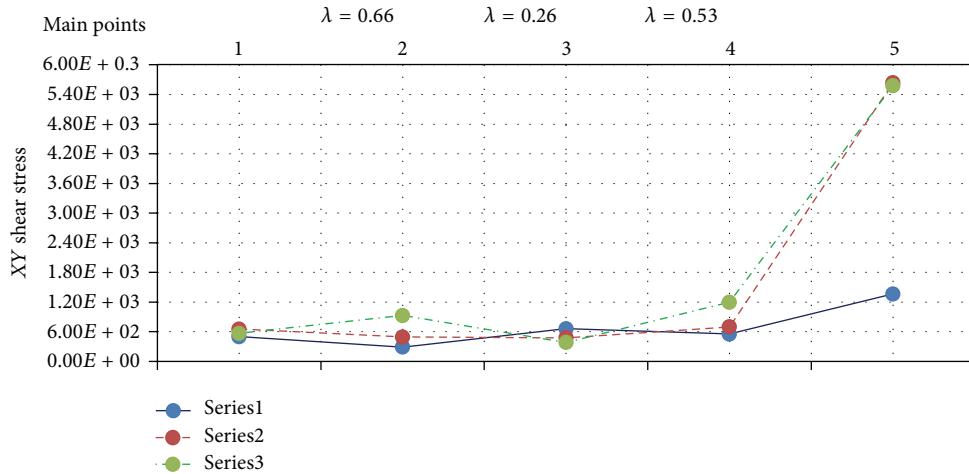


FIGURE 11: XY Shear stress in the end of earthquake for models; horizontal axis is main points, and vertical axis is shear stress (Kg/m²).

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgment

This study is made possible by the support of the International Doctorate Fellowship of Universiti Teknologi Malaysia, and it is very much appreciated.

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