Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

Earth Pressure Reduction on Rigid Cantilever Retaining Wall Using Inclusions

Swetha Sherin Biju[1], Dr. Beena K S[2] and Dr. Anil Joseph[3]

[1] Cochin Engineering & Consultancy Services Pvt. Ltd.
[2] Professor, Cochin University of Science and Technology
[3] Managing Director, Cochin Engineering & Consultancy Services Pvt. Ltd
Swethabiju1995@gmail.com

Abstract. The present study explores the application of locally available compressible inclusions in reducing the lateral earth pressure acting on the rigid cantilever retaining walls retaining dry and cohesionless backfill. A small scale physical model tests on an 80 cm high retaining wall were performed with the presence and absence of inclusions. The backfill at relative densities of 65%, 50%, 40% and 35% were modelled in the study. The effects of different types of inclusions and relative density of the backfill soil were analyzed. The obtained lateral earth pressure from the study was compared with that obtained using Rankine's theory. It was observed that when the surcharge load and the relative density of the backfill increase, the lateral earth pressure increases and decreases respectively. The results showed that the isolation efficiency of coir fiber was greater than bed waste when used as inclusion

Keywords: Rigid retaining wall; Lateral earth pressure; Inclusions; Physical model tests.

1 Introduction

The ground surface is stable so long as it is horizontal or is characterized by gentle slopes. As soil slopes become steeper, stability reduces. Whenever we need to have a vertical discontinuity in the terrain, we need to support the vertical or near vertical face of the soil. This support is provided by earth retaining structures. Cantilever retaining wall is one of the common types of retaining structures. Typical cantilevered walls are T-shaped, L-shaped, or reverse L-shaped. The pressures exerted on these structures can be divided into three categories: at rest, active and passive earth pressures. Earth retaining structures are designed to withstand lateral pressures due to backfill and surcharge load from adjacent structures and traffic.

Geofoam is a very practical solution for reduction of lateral pressure due to its low bulk weight versus soil bulk weight and high compressibility, thermal insulation and resistance against water absorption. It can be used in retaining walls, road construction projects as light fillers and to reduce stress due to vertical loads in base and sub-base layers. They are also used to reduce stress acting on buried pipelines subjected to consolidation settlements of soils. Lateral earth pressure can be reduced by using geofoam as a lightweight alternative for soil backfill because the relationship between lateral pressure and weight of backfill material is proportional [1].

The present study is done on a motive to analyze the results of small-scale model tests for a rigid wall model with and without compressible inclusions. Effect of relative density of soil and surcharge load was also studied.

2 Experimental Program

2.1 Materials used in the present study

For the present study, Clean, dry sand collected from Aluva was used as the backfill material in the physical model tests. Physical characteristics of the sand are summarized in Table 1 and the grain size distribution curve of the sand is depicted in Figure 1. From the grain size analysis, the soil was classified as SW according to the unified soil classification system. Locally available materials like bed waste and coir fiber inclusions were utilized in physical model tests. The thickness of the bed waste was taken as 3.2cm. Hence, t/H=0.04 (t-thickness of inclusion, H-height of the retaining wall). Coir fiber was filled at a relative density 0.155g/cc.

Table 1. Index Properties of the Backfill Sand

Property	Value
Specific Gravity, G	2.81
Maximum void ratio, e_{max}	0.95
Minimum void ratio, e_{min}	0.69
Minimum dry density, γ_{min}	1.44g/cc
Maximum dry density, γ_{max}	1.65g/cc
Uniformity Coefficient, C_u	6.12
Coefficient of Curvature, C_c	1.42
Angle of internal friction for 65% relative density	39.52^0
Angle of internal friction for 50% relative density	38.65^0
Angle of internal friction for 40% relative density	37.77^0
Angle of internal friction for 35% relative density	36.86^0

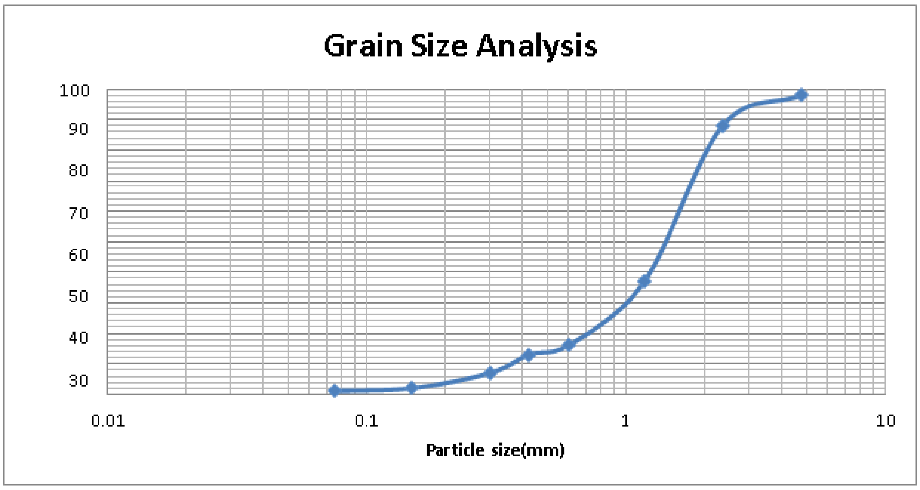


Fig. 1. Grain size distribution curve of the backfill

2.1 Details of experimental model study

Model retaining wall was built using stainless steel of dimensions 900 x 940 x 8 mm rigidly welded to a steel base of 940 x 600 x 8 mm. The retaining wall was placed in a steel tank of dimensions 1000 mm length x 1000 mm width x 1000 mm height. The dimension of the model tank was selected after considering various literatures as listed in Table 2.

Table 2. Dimension of reported laboratory model walls tanks

References	Height H (m)	Width W (m)	Length L (m)	W/H	L/H	W/L
Huey et al. (2008)	0.732	0.45	0.70	0.61	0.96	0.64
Ertugrul et al.(2011)	2.0	1.0	1.0	0.5	0.5	1.0
Juari et al. (2016)	0.95	0.6	0.95	0.63	1.0	0.63
Ni et al.(2017)	1.0	1.0	1.0	1.0	1.0	1.0
Abelsalam et al.(2017)	1.4	0.6	1	0.42	0.71	0.42
Proposed Dimension	1.0	1.0	1.0	1.0	1.0	1.0

The backfill was prepared by sand raining technique to achieve the required relative density 65, 50, 40 and 35% for different experiments. The retaining wall was placed at a distance of 16cm from the face of the model tank. Polyfoam was laid on the side walls of the stiff tank to reduce the boundary effect. This facilitated a smoother interface allowing soil movements in the backfill attributable to the compression of the inclusion in the vicinity of the side boundaries. Lateral supports were installed between the wall stem and the tank as shown in Figure 2 to prevent any lateral deflection and rotation of the wall [3].

Fig. 2. Lateral Supports Provided for the Wall

Three square shaped pressure sensors were mounted at 200mm spacing along the wall height. As per specification, the pressure sensor has an active sensing area of 38.1 x 38.1 mm and a thickness 0.46mm. The sensors were connected with Ardiuno board and recordings were saved to computer. The values were taken at an interval of 1 second. Real time monitoring of pressure was done during the whole duration of load application. Surcharge load was applied using hydraulic jack on a strip of dimensions 94 x 14 x 0.4cm. Load was applied at a distance of 34cm from the face of the retaining wall. The load was measured at 2, 4, 6, 8, 10, 12, 14 and 16kN. The loads were increased after the top settlements measured from dial gauge became constant value. Two dial gauges were placed on the strip to measure the top displacements and also on the face of the wall to measure the wall movement. Upon the completion of the backfilling process, the data acquisition system was activated to record wall pressures. Schematic diagram of test setup showing positions of pressure sensors are shown in Figure 3.

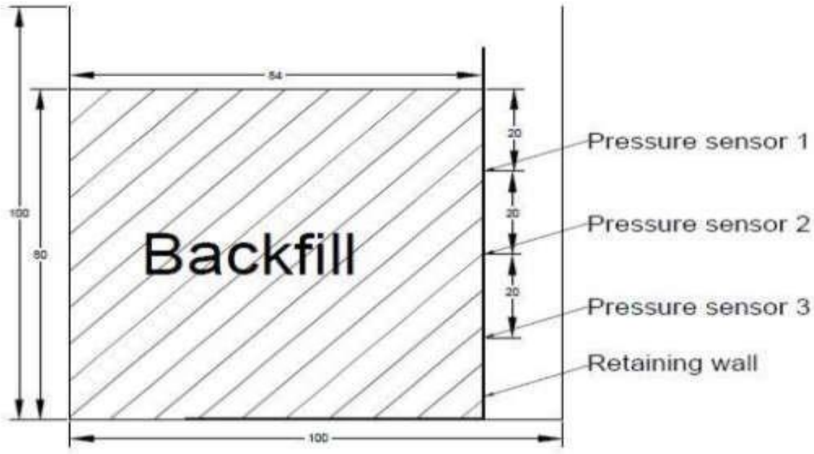


Fig. 3. Schematic Diagram of the Test Configuration (All Dimensions in cm)

3 Results and Discussion

Twelve model tests were conducted in the physical modelling study. Initially, lateral stresses on the wall stem in the absence of inclusions were measured with varying relative density of the backfill (65%, 50%, 40% and 35%). In other test groups includes two different types of inclusions (bed waste and coir fiber) installed behind the rigid retaining wall model. The experimental setup failed at 16kN, 14kN, 12kN and 10kN for 65, 50, 40, 35% relative density respectively.

The figure 4 shows the variation of lateral earth pressure along the depth of retaining wall for different values of relative densities of backfill (say 65%, 50%, 40% and 35%) under incremental loading. A clear trend is observed with different values of applied load and relative density of backfill. It indicates that both the parameters influence the magnitude of the active earth pressure significantly but not the shape of its distribution. The trend of the graph is in such a way that the maximum value occurs at the middle depth of the retaining wall having 0.8m height and decreases after attaining the peak value. This is due to the interface friction occurring at the wall base and backfill. As different relative density backfill fails at different loads, the graphs were drawn only for loads till 10kN for comparison. From figure 4(a), in the case of 65% relative density the value of earth pressure increases from 2.35kPa for rest condition to about 18.5kPa for 10kN at 0.4m depth of backfill. From figure 4(d), in the case of 35% relative density the value of earth pressure increases from 2.94kPa for rest condition to about 21.45kPa for 10kN at 0.4m depth of backfill. Hence from these graphs, it can be inferred that as the load on the backfill increases the lateral earth pressure also increases.

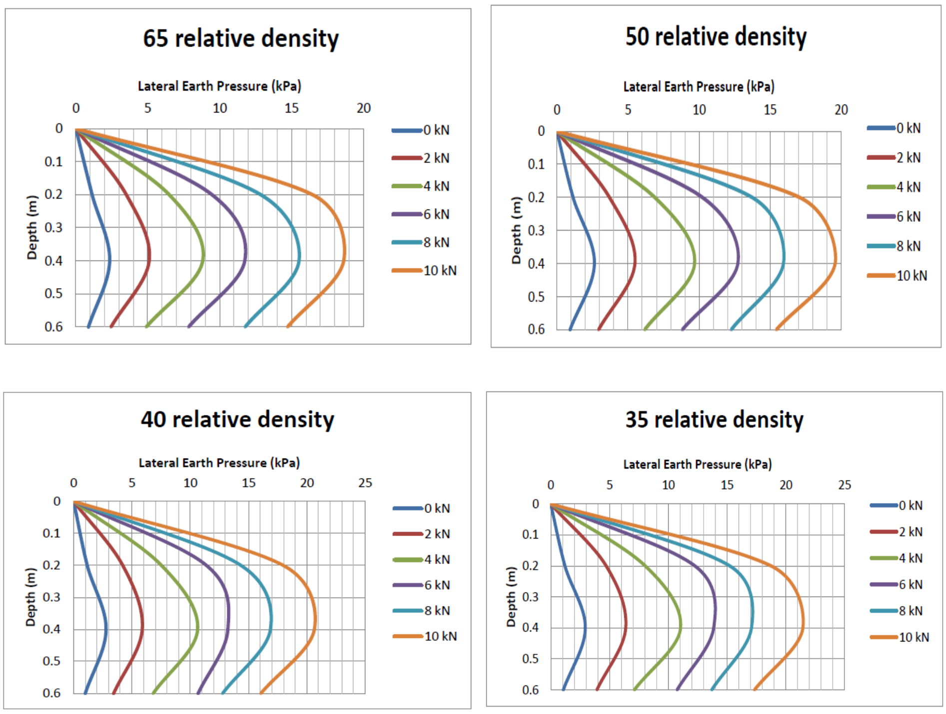
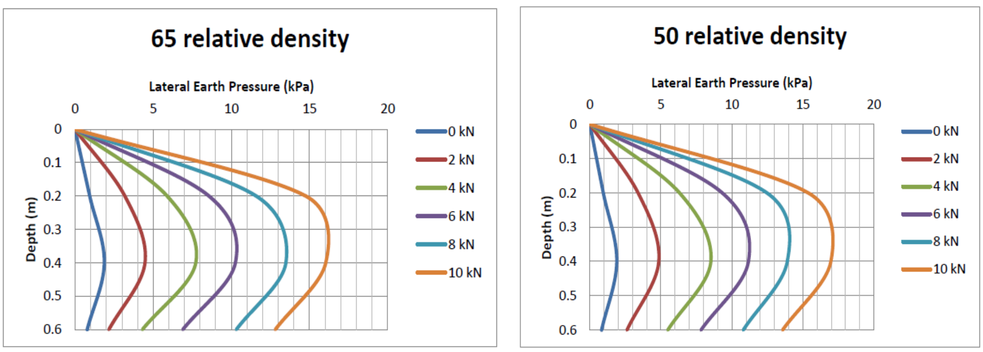


Fig. 4. Lateral Earth Pressure Variation along Depth without Inclusion for various Relative density of backfill (a) 65% (b) 50% (c) 40% (d) 35%

The trend of the graph when bed waste is introduced is similar to graphs drawn when inclusions were absent. From figure 5(a), in the case of 65% relative density the value of earth pressure increases from 1.87kPa for rest condition to about 16kPa for 10kN at 0.4m depth of backfill. From figure 5 (d), in the case of 35% relative density the value of earth pressure increases from 2.2kPa for rest condition to about 19.13kPa for 10kN at 0.4m depth of backfill. About 2% decrease in earth pressure was observed when bed waste was used as inclusion behind the retaining wall.



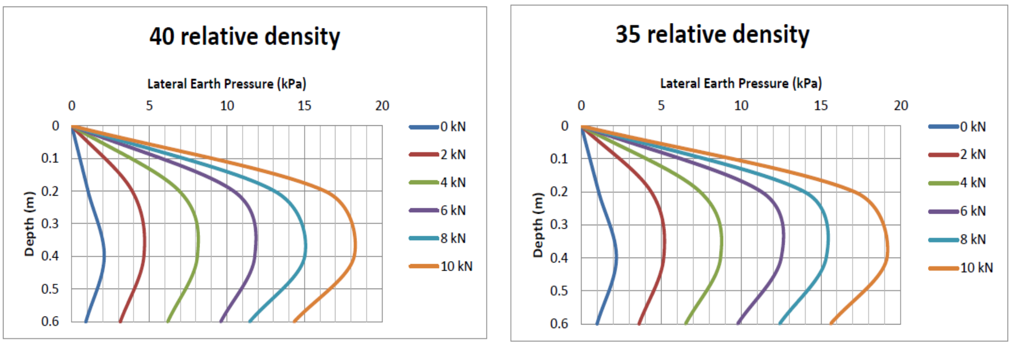


Fig.5. Earth Pressure Variation along Depth with Bed Waste Inclusion for various Relative density of backfill (a) 65% (b) 50% (c) 40% (d) 35%

From figure 6(a), in the case of 65% relative density the value of earth pressure increases from 1.71kPa for rest condition to about 14.1kPa for 10kN at 0.4m depth of backfill. From figure 6(d), in the case of 35% relative density the value of earth pressure increases from 2.18kPa for rest condition to about 17kPa for 10kN at 0.4m depth of backfill. About 5% reduction in lateral earth pressure was observed when coir fiber was used for all relative densities of the backfill.

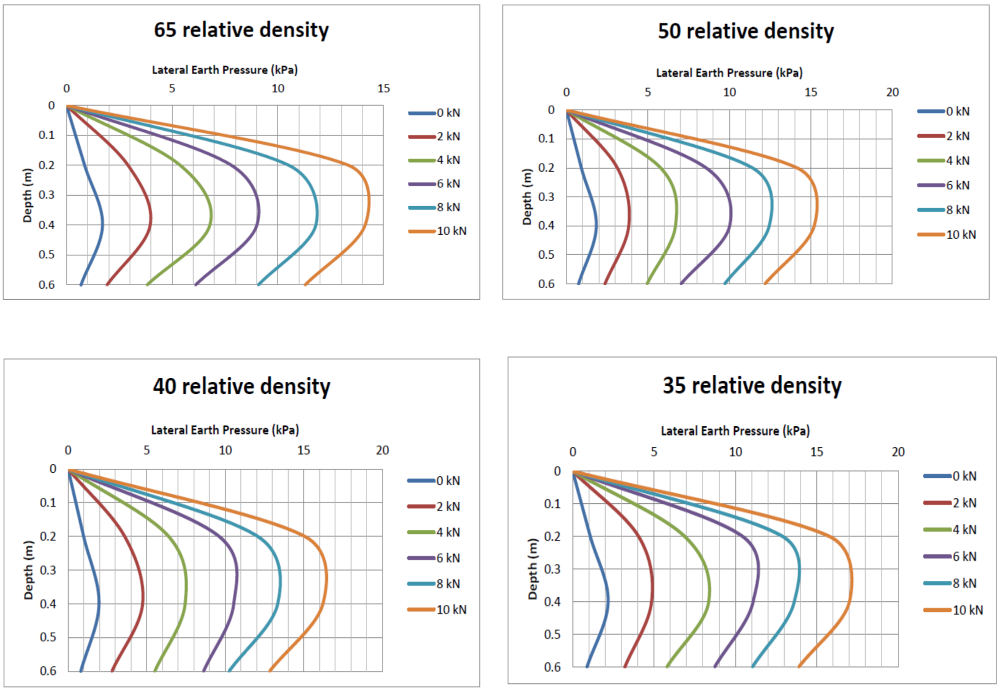


Fig.6. Lateral Earth Pressure Variation along Depth with Coir Fiber Inclusion for various Relative density of backfill (a) 65% (b) 50% (c) 40% (d) 35%

About 1% increase in lateral pressure was observed when the relative density decreases. Thus we can conclude that lateral earth pressure increases with the decreasing value of relative density of backfill. It was also observed that the frictional angle increases as the relative density increases (Table 3 and 4). Hence we can say that as frictional angle increases, the coefficient of active earth pressure decreases and hence the lateral earth pressure also increases.

Table 3. Apparent Increase in Angle of Friction due to Bed Waste and Coir Fiber Inclusions

Relative density	Angle of internal friction	Apparent increase in frictional angle	
		Bed waste	Coir fiber
65	39.52^0	44.03^0	46.12^0
50	38.65^0	42.88^0	43.98^0
40	37.77^0	40.41^0	42.01^0
35	36.86^0	38.69^0	39.26^0

Table 4. Apparent Decrease in Ka value due to Bed Waste and Coir Fiber Inclusions

Relative density	K_a value	Apparent decrease in K_a value	
		Bed waste	Coir fiber
65	0.22	0.18	0.16
50	0.23	0.19	0.18
40	0.24	0.21	0.2
35	0.25	0.23	0.22

A dimensionless parameter, A_p, is the isolation efficiency of the inclusion panel to measure the reduction in wall pressure with and without inclusions of different types of inclusions for different relative densities of the backfill soil and was calculated according to the following equation:

$$A_p = (P_0 - P)/P_0$$

where P_0 and P are the pressures acting on the retaining wall with and without using the inclusion panels respectively.

The figure 7 gives the variation between isolation efficiency and surcharge load. The graph was drawn for earth pressure values when 10kN load was applied on backfill and acting at a depth of 0.4m of retaining wall. From the figure it can be inferred that more the relative density higher will be the isolation efficiency. It can also be observed from the graph that the isolation efficiency increases as the surcharge load increases. For bed waste inclusion, the isolation efficiency varies from 10, 11, 12.7 and 13% for relative densities 65, 50, 40 and 35% when a load of 8kN is applied on the backfill. For coir fiber is used, the isolation efficiency varies from 20, 21, 22 and 23% for relative densities 65, 50, 40 and 35% when a load of 8kN is applied on the backfill.

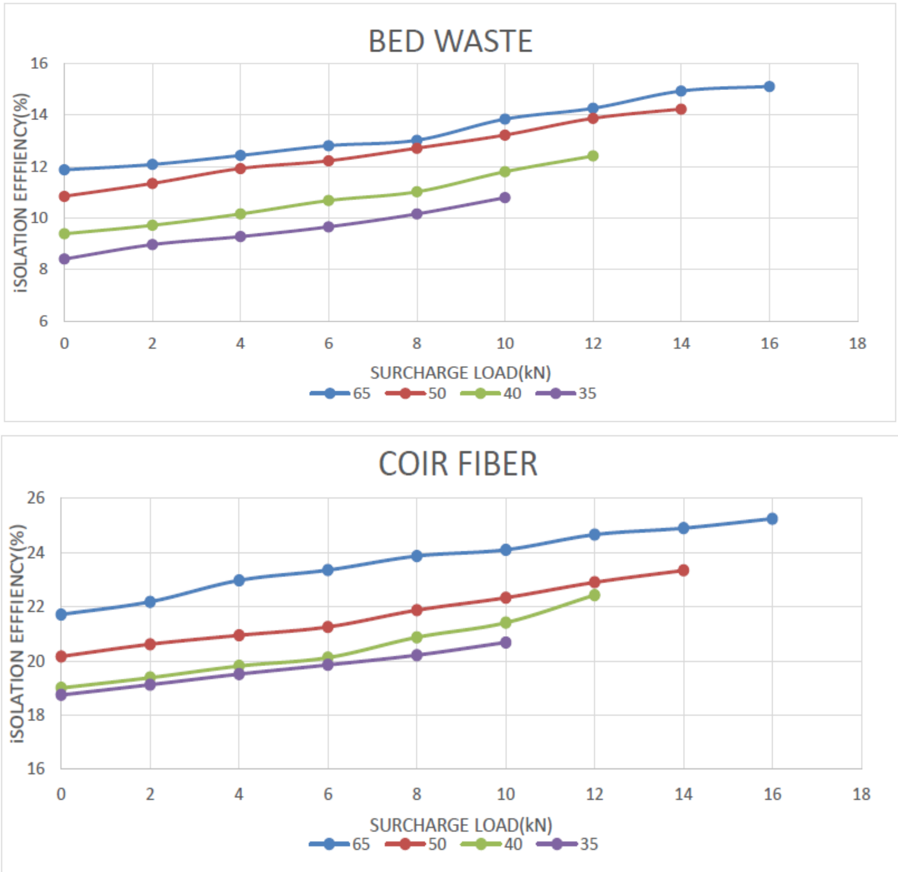


Fig.7. Isolation Efficiency Variation with Surcharge Load with various types of Inclusions (a) Bed Waste (b) Coir Fiber

It was observed that the isolation efficiency of bed waste was in the range of 9-15% whereas for coir fiber the isolation efficiency was observed to be in the range of 19-25%. Hence we can say that the isolation efficiency of coir fiber was greater than bed waste when used as inclusion. About 10% difference in isolation efficiency is observed between bed waste inclusion and coir fiber inclusion for all the different relative densities of backfill. It can be observed that when load increases, the isolation efficiency increases slightly (about 0.3% increase) for all relative densities of backfill.

Table 5 shows the variation in values between the obtained earth pressure and Rankine's theory for various relative densities of the backfill at 0.4m depth of the retaining wall. The maximum variation is about 1kPa.

Table 5. Comparison of Obtained Lateral Earth Pressure with Rankine's Theory for different Relative Density of backfill

Surcharge load	Relative density							
	65		50		40		35	
	Obtained E.P (kPa)	Rankine E.P (kPa)	Obtained E.P (kPa)	Rankine E.P (kPa)	Obtained E.P (kPa)	Rankine E.P (kPa)	Obtained E.P (kPa)	Rankine E.P (kPa)
0	2.35	2.24	2.64	2.26	2.79	2.30	2.94	2.37
2	5.1	4.7	5.49	4.9	5.88	5.07	6.37	5.28
4	8.82	8.04	9.68	8.41	10.63	9.72	11.04	10.07
6	11.77	11.38	12.73	11.92	13.22	12.37	13.85	12.87
8	15.51	14.73	15.93	15.43	16.87	16.02	17.07	16.67
10	18.62	18.07	19.57	18.95	20.64	19.66	21.45	20.47

Figure 8 shows the load settlement curve when inclusions were absent placed behind the retaining wall for different relative densities of the backfill soil. At 10kN load, the settlement for relative densities 65%, 50%, 40% and 35% were noted as 10.64mm, 11.25mm, 12.42mm and 18.69mm respectively. Hence it can be said that for a particular surcharge load, as the relative density of the backfill increases the settlement decreases.

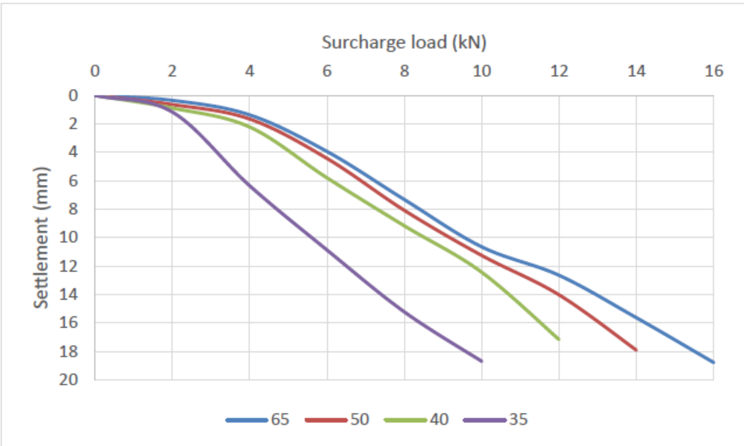


Fig.8. Load Settlement Curve

4 Conclusions

- The lowest earth pressure occurred at the bottom of the wall, in contrast to the usual Rankine's assumption that the earth pressure increases as depth of the retaining wall increases due to the frictional resistance between wall and soil.
- It was inferred that as the load on the backfill increases the lateral earth pressure also increases irrespective of the presence or absence of inclusion and relative density of backfill.
- It was also observed that as the relative density of the backfill increases the lateral pressure decreases irrespective of the presence or absence of inclusion and surcharge load acting on the backfill.
- On addition of bed waste inclusion, a 2% decrease in lateral earth pressure was observed for all relative densities of the backfill tested.
- About 5% reduction in lateral earth pressure was observed when coir fiber was used for all relative densities of the backfill.
- It was inferred that more the relative density higher will be the isolation efficiency.
- It is observed that the isolation efficiency increases as the surcharge load increases.
- It was also observed that the frictional angle increases apparently as the relative density increases. Hence we can say that as frictional angle increases, the coefficient of active earth pressure decreases and hence the lateral earth pressure also increases.
- It was observed that the isolation efficiency of bed waste was in the range of 9-15% whereas for coir fiber the isolation efficiency was observed to be in the range of 19-25%. Hence we can say that the isolation efficiency of coir fiber was greater than bed waste when used as inclusion.
- About 10% difference in isolation efficiency is observed between bed waste inclusion and coir fiber inclusion for all the different relative densities of backfill.
- The variation in values between the obtained earth pressure and Rankine's theory was about 1kPa.
- For a particular surcharge load, as the relative density of the backfill increases the settlement decreases

5 References

1. Horvath, J. S.: Geofoam geosynthetic. Horvath Engrg., P.C., Scarsdale, NY.(1995).
2. Huey C.S., Teng C.S.,Ghani A.N.A., Ibrahim A.:Development of a Laboratory Model Retaining Wall Test Facility, International Conference on Science and Technology: Applications in Industry and Education(2008)
3. Ertugrul O.L., Trandafir A.C: Reduction of Lateral Earth Forces Acting on Rigid Nonyielding Retaining Wall by EPS Geofoam Inclusions, Journal of Materials in Civil Engineering, ASCE, Vol: 23, Issue: 12. (2011).
4. Juari K.A., Khattab S., Shamam M.A: Effect Of Plastic Soil On A Retaining Wall Subjected To Surcharge Loading, UNSAT (2016).
5. Ni P., Mei G., Zhao Y.: Displacement Dependent Earth Pressures on Rigid Retaining Walls with Compressible Geofoam Inclusions: Physical Modeling and Analytical Solutions, Journal of Geomechanics, ASCE, Vol:17, Issue:6. (2017).
6. Abdelsalam S.S., Azzam S.A: Reliability and 3D Modelling of Flexible Walls with EPS Geofoam Inclusions, Journal of Geomechanics, ASCE, Vol: 17, Issue: 7. (2017).