Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Development of Full-Scale Retaining Wall Model to Evaluate Lateral Earth Pressure Reduction using EPS Geofoam

Vikas Patil[1], Mrunmay Junagade[2] and Dasaka S. Murty [3]

[1] Ph.D. Research Scholar, Department of Civil Engineering, IIT Bombay, Mumbai- 400076. Email: saviinfra@gmail.com
[2] Project Research Assistant, Department of Civil Engineering, IIT Bombay, Mumbai – 400076, Email: mrunmay@iitb.ac.in
[3] Professor, Department of Civil Engineering, IIT Bombay, Mumbai – 400076 Email : dasaka@iitb.ac.in

Abstract. Field verification of controlled yielding technique using full-scale retaining wall model is highly important for the design of optimum thickness and density of geofoam for different heights of wall and backfill conditions. In case of walls to be designed for at-rest condition, for locations such as abutment of bridges, culverts, box culverts, basement walls, etc., implementing the controlled yielding technique could substantially minimize lateral thrust on retaining walls and help in all dimensions of retaining wall. This technique consists of placing a compressible inclusion such as Expanded Polystyrene (EPS) geofoam between the retaining wall and backfill and is shown to reduce the lateral thrust on the wall below at-rest condition. The study will present development of a full-scale retaining wall model based on this technique, with the objectives of evaluating optimum thickness and density of geofoam, assessing scale effects and studying long-term creep of the geofoam. Accordingly, a reinforced concrete retaining wall of height 6 m and width 10 m, 4m section with geofoam inclusion, 4m without geofoam is constructed with locally available silty soil proposed for backfilling. This paper aims at presenting an overview of ongoing construction of the model along with required instrumentation setup as well as discussing the challenges encountered.

Keywords: Retaining Wall, Lateral Earth Pressure Reduction, Full Scale Experimental Wall, Geofoam

1 Introduction

Retaining walls are designed to withstand pressures from retained materials, surcharge pressures due to movement of vehicular traffic or loads from foundations of adjacent buildings on their backfills, seismic loading, etc. They may also be vulnerable to catastrophic failures during earthquake due to sudden increase in lateral loads, increase in pore pressures, etc., thus making the appropriate estimation of earth pressures critically important for safe and cost effective designs. Controlling the cross section of retaining walls successfully requires reducing the total lateral thrust acting on the walls. This can be achieved by placing compressible inclusion between wall and the backfill and for this purpose various materials have been examined including

EPS geofoam, tire chips, granulated rubber-soil mixture, soil bags, glass-fiber, cardboard, hay. However, their material behavior is often unpredictable; glass fiber is seen to be over compressible, cardboard and hay are biodegradable with time. Expanded Polystyrene Geofoam is material with predictable stress strain behavior, possesses high strength to density ratio, is weather resistant, light weight, environmentally safe, inexpensive and can be easily shaped or prefabricated (Horvath, 1994). One of the possible methods for lateral thrust mitigation is the Controlled Yielding Technique with Geofoam as compressible inclusion.

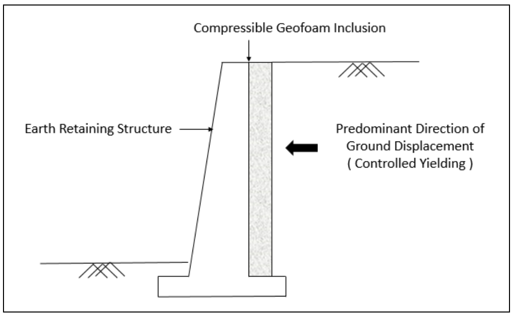

Fig. 1. Illustration of Reduced Earth Pressure Concept (After Horvath, 1998)

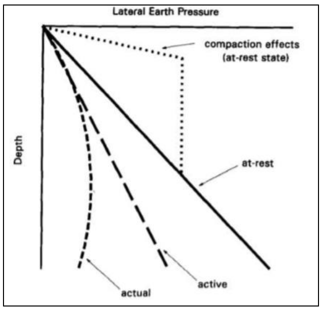

Fig. 2. Illustration of physical behavior of reduced earth pressure (After Horvath 1998)

As shown in Fig. 1, the controlled yielding technique involves installation of a vertical layer of a compressible medium abutting retaining wall and between the wall and backfill so as to allow soil to undergo lateral expansion and bring down lateral pressures to active earth pressures (Horvath, 1998). The lateral expansion of soil depends on stiffness, stress-strain relations and the thickness of the inclusion. Presence of compressible inclusion allows arching to develop within retained soil and consequent mobilization of shear strength of soil, thus causing reduction in lateral thrust. As a result, nonlinear distribution of earth pressures is seen with a peak near mid height of the wall, as shown in Fig. 3.

Small scale studies and numerical studies of using EPS Geofoam as inclusion in backfill have been documented by numerous researchers. Numerical analysis using

FEM approach for different ratios of thickness of geofoam inclusion and wall height has shown that increase in thickness of compressible layers decreased lateral earth pressures (Karpurapu and Bathrust, 1992). Seismic performance analysis of both yielding and non-yielding retaining walls with geofoam using dynamic finite-element analysis suggests that permanent wall displacement under seismic load, decreased steadily with increasing the EPS buffer thickness (Trandafir and Eltugrul, 2011; 2012). Athanasopoulos et al. (2012) and Zisimatou (2009) have reported through validated numerical analysis of yielding, gravity type, earth retaining walls that for both static and dynamic cases, lateral thrusts decreased by using geofoam inclusions. They further noted that seismic isolation efficiency increased in general with increase in geofoam thickness up to a certain limit. Shake table tests on small scale non yielding retaining wall with geofoam backfill show that increase in geofoam thickness leads to higher reduction of earth pressure but becomes constant at higher accelerations (Hazarika, 2003). Similarly, for scaled gravity retaining wall model with combined surcharge and seismic loading it was noted that seismic earth pressure were reduced by more than 28.25% with use of geofoam of density 10 kg/m^3 (Dasaka et al, 2013). Comparison of different geofoam densities in shake table tests shows that lower the EPS Geofoam modulus, greater is the seismic load attenuation (Bathurst and Zarnani, 2007).

Available literature reveals that controlled yielding technique significantly reduces earth pressure on retaining walls under static as well as dynamic loading conditions. However, most of the studies were limited to short term behavior i.e. long-term efficiency of this technique is still under question. Further, the changes in mechanical properties of EPS geofoam in long-term and their effects on lateral earth pressures are not established yet. Murphy (1998) indicated that geofoam creep can have an important influence on compressible inclusion performance as lateral stress were seen to be highest under rapid loading conditions and decrease with time as creep effects become prominent. Secondly, results of scaled experimental and numerical model studies are valid for defined boundary conditions and scaling effects are always possible. It was seen that very limited field studies are reported and the scaling effects, influence of creep on performance of geofoam in this technique are not well defined yet. Thus, keeping in mind the importance of field verification using large scale walls, this study describes the development of full-scale model with cantilever retaining wall of height 6 meters, constructed at Indian Institute of Technology Bombay.

2 Field Set-Up

2.1 Cantilever Retaining Wall

A RCC cantilever retaining wall of 6 m height, 10 m length completely underground was constructed - with 4 m without geofoam, 4 m with geofoam and remaining 2 m for carrying out parametric studies. The wall is designed to act as rigid non-yielding retaining wall presumably subjected to at-rest lateral earth pressures. Height of superimposed load is taken as 1.2m and the extent of backfill is as per the guidelines of IRC 78-2014. Fig. 3 shows the sectional representation of the wall. It is proposed to provide geotextile filter as an alternative to traditional granular material as it may pierce the geofoam inclusion. Sufficient weep holes are provided to ensure dissipation of excess pore pressure. Shear key is provided for provision against sliding along base.

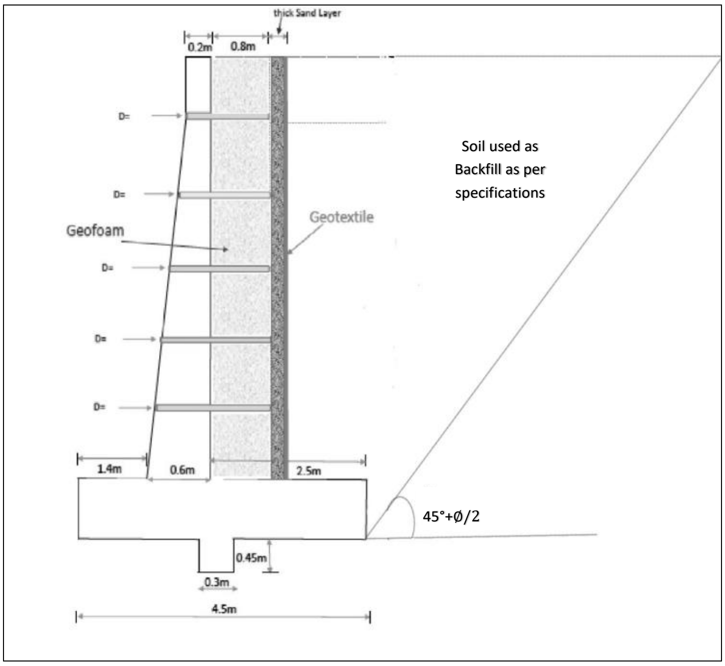

Fig. 3. Sectional view of retaining wall

2.2 Instrumentation setup for wall monitoring

Key aspects of the study involve measuring lateral earth pressures on the retaining wall, quantifying deformation of the geofoam inclusion and finding the tilt of the wall. For above mention goals, earth pressure sensors, laser based displacement transducers and slope inclinometers are to be used respectively.

For the wall to be subjected to at-rest lateral earth pressures, it is necessary to ensure that the wall does not deform. Thus, obtaining slope profile of the wall becomes indispensable for which slope inclinometers are used. Slope inclinometers are geotechnical instruments used to measure horizontal displacements along various points on a borehole; these consist of main components – grooved casings and the probe. In the field model, the casings are to be installed in boreholes within the stem of the wall. These boreholes extend from the top to the bottom of the wall and are constructed by placing vertical pipes of suitable diameters within the wall at concrete pouring stage itself. Wall tilt profile can then be obtained by lowering the probe along the casing. Placing the pipes substantially larger in diameter than the outer diameter of inclinometer is necessary, as the casings can then be grouted firmly into place while ensuring their verticality. Fig. 4 shows a typical inclinometer probe.

Measuring deformation of geofoam in small scale models can be done conveniently with use of potentiometers, strain gauges etc. However, in a full scale model, physical contact to geofoam section is extremely difficult, thus quantifying the deformation along the section is a major challenge. The authors have envisioned using laser based displacement sensors for this purpose. Laser distance sensors are optoelectronic sensors for non-contact displacement and distance measurements. Most commonly, laser displacement sensors operate either according to the time-of-flight measuring principle or phase comparison principle. A typical Laser based Displacement Sensor can be seen in Fig. 5. In the study, lasers from the devices will be targeted on a reflective screen placed at the end of geofoam layer through already provisioned holes with clear line of sight, and based on the transducer output the distance from the sensor to the end of geofoam can be obtained. Successive readings over a period of time from holes along the height of the retaining walls will then give information on deformation of geofoam at different locations.

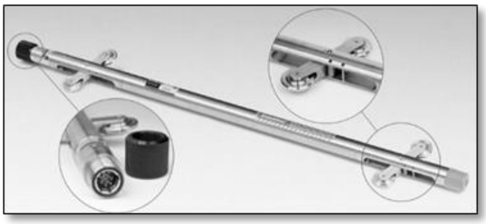

Fig. 4. Slope Inclinometer (After Kyowa Elect. Instruments)

Fig. 5. Laser based Displacement Transducer (After Micro-Epsilon)

2.3 Provisions for Instruments in Wall

In the present standard model of RCC cantilever retaining wall, accounting all possible parametric studies, typical arrangement of weep holes, holes for pressure sensor and laser based displacement transducer are proposed as per guidelines proposed by Lazebnik (1998) for full scale instrumentation as shown in Fig. 6. These holes are created during the casting stage itself by placing PVC pipes of respective diameters. The diameters of holes are chosen such that the cables and the connector pins for earth pressure sensors can be easily extended through the section of the wall. All instruments including data loggers and computer are installed in a portable cabin adjoining the wall to facilitate reliable and continuous data acquisition.

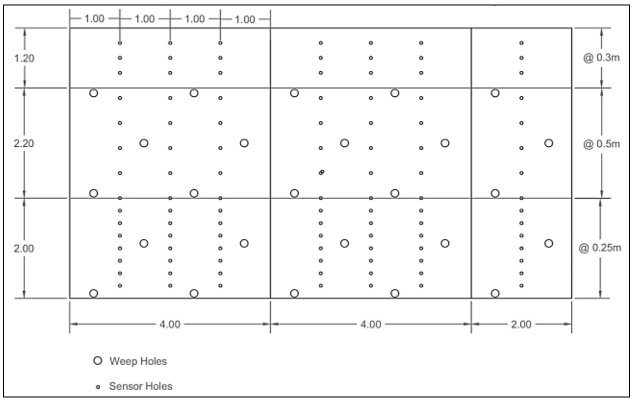

Fig. 6. Arrangement of Weep Holes, Pressure Sensors and Displacement Transducers along the Length of Retaining Wall

3 Material Characterization

3.1 Geofoam

Significant properties of geofoam that influence the selection of its appropriate thickness and density include - Young's modulus (E), compressive strength (σ_c), yield strength (σ_y) and elastic limit of geofoam. Geofoam of densities 15 kg/m^3, 20 kg/m^3 and 25 kg/m^3, designated as EPS15, EPS20 and EPS25 are to be used. Cube specimens are used for evaluating the geofoam properties by static compression test, as suggested by ASTM D7180-05. Typical stress-strain behavior of geofoam and definitions of some of the salient properties from static tests are schematically shown in Fig. 7 .In the present study the compressive load is applied using Servo-hydraulic actuator. Setup of static test of EPS geofoam is show in Fig. 8.

Axial stress corresponding to 10% axial strain from stress-strain curve is defined as compressive strength. Static compression tests were performed on three specimen size of 100 mm x 100 mm x 100 mm of samples of different densities. Average values are reported as specimen properties. Fig. 9 represents a sample axial stress strain response of geofoam sample of density 20 kg/m^3. Average compressive strength of EPS 20 was found to be 87.5 kPa.

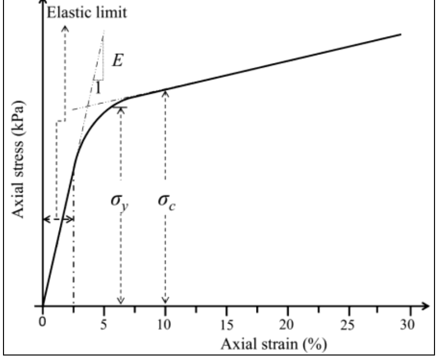

Fig. 7. Mechanical Properties of EPS Geofoam

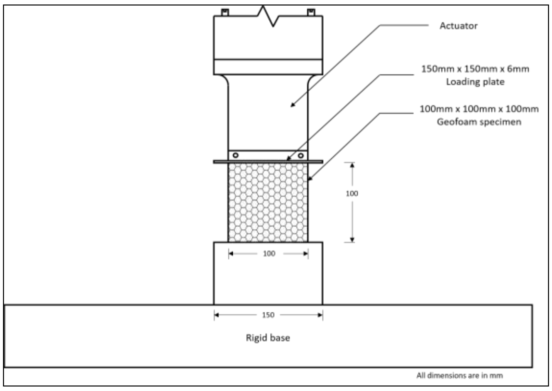

Fig. 8. Experimental Static Test set-up of geofoam.

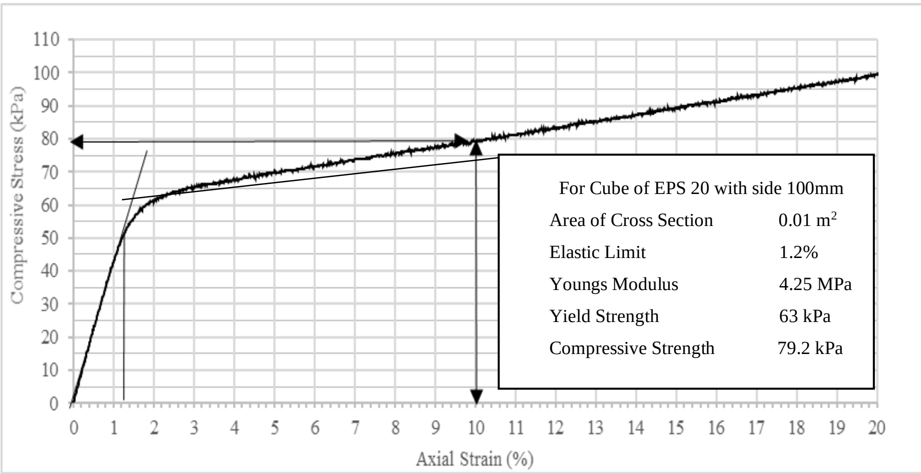

Fig. 9. Axial Stress-Strain response of EPS 20

3.2 Backfill Material

For experimental study, logical choice is to use standardized backfill material, for ex. river sand. However, their use on large scale is a costly affair and they may not e sued in high embankments as it increases cost of the project. Thus, to simulate the field conditions, locally available soil fulfilling the specifications of IRC 78-2014 is decided as sound and more relevant option for backfilling. The soil is identified as Murum / Powai silty soil with cohesion = 54 kPa and angle of internal friction = 20° obtained from direct shear tests on samples prepared at O.M.C and M.D.D. Properties of the soil are listed in table 1. As per guidelines listed in IRC 78-2014 on selection for backfill material, the soil is found to be fair to good for backfilling purposes.

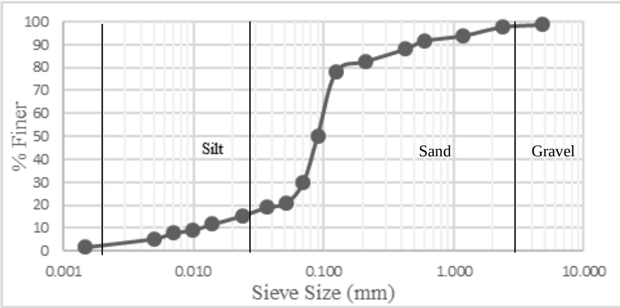

Fig. 10. Particle Size Distribution Curve of Backfill Soil

Table 1. Properties of proposed backfill

Liquid Limit	51%
Plastic Limit	39%
Free Swell Index	0
Field Density	1580 kg/m^3
Water Content	17.44%
Optimum Moisture Content	22.20%
Maximum Dry Density	1620 kg/m^3
Specific gravity of soil solids	2.62
Gravel	≈ 1.2%
Sand	≈ 70%
Fines	≈ 22%
IS Classification	MH (Silt with high porosity)

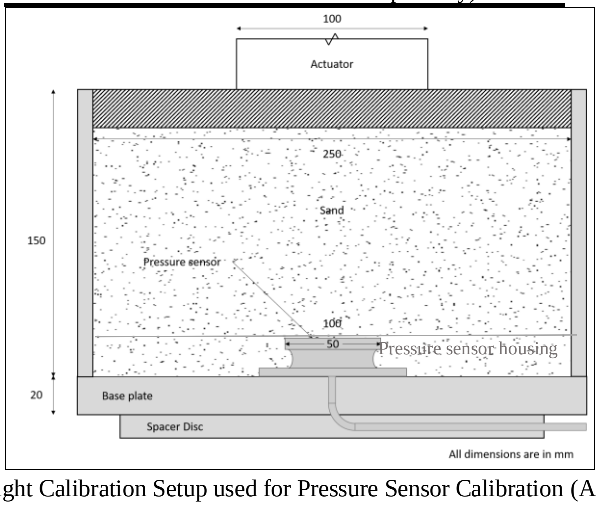

Fig. 11. Dead Weight Calibration Setup used for Pressure Sensor Calibration (After Gade, 2018

4 Calibration of the Earth Pressure Sensors

Earth pressure sensors are widely used for measuring earth pressure on the surface of a structure or in soil and they need to be calibrated near to their intended application conditions (Weiler and Kulhawy, 1982, Selig ET, 1980, Peattie and Sparrow, 1954). Relation between applied pressure and sensor output varies with soil type, soil density and location of sensor, either embedded or boundary (Gade, 2019). The calibration of pressure sensor involves the investigation of the unique relationship between the applied pressure and EPC output response (Labuz and Theroux, 2005). Strain gauge based sensors of capacity 200 kPa are considered for this study. A dead weight calibration set-up (as shown in Fig. 11) previously developed by Gade (2018), was used for calibration of sensors.

The sensors are kept in calibration chamber which is then filled with the soil from field and compacted to the field density. Load is applied on the soil using a Hydraulic Actuator with a loading plate such that a maximum pressure of 170 kPa with a displacement rate of 0.01 mm/s is reached in the chamber. The response of the earth pressure sensors Vs. pressure applied by the actuator gives a unique voltage – pressure relationship for each sensor. The sample is loaded and unloaded three times so as to obtain average calibration factors. A sample graph is shown in Fig. 12

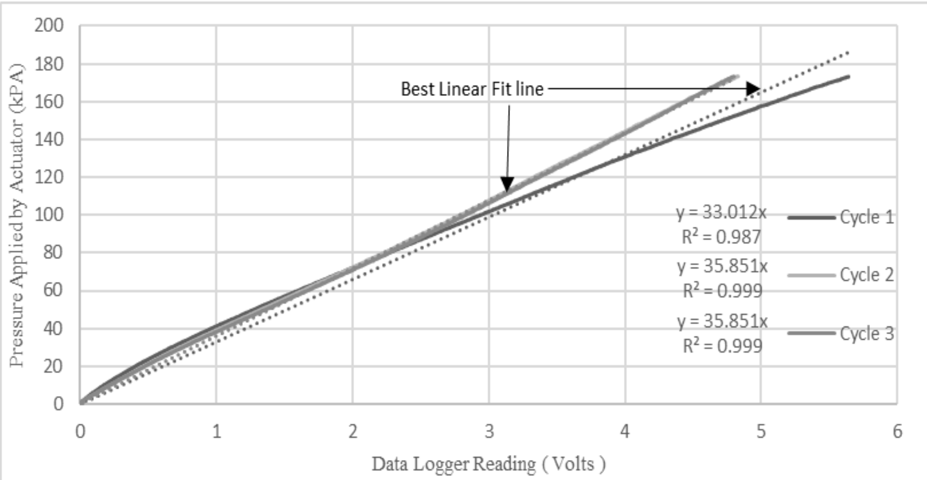

Fig. 12. Response of Earth Pressure Cell vs. Pressure applied by actuator

Literature reveals that strain gauge based sensors pose certain problems, which make them unsuitable for long term use due to drift in zero reference point in strain gauges with passing of time. Furthermore, these sensors respond differently to different soils and densities as well as external temperatures. Hence, it was decided to further use vibrating wire based earth pressure sensors in conjunction with strain gauge based sensors. These sensors consist of two welded plates with cavity between them filled with de aired fluid. Under the external pressure, these plates squeeze the fluid inside. The pressure is then recorded by Vibrating Wire Transducers connected to the cavity. Key benefit of these sensors is very small aspect ratio (typically t/D <0.1) where t is thickness of and D is diameter of the sensor. Tory and Sparrow (1967) noted that for cells with aspect ratios below 0.1, constant over-registration of stresses allow for constant calibration factors. Another advantage over conventional strain based gauges sensors is that Vibrating Wire based sensors are not Susceptible to zero drift over a long period of time and also provide for auto compensation of temperatures due to in built thermistors.

5 Summary

An overview of establishment of full scaled retaining wall model is presented. The model described in this paper will be deployed for achieving the objectives including –to evaluate the scale effects on the earth pressure reduction through full-scale field testing of different heights of retaining walls, to evaluate the long-term creep of the geofoam, and its effect on the earth pressure reduction, to evaluate deformation pattern of retaining wall with and without geofoam, to evaluate distribution of compressive strains in geofoam, to develop design charts for optimum density and thickness of geofoam for achieving maximum earth pressure reduction.

Acknowledgements

The authors would like to thank Indian Institute of Technology Bombay, Ministry of Human Resources Department, Ministry of Earth Sciences, Gov. of India and SAVI Infrastructures, Pune for their support in the project titled "Design and development of advanced yielding technique for static and dynamic earth pressure reduction on retaining structures using compressible geo-inclusions".

References

1. Athanasopoulos, Z. A., Lamote, K. and Athanasopoulos, G. A.: Use of EPS geofoam compressible inclusions for reducing the earthquake effects on yielding earth retaining structures. Int. J. Soil Dynamics and Earthquake Engineering, 41, 59-71, (2012).
2. Bathurst, R. J., Zarnani, S., Gaskin, A.: Shaking Table testing of Geofoam seismic buffers. International Journal of Soil Dynamics and Earthquake Engineering, 27, 324 – 332, (2007).
3. Dasaka S.M., Dave T.N., Khan N., Murali Krishna A.: Evaluation of Seismic Earth Pressure Reduction using EPS Geofoam, Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris, (2013)
4. Ertugrul, O. L. & Trandafir, C. T.: Reduction of lateral Earth Forces on yielding Flexible Retaining Walls by EPS geofoam Inclusions. ASCE, Geocongress, 2068 – 2077, (2012).
5. Ertugrul, O. L., Trandafir, A. C.: Reduction of lateral earth forces acting on rigid non-yielding retaining walls by EPS geofoam inclusions. Journal of Materials in Civil Engineering, 23(12), 1711 – 1718. (2011).

6. Gade V. K. & Dasaka S. M.: Influence of Contacting Material on Calibration Response of Diaphragm Earth Pressure Cells. Indian Geotech Journal, volume 50, pages133–141. (2019).
7. Gade, V. K. & Dasaka, S. M.: Calibration of Earth Pressure Sensors. Indian Geotech Journal, 48(1):142–152. (2018)
8. Hazarika, H., Okuzono, S., Matsuo, Y.: Seismic stability enhancement of Rigid Nonyeilding Structure. Proceedings of the 13th, International Offshore and Polar Engineering Conference, 697 – 702. (2003).
9. Horvath, J. S.: Expanded polystyerene (EPS) geofoam: an introduction to material behavior. Int. J. Geotextiles and Geomembranes, 23, 263-280. (1994).
10. Horvath, J. S.: The compressible inclusion functions of EPS geofoam: An overview of concepts, Applications and products. Res. Rpt. No. CE/GE-98-1, Manhattan Coll. Civ. Engg. Dept., Bronx, NY. (1998).
11. Horvath, J. S.: The compressible inclusion functions of EPS geofoam. Int. J. of Geotextiles and Geomembranes, 15, 77–120. (1997).
12. Karpurapu, R. and Barthurst, R. J.: Numerical Investigation of Controlled Yielding of Soil Retaining wall structure . International Journal on Geotextiles and Geomechanics, 11, 115-131. (1992).
13. Kyowa Electronic Instruments, Manual on Insertion Type Inclinometer, Japan.
14. Labuz J.F., Theroux B.: Laboratory calibration of earth pressure cells. Geotech Test Journal, 28(2):1–9. https://doi.org/10.1 520/GTJ12089. (2005).
15. Lazebnik, G. E.: Monitoring of Soil-Structure Interaction. Instruments for measuring soil pressures, ISBN 978-1-4613-7740-5, DOI 10.1007/978-1-4615—5979-5. (1998).
16. Micro-Espilon, Manual on Laser Based Displacement Sensor.
17. Murphy, G. P.: The Influence of Geofoam Creep on the Performance of a Compressible Inclusion. Geotextiles and Geomembranes, 15, 121-131. (1997).
18. Peattie K.R. and Sparrow R.W.: The fundamental action of earth pressure cells. J Mech Phys Solids, 2:141–155. https://doi.org/ 10.1016/0022-5096(54)90021-6. (1954).
19. Pengpeng Ni, Guoxiong Mei and Yanlin Zhao: Displacement-Dependent Earth Pressures on Rigid Retaining Walls with Compressible Geofoam Inclusions: Physical Modeling and Analytical Solutions. International Journal of Geomechanics, ASCE, (17). (2016).
20. Selig E.T.: Soil stress gage calibration. Geotech Test Journal, 28(2):12089. (1980)
21. Talesnick M. Measuring soil pressure within a soil mass. Canada Geotech Journal, 50(7):1529–1548. https://doi.org/10.1139/cgj2012-0347. (2013).
22. Tory, A.C. & Sparrow, R.W.: The Influence of Diaphragm Flexibility on the Performance of an Earth Pressure Cell. Journal of Scientific Instruments, Vol. 44, No. 9, pp. 781785, (1967).
23. Trandafir, A. C., Bartlett, S. F. and Lingwall, B. N.: Behavior of EPS geofoam in stress-controlled cyclic uniaxial tests. Geotextiles and Geomembranes, 28, 514-524. 3(4):153–158. (2010).
24. Trandafir, A.C., and Ertugrul, O.L.: Earthquake Response of a Gravity Retaining Wall with Geofoam Inclusion. Geo-Frontiers, ASCE, 3177-3185. (2011).
25. Weiler W., Jr., Fred H. Kulhawy,: Factors affecting soil stress cell measurement in soils. Journal of the Geotechnical Engineering Division, Vol. 108, Issue 12, Pg. 1529-1548. (1982).
26. Zisimatou, E.: Seismic isolation of earth retaining walls using EPS Geofoam compressible inclusions-FE numerical analyses. MSc dissertation. Department of Civil Engineering, University of Patras, Greece. (2009).