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Experimental Investigation of Dynamic Behaviour of Retaining Wall

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ABSTRACT

The civil engineering infrastructures such as building, retaining wall, bridge, abutments may be vulnerable to catastrophic failure during earthquake. Earthquake has caused permanent deformation of these retaining structures. Post-earthquake surveys have revealed that many retaining walls suffered damage due to large displacement. The displacement of retaining wall becomes another important consideration in earthquake prone areas as retaining walls have been observed to fail by displacement away from the backfill. The knowledge of behaviour of this retaining wall under dynamic loading plays a very important role in the design of retaining walls in earthquake prone region.

Studies related to the behaviour of any model under seismic excitation can be categorized through carrying out model test, use of analytical/numerical model to simulate ground behaviour and application of the above concept in the field behaviour. Shaking table have the advantages of well controlled large amplitude, different axis input motion, easier experimental measurements to validate the numerical result. Many Researchers have investigated about the stability of the retaining wall under dynamic condition by computing dynamic earth pressure based on pseudo-static and pseudo dynamic approaches Choudhury (2006).

In this study an attempt has been made to investigate the behaviour of retaining wall under static and dynamic condition. Layers of polystyrene sheets are placed between the wall and the backfill soil and its effect is studied. The physical test results are compared with the numerical model which is developed using Finite Difference based Program FLAC.

Keywords: *Earth pressure, static load, LVDTs, Accelerometer, physical model .*

INTRODUCTION

Earth retaining structures are common in earthquake region countries and cause lots of damage to the life and properties during heavy earthquake. Thus, to understand the behaviour of retaining structures during earthquake and to design them in static and seismic condition the knowledge of active earth pressure on a rigid retaining wall is necessary. Computer controlled shaking table test were very popular to simulate the destructive effect of generated earthquakes. A number of studies have been carried out by previous researcher to investigate the behaviour of retaining wall in terms of earth pressure, displacement and its utilisation in design. Various conventional based methods based on limit state analysis pseudo-static and pseudo dynamic approaches were proposed by several researchers. Experimental model test, numerical and analytical based solution techniques on the model test have been highlighted in this chapter.

Coulomb (1776) proposed theoretical solution for the determination of earth pressure. This theory involves the consideration of sliding wedge which tends to break away from the rest of the backfill. It takes into account the friction between the wall and the soil by introducing angle of internal friction. The pressure is due to the thrust exerted by the sliding wedge of soil on the back of the wall and will slip along a plane inclined at an angle $\emptyset$ to the horizontal. Coulomb also determined the slip plane by searching for the plane on which maximum force acts. Rankine (1857) developed a formula for the determination of earth pressure on retaining structure. He derived expressions for active and passive earth pressure coefficient considering the soil is in a state of plastic equilibrium. Mononobe-Okabe (1926) has extended the coulomb-Rankine sliding wedge theory introduced general earth pressure theory using pseudo-static method based on coulomb wedge theory for the active and passive earth pressure in a dry cohesionless soil. Mononobe-Okabe equation includes the additional horizontal and vertical seismic inertial forces. The analysis gives the soil forces acting on a wall. Richards and Elms (1979) summarized a series of theoretical and experimental investigations on the seismic behavior of gravity retaining walls. Richard and Elms method is an extension of the Newmark sliding block analysis (1965) to compute the displacement. Richard and Elms stated that the Newmark sliding-block model is shown to be appropriate for displacement-controlled design. Their test results show that "sliding block behavior only takes place after a high limiting acceleration has been passed. Where rotational failure is expected, walls will be stronger than anticipated. Elastic resonance effects are likely to be significant for full-size walls. They also state three important conclusions on seismic behavior of gravity retaining walls: The dynamic soil pressures on gravity retaining walls are greater than those found by M-O method due to the effect of wall inertia. The inertial effects were first introduced in this paper. The point of application of dynamic thrust is at H/2 with uniform distribution of pressure. It is important to design the walls considering the wall displacements. Richard and Elms used Franklin and Chang's result to develop an expression for displacement. This approach determines the wall dimension based on permissible displacement. Richard and Elms did not suggest about the permissible displacement of the wall.

METHODOLOGY

The model wall is backfilled with locally available sand. These materials were subjected to various laboratory tests for their geotechnical characterization. The details are presented in this chapter. The chapter also contains procedure for laboratory model set up, building of model and different instrumentations used along with the test results are highlighted.

Backfill Material: Sand

Locally available air-dried sand available in the laboratory were used as a backfill materials. The properties of the sand is tabulated in table 1 below. Figure 1 shows the test results of shear stress and shear strain of sand from Direct shear test.

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Table 1 Properties of sand

Specific Gravity, G	2.68 mm	Co-efficient of curvature, C_c	3.66
D_{60}	0.14 mm	Maximum dry density	17.84 kN/m^3
D_{50}	0.45 mm	Minimum dry density	15.03 kN/m^3
D_{30}	0.26 mm	Max. void ratio	0.91
D_{10}	0.11 mm	Minimum void ratio	0.61
Co efficient of uniformity, C_u	1.34		

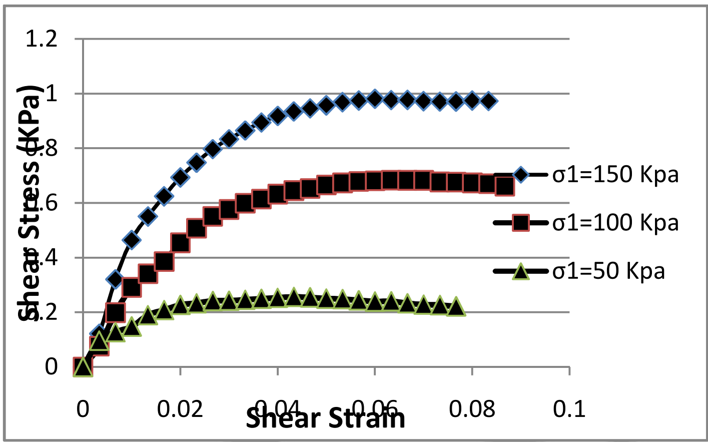

Fig. 1 Shear stress & Shear strain of sand from Direct shear test

MODEL TEST PREPARATION

Rigid Perspex container:

A rigid iron container of size 1200mm× 500mm×930 mm with both sided Perspex sheet attached is used for the test. Model retaining wall of aluminium section is constructed inside this rigid Perspex container monolithically with the plywood sheet placed at the bottom of the container. The main objective of providing this container is to apply the boundary effect.

Preparation of the model

The Model retaining wall consist of aluminium section of size 580 mm× 45mm× 100mm which has been constructed inside the container box of size 1200 mm× 500 mm in plan and 930 mm deep. The container box contains a plywood sheet of size 1000 mm× 580mm× 2mm thick bolted on the aluminium frame. The sides of the container box are made of transparent glass to allow the observation of the model during the test. The thickness of the glass side was 10mm. Wall was constructed using this aluminium section of size 580 mm× 45mm× 100mm by placing in layers one above the other. Three vertical rod of size 10mm ϕ is fixed at the bottom of the plywood sheet which is bolted to the bottom of the plywood base. On the top of the aluminium section three nos. of hole of 10mmϕ is being drilled and inserted one by one through the aluminium rod to form a 600mm high rigid panel of 45mm thickness with a fixed bottom condition.

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On the back of the retaining wall sand is filled inside as a backfill material. To achieve uniform density, sand is placed inside the rigid Perspex container using pluviation (raining) technique. In this technique, the sand was pulvinated through a raining device that is moved to and fro to spread the sand uniformly. This device has a hopper with a pipe an inverted cone at its bottom. The sand passes through the 25 mm internal diameter pipe and disperses at bottom by a 60 inverted cone. The height of fall to achieve the desired relative density was determined by performing series of trials with different heights of fall and maintained same height of fall corresponding to that density. Sand is filled with this technique up to a height of 600mm in ten layers. After filling of each layer black oxide powder is used at the Perspex side to have a black colored line. These black colored lines are provided to observe the failure surfaces during the test.

Sand is filled upto a height of 550 mm from the bottom of the wall. One plywood sheet of size 830mm×580mmm is placed above the backfill materials. Two LVDTs one at the top and another at a depth of 370mm from the top is fixed at the back of the retaining wall to measure the displacement. The schematic views of laboratory arrangements in shown in figures 2 and 3.

Fig. 2 Container box containing Perspex sheet at the side

Fig. 3 Model wall with LVDT fixed at the face of the wall

The experiment has been conducted under static and dynamic loading condition. Under static loading condition (figure 4), two sets of experiment have been conducted, one is by using polystyrene material and the other is without the use of these materials. Polystyrene materials are placed vertically in between the back of the wall and backfill. In case of static loading condition, static load in the form of concrete cube is applied on the top of the backfill material. The displacement response is measured with the help of LVDTs fixed at the back of the wall connected to the HBM instruments. The data are acquired with the help of using HBM software. And then the corresponding displacement in terms of pressure is being plotted. Polystyrene material in between the soil and the back of the retaining wall is vertically inserted and corresponding displacement is also being compared under the same static loading procedure.

Fig. 4 Model wall under static loading

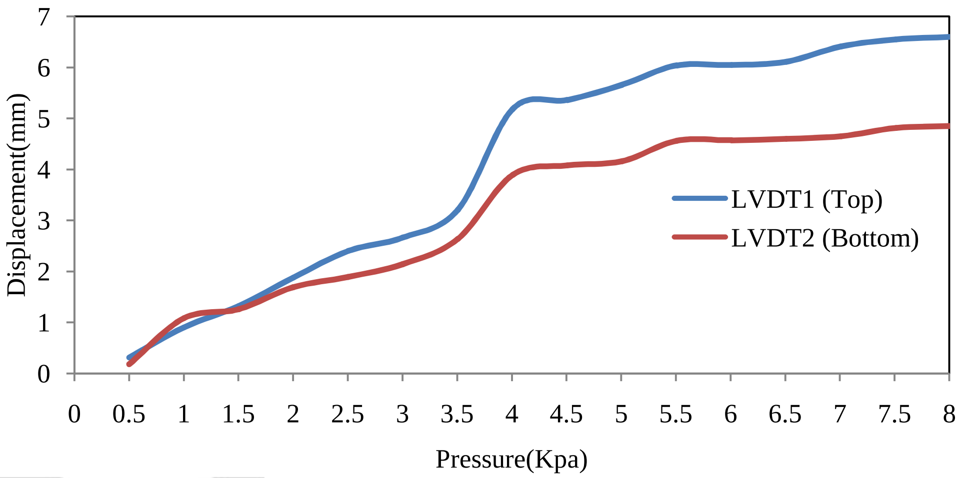

Fig. 5 Pressure vs displacement without the use of geofoam

From figure 5, it can be observed that the maximum displacement at the top of the wall under a pressure of 8 kpa is approximately 7 mm and the corresponding displacement at the bottom under same pressure is approximately 4mm. Thus, the displacement of the wall at the top is more than the displacement at the bottom which itself confirms the theoretical background of the wall.

From the figure 6, it can be observed that the displacement of the wall at the top of the wall is slightly more than 3mm and at the bottom it is approximately 2.5mm in the case of foam using in single layer subsequently from figure 7, the displacement at the top approximately 2.5mm and at the bottom slightly more than 2mm. Thus, with the use of foam the top displacement of the wall is reduced to 50% than the displacement without the use of foam. With the increase in number of layers the displacement is further reduced. Foam can be used as a measure to reduce the pressure acting on the wall.

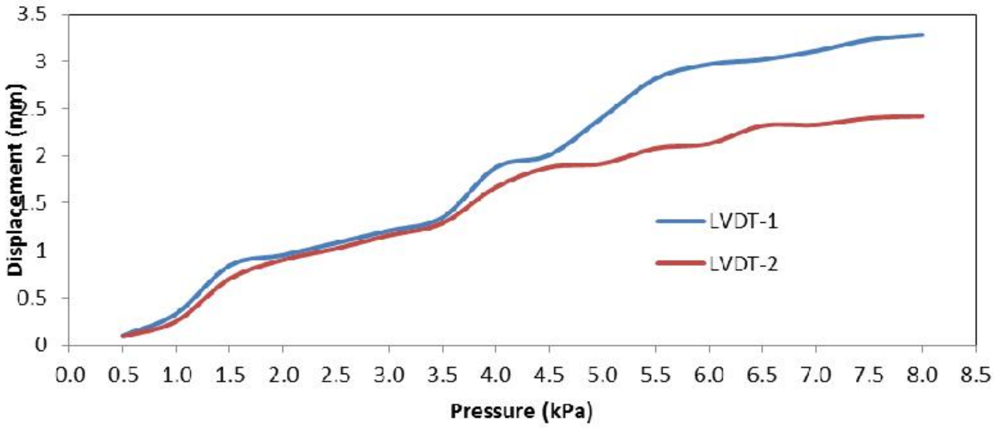

Fig. 6 Plot of Pressure vs. displacement using foam in single layer

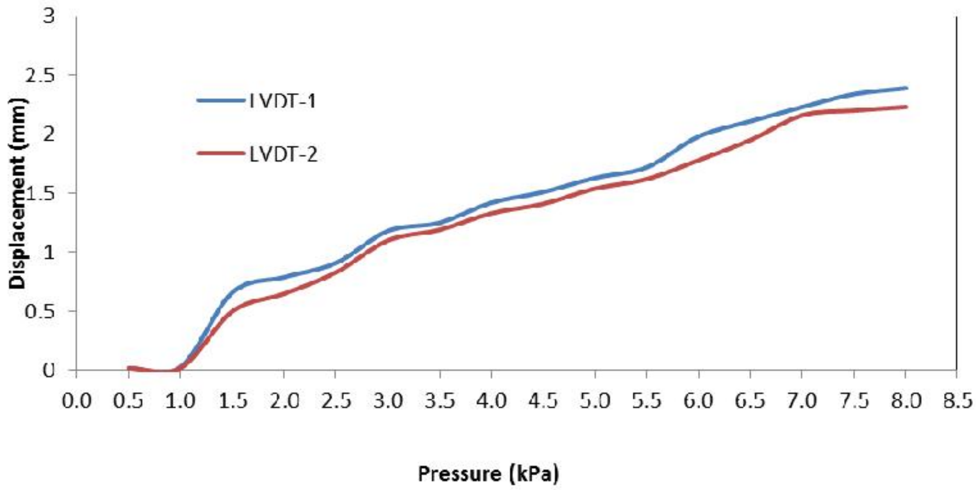

Fig. 7 Plot of Pressure vs. displacement using foam in double layer

Details of Experimental Arrangement for the Model Test

Laboratory test models are excited by Shake Table using time-based earthquake motion. The prescribed earthquake motions are reproducing by digital control system through servo hydraulic system. The responses acquired by accelerometers are recorded and stored in the data acquisition system

Sensors and data acquisition system

Uniaxial accelerometers (Model: ES-U2, make: Kinematics Inc., USA) have been selected for measuring responses of model retaining wall during excitation. These accelerometers can measure acceleration upto±1g it has the facility of amplification and conditioning digital data. The amplified digital data can directly be transferred to compatible data acquisition system. A 48-Channel DAS (Make: HBM Inc., Germany) has been used to record and store the digital data measured by accelerometers.

Testing procedure

The test model has been placed centrally on the table with appropriate clamping. In each test the wall is instrumented with two accelerometers and two LVDTs to record both acceleration and displacement at the top and at the base. Two accelerometers were placed in the backfill one at a depth of 2 cm near the wall and another at the surface. One additional accelerometer was fixed on the table to record the input motion. These accelerometers were connected to DAS (Model: MGC plus, Make: HBM, Germany) for recording model wall response. These input motion data were recorded with the help of data acquisition system and processed through software.

The soil wall system was subjected to an input acceleration slowly increasing with time. Both the table frequency and acceleration were varied until a failure surface is clearly distinguished through the glass surface.

Characteristics of recorded response for the shake table test

Different earthquake ground motion has been considered for subjecting excitation to the test models by the shake table such as El Centro, Parkfield earthquake etc.

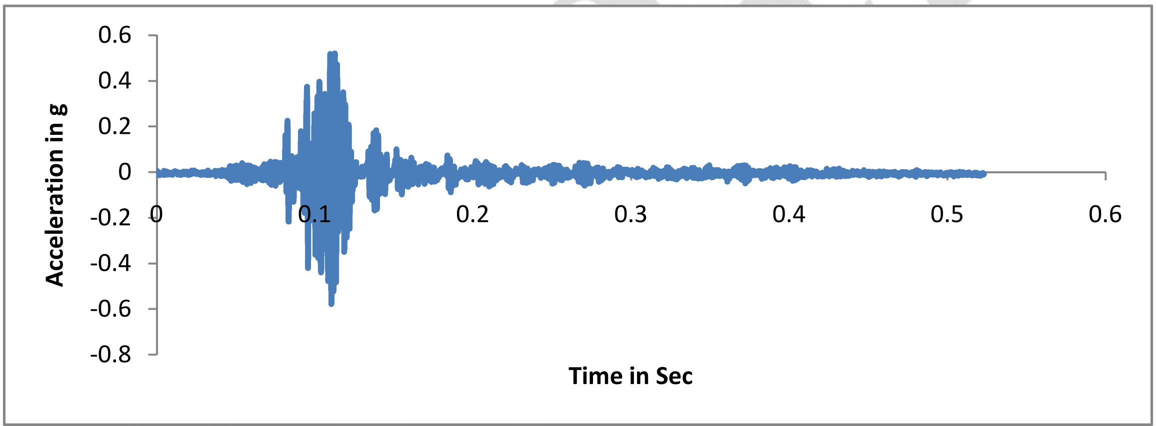

Fig. 8 Input acceleration for Park Field (1966)

From figure 8, it can be seen that park field data is considered as our input motion for the retaining structure. It consists of maximum PGA near about 0.4g and maximum frequency content lies in the range of time between 0.08 sec to 0.12 sec. corresponding output motion for the retaining structure are shown below.

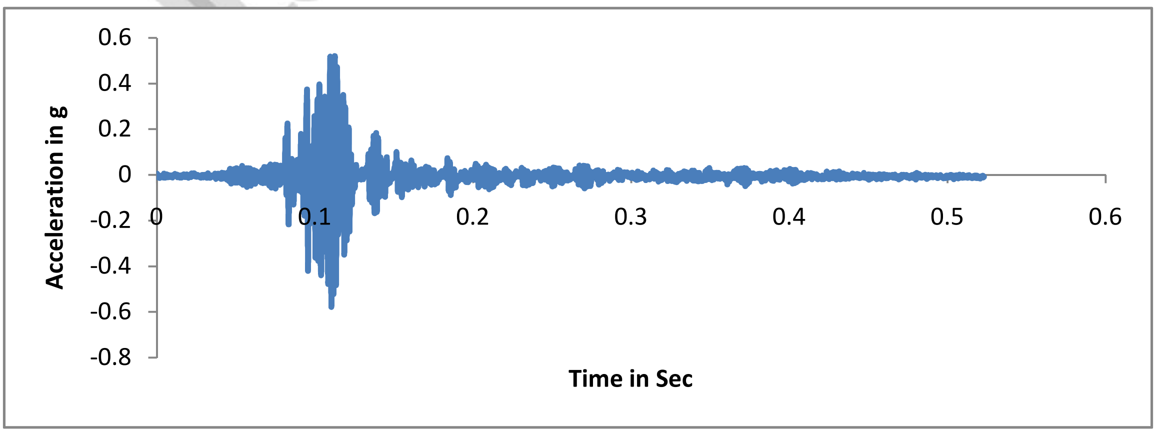

Fig. 9 Response near the wall

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The corresponding signature of the response is almost same as the input data, having peak ground acceleration of 0.6g.

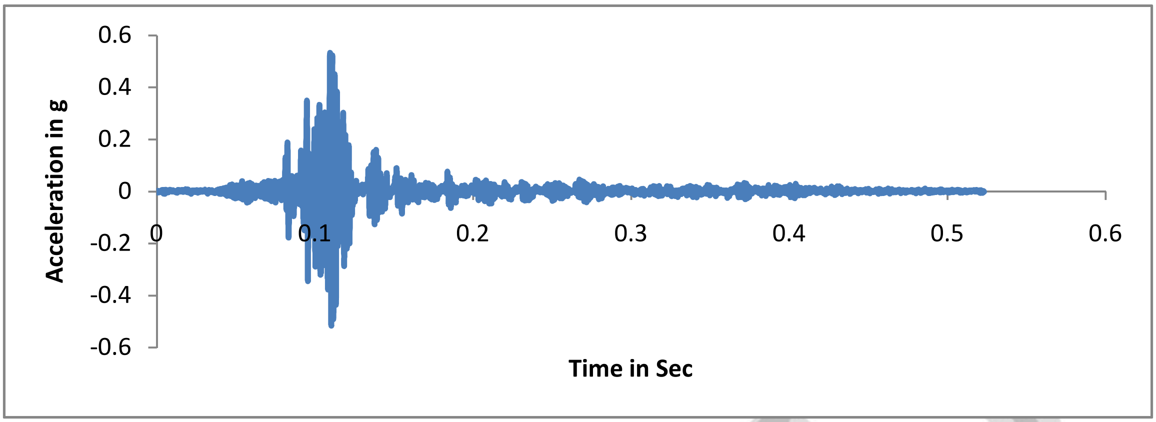

Fig. 10 Response far end of the wall

The corresponding response at the far end of the wall is approximately 0.5g. Thus, it has been observed that the peak ground acceleration near the wall is more than the acceleration at the far end the retaining wall.

The output response shows the same pattern as the response near the wall and is slightly more than the input motion.

Thus, it can be stated from all the input acceleration and corresponding responses that the acceleration near the wall where accelerometer is placed at a depth of 2cm is more than the surface responses at the surface.

Displacement response

The following figure showed the displacement responses at the top and bottom of the wall corresponding to a given input motion. The details of the input motion are same as the earlier one. For the given ground motion the displacement at the top of the wall is 1.5mm

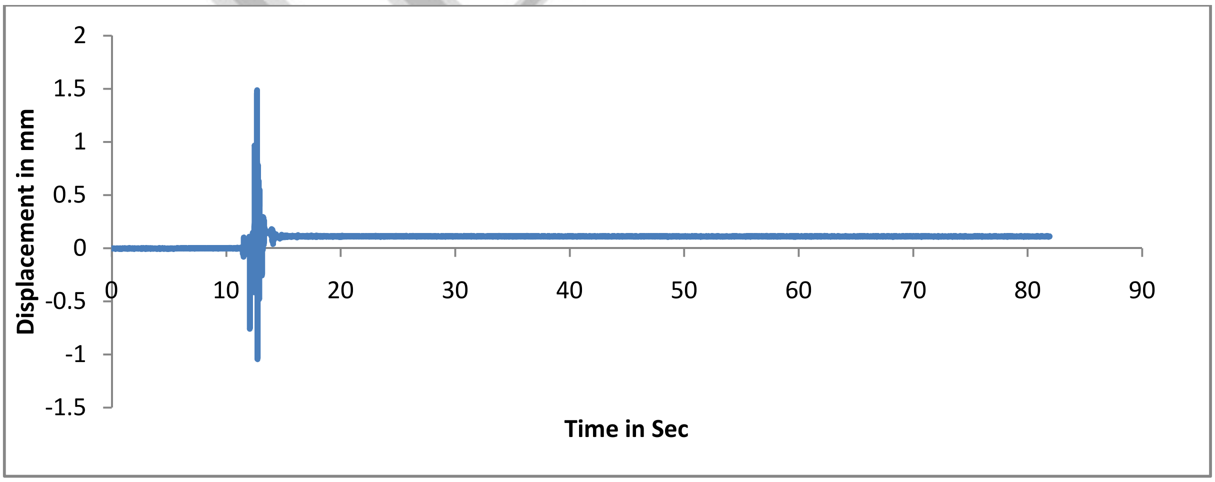

Fig. 11 Displacement of the wall at the top

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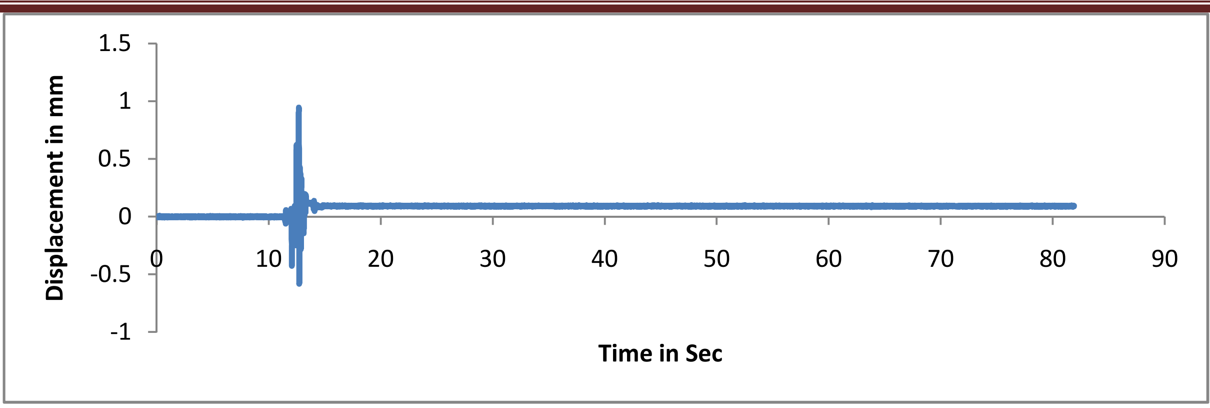

Fig. 12 Displacement of the wall at the bottom.

Displacement of the wall at the bottom is about 0.9mm. For the given input motion displacement at the top is more than the displacement at the bottom. Thus, it can be stated that the wall is oscillating more at the top than at the bottom.

Another input data for Kobe Earthquake has been considered and the displacement response observed at the top of wall displacement is about 1.56 mm (figure 13) approximately and the bottom displacement is 1mm (figure 14).

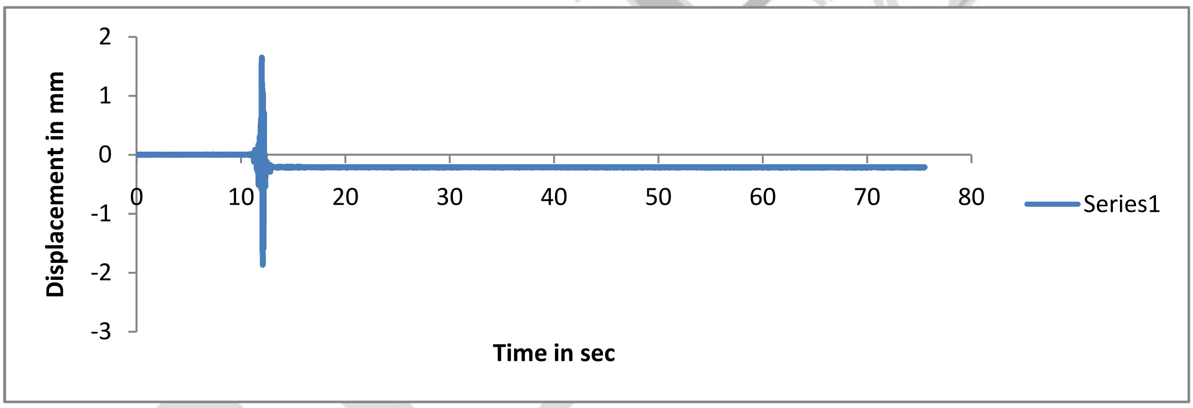

Fig. 13 Displacement of the wall at the top

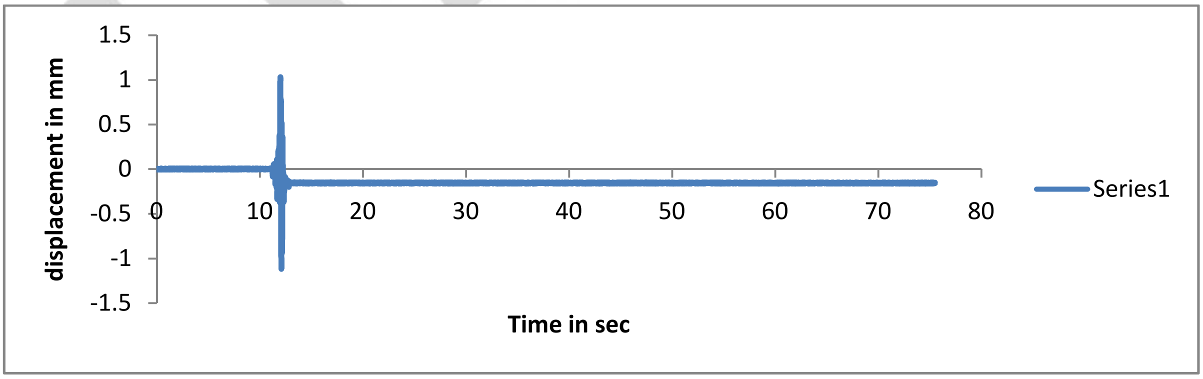

Fig. 14 Displacement of the wall at the bottom

Another sinusoidal input motion has been imparted and it can be observed from the graph that the pattern of displacement response is same with a maximum top displacement of approximately 0.08mm and a bottom displacement of about 0.05mm.

CONCLUSION

In static loading condition since the wall displacement is less the distribution of earth pressure is minimum and irregular. Since there is not such major displacement of the retaining wall shearing resistance has not been mobilized completely. It has been observed that displacement at the top of the wall is more as compared to the displacement at the bottom which confirms the theoretical background for the structure. It has also been observed that with the use of polystyrene material the displacement of the wall is reducing and showing same pattern of deflection. During dynamic condition top displacement presents large amplitude oscillation due to the top of wall moving back and forth during shaking. It has also been observed that the acceleration of the soil goes on increasing with depth. Finally, the behaviour of the model retaining wall under dynamic loading is basically translational. It was observed that base sliding occurred during the dynamic test. Acceleration required is high for backfill to have a failure surface.

REFERENCES

1. Bathurst, R.J., Zarnani, S. and Gaskin, A. (2007). “Shaking table testing of geofoam seismic buffers”, Soil Dynamics and Earthquake Engineering, Elsevier, 27, 324–332.
2. Bhattacharjee, A. and Muralikrishna, A. (2011). “Behavior of gravity retaining walls subjected to seismic excitation using FLAC 3D, International Journal of Earth Sciences and Engineering, 4(6), SPL, 71-74.
3. Chandrasekaran, S.S., Boominathan, A. and Dodagoudar, G.R. (2010). “Group Interaction Effects on Laterally Loaded Piles in Clay”, Journal of Geotechnicaland Geoenvironmental Engineering, Vol. 136, No. 4, 573–582.
4. Choudhury, D., Nimbalkar, S.S. and Mandal, J.N. (2006). “Comparion of pseudo-static and pseudo-dynamic methods for seismic earth pressure on retaining wall”, J. Ind. Geophys. Union, 10(4), 263-271.
5. Choudhury, D. and Chatterjee, S. (2006). “Dynamic active earth pressure on retaining structures”, Sadhana, 31(6), 721–730.
6. Choudhury, D. and Chatterjee, S. (2006). “Displacement – based seismic active earth Pressure on Rigid Retaining walls”, EJGE paper, 1-9.
7. Choudhury, D. and Nimbalkar, S.S. (2008). “Seismic rotational displacement of gravity walls by pseudo-dynamic method”, Intl. J. of Geomech., 8(3), 169-175.
8. Ghanabari, A. and Ahmadabad, M. (2010). “Active earth pressure on inclined retaining walls in static and pseudo static conditions”, 159-173.
9. Giarlelis, C. and Mylonakis, G. 2011. “Interpretation of dynamic retaining wall model tests in light of elastic and plastic solutions”, Soil Dynamics and Earthquake Engineering 31 (2011) 16–24.
10. Hatami, K. and Bathurst, R.J. (2000). “Effect of structural design on fundamental frequency of reinforced-soil retaining walls”, Soil Dynamics and Earthquake Engineering, Elsevier, 19, 137-157.

11. Hatami, K. and Bathurst, R.J. (2005). "Parametric analysis of reinforced soil walls with different backfill material properties", 1-13.

12. Koseki, J., Munaf, Y., Tatusoka, F., Tateyama, M., Kojima, K. and Sato, T. (1998). "Shaking and tilt table tests of geosynthetic-reinforced soil and conventional-type retaining walls", Geosynthetics Internationals, 5(1-2),

13. Krishna, A.M. and Latha, G.M. (2012). "Modeling the Dynamic Response of Wrap-Faced reinforced soil retaining walls", International Journal of Geomechanics, ASCE,12(4), 439-450.

14. Mandal, T., Jadhav, R., Tank, J., Bhagat, B. and Deshmukh, V.B. (2011). "Behavior of retaining wall under static and dynamic active earth pressure", International Journal of Earth Sciences and Engineering, 4(6), SPL, 107-112.