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# Performance Enhancement of Geogrid Reinforced Soil Walls Under Strip Loading With and Without Geofoam Inclusion

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***Abstract:*** *Static response of geogrid reinforced soil walls with and without geofoam inclusion to the externally applied vertically downward strip loading was presented in this paper. A series of small-scale experimental tests was performed on the model geogrid reinforced soil walls. Geofoam inclusion was made at the center of the reinforced zone. Parameters varied in the study were the placement position of the strip loading, density of the geofoam and thickness of the geofoam . Wrap around facing technique was used to represent the flexible facing conditions. Reinforcement spacing was 0.084H for each model configuration. Reinforcement length was 0.70H for each model configuration. A 55mm strip load was incrementally increased at constant strain rate of 5mm/min till the desired settlement of 30mm occurs. Each model test was monitored through front glass of the custom designed strongbox using digital camera. Digital image analysis was performed on captured images to evaluate the movements in reinforced zone of the geogrid reinforced soil wall models at incremental settlements. Performance of the geogrid reinforced soil walls was investigated by through wall face movements and reinforcement strains and failure envelopes. The post failure investigation was performed to assess the rupture points in the geogrid layers at failure of the geogrid reinforced soil wall models. This study demonstrates the use of geofoam in dissipating the external energy applied on geogrid reinforced soil walls.*

***Keywords:*** *Geofoam, geogrid, Soil Stabilization, Image analysis, Energy Dissipation*

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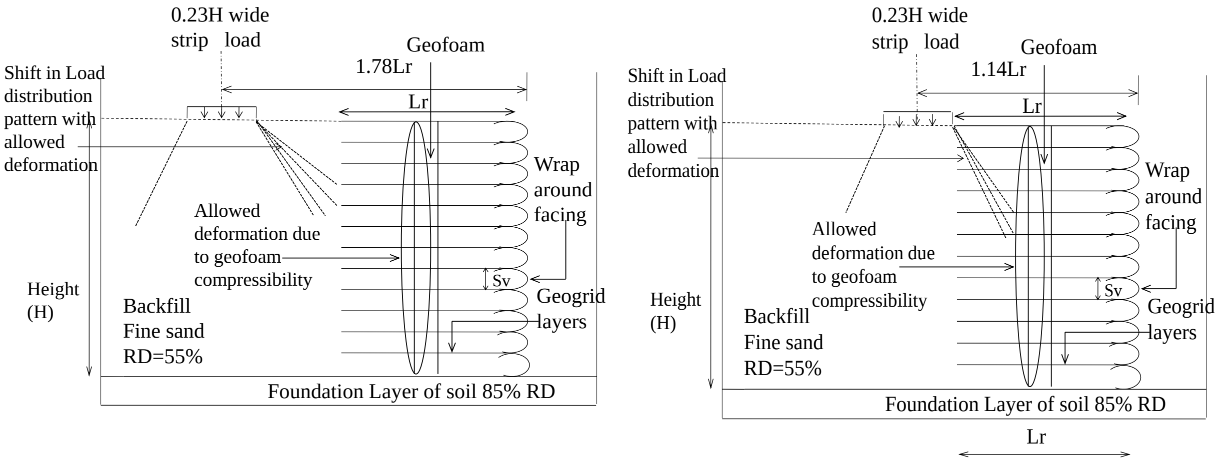
## I. Introduction

Soil reinforcement is a widely used technique to stabilize the geotechnical structures. Different methods of evaluation and design are also established for reinforced soil for various combinations of component parts, geometry, materials and environmental factors [1,2]. Geogrid reinforcements are in widely used as a reinforcement pertaining to their benefits such as higher flexibility, workability, ability to take higher settlements and better bond with surrounding soil. Various studies have been made on geogrid reinforced soil walls through analytical and numerical methods [3,4,5,6,7,8], small scale model tests [9,10,11,12], field studies [13,14,15] and centrifuge model tests [16,17,18,19]. However, majority of these studies are either related to the self-weight loading of the reinforced soil walls or the uniform surcharge over the reinforced zone and backfill. Very few studies report the behaviour of geogrid reinforced soil structures for a narrow strip loading placed over the reinforced zone or backfill [20]. The behaviour of geogrid reinforced soil walls subjected to a strip loading and with a geofoam inclusion is yet to be reported. So, the present study demonstrates a series of small scale model tests on geogrid reinforced soil wall models subjected to a 0.23H wide strip loading over backfill with and without geofoam inclusion at the center of the reinforcement layers horizontally. Reinforcement type, reinforcement length and reinforcement spacing was kept constant for all the model tests performed. Parameters varied were mainly as placement position of geofoam, geofoam density and geofoam thickness.

## II. Motivation Behind Present Study




(a) Footing at 1.78Lr (b) Footing at 1.14Lr

**Figure 1**. Schematic cross section of geogrid reinforced soil wall with geofoam inclusion

Figure 1 shows the schematic cross section of the geogrid reinforced soil wall with 0.23H wide (a) Footing at 1.78Lr from crest of the wall, (b) Footing at 1.14Lr from crest of the wall. Strip load applied at the top of the centre of the backfill should induce the maximum strains in the top layer of the reinforcement, which would reduce further for the following reinforcements subsequently towards the foundation layer. When no compressible inclusion made in reinforced zone, the applied load would transfer towards the face of the reinforced soil wall. This is mainly due to the fact that the only location that allows deformations is the face of the geogrid reinforced soil wall. Which results the wall face movements to be in direct proportion with the strip load settlement. Geofoam, when placed in the centre of reinforced zone should allow the deformations at the end of the reinforcement zone and geofoam panel. Depending on the compressibility of the geofoam inclusion the deformations would allow the reinforcements to develop friction with soil at the end of reinforcements. This may result in mobilization of the reinforcement strength at the face as well as at the end of the reinforced soil wall. So, the proportionality constant between wall face movements and footing settlement should reduce for geofoam inclusion case. At the same time, when footing is placed over backfill, a similar mechanism of geofoam compression would occur. The compression occurred in geofoam mobilizes the backfill shear strength resulting in lower earth pressure than the theoretical predictions for without geofoam case. This compression in geofoam also provides a wider distribution of the applied load. Amount of shift in the load distribution lines depends on the compressibility of the geofoam. Due to this shift the vertical stress at any point below the surface will be lower than the without geofoam case. Which ultimately would produce lower lateral earth pressure.

## III. Model Material

**Sand**

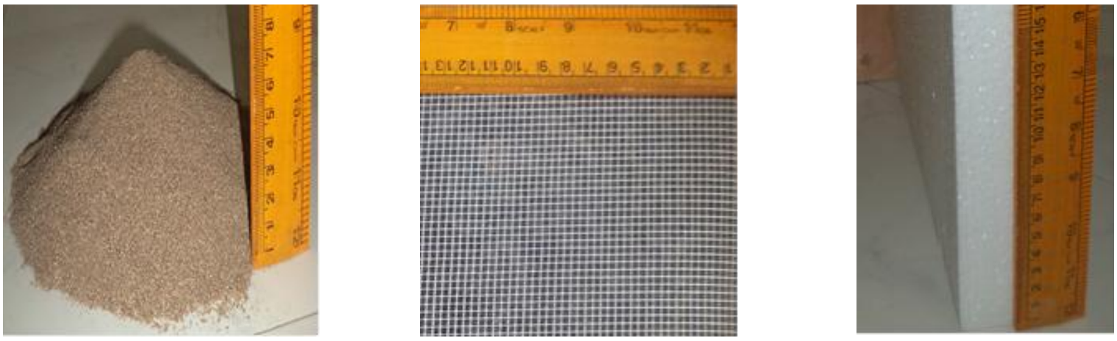
The sand used for this study was Bombay beach sand, composed of rounded and sub rounded particles. Sand was classified as Silty Sand (SM) in the unified soil classification system (USCS). The model sand was found to have internal frictional resistance of 32º, 35º and 38º for 55%, 75% and 85% relative density respectively. Table 1 summarizes the properties of the model sand used in the present study. Figure 2(a) shows the photographic view of the model sand used in the present study. Properties of the model sand are summarized in table 1.

**Geogrid**

The geogrid selected for the present study was on the basis of their physical properties. Openings were found was about 90% and openings was in square in section. For determining the properties of geogrid some test was conducted in universal testing machine. Ultimate tensile load was 3.8 kN/m and ultimate tensile load was 24% according to the test conducted in lab. Model geogrid selected in the present study was falling in the category of the high strength geogrids. Figure 2(b) shows the photographic view of the model geogrid used in the present study. Properties of the model geogrid are summarized in table 1.

**Geofoam**

Geofoam used for the present study was expanded polystyrene type. For the study we vary the density and thickness of geofoam. We used 8 kg/m$^3$, 16 kg/m$^3$, 24 kg/m$^3$ density and 10mm, 20mm, 30mm thickness. Compressive resistance at 2% strain was 17 kPa , 42kPa and 74 kPa for 8kg/m$^3$ 16 kg/m$^3$, 24 kg/m$^3$ density respectively. Compressive elastic modulus was 850 kN/m$^2$, 2100 kN/m$^2$ and 3700 kN/m$^2$ for 8 kg/m$^3$ 16 kg/m$^3$, 24 kg/m$^3$ density respectively. Figure 3 shows the graph of Unconfined uniaxial stress strain behavior of model geofoamused in the present study. Properties of the model geofoam are summarized in table 1.



(a) Model sand (b) Model geogrid (c) Model geofoam

**Figure 2.** Photographic view of model materials used in the present study

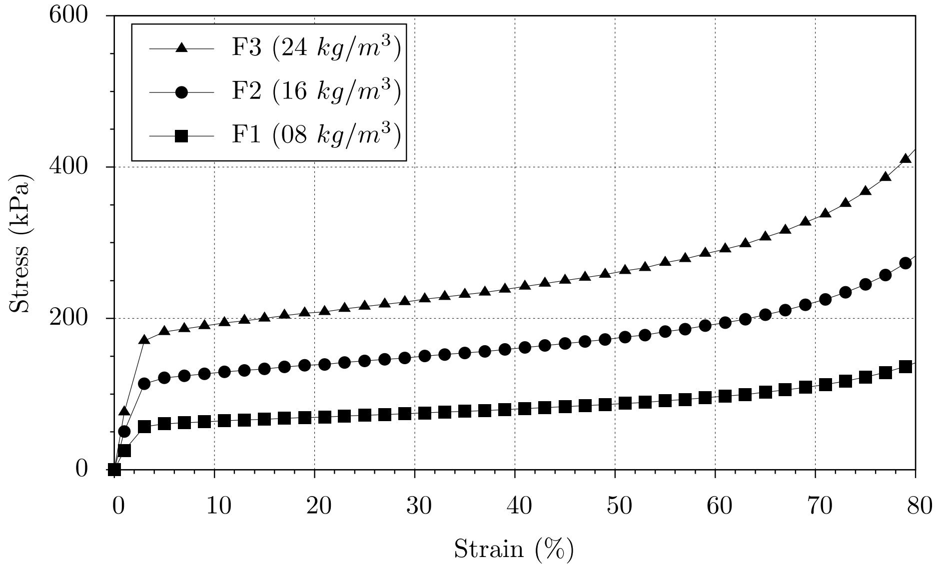



**Figure 3.** Unconfined uniaxial stress strain behavior of model geofoam

**Table 1**. Properties of the model materials used in present study

| **Properties** | | | **Values** |
|---|---|---|---|
| **Sand** | | | |
| Specific Gravity (G) | | | 2.61 |
| Soil classification (USCS) | | | SM |
| Coefficient of curvature (Cc) | | | 1.17 |
| Coefficient of uniformity (Cu) | | | 1.99 |
| Maximum void ratio ($e_{max}$ ) | | | 0.943 |
| Minimum void ratio ($e_{min}$ ) | | | 0.691 |
| Unit weight of soil at 55% relative density (Kg/m$^3$) | | | 1446.7 |
| Unit weight of soil at 85% relative density (Kg/m$^3$) | | | 1510.41 |
| Angle of internal friction at 55% relative density (°) | | | 32° |
| Angle of internal friction at 55% relative density (°) | | | 38° |
| **Geogrid** | | | |
| Ultimate tensile load, $T_{ult}$ (kN/m) | 3.8 | | |
| Ultimate tensile strain, $\varepsilon_{ult}$ (%) | 24 | | |
| **Geofoam** | | | |
| Geofoam type | Expanded polystyrene | Expanded polystyrene | Expanded polystyrene |
| Geofoam legend | F1 | F2 | F3 |

| | | | |
|---|---|---|---|
| Density (kg/m$^3$) | 8 | 16 | 24 |
| Compressive resistance at 2% strain (kPa) | 17 | 42 | 74 |
| Compressive elastic modulus (kN/m$^2$) | 850 | 2100 | 3700 |

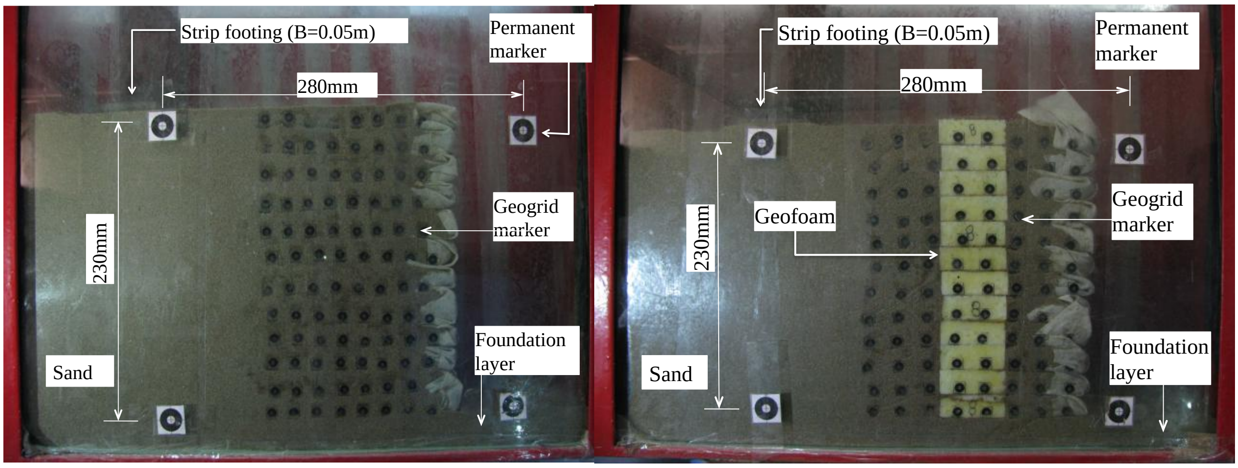
## IV. Model Test Package And Test Procedure

**Model test package**

Figure 4 shows the front view of the geogrid reinforced soil wall model constructed without and with geofoam inclusion. In this study vertical spacing between geogrid reinforcement layers was constant, while maintaining the same soil, geogrid, and wall batter for all tests. Footing position was for first 10 tests were at 1.78Lr i.e. at centre of backfill and for remaining 10 tests at 1.14Lr i.e. at the end of reinforcement. Summary of all twenty tests is shown in table 2. A reinforcement spacing 0.084H was used for all test, and reinforcement length was 0.7H used for all twenty test. A wrap-around technique was adopted. Foundation layer was 30mm thick with 85% relative density and spacing between two layers was 20mm with 55% relative density for all the models. During construction of model, 60mm wide polythene sheet strips was placed at the face of transparent glass by using the white prtroleum greasebefore placing the sandto reduce the boundary friction effect. Sand was placed using a raining technique through a funnel so as to achieve uniform density throughout all the layers. These L-shaped geogrid markers were used for determination of the strain sustained along each reinforcement layer throughout the test and at failure, by tracking the movement of each marker through image analysis. After adding the subsequent layer of sand, the anchoring reinforcement was folded back. Then the next geogrid layer was placed, followed by marker application, and so on. The reinforced zone and backfill were constructed layer by layer in this manner. Total 12 layers were constructed of spacing 20mm and model height was 240mm without considering foundation layer. To prevent the leakage of sand from the face of wall a thin textile was used at the face of the wall. Textile and geogrid was glued together by using fevibond.Four permanent markers werepasted from the inner side of the transparent glass which won't move during the test. Center to center horizontal distance between two permanent markers was 280mm and vertical distance was 230mm. Strip footing was 0.05m wide, position of strip footing are shown in Fig. 1. Digital camera was fixed on a PVC stand arrangement to facilitate the undistorted monitoring of the geogrid reinforced soil wall models. Two sets of lithium battery operated LED lighting panels were used to maintain a constant intensity of illumination throughout the progress of the test. Three different geofoam types were used in the present study, which were placed at the center of the reinforced zone with varying thickness and density under the particular test legend.

**Test procedure**

All the geogrid reinforced soil wall models were tested under a UTM (Universal Testing Machine with a maximum compressive and tensile capacity of 1000kN. Formwork was kept in its position till the desired location of the strong box is identified and fixed for the testing. A 0.023H wide footing was placed at the center of the backfill (1.78Lr from the crest of the wall) for first series of tests followed by at the end of reinforcement (1.14Lr from the crest of the wall) for second series of the tests. A gradual vertical load was applied at a constant strain rate of 1N/Sec till the maximum settlement of 30mm reaches or the maximum load of 35kN reaches (whichever occurs earlier). Images were taken at a constant time interval with the help of a digital camera .Images taken were stored in a connected computer located a few meters away from the test setup.




(a) Without geofoam (b) With geofoam

**Figure 4**. Front view of the model test package

## V. Model Test Program

Table 2 shows the details of the model tests performed in the present study. Total 20 model tests were performed with and without geofoam inclusion behind the reinforced zone. Model RSWS-01 and RSWS-11 were tested without any geofoam inclusion and were treated as the base models for evaluation of the efficiency of the geofoam behind reinforced zone.

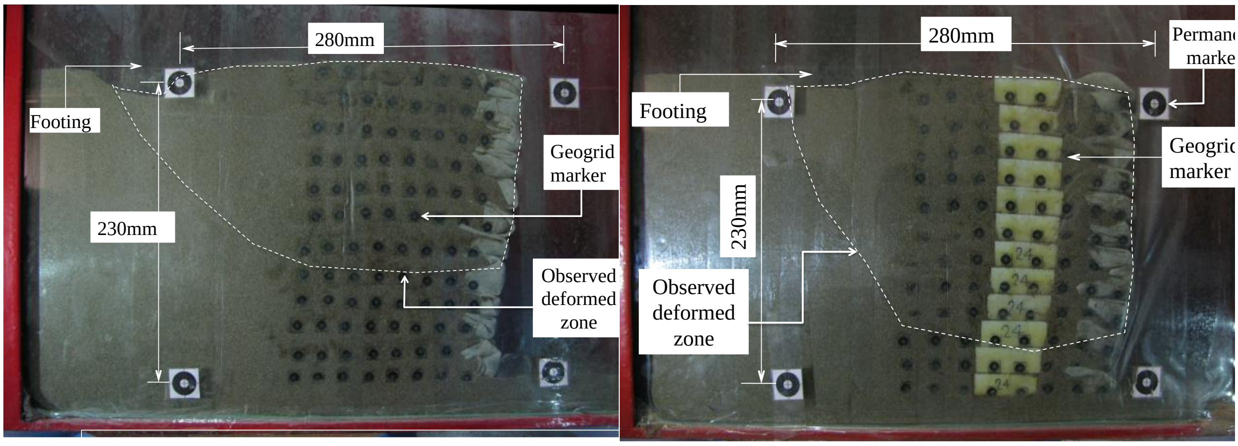
**Table 2.** Details of the model tests performed in the present study

| Test legend | Geofoam thickness (mm) | Geofoam density (kg/m$^3$) | Footing Location from crest of the wall |
|---|---|---|---|
| RSWS-01 | *N.A | *N.A | 1.78$L_r$ |
| RSWS-02<br>RSWS-03<br>RSWS-04 | 10<br>20<br>50 | 8 | |
| RSWS-05<br>RSWS-06<br>RSWS-07 | 10<br>20<br>50 | 16 | |
| RSWS-08<br>RSWS-09<br>RSWS-10 | 10<br>20<br>50 | 24 | |
| RSWS-11 | *N.A | *N.A | 1.14$L_r$ |
| RSWS-12<br>RSWS-13<br>RSWS-14 | 10<br>20<br>50 | 8 | |
| RSWS-15<br>RSWS-16<br>RSWS-17 | 10<br>20<br>50 | 16 | |
| RSWS-18<br>RSWS-19<br>RSWS-20 | 10<br>20<br>50 | 24 | |
| *Not applicable as test was performed without geofoam inclusion | | | |

## VI. Analysis And Interpritation

### Image analysis

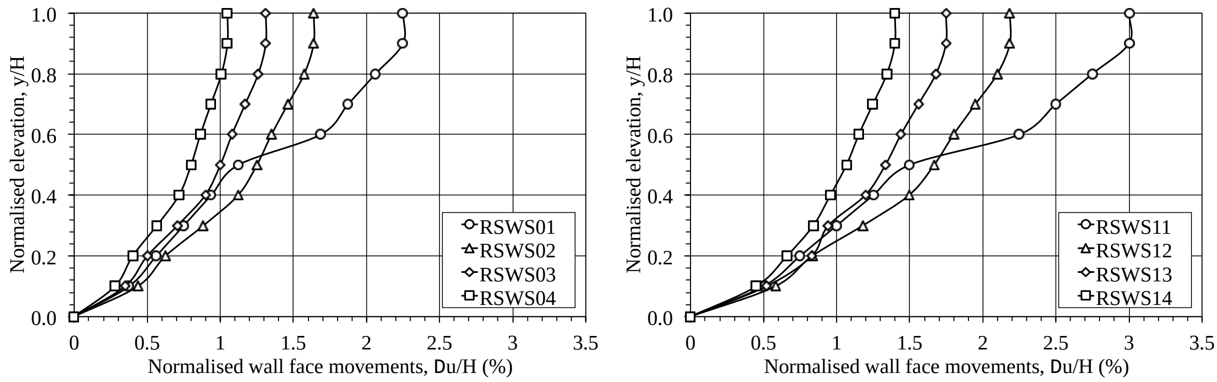
Series of images were captured during the test displacements and strain of geogrid markers were calculated with the help of ImageJ open source software. The displacements occurred in geogrid reinforced soil wall models were depicted using the advanced template matching plugins and PIV (Particle Image Velocimetry) analysis. Fig.5 shows the deformed profile of geogrid reinforced soil wall models with and without geofoam for strip loading over backfill and end of the reinforcement respectively.




(a) Without geofoam, footing at 1.78Lr (b) With geofoam, footing at 1.14Lr

**Figure 5.** Deformed profile of geogrid reinforced soil wall models

### Wall face movements




(a) Footing at 1.78Lr (b) Footing at 1.14Lr

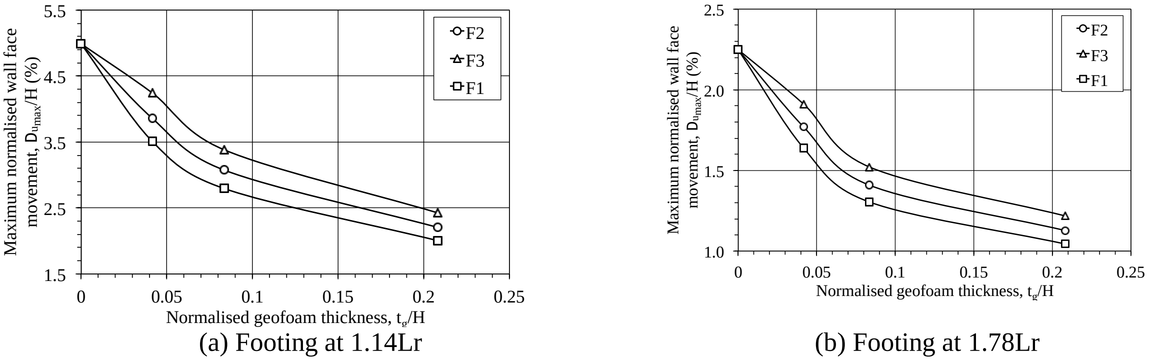
**Figure 6.** Variation of wall face movements along the height of geogrid reinforced soil walls

Wall face movements of geogrid reinforced soil wall models were evaluated through image analysis for various cases with varying density and thickness of the geofoam. Fig.6 shows the variation of normalized wall face movements with normalized height. Wall face movements were observed to be significantly higher at top middle third of the height of the wall when footing was placed near the reinforced zone and no geofoam included. This is mainly due to the fact that, the closer placement of footing to geogrid reinforced soil wall pushes the reinforced soil immediately for less values of settlements than the farther placed footing. Geofoam inclusion within reinforced zone observed to change the pattern of wall face movements significantly, showing the uniformity in distribution of wall face movements along the height. Wall face movements were also observed to decrease at the crest of the wall when geofoam inclusion was made. This is mainly due to the allowed deformations within the reinforced fill. As deformations were allowed within reinforced zone, the movements in geofoam caused the surround soil to mobilise its strength around the reinforcements, and thus the lesser wall face movements. Wall face movements were observed to decrease with decrease in geofoam density and increase in geofoam thickness. However, the density of the geofoam was observed to have more influence than that of geofoam thickness. This is because a small amount of deformation suffices the requirement of shear strength development within the reinforced zone. And so, the higher thickness is not primarily needed.

## VII. Result And Discussion

**Influence of geofoam density and geofoam thickness**

Geofoam density was found to have significant influence on enhancement of deformation behavior of geogrid reinforced soil walls. Lower the density higher the allowed deformations. So, the lower density geofoam provided higher efficiency in performance enhancement of geogrid reinforced soil walls. Figure.7 shows the variation in wall face movements with increase in geofoam thickness for various densities of the geofoam used in this study. Wall face movements were observed to decrease significantly with geofoam inclusion and the decrease in wall face movements was found to be higher for low-density geofoam. A maximum decrease of up to 59.8% was observed for footing placed at the end of the reinforced zone when 50mm thick low-density geofoam (F1) inclusion was made.. A similar trend of decrease was observed in reinforcement peak strains. Table 3 summarizes the results obtained through test series performed in the present study.




(a) Footing at 1.14Lr (b) Footing at 1.78Lr

**Figure 7**.Variation of wall face movements along the height of geogrid reinforced soil walls

**Table 3.** Summary of the results of model tests

| Test legend | Geofoam thickness (mm) | Geofoam density (kg/m3) | Footing Location from crest of the wall | Maximum wall face movement (Dumax/H)% | % Reduction in (Dumax/H) |
|---|---|---|---|---|---|
| RSWS01 | *N.A | *N.A | 1.78Lr | 2.25 | *N.A |
| RSWS02 | 10 | 8 | | 1.64 | 27.20 |
| RSWS03 | 20 | | | 1.31 | 42.00 |
| RSWS04 | 50 | | | 1.04 | 53.60 |
| RSWS05 | 10 | 16 | | 1.77 | 21.38 |
| RSWS06 | 20 | | | 1.41 | 37.36 |
| RSWS07 | 50 | | | 1.13 | 49.89 |
| RSWS08 | 10 | 24 | | 1.91 | 15.09 |
| RSWS09 | 20 | | | 1.52 | 32.35 |
| RSWS10 | 50 | | | 1.22 | 45.88 |
| RSWS11 | *N.A | *N.A | 1.14Lr | 4.99 | *N.A |
| RSWS12 | 10 | 8 | | 3.50 | 29.81 |
| RSWS13 | 20 | | | 2.80 | 43.99 |
| RSWS14 | 50 | | | 2.00 | 59.86 |
| RSWS15 | 10 | 16 | | 3.85 | 22.79 |
| RSWS16 | 20 | | | 3.08 | 38.39 |
| RSWS17 | 50 | | | 2.20 | 55.84 |
| RSWS18 | 10 | 24 | | 4.24 | 15.07 |
| RSWS19 | 20 | | | 3.38 | 32.23 |
| RSWS20 | 50 | | | 2.42 | 51.43 |
| *Not applicable as test was performed without geofoam inclusion | | | | | |

## VIII. Conclusion

Based on the observations made in the present study, Conclusions made are as below,

1. Geofoam as a compressible inclusion provides significant enhancements in performance of the geogrid reinforced soil wall when subjected to a vertical strip loading.
2. Wall face movements of geogrid reinforced soil walls decreases with placement of geofoam within reinforced zone irrespective of the location of the strip loading applied. However the geofoam performs better when strip loading is subjected at the end of reinforcements. A maximum decrease in wall face movements for low density 50mm thick geofoam was observed to be upto 59.8%.
3. Performance enhancement of geogrid reinforced soil walls due to geofoam inclusion is directly proportional to the geofoam thickness and inversely proportional to the geofoam density.

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