International Journal of Civil Engineering Research.
ISSN 2278-3652 Volume 5, Number 2 (2014), pp. 121-128

http://www.ripublication.com/ijcer.htm

Behavior of Slope under Dynamic Condition – An Experimental Study

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Abstract

This paper checks the behaviour in slope profile under dynamic condition. Investigations were carried out on a shake table, which gives one dimensional steady state vibrations. Dynamic parameters used are acceleration of shaking (% of g), frequency (Hz) and dynamic loading duration (cycles). The failure in slope is analyzed on the basis of crest subsidence with respect to initial slope profile. These tests had been performed at constant frequency of 4 Hz. The range of accelerations chosen was 10%, 20%, 30% of acceleration due to gravity. The displacement of soil mass was observed at 3 different duration of 10, 20 and 40 cycles from starting of dynamic loading. The failure surfaces developed during the induced motion were fairly shallow and confined within the slope surfaces. The failure surfaces were circular in the upper part of the slopes. At the toe of the slopes, bulging and translational movements were observed. A Distortion Factor is defined to explain the behavior of slope under dynamic condition.

Keywords: Component; Slope, Dynamic loading.

1. Introduction

The infrastructures are very much vulnerable to the seismic loading. During the Bhuj Earthquake, several road embankments and embankment dams failed or suffered severe distress. Earthquake induced ground shaking is one of the most frequent causes of slope failures. Earthquakes with a very small magnitude may trigger failure in susceptible slopes. The instrumentation and monitoring of actual embankments is the best way to study the performance of embankments during earthquakes. However due to lack of such data, model tests in the laboratory are the only way to study the seismic behavior of embankments. The model test on a shaking table is one of the ways to study the behavior of embankment slopes under dynamic condition in the laboratory. The first well-documented shaking table study of slopes was performed by Clough and Pirtz (1956). Seed and Clough (1963), Arango and Seed (1974), Koga and Matsuo (1990) also used shaking table tests to study the earthquake resistance of embankment slopes and dams. More recently, Wartman et al. (2001) conducted small scale shaking table tests to study slope deformations during seismic condition and to assess the applicability of the Newmark's sliding block method of analyses. Prasad et al. (2004) also reported calibration and testing of slopes using laboratory shaking table. Unlike the previous researchers, they used laminar box to enhance the accuracy in assessing the ground behavior. Lin and Wang (2006) used a large-scale shaking table test model to study the dynamic behavior of a 0.5 m high sandy slope with a slope angle of 30°. They observed that the responses of the slope became nonlinear after 0.5 g loading. Recently Giri and Sengupta (2010) conducted a small scale shaking table test to study the behavior of embankment slopes subjected to cyclic loading conditions. Nine slope models having heights as 15cm. 18cm and 21 cm were subjected to the same base acceleration, which consisted of a sinusoidal motion with a constant peak acceleration of 0.1 g and frequency 4.65 Hz. The results of a series of shaking table tests on model embankment slopes in terms of deformations, settlement of the crest and accelerations at the base and the crest of the slopes measured during the tests were compared to the results of the corresponding numerical analyses performed using a large strain finite difference computer program.

This paper aims to study the behavior of embankment slopes subjected to cyclic loading conditions. This paper presents the results of a series of shaking table tests on model embankment slopes in terms of settlement of the crest and accelerations at the base and the crest of the slopes measured during the tests.

2. Experimental Investigaton

2.1 Shake table Set up

The test tank is a 1050 mm long, 600 mm wide and 600 mm high cubical box made up of steel panels. The tank is mounted on a horizontal shake table. The platform with wheels rests on four knife edges being rigidly fixed on two pairs of rails anchored to the foundation. This is driven in horizontal direction by a 3 H.P. A.C. motor through crank mechanism, for changing rotary motion into translatory motion. The amplitude of motion can be changed through two eccentric shafts. By changing the relative position of two shafts, the amplitude can be fixed as desired. The brake assembly is used for stopping the shake table. The table can produce steady state one-dimensional harmonic excitation. The maximum force of horizontal acceleration which can be generated is up to 0.3 g. The table can be shake at 4 Hz, 8 Hz & 12 Hz frequency.

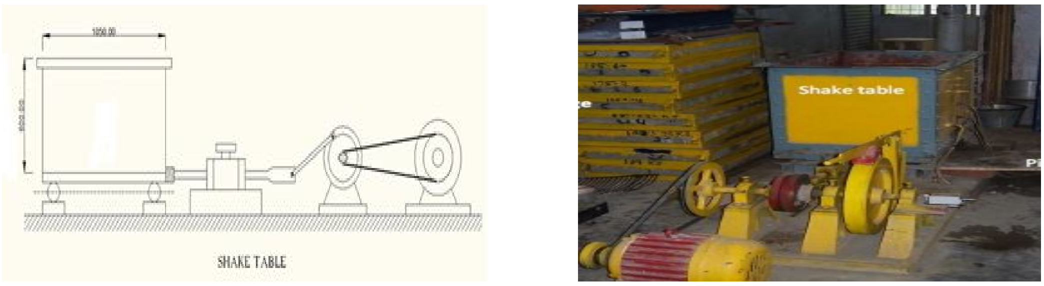


Figure 1: Shake table Facility.

2.2 Material used in the study

The sand collected locally from the bed of river Solani was used in experimental studies. The sand was cleaned and air dried before use. The sand had less than 5% particles passing through IS: 75 micron sieves and showed no cohesion. Table 1 shows properties of Solani sand used in the present study. Its classification was SP as per Universal Classification System.

Table 1: Properties of Sand used in study.

S. No	Property		Notation	Value
1	Soil Classification		SP	-
2	Specific Gravity		G	2.43
3	Uniformity Coefficient		C_u	1.9
4	Grain Size(mm)		D_{50}	0.27
5	Maximum void ratio		e_{max}	0.86
6	Minimum void ratio		e_{min}	0.48
7	Strength parameter	1.428 g/cc (50% RD)	C	0
			□	36.50

2.3 Preparation of sample

The slope models were constructed in the test box by compacting the sand up to the desired height by controlled-volume method. The construction of slope takes in stages. First a layer of 100 mm is compacted and slope is made by hand modelling tool. Then subsequent layers are made and final slope is constructed. The slope angle is kept at critical angle of 36.5° and height of 0.6 m is made. The observations were made for three different acceleration of 10%, 20% and 30% of acceleration due to gravity. The response of slope is observed at three different loading times i.e. after 10, 20 and 40 cycle which corresponds to 2.5, 5 and 10 sec after the initiation of dynamic loading. For each combination of acceleration and dynamic loading duration, a total of three tests were conducted to have a better accuracy for results. A total of 27 tests were conducted. For all these cases, the average unit weight (g) and the relative density (RD) of the sand were maintained at 1.428 g/cc and 50%, respectively. The un-deformed geometries of the slopes are shown in Figures 2(a).

3. Observation

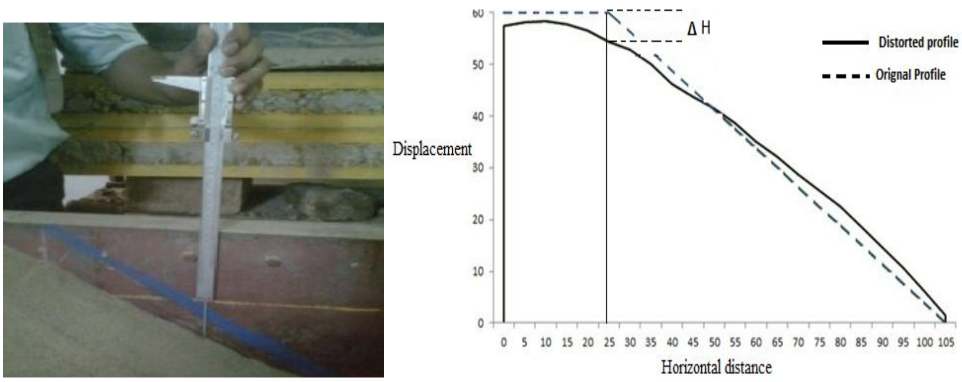
The failure surfaces developed during the induced motion were fairly shallow and confined within the slope surfaces. The failure surfaces were non-circular in the upper part of the slopes. At the toe of the slopes, bulging and translational movements were observed. Figure 2(b) shows the deformed profile of slope after application of dynamic loading at 0.2g of acceleration and shaking duration of 10 cycles. The presentation of these observations is very much tedious so it is decided that the observation to be recorded in terms of crest subsidence. A venire caliper is used to measure the crest subsidence. Figure 3(a) and (b) shows measuring of crest subsidence by venire caliper in shake table and its actual interpretation. A Non Dimensional factor termed as Distortion factor is determined for the proper representation of observed data. The distortion factor is defined as ratio of crest subsidence to the original height of crest (equation 1).

$$\text{Distortion Factor (DF)} = \Delta H/H \qquad (1)$$

Where, ΔH = crest subsidence and H = height of crest

(a) (b)

Figure 2: The un-deformed and deformed slope profile after application of dynamic loading.



(a) (b)

Figure 3: Methodology of taking observations.

Table 2 shows observations in tabular form.

Table 2: Observation for Crest subsidence and Distortion Factor.

Dynamic Loading Duration		**Acceleration of Dynamic force**								
		0.1g			**0.2g**			**0.3g**		
CYCLE	SEC	ΔH (cm)	ΔH_{avg} (cm)	DF	ΔH (cm)	ΔH_{avg} (cm)	DF	ΔH (cm)	ΔH_{avg} (cm)	DF
10	2.5	6.47	6.54	0.109	8.26	8.34	0.139	12.56	12.24	0.204
		6.34			8.38			11.25		
		6.81			8.40			12.93		
20	5	7.66	8.04	0.134	9.54	9.67	0.161	13.60	13.85	0.231
		8.67			9.75			14.18		
		7.79			9.71			13.77		
40	10	9.66	9.68	0.161	12.58	12.12	0.202	18.12	17.26	0.288
		9.26			12.77			17.19		
		10.12			12.92			16.48		

4. Results

Figure 4 shows the variation of distortion factor with acceleration of shaking for various duration of loading cycle. The results can be explained under following subheading.

4.1 Effect of duration of cyclic loading

The Figure 4 clearly shows that for a constant acceleration of dynamic force, The Distortion factor (DF) increase with increase in cyclic loading duration.

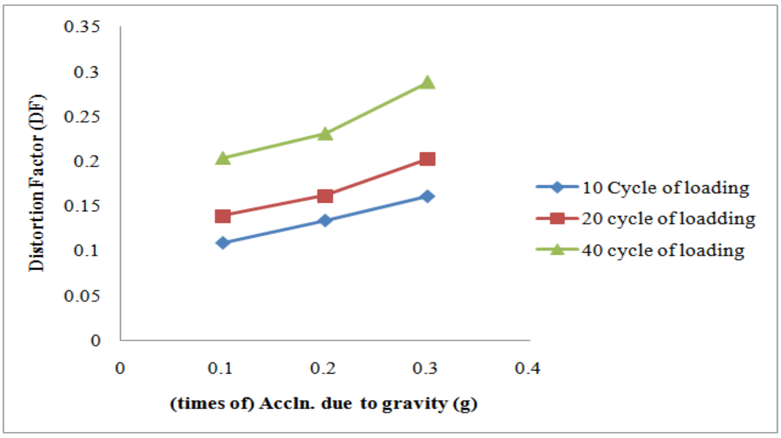


Figure 4: Variation of Distortion factor (DF) with acceleration for various number of loading cycles.

For 0.1g acceleration, the DF increased by about 27% when number of cycle of loading increased from 10 to 20. However when the number of cycle of loading increased to 40 from 20, there is an increase in DF of 46%. Similar pattern were observed for higher value of acceleration. On an average the Distortion factor increased by 20-27% when number of cycle of loading increased from 10 to 20 and when number of cycle of loading increased from 20 to 40, The distortion factor increased by about 42 – 46%.

4.1 Effect of acceleration of cyclic loading

Similar behaviour is observed for increase in acceleration also. At 40 cycle of loading, If loading force acceleration increased from 0.1 to 0.2 times of acceleration due to gravity, The Distortion factor increased by about 13%. However when loading force acceleration increased from 0.2 to 0.3 times of acceleration due to gravity, The Distortion factor increased by about 24%. On an average an increase of about 13 – 22% is observed in Deformation factor when acceleration loading force acceleration increased from 0.1 to 0.2 times of acceleration due to gravity and 20 – 25% when acceleration loading force acceleration increased from 0.2 to 0.3 times of acceleration due to gravity.

5. Conclusion

It is a well-known fact that earthquake trigger landslides. A model slope made up of sand is observed under series of dynamic loading. A distortion factor is discussed to explain the behaviour of slope in terms of crest subsidence. It is observed that with increase in loading duration and acceleration of force, the stability of slope is reduced.

6. Acknowledgements

The Authors are thankful to Head of department, Civil engineering department and coordinator of geotechnical engineering group of IIT Roorkee for allowing us to conduct this research.

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