Magazine of Civil Engineering. 2020. 99(7). Article No. 9904

Magazine of Civil Engineering

ISSN
2712-8172

journal homepage: http://engstroy.spbstu.ru/

DOI: 10.18720/MCE.99.4

Earth pressure reduction on retaining walls using EPS geofoam

Y.E-H. Ibrahim*[a], S.S.A. Abdelsalam[b], M.N.A. Nabil[b], M.E. Elsayed[b]

[a] Prince Sultan University, Rafha Street, Riyadh, Saudi Arabia

[b] Zagazig University, Zagazig, Egypt

** E-mail: yibrahim@vt.edu*

Keywords: EPS geofoam, finite element method, non-yielding, yielding walls, lateral earth pressure, ABAQUS

Abstract. Retaining wall structures are widely used in different civil engineering projects including building construction, highways, railways, water conservancy, harbors, and many other projects in order to resist the lateral pressure of soil and water. According to their deformation behavior, retaining walls can be classified as flexible walls and rigid walls. Deformable inclusions such as expanded polystyrene, EPS, geofoam can be used to reduce the lateral earth pressure on retaining wall structures. In this study, the effect of using EPS geofoam inclusion on the reduction of lateral earth pressure and stability behavior of non-yielding and yielding retaining walls with cohesionless backfills is examined through a finite element analysis using ABAQUS software. A parametric analysis was performed to examine the effectiveness of EPS inclusion considering different parameters including the foam thickness, short and long-term characteristics of the foam density, surcharge load on backfill and the backfill properties. According to the results obtained, the earth pressure and subsequently the sliding forces and overturning moments were reduced on non-yielding and yielding retaining walls due to the EPS inclusion. The percentage of reduction was higher in the case of non-yielding walls with zero surcharge pressure. The reduction in sliding forces and overturning moments reached 47 %. Moreover, it was found that the lateral earth pressure, sliding forces and overturning moment on retaining walls were decreased with the increases of the foam thickness. However, the lateral earth pressure was slightly increased with the increase of the foam density. Empirical equations of reduction in lateral forces and overturning moments were developed as a function of foam thickness.

1. Introduction

The stability of earth retaining wall systems represents a complex balance of external loads versus resistances' problems. Earth retaining walls are generally divided into non-yielding and yielding systems. The former system is inherently constrained against both deformation and displacement in the horizontal direction. Common examples of the non-yielding system include below-grade (e.g., basement) walls of buildings, bridge abutments, and free-standing retaining walls that are restrained against horizontal displacement due to physical restraint or structure geometry. The non-yielding earth retaining wall systems are logically designed assuming the at-rest earth-pressure state within the retained soil. The yielding system can either displace or deform or both in the horizontal direction. The yielding earth retaining wall systems can develop the active earth-pressure state within the retained soil [1].

Active earth pressures evaluation plays an important role in geotechnical engineering. Reduction in lateral earth pressure, sliding force and overturning moment on a retaining wall by providing EPS geofoam inclusions helps in reducing the project cost. The use of expanded polystyrene (EPS) geofoam as a lightweight compressible inclusion has gained extensive popularity in geotechnical engineering. Many researchers have carried out analytical, experimental work and numerical analyses on lateral earth pressure problems. These studies have shown that compressible materials between a rigid retaining wall and backfill reduced static force [2–6]. Chauhan and Dasaka [7] proved the effectiveness of EPS geofoam on reduction of lateral earth pressure. They noticed that provision of geofoam behind the retaining wall provided a thrust reduction in range of 8–42 % for surcharge pressures ranging from 10–50 kPa.

Navid and Rouzbeh [8] conducted a finite difference analysis using a 2-D FLAC computer program by considering yielding and non-yielding states for retaining walls to explore the effectiveness of geofoam panels in improving the static performance of cantilever retaining walls. They found that using EPS15 with density equal to 15 (kg/m^3), which has the lowest density among other geofoam panels, has a significant role in reduction of lateral stresses. Through their small-scale physical model tests, Dave and Dasaka [9] found that, EPS geofoam reduced the total lateral force on the retaining wall by about 23 % and 28 %, for retaining wall with and without hinge, respectively. Yadav [10] conducted a numerical analysis on static and seismic condition with inclusion of geofoam on retaining wall in using Plaxis 2D software. The thickness of geofoam was considered as 0.5 m, 1.0 m, 1.5 m and 2 m. It was found that the reduction in lateral earth pressure increases with the increase in geofoam thickness. Ertugrul and Trandafir [11] conducted experimental study to investigate the reduction of lateral earth forces on rigid retaining walls by using EPS geofoam inclusions. For rigid non-yielding retaining wall, EPS geofoam panels of three different thicknesses (characterized by the ratio of geofoam thickness to wall height, t/h, of 0.07, 0.14, and 0.28) were installed behind retaining wall. When comparing the “no buffer” case with an inclusion of t/h = 0.14, it was found that the reduction in the lateral pressure exceeded 50 %. Salem et al. [12] developed a small-size diaphragm wall with EPS buffer using FE program PLAXIS 3D. They concluded that, lateral pressure on diaphragm walls was significantly reduced by around 37 % using a relatively thin EPS buffer.

Veletsos and Younan [13] investigated dynamic pressures on flexible cantilever retaining walls with fixed base using an analytical approach that involved repeated application of Lagrange's equation. Results of their study emphasized the importance of wall flexibility on the lateral dynamic load and indicated that the total wall force may be reduced to about one half of the force calculated for a rigid retaining wall with a fixed base.

Bathurst et al. [14] investigated the performance of seismic geofoam buffers by carrying out physical shaking table tests on a non-yielding rigid wall with a 1.0 m height with deformable geofoam panels and granular backfill. A maximum dynamic force reduction of 31 % (compared to the control case of a rigid retaining wall with no geofoam buffer) was observed in these tests for a peak base acceleration of 0.7 g.

Fakhry et al. [15] constructed a numerical model using finite element program PLAXIS 2D. They concluded that, the lateral pressure on flexible diaphragm walls can be significantly reduced by 37 % using a relatively thin EPS buffer. Mustafa et al. [16] studied the efficiency of EPS geofoam inclusion in reducing the static earth pressure on non-yielding cantilever retaining walls with a height of 7 m, using finite element program, PLAXIS 2D. They studied the distribution and magnitude of earth pressure on retaining walls with and without geofoam when subjected to surcharge loads. A geofoam density of 10 kg/m^3 and a thickness of 0.50 m were used. The results confirmed that the earth pressure have been reduced with the geofoam inclusion by 36 %. Abdelsalam et al. [17] developed a 3-D model using PLAXIS 3D. They found that reduction in lateral earth pressure acting on flexible retaining walls ranged from 2 % to 25 % by using EPS geofoam with a foam thickness to wall height ratio ranging from 0.01 to 0.05, respectively.

Researchers considered using EPS with other geosynthetics to enhance the effect of EPS in different applications. Moghaddas Tafreshi et al. [18] conducted experimental tests to investigate the effect of inclusion EPS geofoam block and geocell to mitigate the pressure on buried flexible high-density polyethylene pipes. They found that using EPS can reduce the pressure onto the pipe, however, it may cause larger surface settlements. The effect of using EPS was enhanced by using geocell reinforcement and the resulting deformations were kept within allowable limits. Experimental tests were used to study the effect of the use of geogrid and EPS geofoam block to protect unplasticized polyvinyl chloride pipes with 160 mm diameter buried in unreinforced and reinforced trenches under cyclic loadings [19]. It was found that using geogrid with EPS block with appropriate density, thickness and width can control the behavior of these buried pipes under cyclic loading. EPS wall barrier was considered to mitigate the blast load effect on the pile foundation [20]. According to the results obtained, it was observed that the open trench and the EPS wall barrier have the best effectiveness in reducing the blast load effect on such foundations, when compared to other techniques or materials. Other researchers used fibers of polypropylene under retaining walls to enhance the stability of the soil mass [21]. It was found that retaining wall with fiber-sand backfill experience much smaller horizontal movements than that of the retaining wall with sand backfill.

The main goal of this study is to optimize the effectiveness of using geofoam inclusions as a lightweight fill material behind retaining wall structures in order to effectively reduce the lateral earth pressure and enhance the stability of the retaining walls considering the sliding forces and overturning moments on these walls. A detailed FE analysis using ABAQUS was used to model backfill soil, retaining walls and EPS geofoam. In this regard, several parameters were considered including the foam thickness, which varied from 0 to 3.0 m, foam density for short and long-term conditions, surcharge pressures on backfill surface due to foundations of adjacent structures and traffic loading and finally the backfill soil type including loose, medium and dense sand.

2. Methods

The theories proposed by Coulomb [22] and Rankine [23] remain the fundamental approaches to analyze the active earth pressures their formulation is simple, and widely accepted by practicing engineers. FE method can analyze complicated geometries and provide detailed results to the retaining wall problem. Accordingly, it is becoming an effective method of solving the earth pressure problems.

In this research, a three-dimensional FE commercial software (ABAQUS) was used in the analysis to model the retaining wall, backfill soil and soil underneath the wall. The backfill soil comprises loose sand with a height of 8.0 m, followed by dense sand extending down to a depth of 31.0 m. The wall has a height of 8.0 m, and its width varies from 3.0 m at the base to 0.80 m at the top. In the analysis, the wall was modeled as an elastic material.

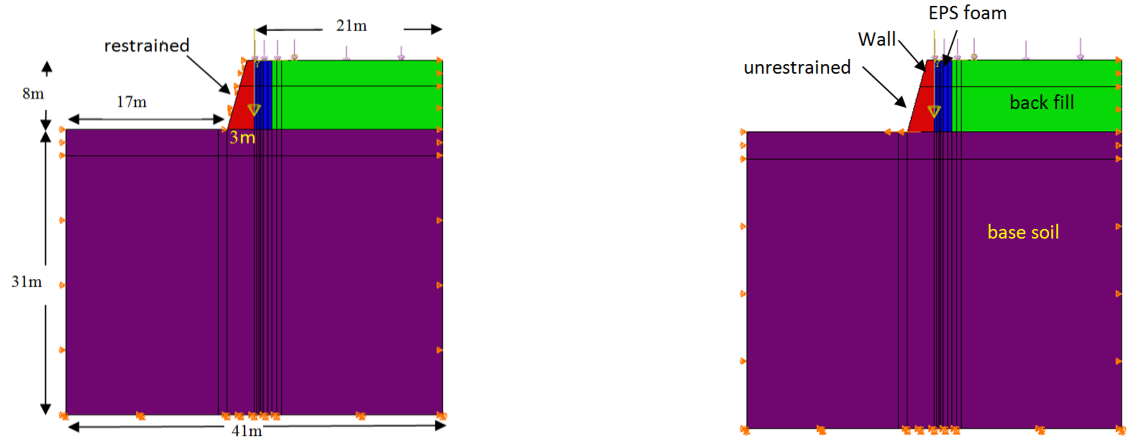
Wall is modeled as elastic materials by an eight-node linear brick element with reduced integration and hourglass control (C3D8R). Soil, EPS geofoam and back fill are modeled by elastic ideal plastic constitutive model following Mohr–Coulomb yield criterion by an eight-node linear brick element with reduced integration and hourglass control (C3D8R). The Mohr–Coulomb Model considers the effect of stresses on the strength of soil. The failure criterion is defined by the friction angles and cohesion of soil. The Main parameters are summarized in Table 1. It should be noted that wall elements are relatively rigid to the surrounding soil deformations. The surface of wall elements that are in contact with the soil elements is referred to as the main surface (master). The surface of the soil elements in contact is set as the secondary surface (slave). In the ABAQUS program these surfaces are called contact pairs. The contact behavior of the two surfaces is determined by the Coulomb law of sliding friction. The Coulomb model of friction applies to the maximum allowable friction (shear), including the normal stress at the interface between the two surfaces.

A finite-sliding formulation was used at these interfaces, which allows any random motion of the surfaces including sliding, separation, and rotation of the surfaces. Hard contact model was used to define the normal contact pressure over closure relationship between the backfill and base soil and the wall. The first step of the analysis was to verify that the initial geostatic stress field is in balance with the applied loads and boundary conditions. The initial step was followed by several static analyses stages to reach an active state.

Boundary conditions of the bottom of the model were fixed. The horizontal displacement was constrained at the right and left sides of the soil block considered. The left side of retaining wall was restraint for non-yielding retaining wall and unrestrained for the case of yielding retaining wall. The vertical stress distributions behind the wall at non-yielding and yielding walls were taken as (Δ = 0.000H) and (Δ = 0.00073H), respectively as presented in Fig. 1 [24, 25].

Table 1. Physical and mechanical properties of soil, backfill and EPS.

	Wall	EPS geofoam	Backfill Loose sand	Base soil
Unit weight, γ (kN/m^3)	24	2.5	15	17
Modulus of elasticity, E (MPa)	2.1E^4	2.736	20	100
Poisson ratio, μ	0.20	0.14	0.3	0.25
Internal friction angle, ϕ °	-	27	30	37
Cohesion, C, kPa	-	47	0	0



a) Non-yield **b) Yield**

Fig. 1: Dimensions and boundary conditions of the retaining walls
a) Non-yielding retaining wall and (b) Yielding retaining wall.

The main purpose of the parametric study is to investigate the effect of using EPS geofoam in reducing the lateral earth pressure on yielding and non-yielding retaining walls. The following parameters were considered in this study:

- Foam thickness (case 1);
- Foam properties including short term and long-term conditions (case 2);
- Surcharge pressure on backfill surface (case 3);
- Backfill soil properties (case 4).

Table 2 through Table 5 show different parameters considered in this study in details.

Table 2. Effect of foam thickness (case 1).

Case	a	b	c	d	e	f	g
Foam thickness (m)	0.0	0.5	1.0	1.5	2.0	2.5	3.0

Table 3. Effect of EPS properties (case 2) [26].

Case		EPS properties				
		γ (kN/m^3)	E (kPa)	μ	ϕ °	C, kPa
a	Short term	25	2736	0.14	27	47
Foam 25	Long term	25	2072	0.14	25	40
b	Short term	30	4307	0.17	33	57
Foam 30	Long term	30	3263	0.17	30	45
c	Short term	35	4924	0.2	36	84
Foam 35	Long term	35	3730	0.2	33	67

Table 4. Effect of surcharge pressure (case 3).

Case	a	b	c	d
Surcharge pressure, q(kPa)	0	16	25	50

Table 5. Effect of backfill properties (case 4).

Case	Backfill properties				
	Soil type	γ (kN/m^3)	E (MPa)	μ	ϕ °
a	Loose sand	15	20	0.3	27
b	Medium sand	18	50	0.3	35
c	Dense sand	20	100	0.25	37

3. Results and Discussion

3.1. Verification of FE Model

First, the developed FE model was verified through a comparison with the Coulomb and Rankine fundamental approaches. Lateral earth pressure distribution along wall for non-yielding retaining walls at different backfill granular soils (loose sand with Young modulus equal to 20 MPa, medium sand with Young modulus equal to 50 MPa and dense sand with Young modulus equal to 100 MPa) and at different surcharge load (q = 0 kPa, q = 16 kPa, q = 25 kPa and q = 50 kPa) are shown in Fig. 2 and Fig. 3, where they are compared with the theoretical approaches at non-yielding lateral earth pressure distribution. From these figures, it can be observed that good agreement was noted between the FE calculations and the theoretical approaches. Fig. 4 and Fig. 5 show the lateral earth pressure distribution versus the normalized height of wall for yielding retaining walls at different backfill material and at different surcharge load, where they were compared with the Coulomb active earth pressure distribution. Again, the theoretical active earth pressure agreed well with the FE results. It should be noted that the limiting active earth pressure condition occurred after the formation of a failing soil wedge adjacent to the retaining wall. The numerical simulations using ABAQUS reasonably predicted the response and the lateral earth pressure of the retaining wall. The developed model was able to predict the lateral earth pressure with a good level of accuracy. From the verification part and the comparisons for each case, it can be concluded that a reliable FE model was developed.

The plastic strain contours, shown in Fig. 6, clearly illustrate the presence of a failure plane similar to the one assumed in the Coulomb active earth pressure theory. This failure surface was inclined at an angle of (45+ϕ/2), according to Coulomb theory.

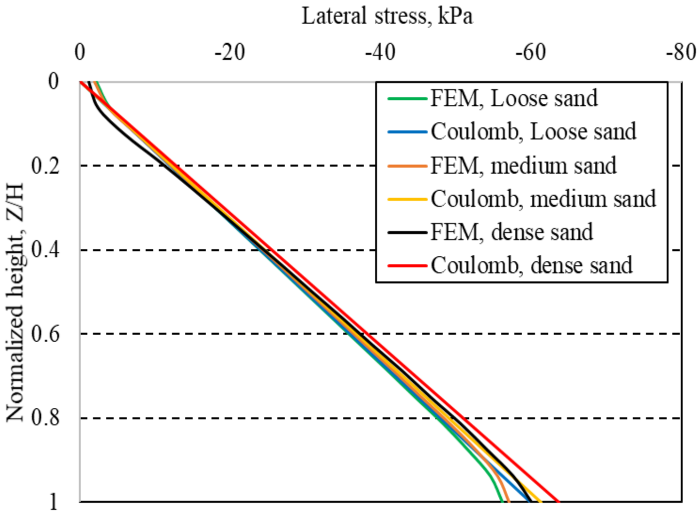


Figure 2. Lateral earth pressure against non-yielding wall model for different backfills.

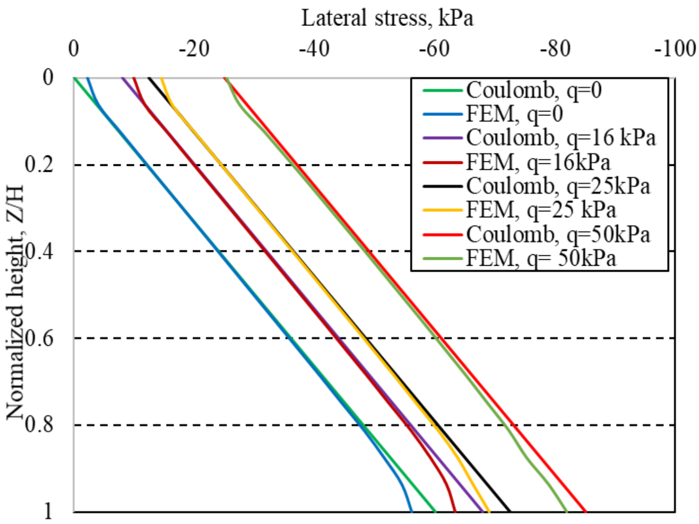


Figure 3. Lateral earth pressure against non-yielding wall model for different surcharge loads.

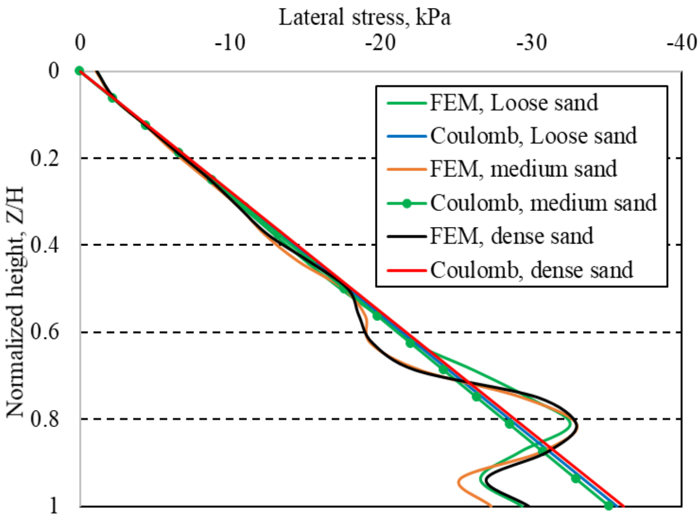


Figure 4. Lateral earth pressure against yielding wall model for different backfills.

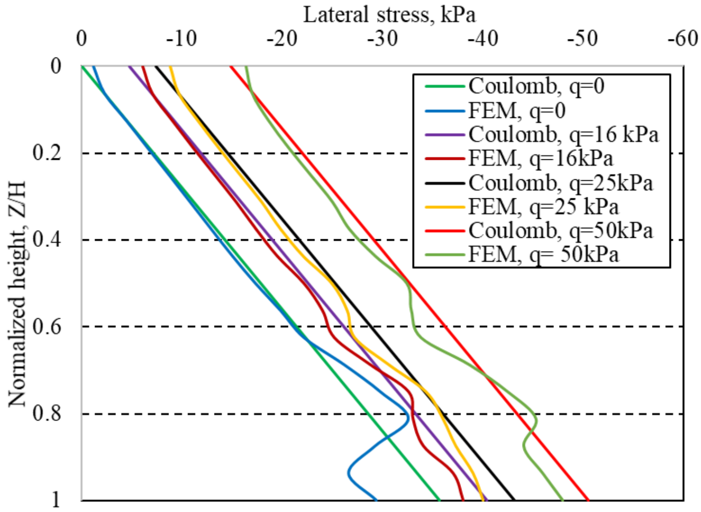
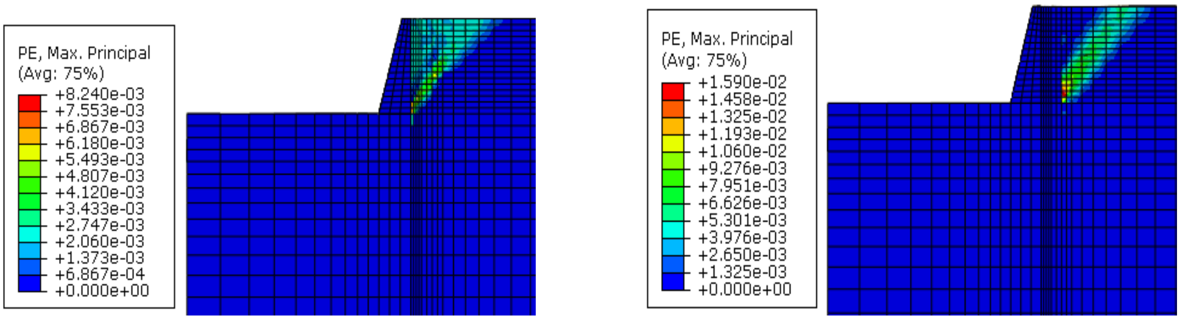


Figure 5. Lateral earth pressure against yielding wall model for different surcharge pressures, *q*.

The analysis was performed for a retaining wall with a height of 8 m, a surcharge load equal zero, the foam density 25 kg/ m^3, loose-sand backfill and a foam thickness varying from zero to 3.0 m as given in Table 2.



a) Without foam b) With foam = 2 m

Figure 6. Distribution of plastic strain without and with foam in the backfill at active failure.

3.2. Effect of Foam Thickness

First, the effect of foam thickness on lateral earth pressure on retaining walls, and accordingly on the sliding forces and overturning moments, was investigated in case 1. In this case, foam was used with different thicknesses ranging from zero to 3.0 m. The foam density was set to 25 kg/m^3 for the whole case. No surcharge pressure was considered. The backfill soil was loose sand with unit weight of 15 kN/m^3 and modulus of elasticity of 20 MPa, Poisson ratio of 0.3 and internal friction angle of 27˚ with no cohesion. Both types of walls were considered; non-yielding and yielding retaining walls.

Fig. 7 shows lateral earth pressure against non-yielding wall for different foam thicknesses. The percentage of reduction in lateral force and overturning moment for non-yielding wall at different foam thicknesses is shown in Fig. 8. Fig. 9 shows factor of safety for sliding and overturning on the non-yielding wall at different foam thickness. From these figures, it can be observed that, the lateral earth pressure was significantly decreased upon using foam in front of the non-yielding retaining wall with a noticeable enhancement in the factor of safety against sliding and overturning. Figures also show that as the thickness of foam increases, the lateral earth pressure is reduced and consequently the factor of safety is increased.

The percentage of reduction in lateral earth force and overturning moment at different foam thickness can be calculated by the following equations: For the lateral force, $Y = 40.50X^{0.208}$, and for the overturning moment, $Y = 23.85X^{0.313}$, where Y is the percentage of reduction and X is the foam: thickness in meters. The factor of safety for sliding and overturning also was increased from 0.75 to 1.50 and from 1.15 to 1.75, respectively.

The effect of foam thickness on the reduction of lateral earth pressure on yielding retaining walls and the enhancement of corresponding factor of safety in terms of sliding force and overturning moment are shown in Fig. 10 to Fig. 12. Fig. 10 shows lateral earth pressure against yielding retaining wall for different foam thicknesses. Fig. 11 shows the percentage of reduction in lateral force and overturning moment for non-yielding wall at different foam thickness. Fig. 12 shows factor of safety for sliding and overturning on the yielding wall at different foam thickness. Similar to the non-yielding retaining walls, the figures show that the lateral earth pressure was decreased as the thickness of foam was increased.

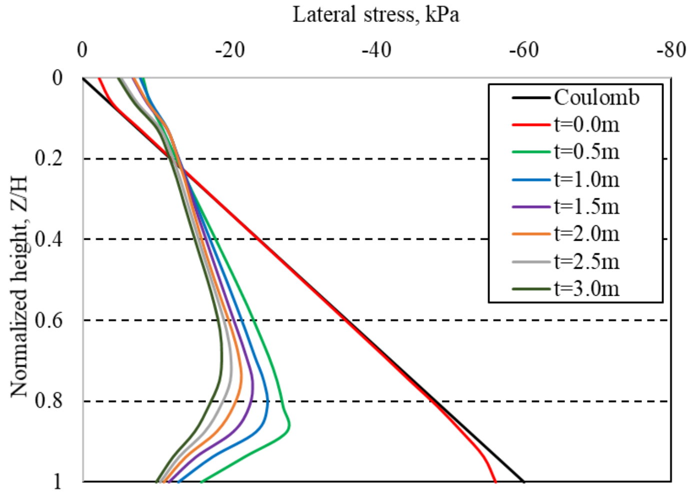


Figure 7. Lateral earth pressure against non-yielding wall for different foam thicknesses.

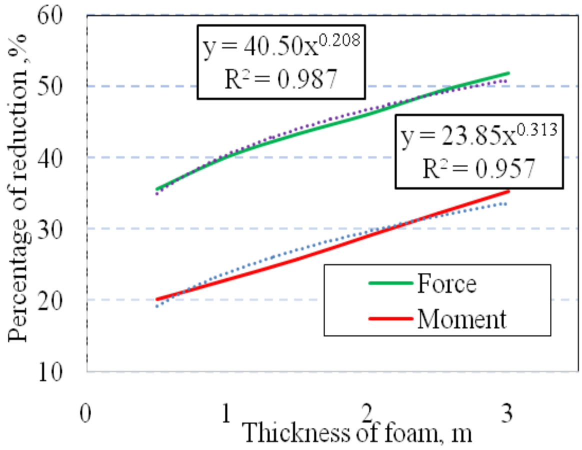


Figure 8. Percentage of reduction in lateral force and overturning moment

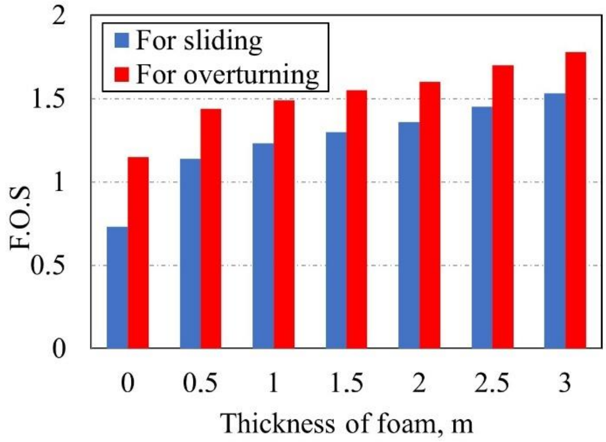


Figure 9. Factor of safety for sliding and overturning.

The percentage of reduction in lateral force and overturning moment at different foam thicknesses can be calculated by the following equations: For the force, $Y = 17.95X^{0.7502}$ and for the moment, $Y = 1.157X^2 + 3.605\,X + 2.894$, as shown in Fig. 11. The factor of safety for sliding and overturning also was increased from 1.25 to 2.10 and from 1.8 to 2.60, respectively, as shown in Fig. 12.

In general, the lateral earth pressure is decreased with the increase of the foam thickness. This reduction in earth pressure reached 52 % for non-yielding walls and 41.14 % for yielding walls, when using foam with 3.0 m thickness, as shown in Fig. 7 and Fig. 10.

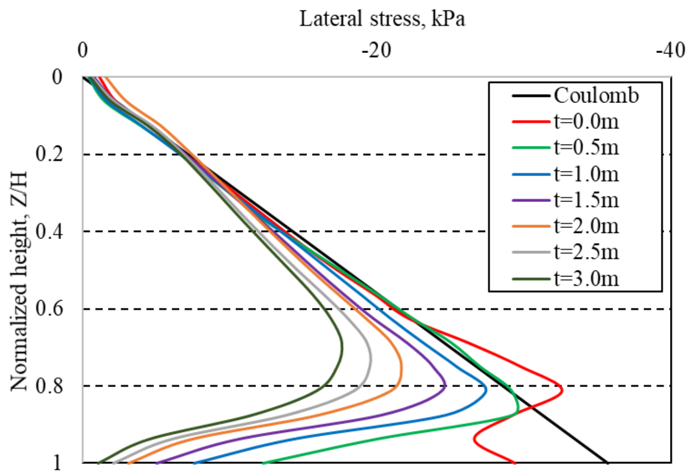


Figure 10. Lateral earth pressure against yielding wall for different foam thickness.

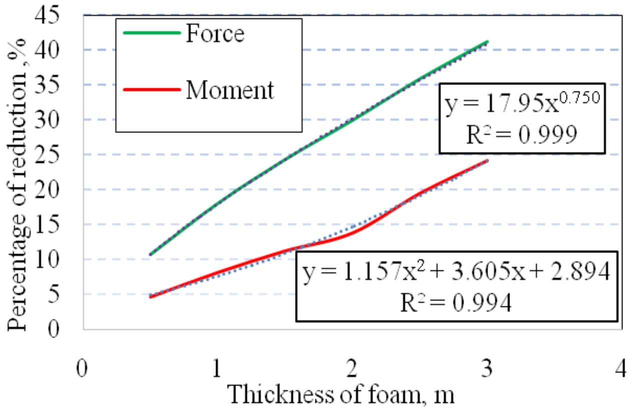


Figure 11. Percentage of reduction in lateral force and overturning moment.

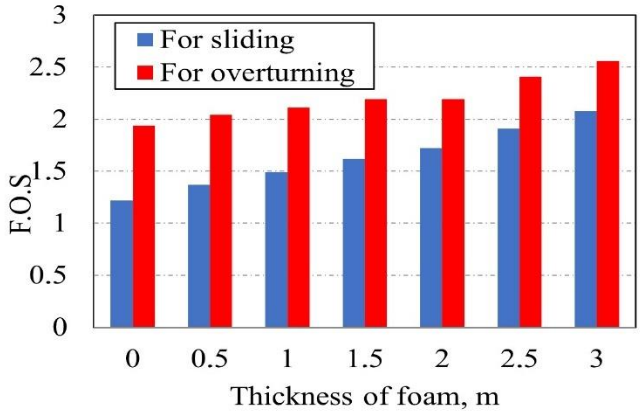


Figure 12. Factor of safety for sliding and overturning.

3.3. Effect of Foam Properties

In case 2, the effect of EPS properties on lateral earth pressure was studied considering the short term and long-term conditions of EPS. During this analysis, loose sand was considered with similar soil properties as in case 1. Also, no surcharge pressure was considered in this case. Table 3 summarizes the details of properties for the three types of EPS used: Foam 25, Foam 30 and Foam 35 in terms of unit weight, modulus of elasticity, Poisson ratio internal friction angle and cohesion. The foam thickness was 2.0 m, in this case.

Fig. 13 shows the lateral earth pressure against non-yielding wall model for different foam densities in short and long-term conditions. Fig. 14 shows the percentage of reduction in lateral force and overturning moment at different foam densities. The lateral force was decreased by 46.4 % for Foam 25, 44.5 % for Foam 30 and 43 % for Foam 35. The overturning moment was decreased by 29 % for Foam 25, 27.7 % for Foam 30 and 26.4 % for Foam 35, for short-term properties. Fig. 15 shows percentage of reduction in lateral force and overturning moment at different foam densities. The lateral force was decreased by 46.6 % for foam 25, 43.9 % for foam 30 and 43.9 % for foam 35. The overturning moment was decreased by 28.1 % for Foam 25, 26.9 % for Foam 30 and 26.9 % for Foam 35, for long-term properties.

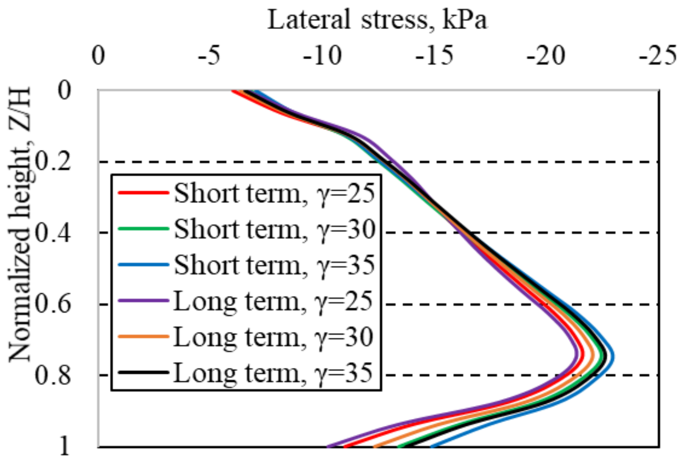


Figure 13. Lateral earth pressure against non-yielding wall model for different foam densities in the short and long-term conditions.

Fig. 16 shows Lateral earth pressure against non-yielding wall model for different foam densities in short and long-term conditions. Fig. 17 shows percentage of reduction in the lateral force and overturning moment at different foam densities. The lateral force was decreased by 29.8 % for Foam 25, 33.1 % for Foam 30 and 32.9 % for Foam 35. The overturning moment was decreased by 13.8 % for Foam 25, 21.9 % for Foam 30 and 22.8 % for Foam 35 for the short-term properties. Fig. 18 shows percentage of reduction in lateral force and overturning moment at different foam densities. The lateral force was decreased by 26.9 % for Foam 25, 30.1 % for Foam 30 and 30 % for Foam 35. The overturning moment was decreased by 7.2 % for Foam 25, 16.2 % for Foam 30 and 18 % for Foam 35 for the long-term properties.

In all studied cases, there is a general trend of having less lateral earth pressures on non-yielding retaining walls with decreasing EPS foam density. Results showed that use of Foam 25, which has the lowest density among other geofoam densities, is the most efficient in reducing the lateral pressure on non-yielding retaining walls. On the contrary, for yielding retaining walls, there is a general trend of reducing the lateral earth pressures with the increase in EPS foam density. The results showed that use of Foam 35, which has the highest density between other geofoam densities, is the most efficient in reduction of lateral stresses on yielding retaining walls.

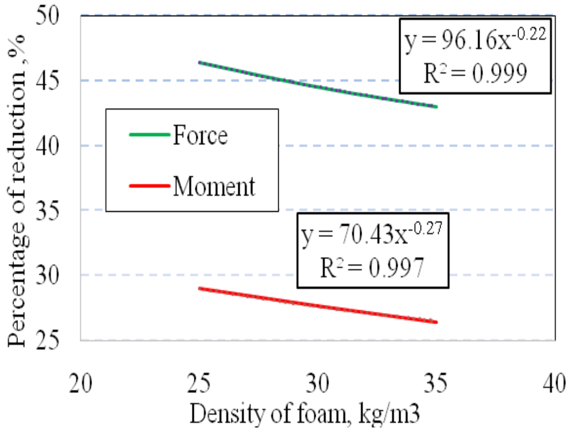


Figure 14. Percentage of reduction in lateral force and overturning moment for non-yielding wall (short-term conditions).

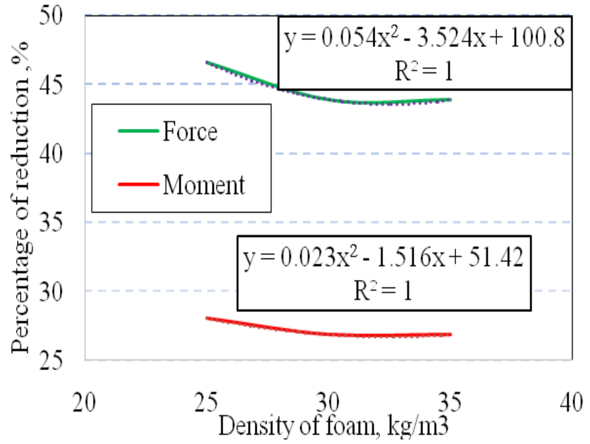


Figure 15. Reduction in lateral force and overturning moment for non-yielding wall (long-term conditions).

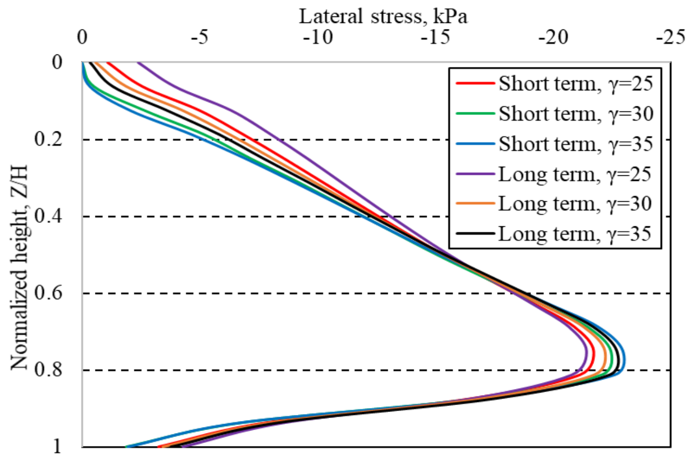


Figure 16. Lateral earth pressure against yielding wall model for different foam densities in short and long-term conditions.

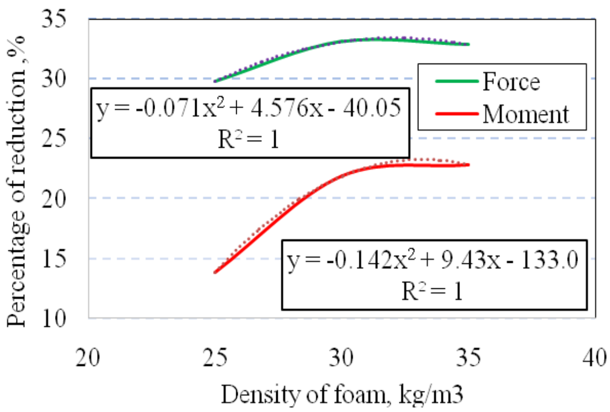


Figure 17. Reduction in lateral force and overturning moment for yielding wall (short-term condition).

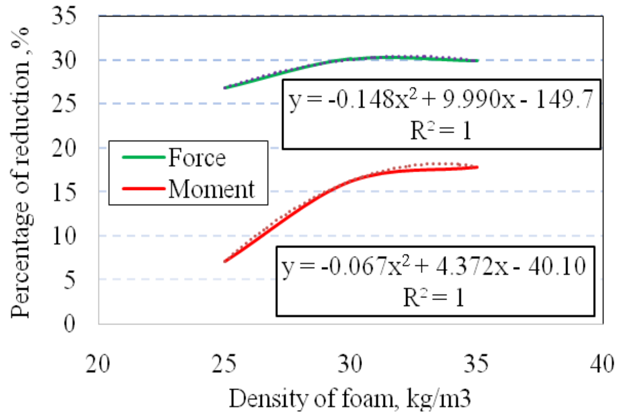


Figure 18. Reduction in lateral force and overturning moment for yielding wall (long-term condition).

3.4. Effect of Surcharge Pressure

Four different values of surcharge pressure were considered in case 3 to simulate pressure from foundations of adjacent structures and traffic loading. In this case, surcharge pressure values on backfill of *q* = 0, 16, 25 and 50 kPa were considered. Similar soil properties were used for loose sand, as in case 1 and 2. Foam 25 with a thickness of 2.0 m in short-term conditions was considered in this case.

Fig. 19 shows the distribution of lateral earth pressure with the normalized height of non-yielding retaining wall for different values of surcharge pressures. As shown in Fig. 20, the percentage of reduction in lateral earth pressure was decreased with the increase of surcharge pressure. Considering the overturning moment, the reduction percentage was around 30 % for surcharge pressure up to 20 kPa. For higher surcharge pressure, the reduction percentage was gradually decreased.

For yielding retaining wall, the distribution of lateral earth pressure on the wall is shown in Fig. 21. The percentage of reduction in lateral force was decreased from 30 % in the case of zero surcharge pressure on the backfill to 21 % for 50 kPa surcharge pressure. On the other hand, the maximum reduction in overturning moment was about 22 % when surcharge pressure of 20 kPa was applied. Only 14 % reduction was observed in the case of zero surcharge pressure on backfill surface. The percentage of reduction in lateral force and overturning moment as well as the fitting equations are shown in Fig. 22.

3.5. Effect of Backfill Soil

To investigate the effect of backfill soil properties on the effectiveness of using EPS foam on the lateral earth pressure on yielding and non-yielding retaining walls, three backfill soils were considered in case 4. These soils are loose, medium, and dense sands. The properties of each soil are presented in Table 5. The analysis was performed to investigate the lateral earth pressure and the safety of yielding and non-yielding retaining wall with a height of 8.0 m. No surcharge pressure was considered on the surface of backfill. Foam 25 in the short-term conditions with a thickness of 2.0 m was considered.

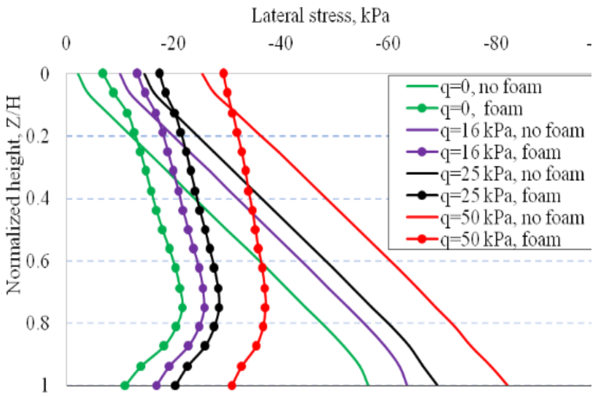


Figure 19. Lateral earth pressure against non-yielding walls for different surcharge loads.

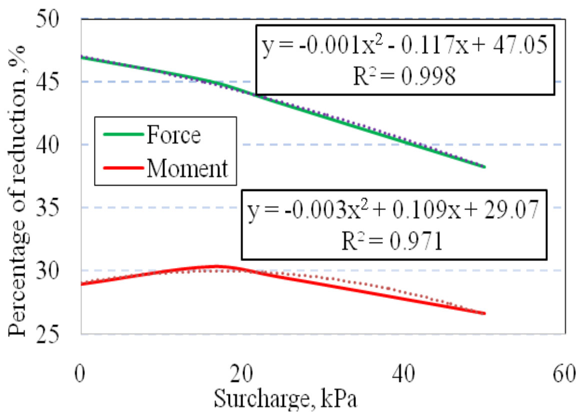


Figure 20. Reduction in lateral force and overturning moment for non-yielding walls at different surcharge loads.

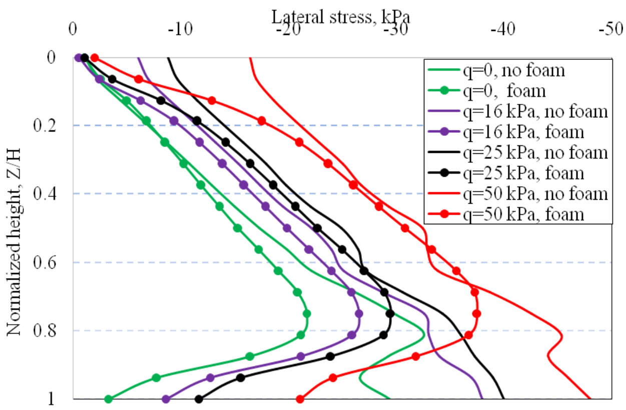


Figure 21. Lateral earth pressure against yielding wall for different surcharge loads.

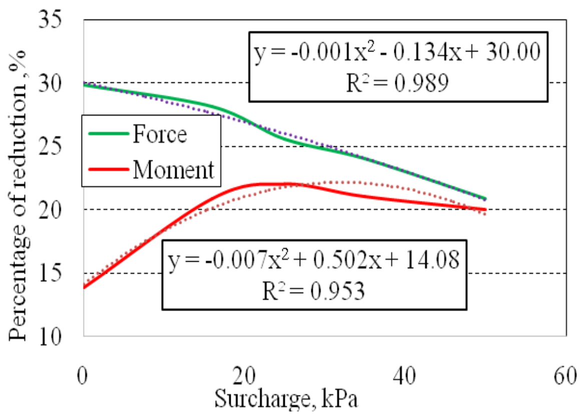


Figure 22. Reduction in lateral force and overturning moment for yielding wall at different surcharge loads.

Fig. 23 shows the distribution of lateral earth pressure on the non-yielding retaining wall for different backfill soils. According to Fig. 24, the lateral earth force and overturning moment were reduced by 49 % and by 29 %, respectively, for loose-sand backfill. Similar results were obtained in the case of medium-sand backfill, where the reduction was 51.3 % and 33 % for lateral earth force and overturning moment, respectively. For dense-sand backfill, the lateral earth pressure and overturning moment were decreased by 51.9 % and by 32.1 %, respectively.

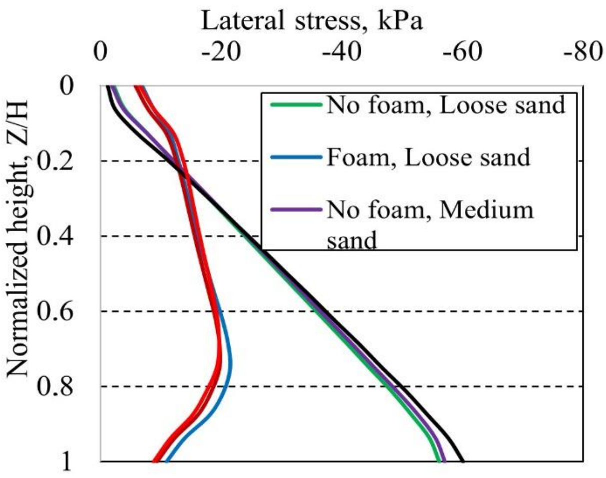


Figure 23. Lateral earth pressure against non-yielding wall for different types of backfill soil.

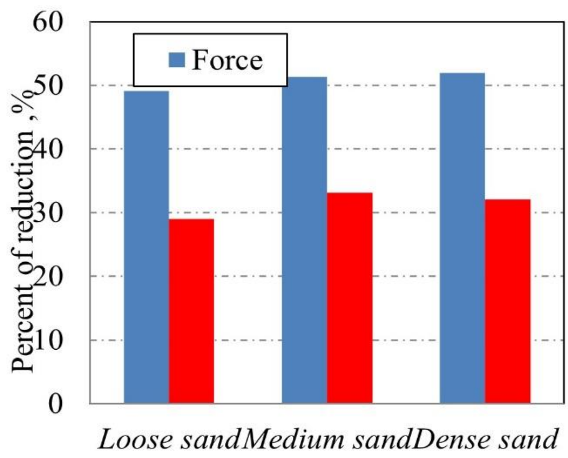


Figure 24. Percent of reduction in lateral force and overturning moment for non-yielding wall of different types of backfill soil.

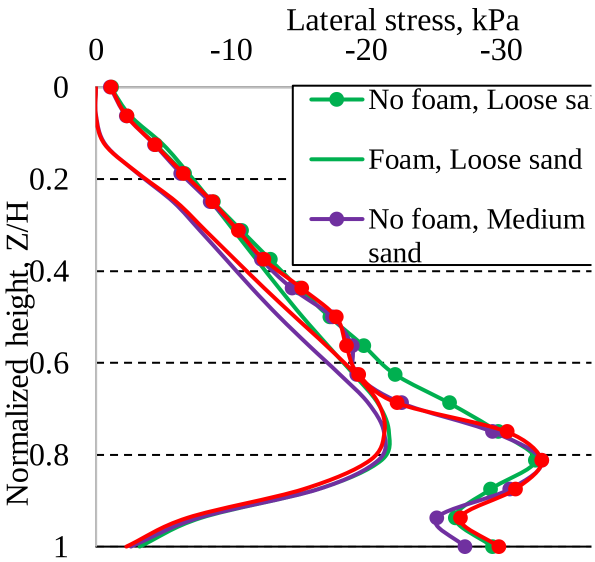


Fig. 25. Lateral earth pressure against yielding wall with different type of backfill soil

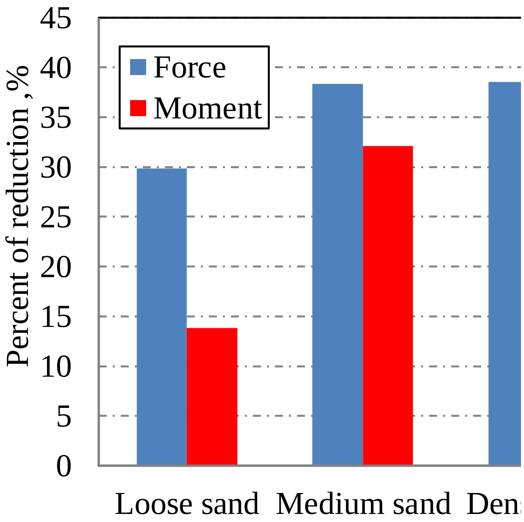


Fig. 26. Percent of reduction in lateral force and overturning moment for yielding wall with different types of backfill soil

Considering the case of yielding retaining wall, the distribution of lateral earth pressure over the wall height is shown in Fig. 25, for different types of backfill soil. The reduction in lateral earth forces and overturning moment for different backfill soils is shown in Fig. 26.The reduction in earth force was 29.8 %, 38.4 % and 38.6 % for loose, medium and dense sand backfills, respectively while the reduction in overturning moment was 13.8 %, 32.1 % and 31 %, for the considered backfill soils, respectively.

In general, using medium sand as backfill soil resulted in the best enhancement in the efficiency of EPS geofoam in reducing lateral force and overturning moment.

4. Conclusions

In this research, the inclusion of EPS geofoam was considered in order to reduce the lateral earth pressure on yielding and non-yielding retaining walls and accordingly increase the wall safety in terms of the sliding forces and overturning moments. A three-dimensional FE analysis was conducted using ABAQUS to model backfill soil, retaining wall, foam, and boundary conditions. The wall has a height of 8.0 m with a wall thickness of 0.80 m and 3.0 m at wall top and bottom, respectively. Four different parameters were considered to assess the efficiency of using EPS foam on lateral earth pressure on retaining walls and according the wall safety. These factors are:

- Foam thickness;
- Foam density and short-term and long-term properties;

- Surcharge pressure on backfill surface;
- Backfill soil properties.

According to the obtained results, the following conclusions were obtained:

1. The developed 3-D FE model using ABAQUS was able to predict the lateral earth pressure of cohesionless soil on both yielding and non-yielding retaining walls with a very satisfactory accuracy. The developed FE model can be used in similar applications to study the earth pressure on retaining walls with different deformable inclusions.

2. Increasing the EPS foam thickness results in reducing the lateral earth pressure on yielding and non-yielding retaining walls and accordingly increases the factor of safety against sliding and overturning. The reduction in lateral earth pressure was higher in the case of non-yielding retaining wall compared to the yielding retaining wall. The distribution of lateral earth pressure over wall height was considerably changed after using the EPS foam, especially in non-yielding retaining walls with maximum pressure values at a depth of 0.85 of the wall height.

3. For non-yielding retaining walls, percentage of reduction in lateral earth force and overturning moment were estimated by 40.50 X0.208 and 23.85 X0.313, respectively. For yielding retaining walls, the percentage of reduction in lateral earth force and overturning moment were estimated by 17.95 X0.7502 and 1.157 X2 + 3.605 X + 2.894, respectively, where X is the foam thickness in meters.

4. The density of EPS foam has a slight effect on the distribution and values of lateral earth pressure on yielding and non-yielding retaining walls considering the short-term and long-term conditions.

5. Inclusion of EPS foam has a considerable effect on reducing lateral earth pressure when having surcharge pressure on backfill surface against non-yielding wall while it has small effect on reducing lateral earth pressure in the case of yielding wall. For non-yielding wall, the maximum reduction in lateral earth force and turning moment was 47 % for zero surcharge pressure and 30 % for 20 kPa surcharge pressure, respectively. For yielding wall, the maximum reduction in lateral earth force and turning moment was 30 % for zero surcharge pressure and 22 % for 20 kPa surcharge pressure, respectively.

6. Similar efficiency of the inclusion of EPS foam was obtained in case of using different backfill soils in case of non-yielding retaining wall. However, the efficiency of EPS foam was higher in case of medium and dense sand backfills against yielding wall, compared to loose sand backfills.

5. Acknowledgement

Authors would like to express their thanks to Prince Sultan University for supporting the publication of this article.

References

1. Horvath, S.J. Seismic lateral earth pressure reduction on earth-retaining structures. Using Geofoams, Geotechnical Earthquake Engineering and Soil Dynamics Congress IV. 2008. Pp. 1–10.
2. Partos, A.M., Kazaniwsky, P.M. Geoboard reduces lateral earth pressures. Proceedings of Geosynthetics 87, Industrial Fabrics Association International. New Orleans, LA, USA, 1987. Pp. 628–639.
3. Karpurapu, R., Bathurst, R.J. Numerical investigation of controlled yielding of soil-retaining wall structures. Geotextiles and Geomembranes. 1992. Vol. 11. No. 2. Pp. 115–131.
4. Koerner, R. Designing with Geosynthetics, Pearson Education, London, UK, 5th edition. 2005.
5. Azzam, S.A., AbdelSalam, S.S. EPS geofoam to reduce lateral earth pressure on rigid wallsю International Conference on Advances in Structural and Geotechnical Engineering, Hurghada, Egypt. 2015.
6. AbdelSalam, S.S., Azzam, S.A. Reduction of lateral pressures on retaining walls using Ggofoam inclusionю Geosynthetics International. 2016. Vol. 23. No. 6. Pp. 395–407.
7. Chauhan, V.B., Dasaka, S.M. Assessment of lateral earth pressure reduction using EPS geofoam-A numerical study. Conference on Numerical Modeling in Geomechanics. 2017.
8. Navid, H.N., Rouzbeh, D. Effects of geofoam panels on static behavior of cantilever retaining wall. Advances in Civil Engineering. 2018. Vol. 2018. Article ID 2942689. https://doi.org/10.1155/2018/2942689
9. Dave, T.N., Dasaka, S.M. Effect of boundary conditions on earth pressure reduction using EPS Geofoam. Japanese Geotechnical Society Special Publication. 2016. Pp. 2232–2237. DOI: 10.3208/jgssp.ind-34
10. Yadav, P.A., Singh, D.K., Dahale, P.P., Padade, A.H. Analysis of retaining wall in static and seismic condition with inclusion of geofoam using Plaxis 2D. Indian Geotechnical Conference, Indian Institute of Science Bengaluru. 2018.
11. 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, ASCE. 2011. Vol. 23. No. 12. Pp. 1711–1718.
12. Salem, A.A., Beshoy, M.S., Sherif, S.A. 3D Modeling of EPS geofoam buffers behind diaphragm walls. Ground Improvement and Earth Structures, GeoMEast 2017. 2018. Pp. 46–53.
13. Veletsos, A.S., Younan, A.H. Dynamic response of cantilever retaining walls. Journal of Geotechnical and Geoenvironmental Engineering. 1997. Vol. 123. No. 2. Pp. 161–72.
14. Bathurst, R.J., Zarnani, S., Gaskin, A. Shaking table testing of geofoam seismic buffers. Soil Dynamics and Earthquake Engineering. 2007. Vol. 27. No. 4. Pp. 324–332.

15. Fakhry, B.M., Azzam, S.A., Abdelsalam, S.S. Using EPS buffers for diaphragm walls. 1st BUE Annual Conference & Exhibition-BUE ACE1 Cairo, EGYPT. 2016. Pp. 8–10.
16. Mustafa, R., Akram, W., Aman, S., Asif, M., (2017), Reduction of lateral earth pressure on rigid retaining walls using EPS geofoam inclusions. International Journal of Innovative Research in Science and Engineering. 2017. Vol. 3. No. 4.
17. AbdelSalam, S.S, Azzam, S.A., Fakhry, B. M. Reliability and 3D modeling of flexible walls with EPS inclusion. International Journal of Geomechanics. 2016. 04016153. Pp. 1–10.
18. Moghaddas Tafreshi, S.N., Joz Darabi, N., Dawson, A.R.. Combining EPS geofoam with geocell to reduce buried pipe loads and trench surface rutting, Geotextiles and Geomembranes. 2020. Vol. 48. No. 3. Pp. 400–418.
19. Azizian, M., Moghaddas Tafreshi, S.N., Joz Darabi, N. Experimental evaluation of an expanded polystyrene (EPS) block-geogrid system to protect buried pipes. Soil Dynamics and Earthquake Engineering. 2020. Vol. 129. 105965.
20. Ibrahim, Y.E-H., Nabil, M. Risk of surface blast load on pile foundations. Magazine of Civil Engineering. 2019. 90(6). Pp. 47–61. DOI: 10.18720/MCE.90.5
21. Grishina, A.S., Ponomaryov, A.B. Assessment of operation of fiber-reinforced soil located behind retaining walls. Geotechnics Fundamentals and Applications in Construction: New Materials, Structures, Technologies and Calculations – Proceedings of the International Conference on Geotechnics Fundamentals and Applications in Construction: New Materials, Structures, Technologies and Calculations, GFAC 2019. 2019. Pp. 82–85.
22. Coulomb, C.A. Essai sur une application des re`gles des maximis et minimis a` quelques proble`mes de statique relatifs a` l'architecture. In Me`moires Acade`mie Royale Pre`sente´s par Divers Savants, Paris. Vol. 7. Pp. 343–382.
23. Rankine, W. The Stability of Loose Earth. Philosophical Transactions of the Royal Society of London. Vol. 147.
24. Clough, G.W., Duncan, J.M. Earth Pressures. In Foundation Engineering Handbook. 2nd ed. Edited by H.-Y. Fang. Van Nostrand Reinhold, New York. 1991. Pp. 223–235.
25. Sadrekarimi, A., Monfared, D. Numerical investigation of the mobilization of active earth pressure on retaining walls. Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris. 2013. Pp. 793–796.
26. AbdelSalam, S.S., Jama, R.A., Salah, M.A. EPS inclusion to reduce vertical stresses on shallow tunnels. Geosynthetics International. 2019. Pp. 1–40.

Contacts:

Yasser Ibrahim, yibrahim@vt.edu

Sayed Abdelsalam, s.salam@link.net

Marwa Nabil, marwa_nabil_amin@yahoo.com

Mahmoud Elsayed, eng.me5591@gmail.com