Decreasing Earth Thrust with EPS Geofoam

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Abstract. Abstract The basic function of retaining walls is to support soil backfill and water. This function has to be adequate under different conditions of loading; with permissible deformations. Researches are addressing the reduction of the exerted lateral earth thrust and water pressures to satisfy the adequacy in reasonable costs. Expanded polystyrene geofoam, EPSG, is the most popular material adopted to decrease lateral earth thrust on retaining walls. This paper presents an article review on researches of this aspect. Equations were proposed for reduction in lateral forces and overturning moments. Its aim is to optimize the design of 8.0 m gravity retaining wall with installation of EPSG.

1 General

Earth-retaining structures retain soil on one of its sides. To design retaining structure, lateral earth thrust has to be determined. Principles of soil mechanics enclosed the design of retaining walls [1]. Retaining walls are designed for safety against the sliding that results from thrust. This thrust depends upon numerous reasons, such as the manner of movement of the wall, the flexibility of the wall, the properties of the soil, surcharge pressure, the drainage circumstances, and man-made or natural dynamic events.

During an earthquake, the lateral earth thrust increases due to the increase of soil deformations. Then the walls become susceptible to failure. Example given, Figure 1 shows failure of retaining wall during the Kumamoto earthquake in Japan occurred on the 16th of April 2016.

Researches are addressing the reduction of the exerted lateral earth thrust and water pressures to satisfy the adequacy in reasonable costs. Researchers [3–8] stated that the lateral loads on retaining walls can be reduced by installing a material of lower stiffness between the backfill soil and the wall structure. Expanded polystyrene geofoam, EPSG, is gaining popularity in decreasing lateral earth thrust on retaining walls. This paper presents an article review on researches of this aspect.

2 Possible forces on retaining walls

There are many sources of loading that could affect retaining walls. Some of them are:

- Weight of the wall and the backfill.
- Live and dead loads on the wall and the backfill.

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- The lateral pressures of the soil resulting from the weight of the backfill.
- The lateral pressures resulting from live and dead loads on the backfill surface.
- Groundwater pressure.
- Forces from wave impact
- Forces resulting from the impact of earthquakes.
- Any other forces generated during the erection of the wall (such as the effect of soil compaction equipment).

Fig. 1. Failure of retaining wall during the Kumamoto earthquake in Japan occurred on the 16th of April 2016 [2]

3 Decreasing earth thrust on retaining wall

The geotechnical engineers are addressing the reduction of the exerted lateral earth thrust and water pressures to satisfy the adequacy in reasonable costs. Hence, the maintenance costs of the wall would be markedly decreased. Relief shelves and EPSG are the most popular material adopted to decrease thrust on retaining walls [6]. Shelves with width from 0.3 - 0.8 of the wall height reduce total thrust up to 26%. In the other hand, inserting compressible layers, such as EPSG, at the soil-wall interface minimize earth thrust [9].

4 EPS Geofoam as a Geotechnical Material

Expanded polystyrene geofoam (EPSG) is a plastic/polymeric material. It is chemical composition of C_8H_8. It has been adapted in geotechnical practice because of its lightweight and high compressibility. The applications started in the 1960s [10].

For civil engineering applications, dimensions of the EPSG blocks vary between 0.5, and 3.0 m [11].

4.1 Advantages of EPSG as a Construction Material

Expanded polystyrene geofoam, EPSG, is gaining popularity in construction, particularly in geotechnical applications. This is because of the following advatages.

1- Lightweight

EPSG is produced in many unit weights ranging from 1.12 to 4.57 kN/m3). Hence, it is substantial in reducing stresses on underlying soils, structures, and utilities [12].

2- Ease of Handling

The EPSG can be shaped on-site to accommodate the existing requirements and services [13].

3- Short erection time

4- Effective construction cost

5- Stability when correctly, specified, and installed
6- Efficient thermal insulation
7-Sustainability and friendly environmental material
8- Chemical Resistance
EPSG is not soluble in water. EPSG can stand certain chemicals, such as bases and diluted inorganic acids resistant, at ambient temperature.

4.2 EPSG Construction Precautions

However, precaution should be addressed for the following aspects.
1- Chemical Exposure
EPSG can be damaged by specific materials, such as organic solvents, oils, and concentrated acids [13].
2- UV Light
EPSG is susceptible to ultraviolet deterioration when exposed to sunlight excessively [13].
3- Wind
As a lightweight material, precautions are required for construction to protect blocks from instability under wind impact. Sandbags may be placed on top of the EPSG [13].
4- Buoyancy
EPSG as a closed-cell structure and lightweight, is buoyant [12].
5- Limited water absorption because of its closed-cell structure [13].

4.3 EPSG Properties

4.3.1 Strength characteristics

Figure 2 depicts the stress-strain response of EPSG. As can be seen from the Figure, EPSG behaves linearly elastic up to a strain of about 1%. As a result, it is recommended to bound the loading to the compressive resistance at 1% strain. Stresses more than this limit may lead to undesirable permanent strains [14].

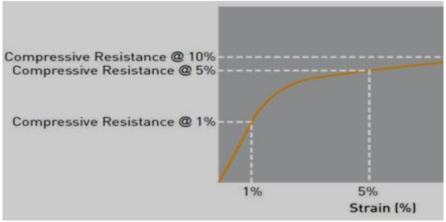

Fig. 2. Stress-strain relationships for EPSG [14]

Figure 3 presents the Stress-strain curve for different density of EPSG; EPSG 20, EPSG 30, and EPSG 40 [15]. The Figure shows that its strength depends on density. A 20 kg/m3 material may have a compressive strength of 100 kPa at 10% strain. EPSG experiences hardening at 70% strain.

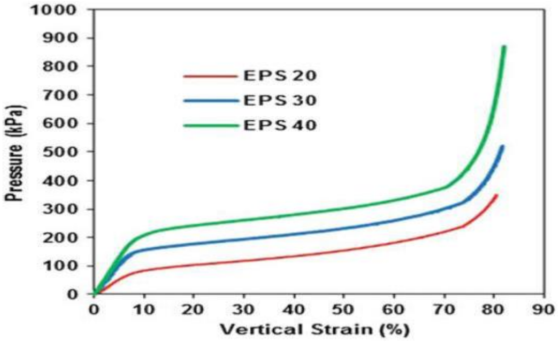

Fig. 3. Stress-strain curve for different densities of EPSG [15]

Poisson's ratio for EPSG is approximately 0.12 within the elastic range [14]. EPSG may experience excessive creep when strained above 5% [14]. Hence, it is recommended to adapt only compression at 1% strain in design EPSG applications. Creep effects increase pointedly at higher strains.

4.3.2 Friction

Friction coefficient, μ, of EPSG is 0.5 or higher depending on the production. AbdelSalam et al. [16] conducted experimental program for the characteristics of EPSG with time. They tested three types of different EPSG density; A, B, C. The densities are 25, 30, 35 kN/m3, respectively. The geotechnical characteristics considered are young's modulus, E, porosity, n, internal angle of friction, ϕ, and cohesion, C. Table 1depicts the result of the experimental program.

Table 1. EPSG properties [16]

Case		EPSG propretés				
		γ (kN/m^3)	E (kPa)	n	ϕ °	C (kPa)
A Foam 25	Short term	25	2736	0.14	27	47
	Long term	25	2072	0.14	25	40
B Foam 30	Short term	30	4307	0.17	33	57
	Long term	30	3263	0.17	30	45
C Foam 35	Short term	35	4924	0.2	36	84
	Long term	35	3730	0.2	33	67

4.4 EPSG Applications

Soil replacement is preferable in practice due to the EPSG light weight relative to its high strength. It is approximately 1% of the soil weight [17]. Also, bearing and settlement safety due to its light weight, Geofoam blocks can assure soil safety for bearing and settlement problems in weak soils. Moreover, because of its closed-cell structure and lightweight, EPSG has the capability to damp major part of vibrations. Consequently, it minimizes the dynamic effects on structures.

5 Researches on Applying EPSG in Retaining Walls

5.1 Experimental Researches

Zekkos, and Athanasopoulos [18], Ozgur, and Aurelian [19] conducted excremental studies and concluded that EPSG can reduce the seismic thrust, and deformation of the wall by up to 50%. The reductions depend on wave intensity, inclusion characteristics, and the wall flexibility. Whereas, Dave, and Dasaka [20] and Dave et al. [21] found out the reduction is about 23% in their experimental investigation.

5.2 Numerical Researches

Azzam, and AbdelSalam [17] adapted finite element program of Plaxis to model rigid retaining wall with geofoam insertion. Static loading conditions were modeled to investigate the decrease in the lateral thrust as a result of geofoam insertion. It was found that a 5 cm geofoam insertion is enough to reduce the lateral thrust for a rigid wall of 1 m height by 50%.

Karpurapu, and Bathurst [6] performed a numerical study using the computation tool FLAC3D to study the impact of EPSG density on the lateral earth thrust under different surcharge loads. They noted that the providing of geofoam behind the retaining wall reduces the thrust in the range of 8% to 42% for 10 kPa to 50 kPa surcharge, respectively.

Hazarika et al. [22] performed a numerical analysis for a rigid retaining wall under earthquake loading. The EPSG was placed between the wall and the backfill soil. The seismic forces acting on the wall were determined by simulating both sinusoidal load and the earthquake episode of a real earthquake. The effect of sand replaced with EPSG on the established seismic thrust was determined. They concluded that EPSG replacement reduces up to 60% of the seismic thrust.

Deling, and Bathurst [23] studied the impact of inserting (EPSG) layer behind a rigid retaining wall on the mitigation of seismic earth thrust. They found that with the increase of the load duration, the compressive strain of EPSG upsurges. Weaker EPSG yields more strains as it absorbs more seismic work.

AbdelSalam et al. [24] adapted PLAXIS 2D FE program to investigate the impact of EPSG thickness on the lateral earth thrust. Various thicknesses of EPSG were utilized and simulated in the FE analysis. They concluded that the lateral thrust can be pointedly reduced up to 25%.

Rashid et al. [25] studied the efficiency of EPSG insertion in decreasing the earth thrust on non-yielding cantilever retaining walls. In their study, the magnitude and distribution of earth thrust on retaining walls with and without geofoam subjected to surcharge loadings were evaluated. Geofoam densities 10 kg/m3 and compressible inclusion thickness, (t), of 0.07h were used. The results confirmed that the earth thrust has been reduced by 12.5% with geofoam inclusion.

ElSayed [26] conducted a parametric study to examine the effectiveness of EPSG thicknesses to reduce lateral earth pressure, displacement, and non-yielding wall rotation under seismic loads. He found that the percentage of reduction in lateral force ranges between 49.9% for thick ness 1.0 m and 63.26% for 3.0 m thickness. The percentage of reduction in overturning ranges between 38.9% for thickness 1.0 m and 49.63% for 3.0 m thickness.

5.3 Semi-empirical equations for reduction in lateral forces and overturning moments

The findings of these researches are illustrated in Table 2. From Table 2, it can be depicted that EPSG decreases earth pressure considerably. The range of decrease is between 8% and 60%. 8% is for the case of 10 kPa surcharge load and foam density 10 kg/m3 under effect of static loads. 62.3% is for the case of thickness change under the effect of seismic loads.

Table 2. Summary of the published effects of EPSG

Wall Status	Loading	Type of Study	Effect of Foam	Reference
Yield	Static	Numerical	50% reduction	[17]
		Numerical	% to 42% reduction	[6]
	Seismic	Experimental	23% reduction	[19]
		Experimental	50% reduction	[20]
		Experimental	23% reduction	[21]
		Numerical	25% reduction	[24]
Non-yield	Static	Numerical	50% reduction	[17]
		Numerical	12.5% reduction	[25]
	Seismic	Experimental	28% reduction	[19]
		Numerical	50% to 60% reduction	[22]
		Experimental	12.3% reduction	[23]
		Numerical	14.6% reduction	[23]
		Numerical	63.2% to 38.9% reduction	[26]

From Table 2, it can be noticed that the wide change of the effect depends on different variables of the modeling such as thickness, case of loading, surcharge loads on the backfill surface, and boundary conditions. These publications consider one or two of these variables.

A comprehensive study was conducted by ElSayed [26] to recognize the interaction of different variables of EPSG on 8.0 m gravity retaining wall. He investigated the impact of EPSG inclusions on reduction of lateral thrust and stability behavior of non-yielding and yielding retaining walls. The backfill soil was loose sand with a unit weight of 15 kN/m3, modulus of elasticity of 20 MPa, Poisson's ratio of 0.3, and the internal friction angle of 27° with no cohesion.

The investigation adapted 3D-ABAQUS software under the effect of static loads. The parameters studied in this research are the foam thickness, T, foam density in short and long-term, γ_S, and γ_L, respectively, and surcharge load on backfill, q.

According to the results obtained, lateral earth thrust, sliding forces and overturning moments are decreased on non-yielding and yielding retaining walls due to the EPSG insertion.

Statistical regression analysis was conducted to propose equations for reduction in lateral forces and overturning moments.

Table 3 depicts the equations for the percentage reduction, R, of the total static lateral force, and the overturning moment.

Where:

$(\%R_F)_{TN}$ and $(\%R_M)_{TN}$: R in the lateral force and the overturning moment, respectively, according to thickness change for non-yielding walls.

$(\%R_F)_{TY}$ and $(\%R_M)_{TY}$: R in the lateral force and the overturning moment, respectively, according to thickness change for yielding walls.

$(\%R_F)_{SN}$ and $(\%R_M)_{SN}$: R in the lateral force and the overturning moment, respectively, for non-yielding walls with 2.0 m foam in short term properties.

$(\%R_F)_{LN}$ and $(\%R_M)_{LN}$: R in the lateral force and the overturning moment, respectively, for non-yielding walls with 2.0 m foam in long term.

Table 3. Equations of the percentage reduction of static lateral force, and overturning moment

Effect	Case of loading	Lateral earth pressure	Overturning moment	Range of input data
Thickness, T	Non yield	$(\%R_F)_{TN} = 40.50\ T^{0.208}$	$(\%R_M)_{TN} = 23.85\ T^{0.313}$	foam density = 2.5 kN/m^3
	Yield	$(\%R_F)_{TY} = 17.95T^{0.7502}$	$(\%R_M)_{TY} = 1.157T_Y^2 + 3.605T + 2.894$	
Density of EPS short, γ_S	Non yield	$(\%R_F)_{SN} = 96.16\ \gamma_S^{-0.22}$	$(\%R_M)_{SN} = 70.43\gamma_S^{-0.27}$	T= 2.0 m
	Yield	$(\%R_F)_{SY} = -\ 0.071\gamma_S^2 + 4.576\gamma_S - 40.05$	$(\%R_M)_{SY} = -\ 0.142\gamma_S^2 + 9.43\ \gamma_S - 133$	
Density of EPS long, γ_L	Non yield	$(\%R_F)_{LN} = 0.054\gamma_L^2 - 3.524\ \gamma_L + 100.8$	$(\%R_M)_{LN} = 0.023\gamma_L^2 - 1.516\ \gamma_L + 51.42$	
	Yield	$(\%R_F)_{LY} = -\ 0.067\gamma_L^2 + 4.372\gamma_L - 40.1$	$(\%R_M)_{LY} = -\ 0.148\ \gamma_L^2 + 9.99\gamma_L - 149.7$	
Surcharge load, q	Non yield	$(\%R_F)_{qN} = -\ 0.001q^2 - 0.117q + 47.05$	$(\%R_M)_{qN} = -\ 0.003q^2 + 0.109q + 29.07$	
	Yield	$(\%R_F)_{qY} = -\ 0.001q^2 - 0.134q + 30$	$(\%R_M)_{qY} = -\ 0.007q^2 + 0.502q + 14.08$	

$(\%R_F)_{SY}$ and $(\%R_M)_{SY}$: R in the lateral force and the overturning moment, respectively, for yielding walls with 2.0 m foam in short term.

$\%R_F)_{LY}$ and $(\%R_M)_{LY}$: R in the lateral force and the overturning moment, respectively, for yielding walls with 2.0 m foam in long term.

$(\%R_F)_{qN}$ and $(\%R_M)_{qN}$: R in the lateral force and the overturning moment, respectively, with existence of surcharge loads for non-yielding walls.

$(\%R_F)_{qY}$ and $(\%R_M)_{qY}$: R in the lateral force and the overturning moment, respectively, with existence of surcharge loads for yielding walls.

6. Concluding remarks

This paper presents review on employing EPS geofoam to reduce the lateral earth pressure and then describes numerical investigation on an 8-m high retaining wall manipulating 3D-ABAQUS. The investigation concluded that lateral earth thrust, sliding forces and overturning moments are decreased on non-yielding and yielding retaining walls due to the EPSG insertion. Moreover, the results are presented in the form of empirical formulas obtained by regression analysis. The equations are strictly applicable to specified wall height and soil conditions. The aim of this investigation is to optimize the design of 8.0 m gravity retaining wall with installation of EPSG. Future studies can address different heights, dimension, and type of retaining walls, as well as different configurations of EPSG.

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