Seismic Evaluation of Embankment by Shaking Table Test and Finite Element Method.

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ABSTRACT

The shaking table test and finite element method were used for simulation embankment model. In the shaking table test through the acceleration and pore pressure type of sensors and in the finite element software based on mathematical modeling, seismic behavior of embankment has been analyzed. The results clearly revealed that the embankment suffers collapse during increasing stress which is resulted in decreasing embankment stability and growing strain and deformation, and there is possibility of embankment mitigation. The Poisson ratio is obtained from the shaking table test is very close to value assumed previously by other scientist, this is an evidence of experimental accuracy. The results of two dimensional finite element method shown good agreement with shaking table test result and this is support for modeling of any types of earth dams by these methods.

(Keywords: *modeling, stress, strain, Poisson ratio, accurate method, deformation, earth dams, geotechnical engineering, earthquake resistance*)

INTRODUCTION

There are several research activities in the geotechnical engineering trough the analytical/numerical model to simulate ground behavior for understanding and application of concepts to field problems and to ensure their behavior [1-6]. Earthquake-resistant design of earth retaining structures like retaining walls, earth dams and foundations are very important problems to minimize the devastating effect of earthquake hazards [7]. A simplified procedure is developed to evaluate dynamic behavior of buried pipe during earthquake, a small- scale shaking table test was applied to study seismic uplift safety factor (FS). Through the experimental works, it is concluded that friction resistance surrounding the pipe and fluid drag should be included for calculation of FS [8].

There is a scientific attempt using finite element analysis to predict the JNES/NUPEC cyclic and shaking table RC shears wall test data, as part of a collaborative agreement between the U.S.NRC and JNES to study seismic issues important to the safe operation of commercial nuclear power plant (NPP) structures, systems and components (SSC) [9]. There is a comparison between finite difference code and an unstructured tetrahedral finite element code for a simulation of the 1994 Northridge Earthquake. The numerical tests all show very good agreement with analytical solutions and other codes [10].

The shaking table used under a series of one and two-dimensional base excitations with gradually increasing acceleration amplitudes for investigation on dynamic characteristics, the seismic responses and the failure mechanism of the structure. The test results demonstrate that the structural system is a good solution to withstand earthquakes [11]. There have been few attempts to improve the basic concept to compute displacements along a non-planar surface, and compute along a slip surface. There is developed a multi block model which takes into account the effect of internal deformations and transfer of mass between successive blocks. Permanent displacement of a slope subjected to dynamic force was also obtained using finite element analysis.

Various approaches based on finite element method vary with the constitutive model adopted to model the behavior of soil. Thus in most of the methods available for the dynamic analysis of slopes, importance is given for finding the displacement of the slope rather than the factor of safety. Even though the displacement of a slope is a very important criterion for the design of a slope, it is also important to know the factor of safety of a slope when subjected to dynamic load [12-16].

This paper deals with understanding the applications of finite element software in geotechnical engineering and providing evidence of experimental accuracy in the laboratory using shaking table test.

METHODOLOGY AND EXPERIMENTS

In the present experiments, a transparent rigid boundary acrylic box with opening at the top has used to study the behavior of embankment in fully saturated ground. The box is made of perplex glass of thickness 12 mm with dimensions of 1650 mm in length, 500 mm in breadth and 600 mm in depth.

The bottom portion of box has an arrangement of baffle walls for regulating water uniformly to saturate the sand placed in the box. A small orifice is provided at the bottom to allow water for saturation of the model. Filter plates with size of 2 micron were provided above the baffle walls, which could be easily removed and placed back. The use of filter plates helped in restricting the entry of sand into the baffle wall portion. The outer surface of the acrylic box was marked with grids of 100 mm by 100 mm using a permanent marker in order to lay the color sand in proper layers.

The manual-shaking table has used to vibrate in one direction. It consisted of two wooden panels with steel plates between them for producing harmonic vibration at frequency of 1 Hz to 3 Hz. The thickness, height and number of plates were so designed to achieve a relatively rigid platform and to vibrate at resonance. The platform was 1.8 m long, 0.6 m wide and 0.35 m in depth. The steel plates were bolted between the top and bottom surfaces of the wooden panels using angle sections. The pore pressure sensors (P1-P4) and acceleration sensors (A1-A3) were used to measure the excess pore water pressure and acceleration respectively developed during dynamic loading (Figures 1-2).

The respective transducers were connected to their signal conditioners. These were in turn connected to the CPU of a computer [17]. The shaking table experiment and finite element software (Geoslope) used for seismic performance assessment of embankment fully vulnerable against liquefaction.

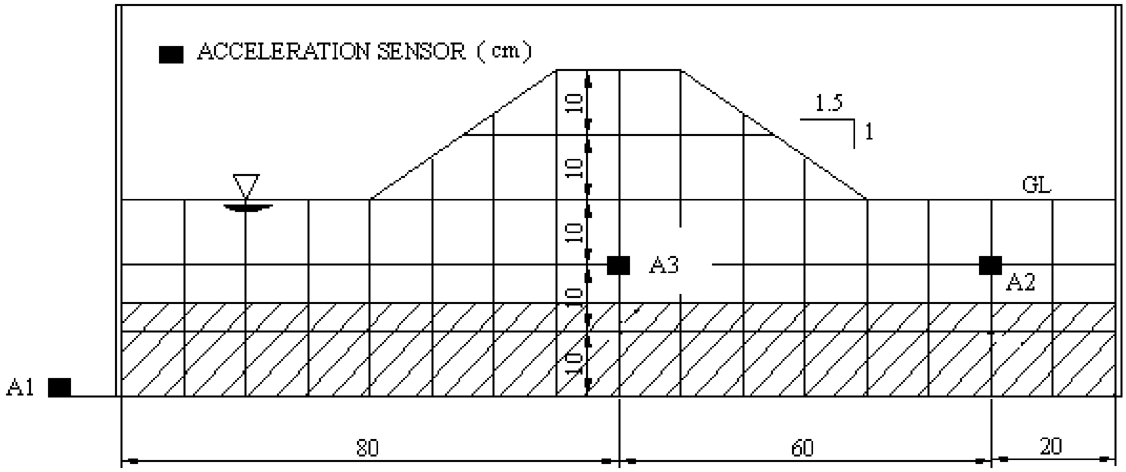


Figure 1: Model of Moist Loose Embankment and Loose Subsoil in 15cm Height and 15 cm Dense and Fully Saturated.

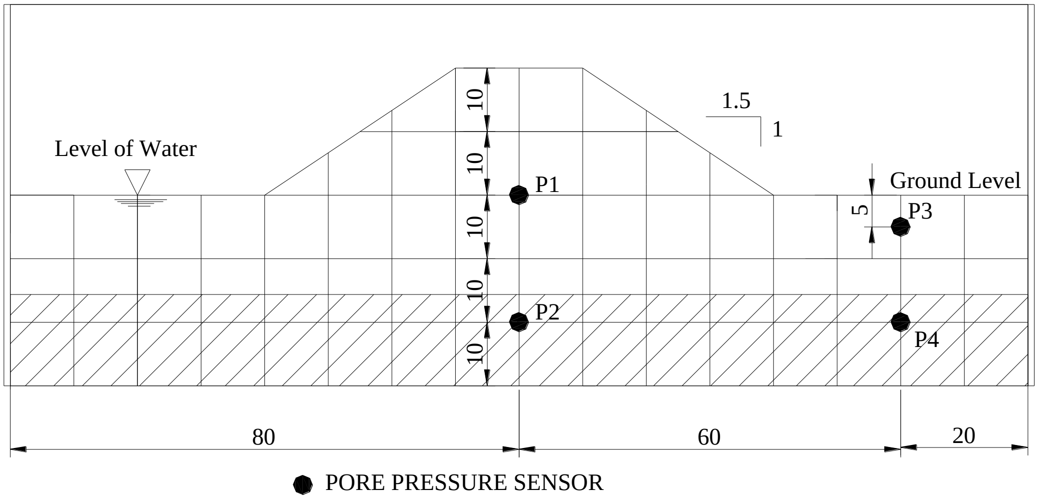


Figure 2: Model of Moist Loose Embankment and Loose Subsoil in 15cm Height and 15 cm Dense and Fully Saturated.

The embankment experimental model is considered in Figures 1-2 with the cross section of ground level with sand, water level and positions of pore pressure and acceleration sensors, and geo-slope software used to understanding seismic embankment model behavior. In this investigation the modulus of elasticity, a property of elastic material, is defined as a constant of proportionality between stress and strain as [18]:

$$E = \frac{\Delta\sigma}{\Delta\varepsilon}$$

We may also take volumetric measurement as the test proceeds, which require completely filling the cell with a liquid during sample consolidation.

If we measure the change in sample volume ΔV, the volumetric stain $_V$ can be computed as [18]:

$$_V = \frac{\Delta V}{V_0}$$

$$_V = \frac{(\sigma_1+2\sigma_3)}{E}(1-2\mu)$$

RESULTS AND DISCUSSION

In this investigation shaking table and finite element software employed for evaluating of embankment seismic stability behavior.

The results of shaking table test shown in Tables 1 and 2 and Figures 3-5, and the results of modeling by finite element software in Figures 6-9 have been mentioned. In the shaking table test, dynamic force is applied on the system and collapsing mechanism were studied.

In shaking table test modulus elasticity during the shaking is equal $E = \frac{\Delta\sigma}{\Delta\varepsilon} = 14.145$

In shaking table test volumetric strain during the shaking is equal $_V = \frac{\Delta V}{V_0} = 0.896$

In shaking table test $_V = \frac{(\sigma_1+2\sigma_3)}{E}(1-2\mu)$

In shaking table test μ = 0.538

Table 1: Characteristics of Embankment Model Under Shaking Table Test.

1	Method of sample preparation			Moist placement	
2	Slope of Embankment			1 in 1.5	
3	Weight of dry sand	Embankment		0.6	kN
		Subsoil		3.31	kN
4	No. of pore pressure sensors			4	
5	No. of acceleration sensors			3	
6	Quantity of water used for saturation			86	Liters
7	Duration of saturation			178	Minutes
8	Duration of shaking			12	Seconds
9	Duration of data collection			16	Seconds
10	Sampling frequency			500	Hz
11	Maximum displacement recorded during shaking			16	mm
12	Water level	After complete saturation		300	mm
		After Shaking		350	mm
13	Saturated Density			17.2	kN/ m^3
14	Volume of sand	Before saturation	Embankment	0.05	m^3
			Subsoil	0.24	m^3
		After saturation	Embankment	0.05	m^3
			Subsoil	0.23	m^3
		After shaking		0.26	m^3

Table 2: Detail of Embankment Characteristics under Shaking Table Test.

Sl. No.	Features	P1	P2	P3	P4
1	Position of sensor w.r.t GL after saturation (mm)	0	200	50	200
2	Total pressure (kPa)	-	3.44	0.86	3.44
3	Initial effective pressure (kPa)	-	0.94	-	0.94
4	Maximum excess pore water pressure (kPa)	1.06	3.37	2.01	2.69
5	Time of occurrence of maximum excess pore water pressure (sec)	5.08	5.41	7.38	9.53
6	Pore pressure ratio	-	3.59	-	2.86
7	Rate of increase of pore water pressure (kPa/sec)	0.13	6.34	0.61	1.07
8	Rate of dissipation of pore water pressure (kPa/sec)	0.02	0.52	0.42	0.38
9	Duration of occurrence of maximum pore water pressure (sec)	11.9	11.79	13.5	11.97
10	Frequency of excess pore water pressure history	Same as input	Same as input	Same as input	Same as input
11	Shape of excess pore water pressure history	Gradually decrease	Gradually decrease	Gradually decrease	Gradually decrease

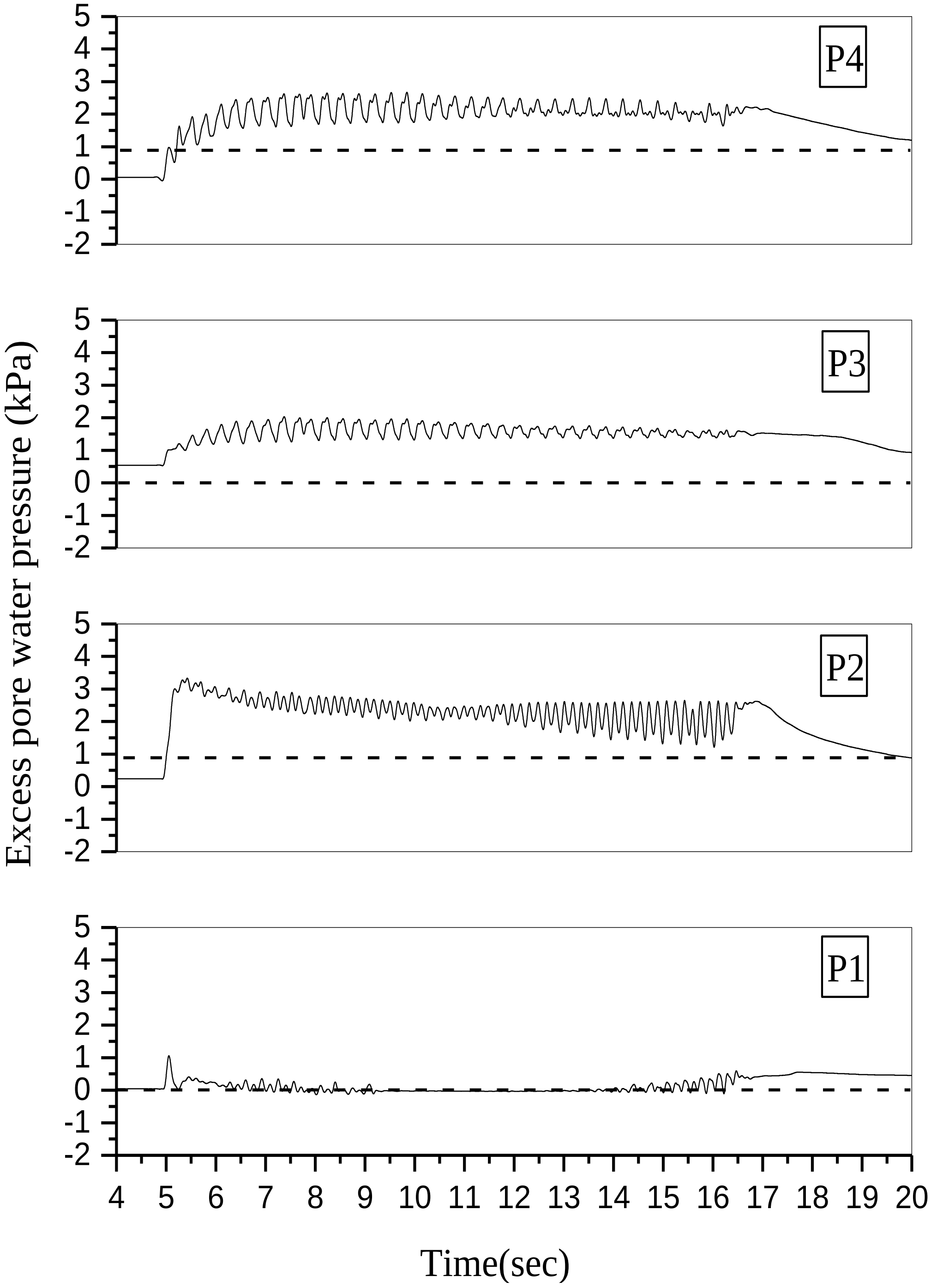


Figure 3: Time Histories of Excess Pore Water Pressure [17].

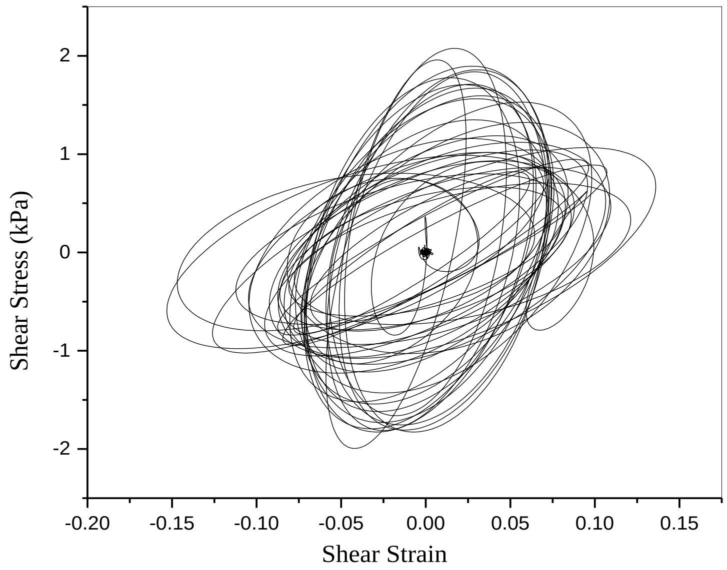
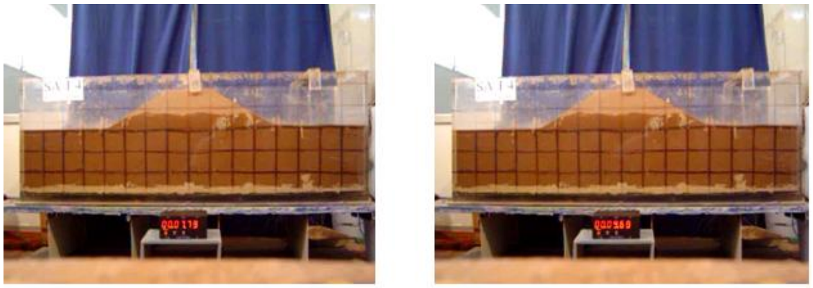
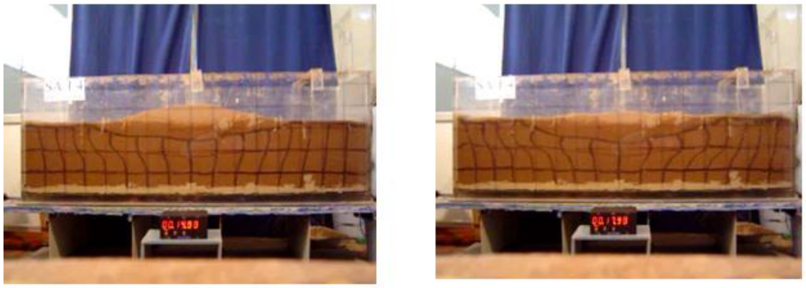


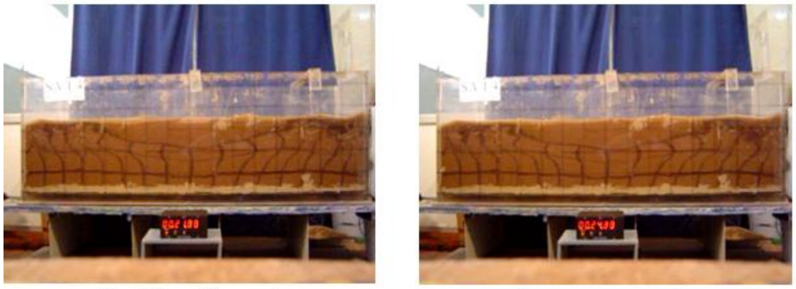
Figure 4: Stress Strain History in the Subsoil Below Embankment [17].


Initial Condition

Initial Condition


After one Second

After Two Seconds


After Three Seconds

After Four Seconds

Figure 5: Deformation Shape of Embankment-Subsoil System at Different Instants of Time.

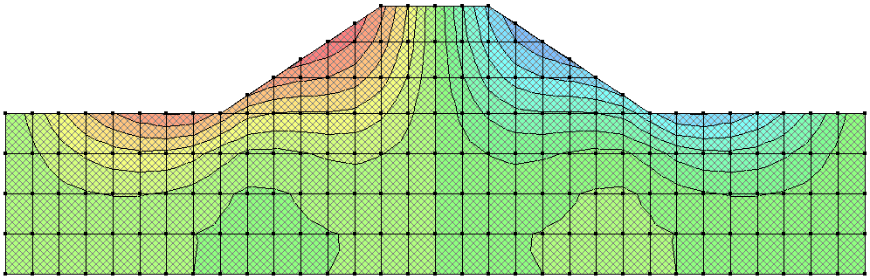


Fig 6 embankment displacement counters in finite element method

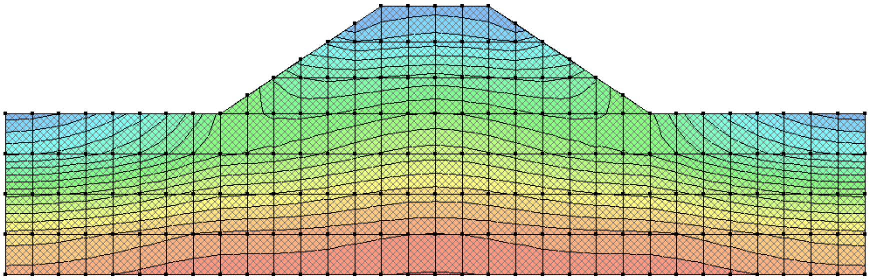


Figure 7: Embankment Shear Stress Counters in Finite Element Method.

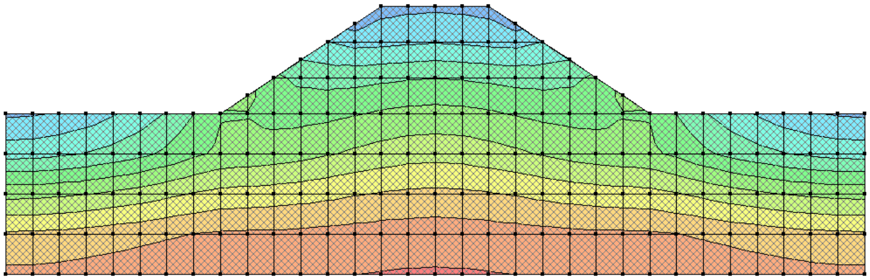


Figure 8: Embankment Shear Strain Counters in Finite Element Method.

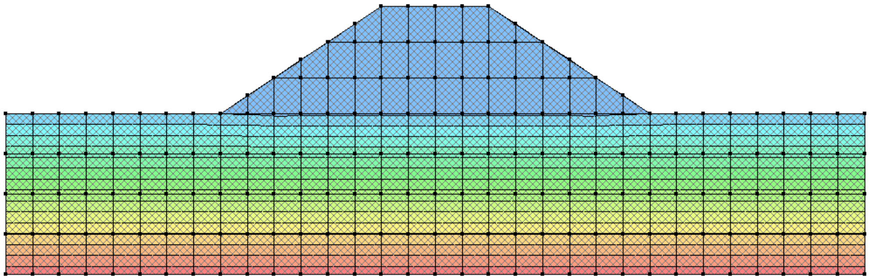


Figure 9: Embankment Pore Water Pressure Counters in Finite Element Method.

A value of 0.5 is usually used for saturated soils, [18] from the above Poisson ratio result could observe validity of experimental and calculation. For more investigation on the shear stress-strain behavior the Geo-slope software based on finite element method has been employed. The model evaluated by the Geo-slope is same as model in the laboratory and examined under seismic force by shaking table.

The displacement on the system by finite element software, the maximum displacement is observed on embankment and minimum in subsoil respectively and there is negative correlations between displacement and system depth, and also in the toe of embankment and near to that, is displacement sensitive area (Figures 5-6).

The authors suggested that based on finite element method and shaking table test could find place in the system is required for installation of dense wall or any other material for increasing system time stability.

Figure 5 indicated deformation by the shaking table test and Figures 7-8 shown shear stress and shear strain from finite element software. In Figure 5, we observed that minimum deformation is in the dense part of subsoil and from Figure 7-8 it is understood that minimum shear stress and strain is in the dense zone. Figure 9 shows that negative correlation between pore water pressure with subsoil density and system depth.

In this research, acceleration and pore pressure sensors provided a chance to assess the precision and trustworthiness of conservative geotechnical procedure for embankment, dynamic behavior. Present in this work is a comparison of experimental and finite element methods. The results of two dimensional finite element method show good agreement with the shaking table test and support for modeling of any types of earth dams.

The existing unusual soil volume change behavior like settlement under effective stress decrease during wetting and massive settlement near saturation, another odd behavior was encountered during laboratory inundation tests at different net stress [19].

CONCLUSION

- The investigation shows good agreement between two dimensional finite element methods and shaking table test results. The pore water pressure, displacement, shear strain, and shear stress are evidence for the validity of work.

- The Poisson ratio is obtained from the shaking table test is very close to value assumed previously by other scientists [8]. It is an evidence of experimental accuracy.

- It could be suggested that shaking table equipment along with the finite element method are acceptable techniques for modeling and construction of embankment

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