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Effect of EPS geofoam on retaining wall subjected to seismic forces

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Keywords

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Abstract

The lateral deflection of the retaining wall under seismic loading is a major issue as it causes failure of backfill in most of the cases.
Expanded polystyrene (EPS) geofoam is a light weight material which is usually used as a fill in embankments and as a compressible inclusion behind the retaining walls. However, the position and orientation of EPS geofoam effects the deflection of retaining wall under the seismic force and has got very less attention. So, this paper mainly focuses on the position of EPS geofoam behind the L-shaped retaining wall to control the deflection under the seismic forces. Along with the orientation of EPS geofoam, the length of the base slab of L-shaped retaining wall was also varied. The analysis performed in Plaxis 2D for both static and dynamic cases. The combination of vertical and horizontal EPS inclusions was found to reduce the lateral earth pressure by more than 80% thereby reducing the lateral deflection of L-shaped retaining wall.

1.Introduction

The earth retaining structures are the structure which retains the soil behind and is designed to safely withstand the lateral earth pressures exerted by earth masses without any significant deflection. However, the lateral pressure and deflection of flexible retaining wall may increase beyond acceptable limit during the seismic forces. In the mid twentieth century, bales of hay were placed over buried pipes to induce vertical arching [1]. Compressible inclusions material such as cardboard [2] and glass-fibre [3] have been used prior to EPS geofoam in retaining structures to induce seismic forces.

However, due to unpredictable behavior of these materials such as cardboard and hay are biodegradable with time and glass-fibre is too compressible, they have limited application [1]. EPS geofoam on the other hand is preferred as a compressible inclusion, as it doesn't experience the same of the above shortcomings.

Thus, EPS geofoam is a better alternative and cost-effective fill material to reduce seismic forces on retaining earth structures. Many investigations on the properties of EPS geofoam and the related design problems have also been carried out [1-24]. Advantages of using EPS geofoams are well discussed by Horvath [1,4,5,6] and Stark et al. [7].

Horvath [5] describes the concept of EPS geofoam compressible inclusions to attenuate earthquake induced forces against rigid earth retaining wall structures. Shaking table test was done on non-yielding earth retaining walls with and without EPS geofoam seismic buffer where large differences in dynamic force reduction was observed. Reduction in dynamic load was observed with increased seismic buffer density. The dynamic force reduction on the facing panel was around 31% at a peak base acceleration of 0.7g.

Athanasopoulos et al. [9] performed a numerical analysis on EPS geofoam seismic buffers. The performance of EPS geofoam buffers on flexibility of the retaining wall was investigated. In the study, five deformable EPS geofoam buffers with densities varying between 1.3 kg/m^3 to 16kg/m^3 were used between the granular backfill and the rigid retaining wall. It was found that increasing the flexibility of wall increases the load isolation efficiency. EPS geofoam buffers significantly reduced the dynamic load with increasing peak amplitude of the excitation. It was also observed that isolation efficiency decreased significantly for excitation frequencies in the backfill-buffer zone of the retaining structure.

Bathurst et al. [10] investigated the effect of EPS seismic buffers on the lateral earth pressure against retaining walls under dynamic excitations. Table shaking tests of 1-g was performed on a 1m high rigid walls with compressible EPS geofoam inclusions. The deformable EPS inclusion and backfill were subjected to different loading conditions. The base of the rigid backfill model was allowed to undergo harmonic base excitations. It was observed that reductions up to 40% in seismic thrust could be achieved at the peak excitation amplitude of 0.7g. The initial tangent modulus of the EPS geofoam played a significant role in decreasing lateral forces.

Zarnani and Bathurst [11] used FLAC to carry out a numerical modeling on EPS geofoam buffer to reduce seismic forces against rigid wall structures. Lateral earth pressure and EPS geofoam buffer strains subjected to different earthquake loads were calculated for rigid retaining walls. The presence of vertical EPS geofoam significantly reduced the seismic induced loads on wall. Also, lateral deformation decreased with increasing thickness of EPS geofoam. The stiffness of EPS geofoam buffer played a significant role in reducing load efficiency.

Ertugrul et al. [12] studied the importance of application of EPS geofoam used as a compressible vertical inclusions behind non-rigid retaining walls. Significant reduction in the lateral earth pressure behind the wall was mostly affected by the relative thickness and stiffness parameters of the geofoam inclusion. The presence of EPS inclusion with lower density at the upper half of the retaining wall improved the load performance.

Padade et al. [13] carried out a numerical analysis and experimental studies of series of tests on EPS geofoam under triaxial loading conditions on EPS geofoam of densities 15 kg/m^3, 20 kg/m^3, 30 kg/m^3. It was observed that the deviator stress values of EPS geofoam increased with the increase in density of geofoam, whereas marginal increment was observed for internal friction angle.

Padade et al. [14] carried out a numerical analysis to understand the function of EPS geo blocks as a compressible vertical inclusion in retaining wall. 2-D plain strain analysis were carried out using Plaxis 2D software on the three densities of geofoam 15kg/m^3, 20kg/m^3, 30kg/m^3 with thickness 50mm, 100mm and 150mm respectively. It was observed that the lateral deformation of the wall decreased with increasing thickness and density of geofoam. Also, vertical deformation of backfill decreased with increasing thickness and density of geofoam. Lateral pressure was decreased with increasing density and thickness of geofoam.

Salam and Azzam [15] carried out a numerical analysis to study the behavior of vertical EPS geofoam inclusions on yielding and rid walls. Laboratory tests were performed to obtain the value of shear strength and interface properties between geofoam-soil, and geofoam-concrete and geofoam-geofoam. Results showed that water effect on geofoam-sand interference was negligible but significant on the geofoam-geofoam interface, as the properties of geofoam-geofoam interface decreased by approximately 19%. The surface roughness of concrete significantly affected geofoam-concrete interface. Lateral pressure was significantly reduced by 65% using EPS geofoam inclusions with t/H =0.5.

Several researchers have investigated the effect of the EPS geofoam on the performance of retaining walls [3],[5],[9],[10],[11],[12],[14],[15],[17]. However, the studies of the effect of EPS on L-shaped retaining wall under seismic force is not available in the best knowledge of authors. So, this study was mainly focused on the effect of position and thickness of EPS geofoam on the performance of L-shaped retaining wall with fly ash backfill under seismic force. The Plaxis 2D plain strain finite element stimulations were used to study the lateral earth pressure and deformation of wall.

2. Materials and methodology

In the present study, class F fly ash was used as an alternative backfill material. The fly ash was collected from NTPC, Dadri. Various laboratory tests were performed to obtain the material properties of fly ash. The specific gravity of Dadri fly ash is 2.05. It contains sand size particle 53%, silt size particles 43%; and clay size particles 2%. The uniform coefficient (C_u)is 15 and coefficient of curvature (C_c) is 1.28. The maximum dry unit weight (γ_{dmax}) obtained from standard proctor tests results is 13.35kN/m^3 and optimum moisture content (OMC) is 18%. The value of cohesion of fly ash was 0.28kg/cm^2 and internal friction angle was 33.7° which was obtained from Unconsolidated Undrained (UU) triaxial test performed at three confining pressure 0.5kg/cm^2, 1kg/cm^2 and 1.5kg/cm^2.

Compressible EPS geo blocks were used as a vertical inclusion behind facing panel and horizontal inclusion above backfill to attenuate earthquake induced forces. EPS geofoam with densities of 20kg/m^3 and 30kg/m^3 at three relative thickness of t/H =0.12, 0.18 & 0.25(where t= thickness of EPS, H= Height of wall) were modeled in this numerical study.

Height of L-shaped retaining wall(H) was taken as 8m for the analysis. The length of base slab(B) was varied as 2.5m, 4m and 5.5m.

2.1. Materials modeling

Unconsolidated Undrained (UU) triaxial tests were performed at three confining pressure 0.5kg/cm^2, 1kg/cm^2 and 1.5kg/cm^2 to obtain the value of cohesion and internal friction angle. The properties of fly ash used in the finite element stimulation are given in table 1.

Table 1. The properties of fly ash used in the finite element stimulation

Property	Value
Dry unit weight	13.35kN/m^3
Young's modulus, (E_{50})	4117kN/m^3
Cohesion, (C)	28kN/m^3
Internal Friction Angle, (ϕ)	33.7°
Poisson's ratio, (ν)	0.32
Dilation angle, (ψ)	3.7°

The expanded polystyrene (EPS) geofoam was modeled as Mohr Coulomb model with 15 node triangular elements considered. Varying EPS thickness of 1m, 1.5m and 2m was taken for the analysis to study its effect on retaining wall. It was seen that EPS geofoam with density equal to 20kg/m^3 showed more reduction in lateral stresses as compared to EPS geofoam with density 30kg/m^3 due to its lower density. Thus, EPS geofoam density of 20kg/m^3 was used in the numerical analysis throughout the study.

Table 2. The properties of EPS geofoam used for the finite element stimulation [8]

Density	Cohesion (kN/m^2)	Elastic Modulus (kN/m^2)	Poisson's ration(υ)	Internal Friction angle(ϕ°)
20	38.75	4000	0.12	2
30	62.00	7800	0.17	2.5

Height of L-shaped retaining wall(H) was taken 8m and modeled as a plate element. The length of the base slab(B) was taken as 2.5m, 4m and 5.5m. The facing panel was modeled as a plate element. The thickness of plate and base slab was taken 0.3m for the numerical analysis. The retaining wall model was stimulated with one dimensional linear beam that can withstand axial load and bending moments. The stiffness of the wall element was represented by means of flexural rigidity EI and axial stiffness EA, where E and A are the young's modulus and cross-sectional area of the reinforced concrete structural wall.

Table 3 shows the properties of retaining wall used in the finite element analysis. The input properties of foundation soil are given in table 4.

Table 3. Input properties of wall/slab

Material type	Linear Elastic
Axial stiffness, (EA)	13.35kN/m^3
Inertial stiffness, (EI)	4117kN/m^3
Equivalent thickness, (d_{eq})	28kN/m^3
Unit weight,(w)	33.7°
Poisson's ration,(ν)	0.32

Table 4. Input properties of foundation soil

Material Model	Mohr-Coulomb
Unsaturated Unit weight (γ_{unsat})	18.35kN/m^3
Saturated Unit weight (γ_{sat})	19.12kN/m^3
Modulus of Elasticity, (E)	6525kN/m^3
Poisson's ratio, (ν)	0.25
Cohesion, (C)	30kN/m^3
Angle of Internal Friction, (ϕ)	17°

2.2. Numerical Analysis

Plaxis 2D software analysis was used to visualize the lateral deformation and lateral earth pressure of the back fill. The backfill was analyzed as Mohr-Coulomb model and 15 node triangular elements were considered. Plane strain analysis was selected for the retaining wall model. The nodes at the right vertical boundary were provided with horizontal fixity but were allowed to undergo vertical displacements, whereas for the nodes at the bottom surface, both horizontal and vertical displacements were fixed. The value of default gravitational constant is 9.8m/s.

Numerical stimulations were carried out with the strength reduction factor in the interface (R_{inter}) taken as 0.67 between fly ash and EPS geofoam block and 0.92 between EPS block and facing wall [14]. A series of numerical analysis were performed to study the performance of EPS geofoam inclusion behind retaining wall model under static and dynamic loading conditions.

The virtual thickness factor was taken to be 0.05 which was used to calculate the virtual thickness of the interface elements. The geometry and boundary conditions were represented in Fig. 1. To avoid disturbances at the boundaries, the geometry of the model was extended 36m horizontally and 16m vertically. Acceleration-time record of Upland Earthquake was used for dynamic analysis.

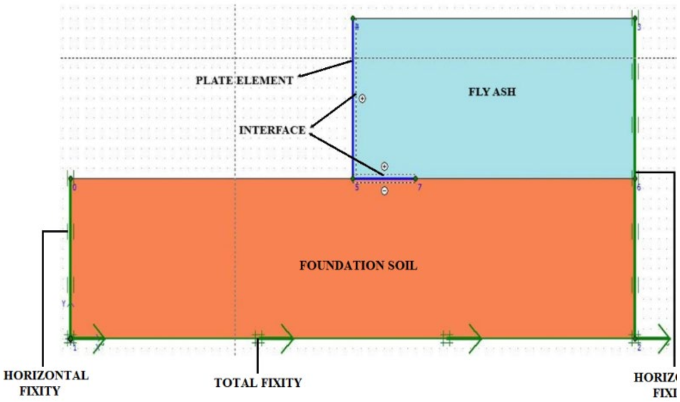


Figure 1. Case I- Geometry and boundary conditions of retaining wall model without EPS.

Plaxis input program was used for the generation of finite element mesh. A typical mesh generated by plaxis 2D is given in Fig.2. The texture of mesh was set to fine to give high accuracy and reliable results.

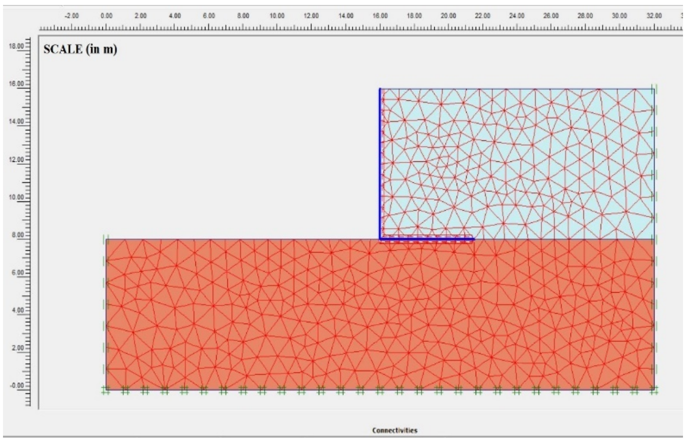


Figure 2. Very fine mesh generated by plaxis 2D software

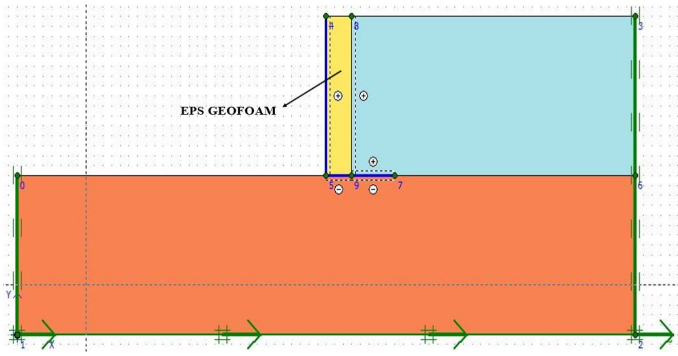


Figure 3. Case II- Geometry model of retaining wall model with vertical EPS inclusion.

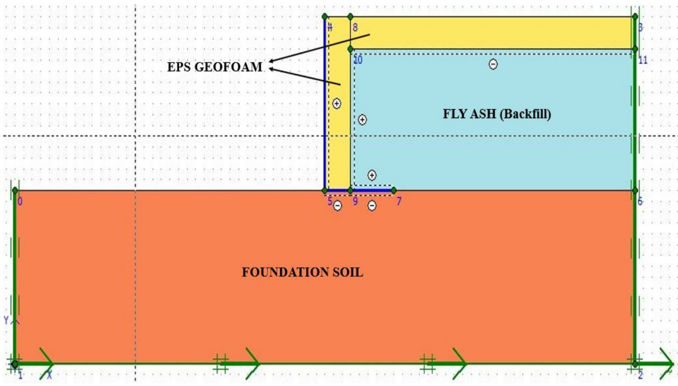


Figure 4. Case I- Geometry model of retaining wall model with both vertical and horizontal EPS inclusion.

The above three cases shown in Fig.1, Fig.3 and Fig.4 were investigated by varying the thickness of EPS geofoam and the length of base slab of L-shaped retaining wall to study the performance of EPS compressible inclusions to attenuate earthquake forces. Fly ash was used as an alternative backfill.

2.3. Dynamic Analysis

Dynamic analysis was carried out after the static analysis by considering earthquake input motion. In dynamic analysis, earthquake boundary conditions are considered to absorb the incoming waves as without these boundaries the waves would be reflected on the model boundaries causing perturbation. Acceleration-time record of Upland Earthquake was used for dynamic analysis (Fig. 5).

Peak ground Acceleration: 0.245g

Local magnitude: 5.40

Epicentral distance: 5km

Duration of Earthquake: 10sec

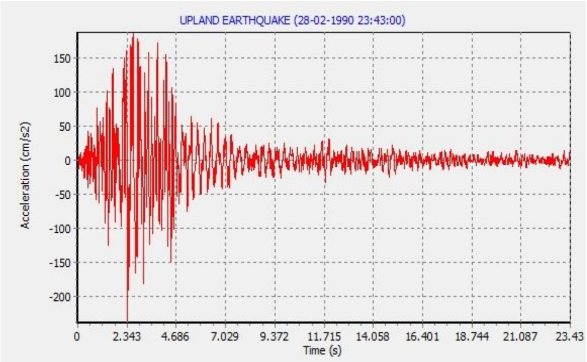


Figure 5. acceleration-time record of Upland Earthquake (Southern America, 28/2/1990)

2.4. Parametric study

The parameters such as length of base slab of L-shaped retaining wall, thickness and position of EPS geofoam are taken for the parametric analysis. The various possible combinations of EPS geofoam thickness and its positions behind retaining wall are presented in table 5.

Table 5. EPS geofoam thickness and its position used for the numerical stimulation

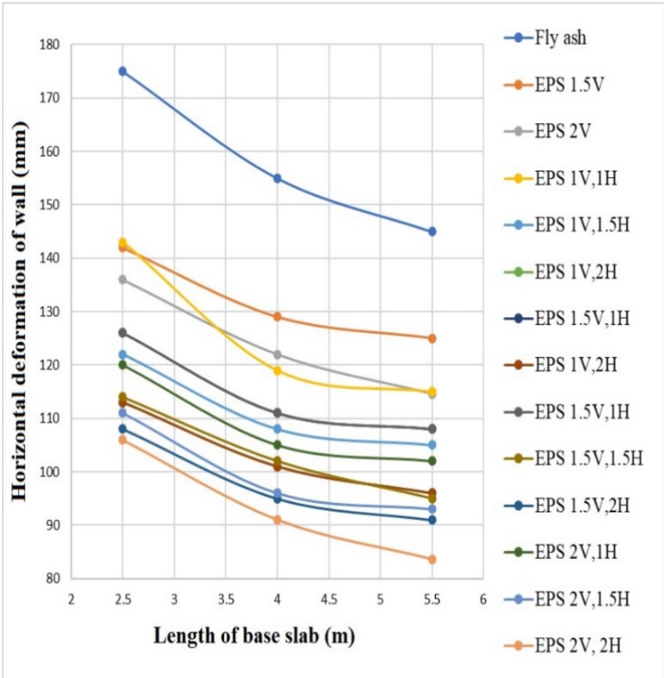
No. of Analysis performed	Thickness of Vertical EPS geofoam positioned behind facing pane(m)	Thickness of Horizontal EPS geofoam positioned above fly ash backfill (m)
1	Without EPS	Without EPS
2	1	Without EPS
3	1.5	Without EPS
4	2	Without EPS
5	1	1
6	1	1.5
7	1	2
8	1.5	1
9	1.5	1.5
10	1.5	2
11	2	1
12	2	1.5
13	2	2

Each of the numerical analysis given on Table.5 is is repeated three times by varying the length of base slab of L-shaped retaining wall as 2.5m, 4m and 5.5m in order to study the effect of thickness and position of EPS geofoam in Static case as well as in Dynamic case.

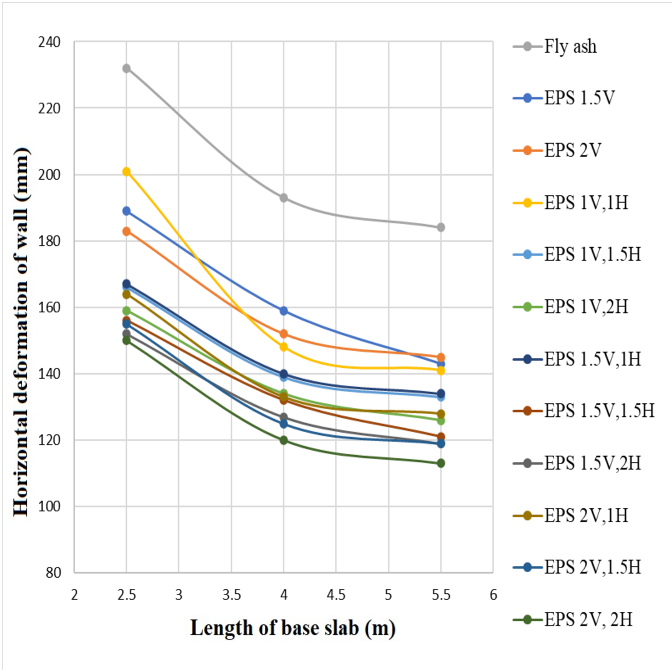
3. Results and discussion

The thickness of base slab of L-shaped retaining wall was taken 0.3 m for the numerical analysis. The retaining wall model was analysed using different possible combinations such as varying the thickness and position of EPS geofoam inclusion and, also varying the length of base plate element. The variation of horizontal displacement of facing wall with change in length of base slab is represented in Fig. 6. The numerical analysis results showed that with increase in length of base slab, the horizontal displacement of wall decreased significantly.

In Fig. 6, the symbol V represents EPS geofoam in vertical position behind facing wall and H represents EPS geofoam in horizontal position above fly ash backfill. The coefficients of V and H represents the thickness of EPS geofoam in meter(m). As for example: [EPS 2V,2H] represents EPS geofoam thickness of 2m positioned in both vertical (behind facing wall) and horizontal(above fly ash) directions. Similarly, [EPS 2V] represents EPS geofoam thinkness of 2m positioned only in vertical direction (behind facing wall).



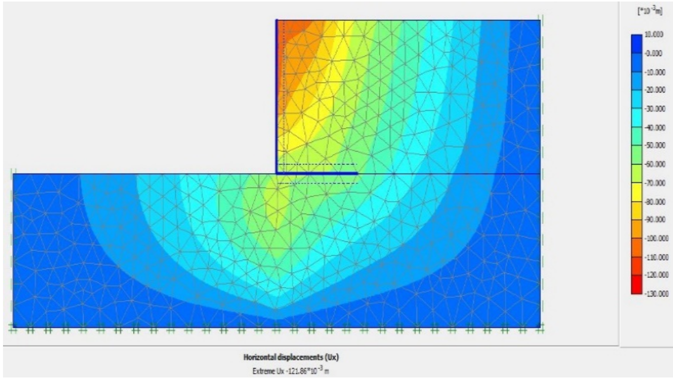
(a)



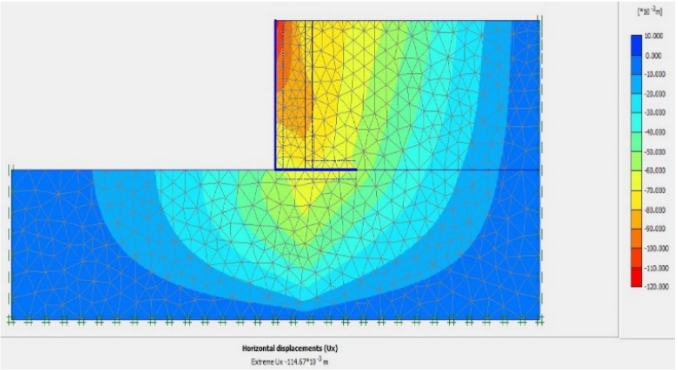
(b)

Figure 6. Comparison of horizontal displacement (in mm) of facing wall with change of length of base slab (in m) of L-shaped retaining wall (a) Static case (b) Dynamic case

During the study, the presence of EPS thickness of 2m in both vertical and horizontal positions in case of retaining wall with length of base slab 5.5m, showed significant reduction in horizontal deformation. The maximum horizontal deformation was 83.64mm (42% reduction) in static case and 113mm (36% reduction) in dynamic case as compared to without EPS geofoam. It was observed that with increase in length of base slab, the horizontal deformation of facing wall decreased. However, increase in length of base slab above 5.5m didn't show any significant reduction in horizontal deformation.



(a)



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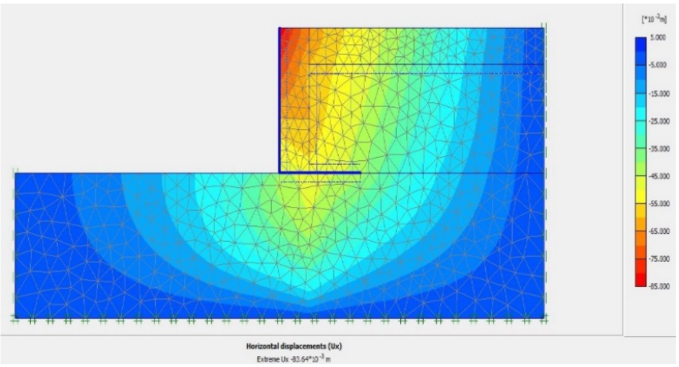
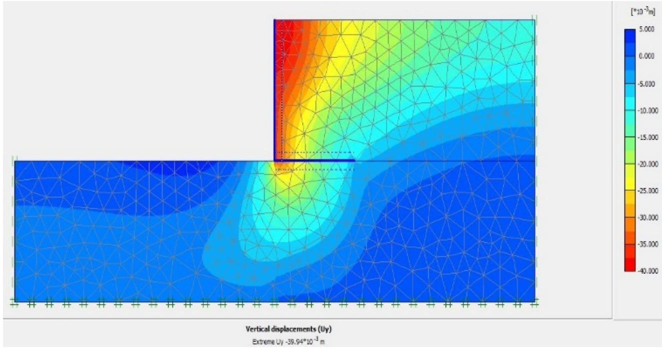


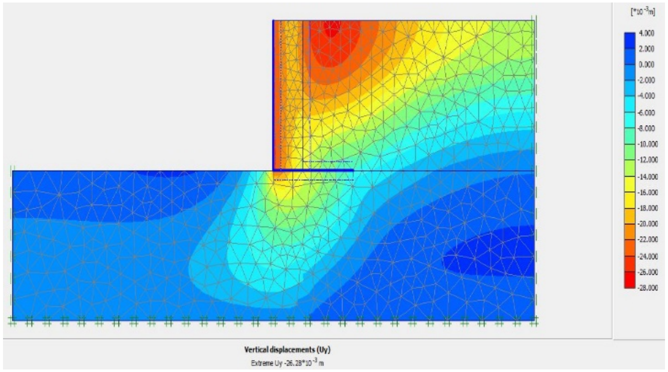
(c)

Figure 7. Horizontal deformation shadings [Static case] with length of base slab 5.5m for (a)without EPS (b) EPS thickness of 2m in vertical position (c) EPS thickness of 2m in both vertical and horizontal positions

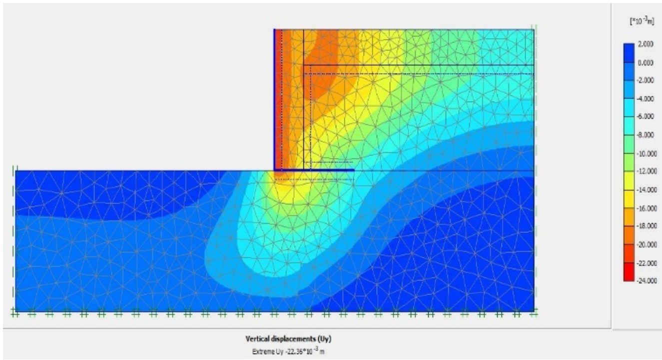
The backfill settlement pattern [Static case] of the retaining wall with length of base slab 5.5m for various positions of EPS Geofoam thickness of 2m are given in Fig.8. It was observed that without use of EPS inclusions, the facing wall settlement value was 39.94mm. With the presence of EPS thickness of 2m in vertical position behind retaining wall, the settlement value reduced to 26.28mm. Whereas presence of EPS thickness of 2m in both vertical and horizontal positions reduced the settlement further to a value of 22.36mm.



(a)



(b)



(c)

Figure 8. Vertical deformation shadings [Static case] with length of base slab 5.5m for (a)without EPS (b) EPS thickness of 2m in vertical position (c) EPS thickness of 2m in both vertical and horizontal positions.

Comparison of lateral earth pressure with and without EPS subjected to static and dynamic load is given in Fig. 9. In this case, lateral earth pressure was considered for the L-shaped retaining wall with base slab 5.5m as it gave the maximum reduction in horizontal deformation of the facing wall. The analysis results showed that presence of EPS geofoam with relative thickness t/H= 0.25 (where t=thickness of EPS geofoam and H= height of retaining wall) in both vertical and horizontal positions can significantly reduce the lateral earth pressure up to approximately 80% compared to without EPS geofoam.

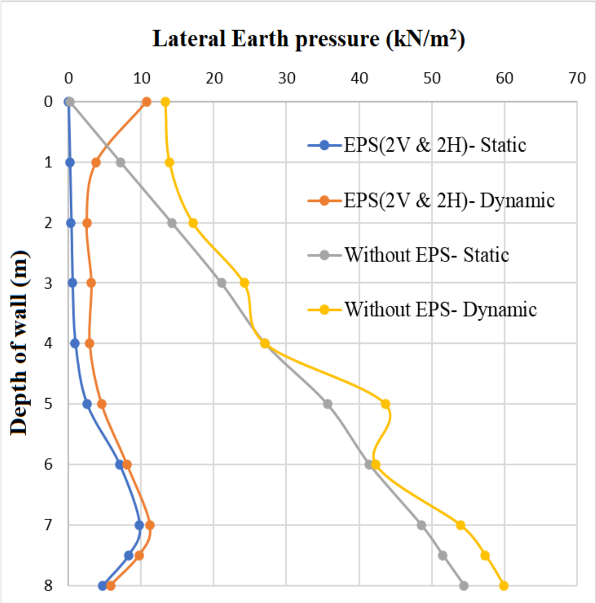


Figure 9. Comparison of lateral earth pressure with and without EPS subjected to static and dynamic load

4. Conclusion

Based on the numerical analysis performed with different positions and thickness of EPS inclusions, the following conclusions were drawn from the study:

- EPS geofoam can be effectively used fir reducing static and earthquake induced forces
- The maximum reduction of horizontal deformation of facing wall was achieved by using relative length of base slab B/H= 0.68 and relative thickness of EPS geofoam as t/H= 0.25 in both vertical position (behind facing wall) and horizontal position (above fly ash backfill)
- Lateral earth pressure was significantly reduced by approximately 82% in static and 81% in dynamic case as compared to the one without EPS geofoam.
- Increase in EPS thickness above 2m didn't show any significant reduction in wall deformation. Thus, a maximum relative thickness of 0.25H can be adopted.
- Horizontal deformation of facing wall was significantly reduced by 42% in static case and 38% in dynamic case as compared to without EPS geofoam.

Nomenclature

EPS Geofoam = Expanded Polystyrene Geofoam
t = thickness of EPS
H = Height of retaining wall
B = Length of the base slab of L-shaped retaining wall
1V = EPS Geofoam thickness of 1 m in Vertical position
1.5 V = EPS Geofoam thickness of 1.5 m in Vertical position
2V = EPS Geofoam thickness of 2m in Vertical position
1H = EPS Geofoam thickness of 1m in horizontal position
1.5H = EPS Geofoam thickness of 1.5m in horizontal position
2H = EPS Geofoam thickness of 2m in horizontal position

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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