Geofoam: A potential for Indonesia’s soil problem III – stabilizing retaining wall

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Abstract. Increasing elevation of ground level is a common necessity in the construction world. For steep inclination, a retaining system is necessary to retain the soil embankment. When the embankment height is high, the required dimensions for the retaining wall can become humongous. This will result in excessive use of concrete, hence higher carbon footprint for the construction. To enable high retaining wall to be built without the support of huge retaining wall, light-weight backfill materials, such as geofoam can be used. In this paper, the use of geofoam to stabilize an eleven metre high retaining wall is presented. The eleven metre high retaining wall was filled with soil up to seven metre high, when cracks started to form in the retaining wall. Analysis show that failure would occur if the embankment continue to be filled. By replacing three metres out of the leftover four metres embankment with geofoam, the displacement of the retaining wall can be reduced from 2.1 m to 0.1 m.

Keywords: Geofoam, Expanded Polystyrene, EPS, Retaining Wall

1. Introduction

Increasing elevation of ground level can be due to technical needs, such as flooding, road access etc., or aesthetic needs, such as obtaining scenic views. Depending on the slope of embankment, retaining system may or may not be required. Where a retaining system is required, the size of retaining system is governed by the height of embankment, as well as ground conditions. A high embankment on poor soil conditions requires huge retaining wall, hence high carbon footprint.

One way to reduce the size of retaining wall required is by the use of light-weight materials such as geofoam. By reducing the weight of embankment, the lateral force applied on the retaining wall can also be reduced. Lower lateral force means retaining wall can be built smaller, and its steel reinforcement (if any) can also be reduced. Furthermore, geofoam is capable of standing vertically without any support, i.e. coefficient of lateral pressure = zero. Embankment built completely with geofoam does not require any retaining structure, only surface protection is needed.

In this paper, a case study of how the use of geofoam can save an eleven metre high retaining wall is presented. The retaining wall was filled up to seven metres high before cracks started to form. In order to complete the construction without compromising the stability of the retaining wall, solution using geofoam is sought for. Analysis with finite element software is conducted to show the response of retaining wall if the wall is constructed with soil fill and geofoam fill.

The paper begins by brief introduction to geofoam materials, followed by the case study. For the case study, plan view of the retaining walls and photographs of the damaged retaining wall is shown first. The critical cross section as well as soil profile is shown second, theory behind stabilization of retaining structure is shown third, and finally analysis with and without geofoam replacement is presented.
2. Geofoam

Geofoam is a type of expanded polystyrene (EPS) made from polystyrene, a byproduct of crude oil. It is formed from pre-expanded polystyrene beads which is expanded by using expanding agent [1]. When expanded, the polystyrene only made up 2% of the volume formed, while the other 98% is just air, making EPS an ultra-light material [2]. Despite having a majority of its volume as air, it has a closed-cell structure, making it rigid and tough [1]. The standard range of density and stiffness for geofoam is 11.2 to 45.7 kg/m$^3$, and 1,500 to 12,800 kPa respectively [3].

Trapping 98% air into its structure, geofoam has low thermal conductivity, making it a very good heat insulator. Buildings incorporating geofoam as thermal insulator can have up to 50% energy savings. With this rate of energy savings, energy spent in manufacturing of geofoam can be recovered within six months [2, 4]. With the exception of petroleum, geofoam is chemically inert and non-biodegradable, making it suitable for construction materials. Geofoam’s density is only 1-3% of soil’s density [5], can be handled manually without the help of heavy machineries, further enhancing geofoam’s environmental-friendliness.

On the construction side, geofoam has a vast range of applications, amongst them, construction of road embankment and stabilization of slope have been presented in the author’s earlier publication [6, 7]. In this article, geofoam application for stabilization of retaining wall is discussed.

3. Case Study

The project site is located in Setiabudhi, Bandung, Indonesia. Initially, there is an existing concrete retaining wall of about 4-5 m high and the wall is already filled with soil. The owner then intends to further increase the elevation by 7 m. The new retaining wall is stone masonry type. As such, no steel reinforcement are installed within the body of the new retaining wall, making the bending moment capacity of the retaining wall to be low. When the new wall was being filled, cracks started to form in the wall. To stop further damage to the retaining wall, the filling was stopped and soil near the wall was excavated to 4 m below the design level. The plan view and photographs of the cracked wall are shown in the next sub-section.

3.1. Plan view and photographs of the retaining wall

Figure 1 shows the plan view of the project site. The crack that occurred happened in the 9.1 m x 2.1 m corner of the retaining wall (circled in red). Figure 2 shows the photograph taken from the line of sight shown in Figure 1. The blue line in Figure 1 corresponds to the blue line in Figure 2 to show which part of the retaining wall is being shown. The red circle and eclipse in Figure 1 and Figure 2 respectively shows the cracked part of the wall. Figure 3 shows the enlarged photographs of the crack.

3.2. Cross section and soil profile

Fifteen cone penetration tests (CPTs) were conducted to characterize the soil. A critical cross section is drawn perpendicular to the 910 mm section of the retaining wall. Four out of the fifteen CPTs were used to create the soil profile, as well as to estimate the soil parameters. Figure 4 shows the original soil profile (before the filling), as well as the soil parameters used to analyze the retaining wall.

The total height of the retaining wall is 12.5 m, embedded by 1.3 m in stiff silty clay. The retaining wall is 3.5 m wide at the base, and 0.5 m wide at the top. Beneath the silty clay is hard sandy clay, underlain by very dense gravelly sand. The retaining wall is used to retain roughly 35 m long of soil, with height varying from 3 m to 11 m deep. The soil used for filling is silty clay and is rather weak in terms of strength or stiffness, even after compaction. This can be seen from the low cone resistance ($q_c$), ranging only from 2 to 5 kg/cm$^2$. 


Figure 1. Plan view of project site. *Note: Blue line shows the top of the wall (refer to Figure 2); Dimensions are in cm*

Figure 2. Photograph of the project site. *Note: Blue line is marked in Figure 1*
Figure 3. Photograph of the crack in retaining wall

Figure 4. Critical cross section, soil profile and soil parameters
3.3. Numerical analysis

To analyze the stability of the retaining wall and provide solutions to remediate the problem, PLAXIS [8], a finite element software is used. Firstly, the current condition of the retaining wall is modelled, i.e. retaining wall fully built, with 7 m fill. Next, the stability and wall deflection is analysed if the final 4 metres was constructed using soil fill. Another analysis is conducted with 3 metres of geofoam and 1 m of soil.

Figure 5 shows the current conditions of the retaining wall. As aforementioned, the soil has been filled until 4 m away from the design level. Two analysis is then conducted, one analysis is with soil fill, and another is with geofoam. The soil is modelled with Mohr-Coulomb constitutive model, with the parameters shown in Figure 4, while the retaining wall is modelled as linear elastic, with a Young’s modulus of 21 GPa and unit weight of 23 kN/m$^3$.

![Figure 5. Current conditions of the retaining wall](image)

3.4. Numerical results with soil fill

Figure 6 shows the results of the analysis if the fill were to be completed with soil. The analysis shows that the retaining wall will collapse, with a huge deformation of 2.1 m. The analysis clearly shows that it is not possible to complete the construction without any treatment or replacement. Therefore, it was the right decision to stop the construction and reduce the load on retaining wall by excavating some of the already placed fill. In the next sub-section, the theory behind determining volume of geofoam to be used as well as the numerical results are presented.
3.5. Numerical results with geofoam replacement

The geofoam used for the replacement is EPS19, with a density of 18.4 kg/m³ and Young’s modulus of 2500 kPa. The geofoam is also modelled as linear elastic. If the rest of 4 metres were to be replaced with geofoam, the additional surcharge on the current level of soil is only 0.74 kPa. This level of loading is practically non-existent for geotechnical purpose, and the structure would be safe. To optimize the cost and make allowance for topsoil, the final 1 m of fill is still silty clay, the material previously used for the first 7 m. Next, it is also not necessary to replace the whole section (> 30 m) of soil with geofoam. Retaining wall in active state forms a failure wedge of $45 + \phi/2$, where $\phi$ is the friction angle of soil, from the toe of retaining wall (refer to figure 7). This means that only the soil within the failure wedge contributes to the lateral force being applied on the retaining wall. Therefore only the soil within the failure wedge has to be replaced by geofoam, which leads to the geometry of geofoam shown in Figure 8.

The slanted line shown in Figure 8 shows the failure wedge of the fill soil. The geofoam replacement from 7 m to 10 m height extends slightly behind the failure wedge line to account for possible variation in soil fill properties. With 3 m geofoam replacement, it can be seen that the deformation is significantly reduced, from 2.1 m to 0.1 m. The factor of safety obtained is 1.46. The deformation is slightly higher than the recommended allowable deflection in Indonesian’s National Standard [10], which is 0.5% of the retaining wall’s height = 0.06 m. The factor of safety is slightly below the Indonesian’s National Standard of 1.5. Despite not meeting the requirement of National Standards, the difference between obtained values and the standard is marginal. Furthermore, behind the retaining wall is a garden. Hence, replacement with 3 m of geofoam is acceptable.
Figure 7. Failure wedge for active lateral earth pressure [9]

Figure 8. Deformation of retaining wall with geofoam (light grey) replacement; maximum deformation = 0.1 m
4. Conclusions and discussion

The case study exhibits the capabilities of geofoam in stabilizing a retaining wall. By replacing 3 m out of the 11 m fill with geofoam, a failing retaining wall can be saved. A reduction from 2.1 m deflection to 0.1 m, and an increase in factor of safety from less than 1 to almost 1.5.

This showcases the potential contribution of geofoam to sustainability. With minimal geofoam replacement, the imminent reconstruction of damaged retaining wall can be avoided. Reconstruction of retaining wall or strengthening of the backfill soil with foundation piles is not only expensive, but costly in terms of carbon footprint.

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