Evaluation of Seismic Earth Pressure Reduction using EPS Geofoam

Evaluation de la réduction de la poussée sismique en utilisant du Polystyrène Expansé

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ABSTRACT: Retaining structures are designed to withstand lateral pressures due to backfill, surcharge load from adjacent structures and traffic and earthquake loads. The cost of these structures is directly proportional to the earth pressures they are subjected to. Several techniques have been tried in the literature to minimize the earth pressure exerted on retaining walls. Among them, use of geofoam as a compressible inclusion placed at the wall-backfill interface, is found to be a simple and effective solution, based on preliminary studies. However, behaviour of EPS geofoam and its influence on the earth pressure reduction under seismic loading conditions are not well understood, and need to be investigated further. In the present study, small scale physical model tests were performed on an instrumented retaining wall subjected to 1-D shaking, to evaluate earth pressures on the wall and to assess effectiveness of EPS geofoam to reduce seismic earth pressures. Firstly, static surcharge loading was applied in order to evaluate magnitude and distribution of earth pressure. Further, under maintained surcharge, a seismic load in the form of a stepped sinusoidal wave from 0 to 0.7 g was applied in increments of 0.045 g, each increment being applied for 5 seconds at 3 Hz frequency. The experimental results indicate that the earth pressures under the influence of a seismic load show an increase of the order of 23%. Moreover, by using the geofoam as a seismic buffer, it was observed that the total seismic force on the retaining wall reduced by about 23% with a corresponding reduction in maximum lateral thrust by 27%.

RÉSUMÉ : Les structures de soutènement sont conçues pour résister à des pressions latérales dues au remblai, à la surcharge de structures adjacentes, au traffic et aux charges sismiques. Plusieurs études ont été réalisées dans la littérature minimiser la pression des terres sur des murs de soutènement. Dans la présente étude, des expérimentations ont été exécutées sur un mur de soutènement instrumenté pour évaluer la pression des terres et l'efficacité du Polystyrène, sous sollicitation sismique générée par une table vibrante 1D. Premièrement, une surcharge statique était appliquée afin d'évaluer la distribution de la pression des terres. Puis, sous la surcharge maintenue, une charge sismique sous forme de vague sinusoïdale de 0 à 0,7 g était appliquée par paliers de 0,045 g, chaque augmentation étant appliquée pendant 5 secondes à 3 hertz de fréquence. Les résultats expérimentaux indiquent que les pressions des terres, sous l'influence d'une charge sismique montrent une augmentation de l'ordre de 23%. De plus, avec le polystyrène comme amortisseur sismique, on a observé que la force sismique totale sur le mur de soutènement diminue d'environ 23% avec une réduction de la poussée latérale maximum de 27%.

KEYWORDS: seismic load, earth pressure reduction, geofoam, shake table

1 INTRODUCTION

Earth-retaining structures are integral part of many infrastructure projects, and underground urban construction to retain soil on one of its sides. Rigid retaining walls are commonly found in basements, bridge abutments, box culverts etc. and they cannot be entirely replaced by reinforced soil walls. Lateral pressure acting on rigid retaining walls due to backfill, surcharge load from adjacent structures and loads due to traffic and natural calamities like earthquake etc. decides their sectional dimensions. Intensive earthquake loading, which impose larger forces compared to that of static active or at-rest conditions. The geotechnical profession has been constantly working for a viable solution to reduce the earth pressures exerted on retaining walls, which would eventually reduce the construction cost of the wall, and post-construction maintenance cost. A technique of placing a compressible inclusion at the soil-wall interface has come into existence to minimize earth pressures on retaining walls. Previous research studies indicate that provision of a compressible inclusion behind a rigid non-yielding/limited yielding or yielding wall would contribute to the economical design of the wall by imparting controlled yielding in the backfill material. Deformations in a retained soil mass mobilize a greater portion of the available shear strength of the material and decrease the unbalanced lateral forces acting on the retaining structure.

2 REVIEW OF LITERATURE

Among all the methods, provision of a compressible inclusion in the form of Expanded Polystyrene (EPS) geofoam at the wall-backfill interface proved successful because of ease in construction and predictable stress-strain characteristics of the inclusion. In the past, studies were conducted with materials such as glass-fiber insulation (Rehnman & Broms, 1972) and cardboard (Edgar et al., 1989) for similar applications. However, they were not successful, as their stress-strain behavior was unpredictable and uncontrollable. On the other hand, Expanded Polystyrene (EPS) geofoam is considered as a suitable material as it fulfills the required stress-strain behavior and has smaller stiffness than any other geofoam materials. Additionally, Horvath (1997) documented 30 years of proven durability of EPS geofoam in several geotechnical applications.

A field study on reduction in lateral earth pressure behind rigid wall by using compressible geo-inclusion has been reported by Partos and Kazaniwsky (1987). Using instrumented model studies, McGown et al. (1988) demonstrated significant reduction in lateral earth pressure even below active earth pressure, when soil was allowed to yield in a controlled manner.

Karpurapu and Bathurst (1992) used a non-linear finite element analysis to simulate the controlled yielding concept for static load and concluded that compressible inclusion with t=0.01h (t – thickness of compressible inclusion, h – height of the wall) would provide active stress conditions in the backfill, if the stiffness of the compressible inclusion is sufficiently small.

Experimental investigations of the concept of reduction of seismic load on the retaining wall in the presence of geofoam inclusion were performed by several researchers on reduced scale models tested on shaking table (Hazarika et al. 2002, Bathurst et al. 2006, Zarnani and Bathurst 2007). Hazarika et al. (2002) showed reduction in the peak lateral loads in the range of 30% to 60% compared to that on an identical structure but with no compressible inclusion. Zarnani and Bathurst (2007) noticed that the magnitude of dynamic lateral earth force was reduced with decreasing geofoam modulus. Horvath (2010) highlighted compressive stiffness as the single most important behavioural characteristic of any compressible inclusion influencing the reduction. Athanasopoulos–Zekkos et al. (2012) observed that EPS of 20 kg/m^3 density and relative thickness (t/h) of 15% to 20% can reduce the seismic pressure by up to 20%, and the seismic displacement of the wall by up to 50%, depending on shaking intensity and height of wall.

The available literature highlighted that with the use of EPS geofoam, the earth pressures on the rigid retaining walls can even be reduced below the active earth pressures. However, behaviour of EPS geofoam and its influence on the earth pressure reduction under seismic loading conditions are not well understood, especially in the presence of realistic surcharge loads, and need to be investigated further. Hence, the present study is aimed at evaluation of earth pressure under combined surcharge and seismic loading and to assess effectiveness of EPS geofoam, through experimental investigations on small scale models tested on 1-D shaking table facility.

3 EXPERIMENTAL PROGRAM

The physical tests described in this paper were carried out on 1.2 m × 1.2 m shaking table located at the Indian Institute of Technology Bombay. The table has 10 kN payload capacity and is driven by a 100 kN capacity Schenk hydraulic actuator with ancillary controller and PC software. The table was driven in the horizontal direction only, as it is noted that the horizontal component of seismic induced dynamic earth loading is typically the most important loading for the application under investigation. The table can excite the rated payload at frequencies up to 50 Hz and ± 5g. The maximum displacement of the table is ±125 mm. The instrumented retaining wall models were built in a stiff strong box (1.2 m long × 0.31 m wide and 0.7 m high) and bolted to the steel platform of the shaking table. Detailed diagram and pictorial view of experimental set up are illustrated in Figs. 1-2. The model retaining wall was placed at a distance of 0.10 m from one of the ends, allowing 1.1 m as backfill length behind retaining wall. A 15 mm thick stainless steel plate was used as a model retaining wall and was instrumented with 7 diaphragm type earth pressure cells, attached flush with the surface of the wall. The wall was restrained laterally using three universal load cells rigidly connected to the other side of the retaining wall at 125, 325 and 555 mm elevations. One side of strong box was made-up of Plexiglas and other sides of stainless steel. The inside surface of the Plexiglas is covered by 120 mm wide and 60 µm thick greased polyethylene sheet with 10 mm overlap with each other. The combination of friction-reducing membrane and rigid lateral bracing was adopted to ensure that the test models were subjected to plane strain boundary conditions. A plywood sheet was bolted to the bottom of strong box, and a layer of sand was epoxied to the top surface of plywood to create a rough surface, so as to simulate backfill continuity in vertical direction.

A series of experiments were carried out without geofoam and with geofoam inclusion at wall-backfill interface. In all experiments, the sand was backfilled at 68% relative density using portable travelling pluviator (Dave and Dasaka, 2012) and top surface was manually leveled. The actual relative densities achieved in each test during the backfilling were monitored by collecting samples in small cups of known volume placed at different locations. Previous studies of the authors highlighted that EPS panel of density of 10D (10 kg/m^3) and 75 mm thickness (t/H = 0.125) helps in maximum reduction in earth pressure by mobilization of its elastic compression. Hence, EPS panel of 10 kg/m^3 density and dimensions of 700 mm x 300 mm and 75 mm thickness, prepared using hot-wire cutter, was pasted to retaining wall using ABRO tape to have proper contact of EPS panel with retaining wall during the test. Uniaxial compression tests were carried out on EPS samples at an axial strain rate of 10%/minute, and yield strength of the EPS geofoam was found as 29.3 kPa, as shown in Fig. 3.

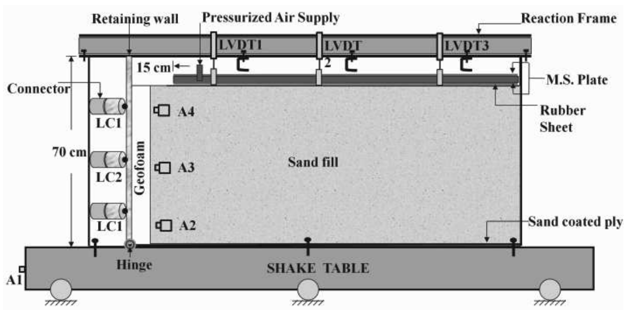

Figure 1. Detailed diagram of experimental setup

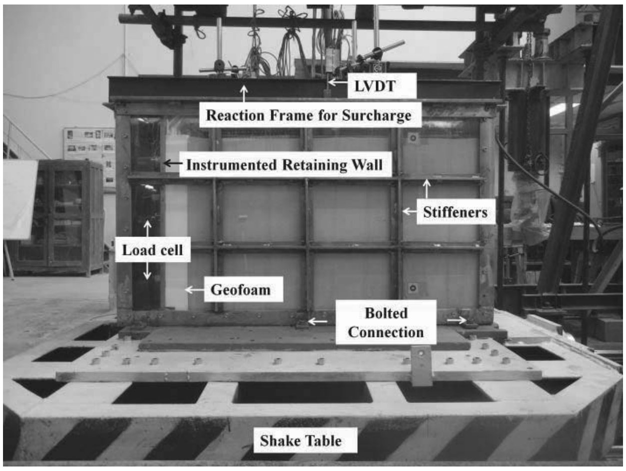

Figure 2. Picotrial view of experimental setup

To apply uniformly distributed surcharge on the backfill, a rubber bellow was placed over an 8 mm thick rubber sheet laying on the surface of the backfill. Specially designed neoprene rubber bellow of 250 kPa capacity with non-return pneumatic valve was connected to a compressor to apply regulated pressure. A steel plate of 10 mm thickness with attachments to measure surface settlement was placed between rubber bellow and rubber sheet and a steel plate of 10 mm thickness was placed on the rubber bellow such that when inflated with compressed air, the plate moved upwards to mobilize reaction from frame, which was rigidly connected to the tank, thereby transferring pressure to the sand fill.

Three LVDTs were used to measure vertical settlement at top of the backfill at 150 mm, 450 mm and 750 mm from retaining wall. The LVDTs were firmly mounted on the reaction frame with magnetic stand and were rested on angles welded on steel plate. Four accelerometers (PCB Piezotronics) were used to obtain acceleration-time excitation history. Out of these, three were embedded in backfill at 100 mm, 300 mm and 500 mm from bottom and one accelerometer was mounted directly on the shaking table to record the input base acceleration–time excitation history, as shown in Fig. 1. The accelerometers were attached to mounting blocks before placing them at desired locations, to ensure that the devices remained level and moved in phase with the surrounding sand during shaking, as shown in Fig. 4.

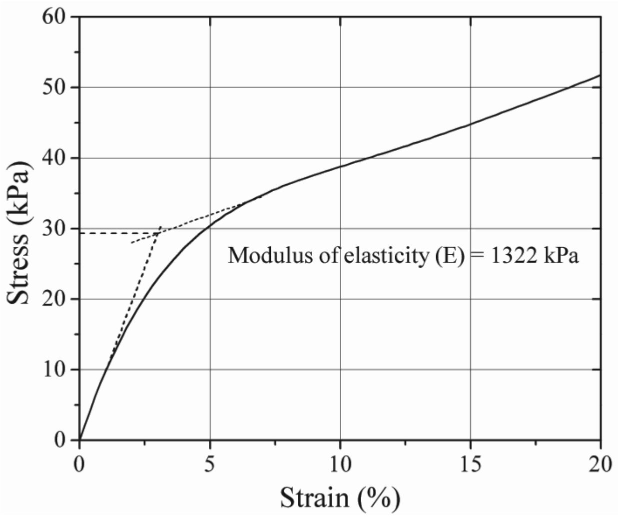

Figure 3. Stress-strain behavior of 10D EPS geofoam

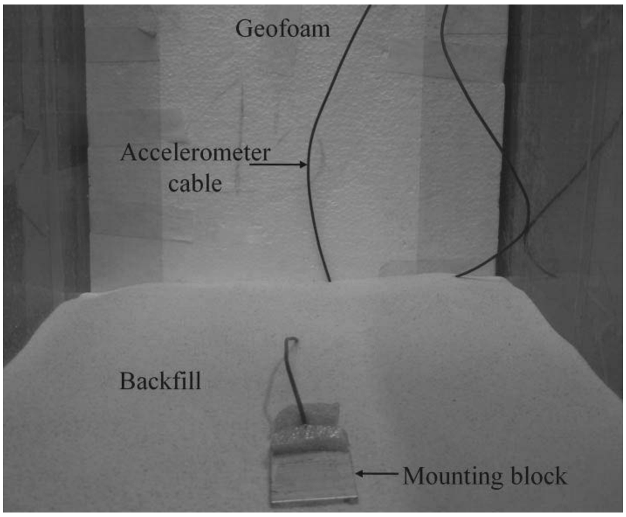

Figure 4. Positioning of Accelerometer in the backfill

The instruments were monitored by a separate high speed data acquisition system (MGC plus – HBM Inc. and Catman professional software). Data from a total of 17 instruments were recorded at a speed of about 100 Hz in order to prevent aliasing and to capture peak response values. After the model preparation was completed, surcharge pressure was applied in increments of 10 kPa up to 50 kPa and corresponding magnitude and distribution of earth pressure were monitored. Further, under maintained surcharge pressure, models were excited using a displacement–time history selected to match a target stepped-amplitude sinusoidal accelerogram with a frequency of 3Hz as shown in Fig. 5. The acceleration record was stepped in 0.045 g increments and each amplitude increment was held for 5 s. The maximum base acceleration was 0.7 g. The above frequency was adopted, as frequencies of 2–3 Hz are representative of typical predominant frequencies of medium to high frequency earthquakes (Bathurst and Hatami 1998) and fall within the expected earthquake parameters for North American seismic design (AASHTO, 2002). This simple base excitation record is more aggressive than an equivalent true earthquake record with the same predominant frequency and amplitude (Bathurst and Hatami 1998, Matsuo et al. 1998). The models were only excited in the horizontal cross-plane direction to be consistent with the critical orientation typically assumed for seismic design of earth retaining walls (AASHTO 2002).

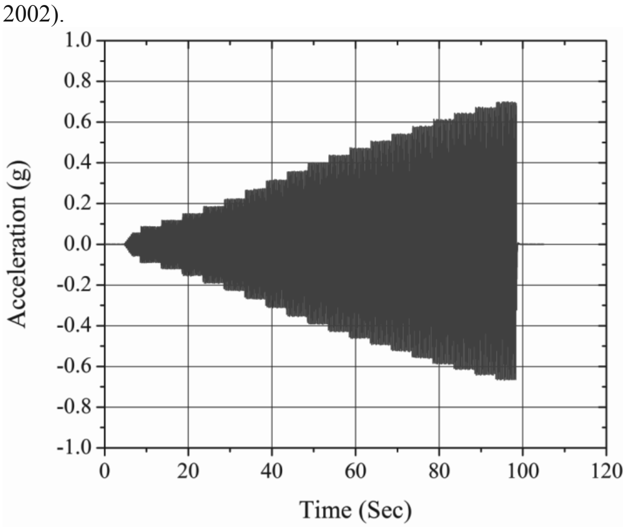

Figure 5. Stepped-amplitude sinusoidal excitation input

4 RESULTS AND DISCUSSION

Experimental evaluation of earth pressure under combined static surcharge and seismic acceleration was carried out for model tests without and with geofoam inclusion. In this paper, results of model tests with 10D geofoam are compared with experiments without geofoam. For the sake of brevity, earth pressure results corresponding to the maximum surcharge load of 50 kPa and seismic loading are only presented here. Under static surcharge load, observed earth pressure distribution was approximately triangular in shape as shown in Fig. 6. However, just above the base of wall, lower earth pressures were observed, this may be due to arching of backfill soil. Experimental evaluation of seismic earth pressure on retaining wall by application of seismic acceleration revealed reduction in the earth pressure in top 1/3 portion of wall, while increase for remaining wall height as shown in Fig. 6.

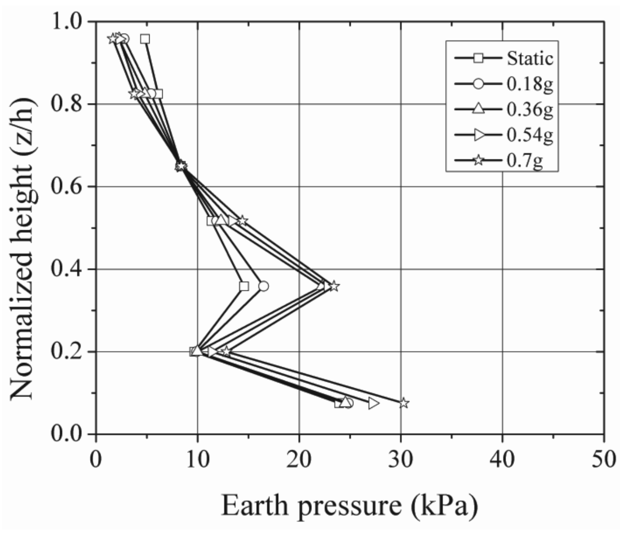

Figure 6. Earth pressure distribution for experiments without geofoam inclusion

During seismic loading, top portion of the wall might have moved sufficiently to achieve active condition, showing reduction in pressure in top portion of the wall; whereas, rest of the wall might not have undergone sufficient displacement, and hence resisted the seismic loading, causing increase in the pressure. The increase in total lateral thrust was negligible for 0.18 g (about 2.36%), however, after 0.36 g, increase in earth pressure was observed throughout the wall height. The total lateral thrust increased with increase in seismic acceleration and the maximum increase in total lateral thrust was observed to be of 23% at 0.7 g. Maximum increase in lateral thrust of 49.5% was observed at about 0.35h from bottom; however reduction in lateral thrust near the top was observed. The observed reduction may be due to sufficient lateral movement of retaining wall, and subsequent mobilization of backfill strength and reduction in effect of surcharge load due to wall movement as shown in Fig. 6.

Earth pressure distribution with geofoam inclusion is presented in Fig. 7. The measured total thrust under 50 kPa surcharge pressure was 23.2% less than that on wall without geofoam inclusion. Reduction in total lateral thrust under surcharge loading is attributed to compression of geofoam and associated backfill strength mobilization which resulted in settlement of backfill. As during surcharge load application phase, compression of geofoam had reached its elastic limit, hence further reduction in earth pressure was negligible during seismic loading phase.

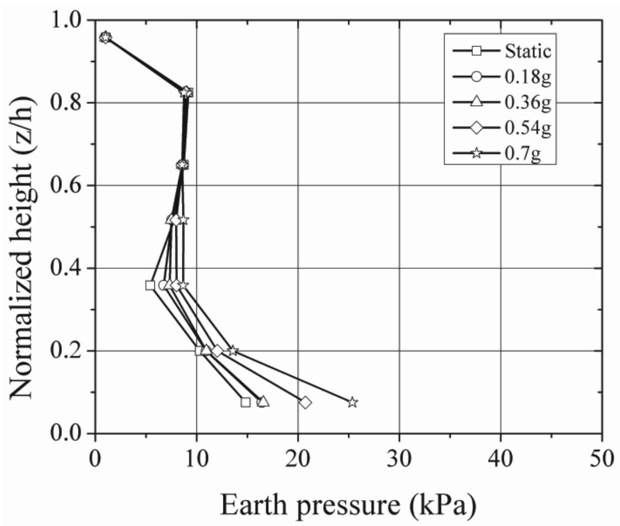

Figure 7. Earth pressure distribution for experiments with geofoam inclusion

Maximum reduction in total lateral thrust under combined loading was 26.9% corresponding to applied seismic acceleration of 0.36 g. At the seismic acceleration of 0.7 g, the reduction in maximum total lateral thrust was about 23%. Experiments with geofoam inclusion showed 54% increase in maximum lateral thrust under seismic loading, though it was 9.75% lower than the corresponding lateral thrust in the absence of geofoam inclusion. The maximum lateral thrust was reduced by 54% due to geofoam inclusion at location h/3 from base of wall. Though, provision of EPS geofoam at backfill-wall interface showed significant reduction in static and seismic loads, due to small scale model studies and associated boundary conditions, the reduction in magnitude of earth pressure was less than that noted from numerical study on a 6 m high wall carried out by the authors.

5 CONCLUSIONS

Following are the salient conclusions derived from the present studies:

- Increase in total lateral thrust was found negligible up to 0.18 g seismic acceleration. However, after 0.36 g, increase in earth pressure and total lateral thrust were observed throughout the wall height.
- Increase in total lateral thrust was observed to be around 23% at 0.7 g with maximum increase of 49.5% at 0.35h from bottom of the wall.
- Provision of EPS geofoam as compressible inclusion at backfill-retaining wall interface reduced the earth pressure under static surcharge loading and combined surcharge and seismic loading by 23.2% and 23%, respectively.
- Maximum reduction in total lateral thrust was found to be 26.9% at 0.36 g seismic acceleration.

6 ACKNOWLEDGEMENT

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