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RESEARCH ARTICLE

Analysis of dynamic soil properties: shaking table testing

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Abstract

This paper presents an analysis of shaking table tests on wrap-faced embankments situated on soft clay. The model embankment was placed in a laminar box mounted on a shaking table. The results from these tests were verified through numerical analysis. Different model tests were conducted with varying surcharge loads and acceleration levels. It was observed that the response of the embankment on soft clay was significantly influenced by the base acceleration levels and the magnitude of the surcharge pressure. Data from the Loma Prieta earthquake (1989) was utilized in this experiment. The effects of various parameters on the acceleration response at different eleva-tions of the embankment and face deformations were also examined. The results indicate that the proposed wrap-faced embankment demonstrates significant resistance to earthquakes, particularly those similar to the Loma Prieta event, and provides an indicative performance measure of the wrap-faced embankment on soft clay soil.

Keywords: soft clay; embankment; earthquake

1. Introduction

Analyzing the influence of earthquakes on soil structures, shake table testing has been widely used over the last few decades. Shaking tables are extensively utilized in seismic research, providing a means to subject structures like embankments to conditions representative of actual earthquake ground motions. Sakaguchi et al. (1992) and Sakaguchi (1996) conducted shaking table tests on a reinforced model with a specific height and observed the effects on various parameters such as the relative density of soil, frequency, and amplitude of the motion.

Numerous studies have been conducted on reinforced soil structures related to seismic analysis. Notable research includes works by Latha and Krishna (2006, 2008), Krishna and Latha (2007), Sabermahani et al. (2009), Latha and Nandhi Varman (2014), and Hore (2022). Latha and Manju (2016) described the performance of geocell retaining walls under different seismic conditions. Krishna and Bhattacharjee (2017, 2019) analyzed the input ground motions at the base of rigid-faced reinforced soil-retaining walls. Sahoo et al. (2019) conducted shaking table tests to analyze the behavior and response of a steep soil slope at a specific angle.

A recent study by Chakraborty (2022) and Hore (2023) involved a series of shaking table tests to evaluate the response of model sand walls in different types of local sandy soil.

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Different research on wrap faced embankment on sandy soil of the different countries. The research on dynamic analysis of wrap faced embankment on soft clay soil especially Bangladeshi region is very scarcity. In the present research, a scale model testing platform developed for wrap faced embankment on clayey soil where a wrapped geotextile-sand retaining wall was erected on clay soil subjected to cyclic loading. The effect of base accelerations and displacement of the wrap faced embankment on soft clay foundation along the different elevations are observed in this research where the **Figure 1**(After Hore, R. et al.2019) represent the availability of clay soil layer in Bangladesh and

2. Experimental model

A computer-controlled servo-hydraulic single degree of freedom shaking table facility was used in this experiment, as shown in **Figure 2** where the platform is 2 meters by 2 meters size. The payload capacity is 1500 Kg. It had an acceleration range of 0.05g to 2g. The frequency range is 0.05Hz to 50. A large-sized shear box consisting of 24 hollow aluminum layers, built such that the friction between the layers is minimum, as shown in **Figure 2**. The dimension of laminar box is 915 mm × 1220 mm × 1220 mm.

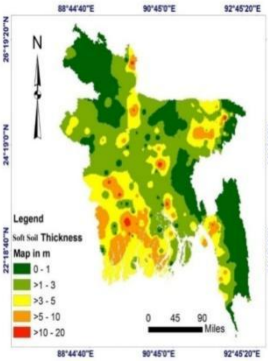

Figure 1. Thickness map.

Figure 2. shaking table facility.

The soil is found from BUET area indicated as Dhaka soil. The model soil has a unit weight of 14.8 kN/m3. A specific gravity is 2.64. The undrained shear strength is 28 kPa. The ultimate bearing capacity is 17.20 kPa. The sand is classified as poorly graded sand (SP) according to the Unified Soil Classification System. General geotechnical properties of the sands are presented in **Table 1** (Hore 2021). A woven polypropylene multifilament geotextile (D50) was used for reinforcing the sand in the tests.

Table 1. Geotechnical properties of Sylhet Sand.

Physical properties	Sylhet sand
Effective size, D_{10} (mm)	0.38
Average size, D_{50} (mm)	0.67
Coefficient of uniformity (C_u)	2.00
Coefficient of curvature (C_c)	0.92
Friction angle (°)	29
Specific gravity (G_s)	2.64

The present study was conducted with a height of 300 mm clayey soil layer foundation above which a 50 mm sand blanket was provided as shown in **Figure 3** with approximately 1 m^2 geotextile was placed between the clayey soil foundation and sand blanket. The model scale is N=10 and scale factor 1/N. Accelerometers were used to monitor the accelerations of the shaking table. The Linear Vertical

Displacement Transducers (LVDT) were placed. The Loma Preita earthquake was fixed for each shaking. Exactly Twelve (12) numbers of earthquake shaking were applied for this research. Embankment model was subjected to several different excitations from 0.05g (low amplitude) to 0.2g (high amplitude) peak base accelerations. The surcharge pressures are 0.70, 1.12, and 1.72 kPa.

3. Numerical method

The PLAXIS 3D software version is employed for performing the analyses. PLAXIS is a finite element package that is developed the specific purpose such as i) analysis of deformation ii) stability, and iii) flow in geotechnical engineering. Definition of soil stratigraphy embankment and retaining wall, Mesh generation are performed to calculate. The initial step for analyzing the model is to create the geometry of the model and the geometry characteristics such as embankment height slope and crest width with the second step is to provide the material properties of the embankment and the under-laying soil. Numerical analysis of wrap faced embankment as shown in **Figure 4**. As the demonstrated model is symmetric in this research, only half of the whole setup is modeled (in this case the right half is chosen). A representative section of 2 m width is taken for the research with the boundary of the model are $x_{min} = 0$, $x_{max} = 6$, $y_{min} = 0$ and $y_{max} = 2$. A model embankment is four layers of sand. The slice wrapped with geotextile is modeled and the under laying soft layer are inserted. In this model the ultimate tensile strength is 16 kN/m. The normal elastic stiffness of the geotextile was considered as and 2500 kN/m.

Figure 3. Experimental Model.

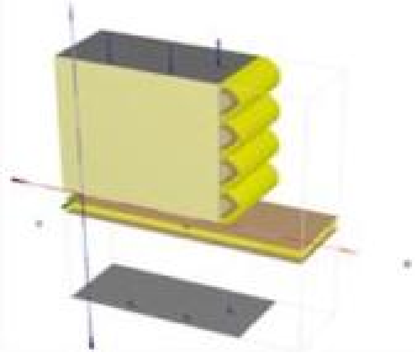

Figure 4. PLAXIS model.

4. Result and discussion

The soil layer in equal lifts is 100 mm. To achieve a total wall height (H) of 400 mm the equal lifts (each 100 mm) are inserted. A series of twelve shaking table tests were performed were performed for this research. The variation of the different soil parameters like acceleration amplification, displacement, pore water pressure and strain (LST1, LST2, LST3, LST4, LST5 and LST9) with respect to height for various Loma Prieta earthquakes are presented in this section.

4.1. Acceleration amplification profile

The different base accelerations are 0.05g, 0.10g, 0.15g, and 0.2g. The test pattern are LST1, LST2, LST3 and LST4 tests, respectively, which was conducted at 1.72 kPa surcharge pressure. Acceleration amplifications were increased with increased base accelerations. From the **Figure 5**, it is observed that the maximum acceleration amplification was 1.52 at an acceleration of 0.2g, whereas it decreased to 1.28 at an acceleration of 0.05g. Results from By PLAXIS 3D analysis showed that acceleration amplification [Profile for tests LST1(P), LST2 (P), LST3(P), and LST4(P)] also at all elevations increased with an increase in Acceleration. The maximum and minimum acceleration amplification from PLAXIS 3D was 11.18% and 12.50% higher than the shake table model test respectively. Acceleration response against different surcharge pressures was presented from tests LST1, LST5 and LST9 are depicted in **Figure 6**. These tests were conducted with 1.72 kPa, 1.12 kPa and 0.7 kPa surcharge pressures at 0.05g base acceleration. Accelerations at the top of the wall were inversely proportional to the surcharge pressures from the range of tests that were conducted. Results from By PLAXIS 3D analysis showed that acceleration amplification [Profile for tests LST1(P), LST5(P) and LST9(P)] also at all elevations decreased with an increase in surcharge as can be seen from **Figure 6**. The maximum and minimum acceleration amplification from PLAXIS 3D was 4.27% and 12.50% higher than the shake table model test respectively.

4.2. Displacement profile

Figure 7 depicts the normalized displacement profile for different base accelerations of 0.05g, 0.10g, 0.15g and 0.20g. The tests are LST1, LST2, LST3 and LST4. By PLAXIS 3D analysis showed that displacement [Profile for tests LST1(P), LST2(P), LST3(P), and LST4(P)] also at all elevations acceleration variation was directly proportional as can be seen from **Figure 7**. From the same figure, it can also be observed that the maximum displacement was 0.280 mm at an acceleration of 0.20 g, whereas it decreased to 0.088 mm at an acceleration of 0.05 g. The maximum and minimum displacements from PLAXIS 3D were 12.00% and 10.00% higher than the shake table model test respectively.

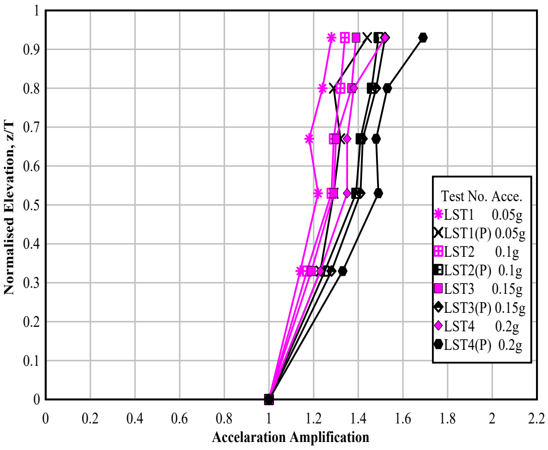

Figure 5. Effect of base acceleration.

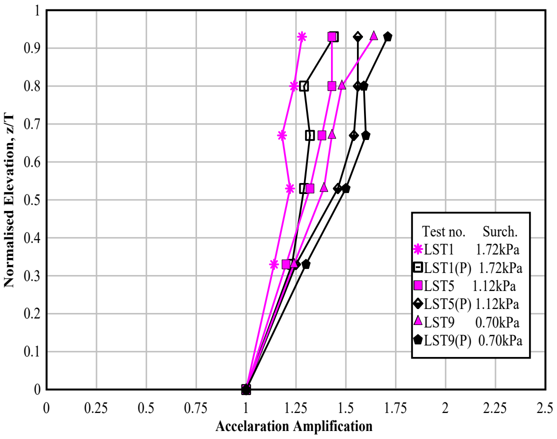

Figure 6. Effect of surcharge.

The normalized displacement profile for tests LST1, LST5 and LST9 which were conducted at 0.05g base acceleration were providing an insight into the effect of different surcharge loadings of 1.72 kPa, 1.12kPa and 0.7kPa as shown in **Figure 8**. It was observed that the displacement response against surcharge variation was inversely proportional at all elevations. The maximum and minimum displacements from PLAXIS 3D were 9.68% and 10.00% higher than the shake table model test respectively. **Figure 9** shows the PLAXIS output result.

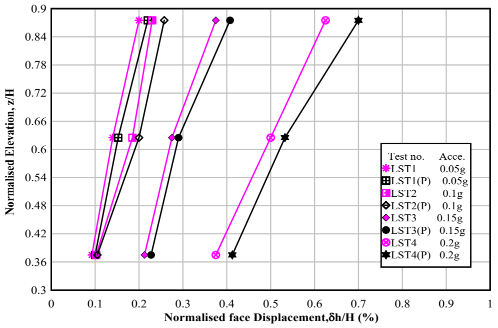

Figure 7. Effect of base acceleration (Disp.)

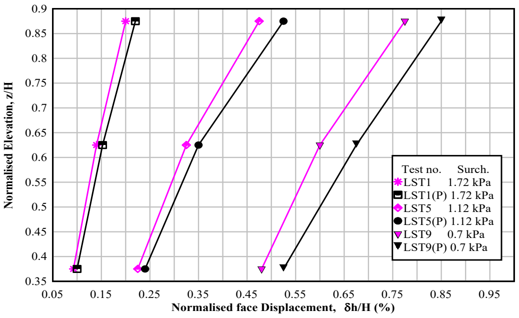

Figure 8. Effect of surcharge (Disp.)

5. Conclusion

This paper presents an analysis of the behavior of wrap-faced embankments on soft clayey soil. The tests revealed that acceleration amplifications increased with higher base accelerations, and the accelerations at the top of the wall were inversely proportional to the surcharge pressures. Additionally, displacement at all elevations varied directly with acceleration, and the experimental results were found to be lower than the numerical results obtained using PLAXIS 3D, with deviations of less than 5% in all cases. These findings are valuable for planning the construction of large wrap-faced embankments on soft soil following a 200-meter pilot project. The design specifications, incorporating dynamic loading considerations for this type of wrap-faced embankment (such as for railway and road embankments), will be accelerated based on these results.

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