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The Use Of Lightweight Material At Road Access Construction On Slope

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ABSTRACT To achieve the design elevation from the existing ground level, an embankment work with a thickness of 8-10 meters thick on the slope should be conducted considering both the safety aspect as well as the economic aspect. Based on the conceptual drawing by Contractor, the embankment will sit on the slope without any grading works. The drawing shows that the embankment will be constructed directly on the existing slope. Any fill work on the original slope without any proper reinforcement will cause stability issues. The discussion about the embankment area construction concept has come up with some options such as the use of a slab-on-pile system and the use of a combination sheet pile - bore piles and the use of mini piles under the embankment. Based on further discussion with Contractor and Owner about the technical aspect and construction cost required, it is recommended to construct an embankment with lightweight material (geofoam). The use of lightweight geofoam is a suitable solution to be considered. Another advantage of using geofoam is that the construction period is faster than conventional methods. Geofoam installation work already started on November 2022. On February 2023, the geofoam slope construction finished.

KEYWORDS Embankment; Failure; Geofoam; Geosynthetic; Light Weight; Slope; Road Access

1 Introduction

An area will be developed within the Geothermal Area. At one particular location, an infrastructure will be built near to the existing slope. In order to rise elevation of existing ground level, there was a plan to conduct embankment work with a thickness of 8-10 meters on slope.

The morphology of the site was hilly and rolling and shows gullies erosion. The exposure of outcropped soil along the road can be described as weathered tuffs, tuffaceous silt, clay and sand, yellowish brown in color, very thick deposit.

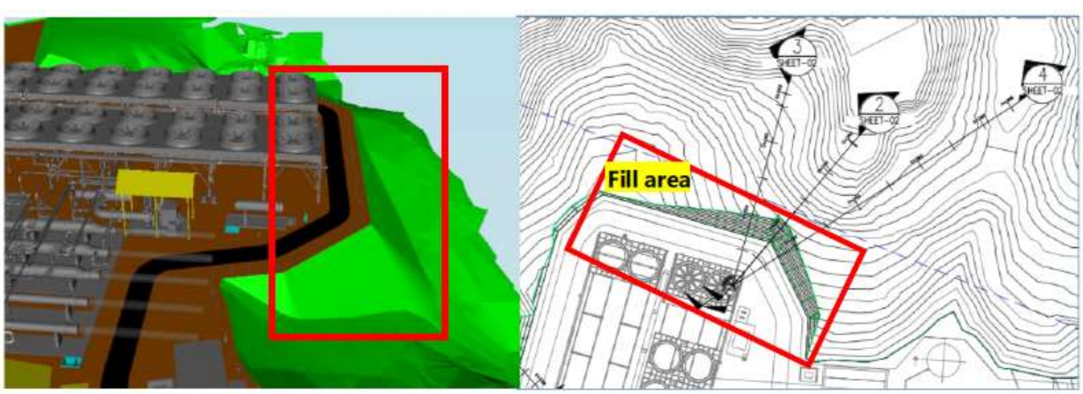

Figure 1. General plan illustration and cross section

The topography and layout of the embankment area are shown in the Figure 1. The embankment perimeter area in for the purposes of the access road is shown as a region tinted in black.

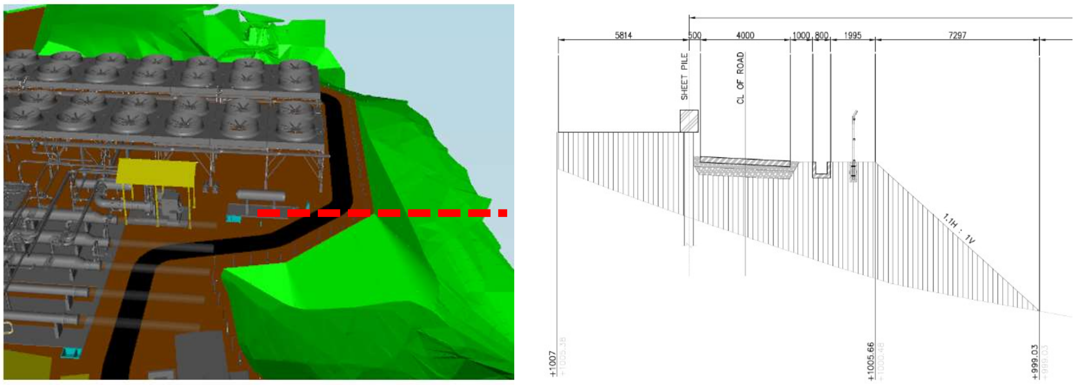

Figure 2. General plan illustration and cross section

Figure 2 displays both the schematic sections of the original contours and design contours as well as the location of the cross sections in the three-dimensional representation.

The low shear strength of the subgrade can lead to instability of the embankment structure, especially if the load of the embankment is too heavy to be carried by the subgrade with very soft consistency. Construction on soft foundation soils, such as peats or soft clays, has long been problematic (Arrelano, 2010). Meanwhile, the additional weight from a backfill would add significantly more weight to the foundation which could lead to overstressing the soil.(Gaebe, 2019).

Those slope area was originally designed by using CCSP with soil embankment (see Figure 2). The design was not approved and proposed to be modified. The discussion about the embankment area on slope concept with relevant parties has been going with some options such as the use of a slab on pile system, the use of a combination sheetpile – bored piles and the use of mini piles beneath the embankment.

One of the causes of landslides on slopes is too heavy embankment that must be carried either by the embankment itself or by the subgrade. The use of geofoam with a relatively low density is one solution that has provided quite satisfactory results (Hidayat, 2017). Considering the need of space and access road construction and construction cost, it was decided to construct embankment with light weight material (geofoam).

Another advantage of using geofoam is that the construction period most likely will be faster than conventional methods. Gunawan (2020) explained that the geofoam usage can minimize construction time because the geofoam can be installed in any weather conditions, unlike soil fill, which cannot be compacted when wet.

2 Geological and Geotechnical Condition

2.1 Geological Condition

Study location is situated in the Mount Salak area, encompassing a lot of the Quaternary-age Salak-Kiaraberes-Gagak-Perbakti volcanic complex (Effendi, 1974; Ganefianto and Shemeta, 1996). These overlapping composite volcanoes are typical of the Javanese sector of the Sunda-Banda volcanic arc. Mount Salak is an eroded volcano, which has several satellite cones on its southeast flank and the northern foot, along with two additional craters at the summit.

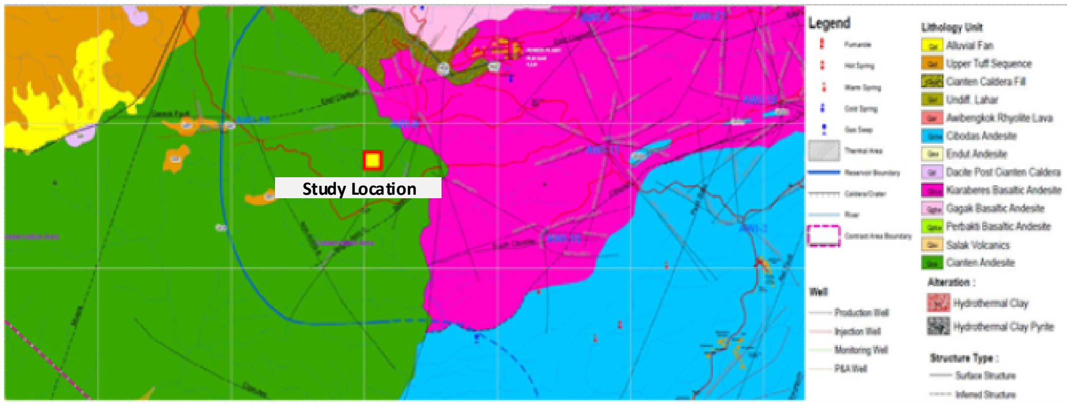

Figure 3. Geological map of site study

Mount Salak landforms hills and valleys, composed of typical volcanic deposit which is controlled by the geological structures. Foothills from lower to upper consecutively composed by pumiceous tuff volcanic deposit, breccia, lapili and pumiceous tuff with paleo soil layer intercalations, and andesitic lava. Figure 3 shows the position of the study location on a geological map.

2.2 Soil Stratification

The following are available geotechnical data that was obtained from geotechnical investigations using Dutch Cone Penetration Test (DCPT) namely DCPT-6, DCPT-7 and drilling log boreholes with SPT values of BH-3. On a scaled topographic map, Figure 4 presents the location of the nearest soil investigation in the project's area. A red triangle and circle denote the nearest testing spot.

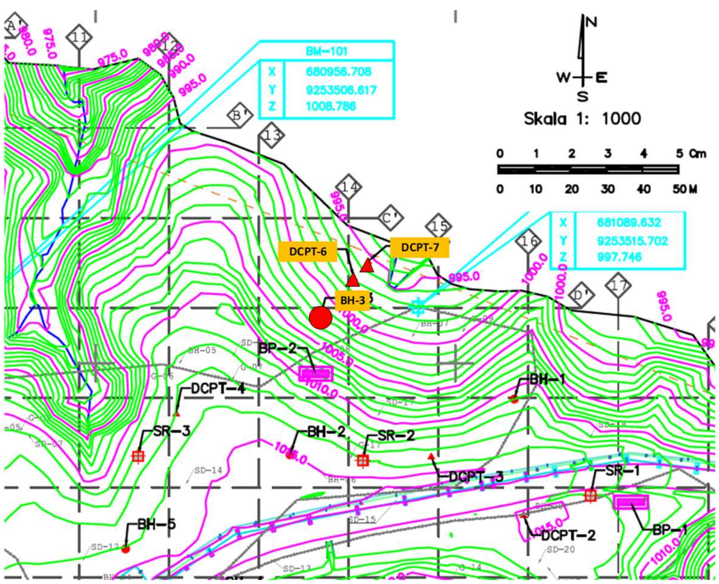

Figure 4. Geotechnical investigation location

Based on Dutch Cone penetration test and boring log of BH-3 results, soil stratification of study area can be interpreted. The following is soil profile at the study location:

- First Layer, yellowish brown residual silty clay, soft and high plasticity. The thickness of this layer is 9 m from the ground surface. SPT value is about 2 – 8.
- Second Layer, brownish yellow stiff to hard sandy clay, its underlying the first layer until 21 m depth.

- Third layer, brownish grey sandy clay, medium to very stiff consistency, can be encountered at 22 m to 28 m depth from the ground surface.
- Fourth layer, blackish brown sandy clay and sandstone with very stiff to hard consistency that can be encountered at 28 – 40 meter depth from the ground surface.

Soil profile can be generated by using actual CPT result represented by BH-3, DCPT-6 and DCPT-7. Based on BH-3, ground water level is 15.5m, depth from the ground surface. Cross section for site elevation is shown in the following Figure 5.

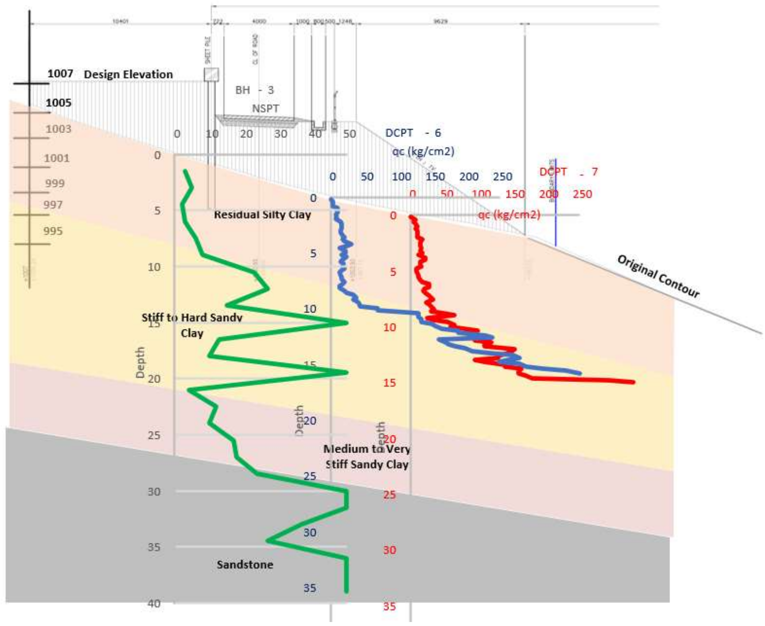

Figure 5. Soil profile interpretation from drilling log and CPT results

3 Laboratory Test Result

Following are the results of laboratory tests for all technical drilling samples that have been carried out at the study site. Considering the land area is in a volcanic area, the condition of the surface soil is suspected to be residual soil so that the parameter of residual soil should be determined using CU-Triaxial test and/ or correlation from Atterberg Limits Test (Liquid Limit, Plastic Limit, and Plasticity Index) especially developed for residual soils.

The soil type at the project site is dominated by clay with high plasticity, as determined by the plasticity chart from Casagrande (CH). Figure 6 below is the result of the plot of the Liquid Limit and Plasticity Index values on the Casagrande Chart.

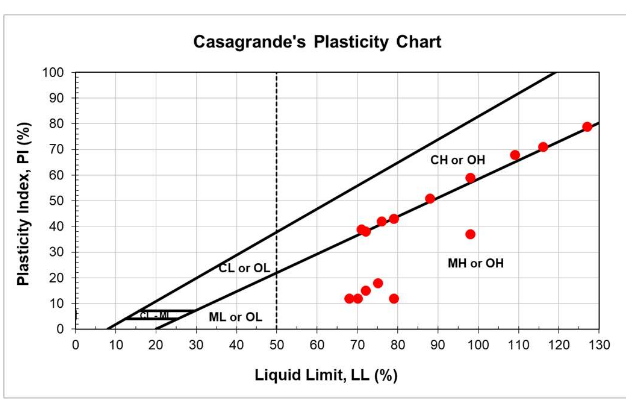

Figure 6. Determination of soil type based on plasticity chart

The behavior of fine-grained soil is determined from its moisture content so that the consistency of in situ tests compared to laboratory test results shall be interpreted based on the soil sample moisture content.

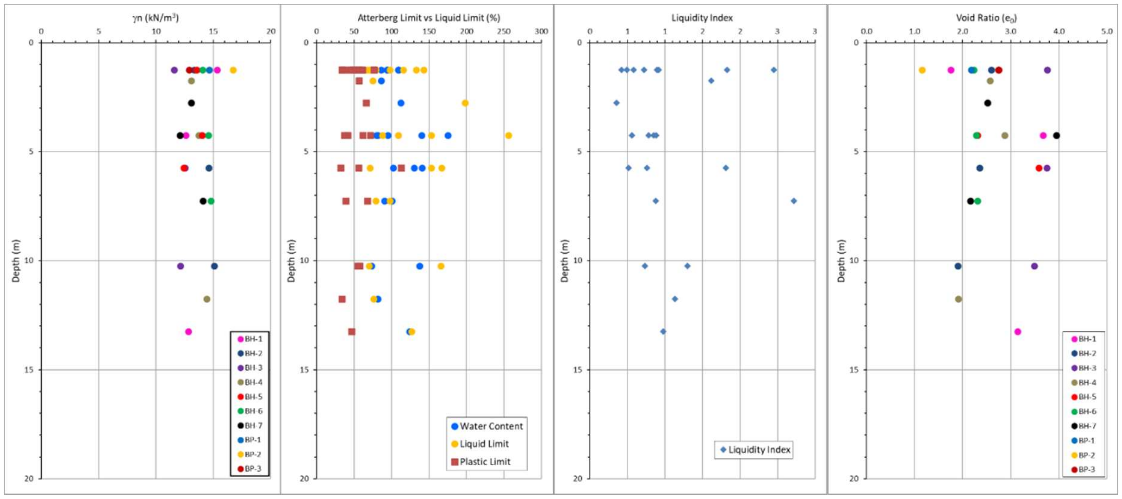

Figure 7. Unit Weight, Atterberg Limit, Void Ratio

According to Figure 7, the range of natural soil weights is between 11 and 16 kN/m^2. The range of the water content is between 60 and 160% and the void ratio value shows a result greater than 1 (1 to 4).

In determining soil shear strength, especially for cohesive soil, two different approaches are employed. In order to determine the total stress parameters, shear strength parameter which will be used for undrained analysis are undrained shear strength (Su). Figure 8 shows the values of cohesion and friction angle.

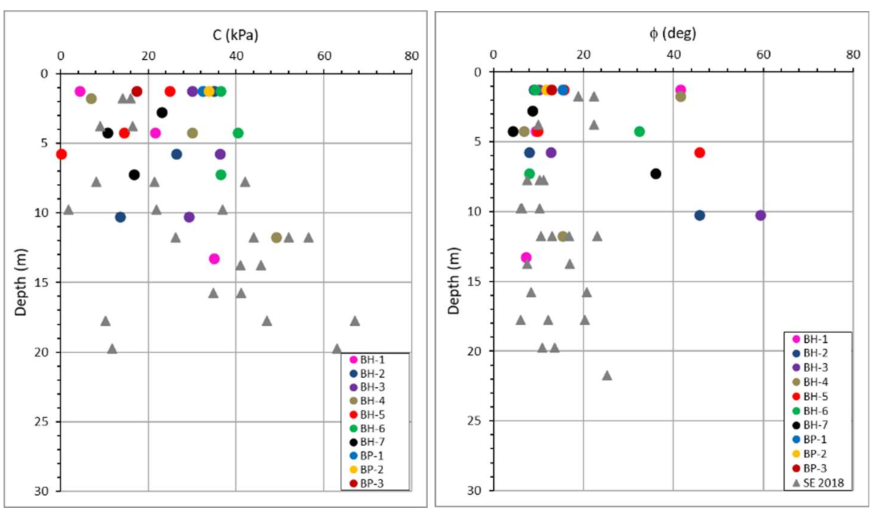

Figure 8. Cohesion (C) vs depth, (CU) and friction angle ϕ vs depth

Meanwhile, for effective stress parameters, the shear strength parameter which will be used for drained analysis are parameter represented by effective cohesion (c') and effective friction angle (ϕ'). Figure 9 shows the values of effective cohesion and effective friction angle.

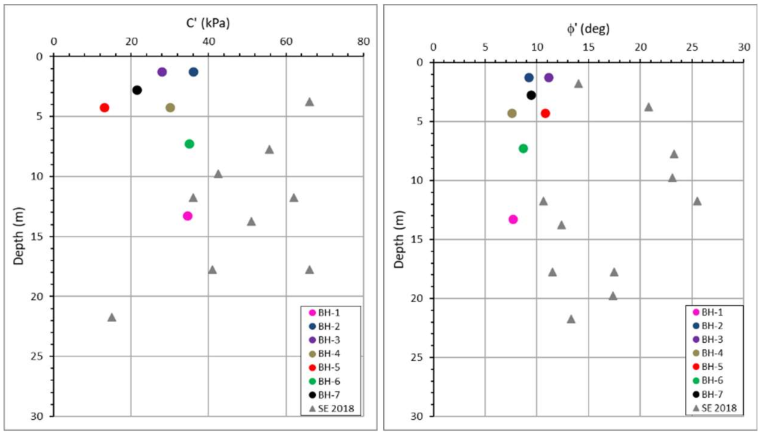

Figure 9. **C'** Vs depth and effective friction angle ϕ' vs depth

Based on comparison study of in-situ test during site investigation and shear strength test from the laboratory, the estimated Undrained Shear Strength (Su) value are about 2 – 6 NSPT (kPa). Figure 10 below shows the correlation of Nspt and Su on the Terzaghi, Peck and Sowers chart.

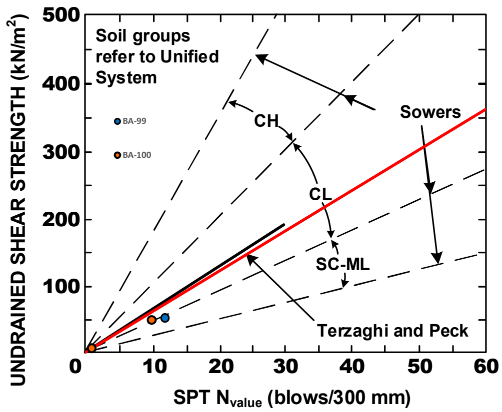

Figure 10. Correlation NSPT and Su (Terzaghi and Peck, 1967 & Sowers, 1979)

Compressibility value of fine-grained soil is dependent on the stress strain relationships approach. General approach for the relationship is either linear or non-linear. For linear stress strain relationships, compressibility parameter is determined by short term or undrained term modulus (Eu) and long term or drained modulus (Ed). Both parameters generally are obtained from Triaxial CU and Triaxial CD test in the laboratory.

For non-cohesive soil or sandy and coarse-grained material the linear stress strain relationship approach can be estimated by using the following publication which used SPT test value.

Table 1. Soil elastic modulus (Briaud,2013)

Soil Type	Correlation
Silt and Sandy Silt	400 N_{SPT}
Fine to Medium Sand	700 N_{SPT}
Gravelly Sand	1000 – 1200 N_{SPT}

For non-linear stress strain approach, compressibility parameter can be directly determined by using consolidation test result from the laboratory.

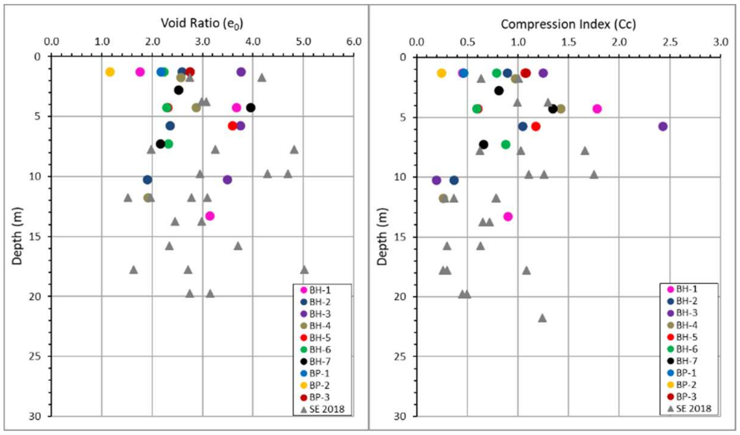

Figure 11. Void ratio Vs depth and Compression Index (Cc) Vs depth

Water level in the boreholes situated at the lower area (near toe of slope) found at about 7,5 m depth from the existing ground surface. While at the boreholes situated on higher place near the top of slope is at as deep as 16 m from the existing ground surface.

4 Design Concept

In order to achieve the design elevation, the construction concept must accommodate additional load on slope that endanger the slope stability and affect the structures or infrastructures at the surface. Based on further discussion with other parties about technical aspect and construction cost, it is mutually agreed to construct embankment with light weight material or namely as geofoam. Koerner (2012) explained that geofoam is a type of expanded polystyrene (EPS) which has material properties suitable to be used for construction. It has a unit weight of about 1-3% of traditional fill. Geofoam to be considered as a new category of light fill, i.e. “ultra-light” fill (Horvath, 1994).

Jutkofsky, et al (2000) explained that Expanded polystyrene (EPS) and extruded polystyrene (XPS) are the most common types of geofoam. EPS, the kind used in the following case history, is formed into low-density cellular plastic solids that have been expanded as lightweight, chemically stable, environmentally safe blocks.

Geofoam mechanical properties such compressive strength, elastic modulus, possion's ratio, shear strength, flexural strength, stiffness, creep behavior and other mechanical properties depend on the Geofoam unit weight (EL-Kady, et al, 2014). Geofoam properties based on ASTM D6817 is as below.

Table 2. Geofoam properties based on ASTM D6817

PER-ASTM D6817	Units	EPS-12	EPS-15	EPS-19	EPS-22	EPS-29	EPS-39	EPS-46
Density[1], min.	lb/ft^3	0.70	0.90	1.15	1.35	1.80	2.40	2.85
Compressive Resistance[1] min. @ 1% deformation	PSI (PSF)	2.2 (320)	3.6 (520)	5.8 (840)	7.3 (1050)	10.9 (1570)	15.0 (2160)	18.6 (2680)
Compressive Resistance[1] min. @ 5% deformation	PSI (PSF)	5.1 (730)	8.0 (1150)	13.1 (1890)	16.7 (2400)	24.7 (3560)	35.0 (5040)	43.5 (6260)
Compressive Resistance[1] min. @ 10% deformation	PSI (PSF)	5.8 (840)	10.2 (1470)	16.0 (2300)	19.6 (2820)	29.0 (4180)	40.0 (5760)	50.0 (7200)
Flexural Strength[1] min.	PSI	10.0	25.0	30.0	40.0	50.0	60.0	75.0
Elastic Modulus[1], min	PSI	220	360	580	730	1090	1500	1860

Table 1 shows the property values for each geofoam class from EPS-12 to EPS-46 based on ASTM D6817. As for this study, the EPS-22 class was used.

The low shear strength of the subgrade can lead to instability of the embankment structure, especially if the load of the embankment is too heavy to be carried by the subgrade with very soft consistency. The use of lightweight geofoam is a suitable solution to be considered. Another advantage of using geofoam is that the construction period would be faster than conventional methods.

A few factors must be considered during the geofoam is being maintained:

-Chemical Exposure ; when exposed to specific hydrocarbon chemicals, EPS geofoam is susceptible to damaged and might require protection.

-Fire ; EPS is a flammable substance, just like many building supplies.

-UV Light; EPS can degrade when exposed to ultraviolet light over a long duration of time.

-Wind ; during construction, wind speeds should be observed to figure out whether additional weight restraints like sandbags are required on top of the EPS geofoam in order to prevent the blocks from shifting.

To mitigate potential uplift forces, drainage (often a sand or gravel layer) may be added between the native soils and the EPS geofoam fill. Underneath the EPS geofoam, providing for proper drainage of groundwater and/or surface waters reduces the formation of uplift forces and prevents water infiltration.

Considering the base of geofoam will be placed on residual silty clay, the geofoam base will be reinforced by constructing square pile 25x25 ctc 1 m. Figure 12 below shows a concept sketch of heap construction with geofoam material in the slope area.

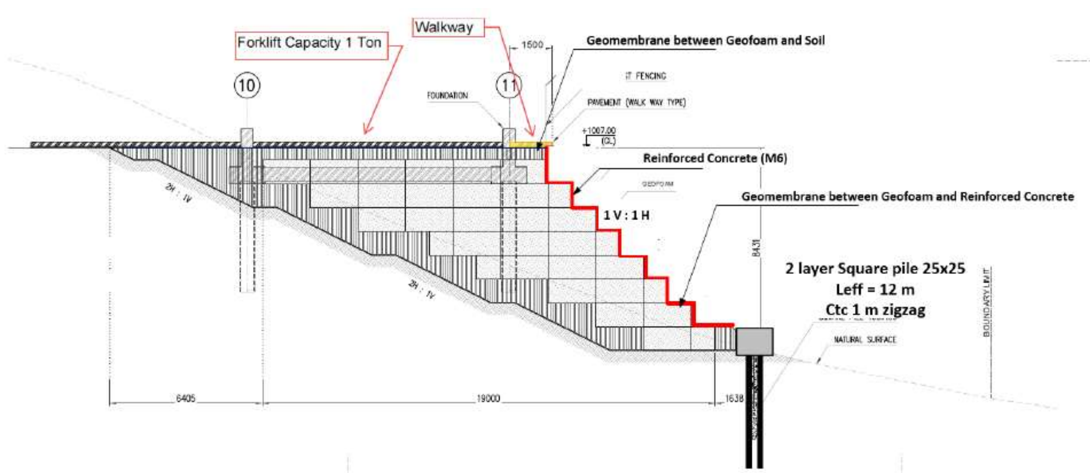

Figure 12. Slope area concept

The work sequence plan as follows :

- Land clearance and excavation grading up to an elevation of +1007 meters.

- Excavation work can be continued by excavating a berm in stages with a 2H:1V gradient. Surface drainage shall be constructed to drain runoff water

- Subdrain installation and square pile foundation installation below light weight material embankment.

- After all of the foundation piling works are completed, construction proceed on the geofoam embankment construction.

- It shall be ensured that there are interlockings between geofoam. Figure 12 below shows the geofoam material and gripper material.

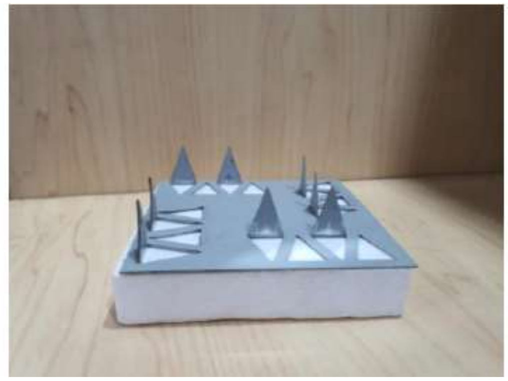

Figure 12. Illustration of geofoam material and gripper

- The work continues with the laying of the geomembrane as a separation

- Installation for geofoam surface cover using reinforced concrete.

5 Soil Modelling and Static Analysis Result

The slope stability study was carried out using the finite element method and the PLAXIS 2D computer program, which was developed by the Dutch Department of Public Works and Water Management and began in 1987 at the Technical University of Delft. A construction stages analysis can be performed in PLAXIS. During the construction of geotechnical structures, staged construction is highly beneficial for analyzing excavation, earth filling, and anchoring. Displacements at nodes and stresses at stress points are the major outputs of finite element calculations. The stresses and moments acting on the structural elements can be determined, allowing for better design. Based on Geofoam Applications in the Design and Construction of Highway Embankments, after the design loads, subsurface conditions, embankment geometry, preliminary type of EPS, have been obtained, the design continues with external (global) stability evaluation. Figure 13 below shows soil stratification model.

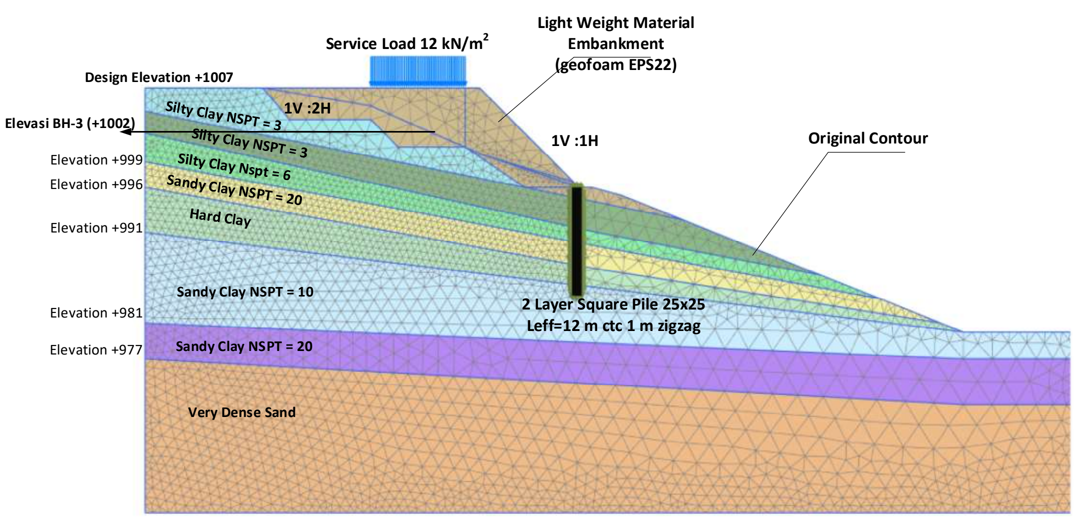

Figure 13. Soil stratification model

The factor of safety is defined as the ratio of the shear strength divided by the shear stress required for equilibrium of the slope (Duncan, 1996). After the construction sequence global safety factor is conducted. The following Figure 14 shows sliding plane and factor of safety from the results of the analysis on the effective stress parameters. The analysis phase from PLAXIS2D shows that the slope satisfied static conditions requirement.

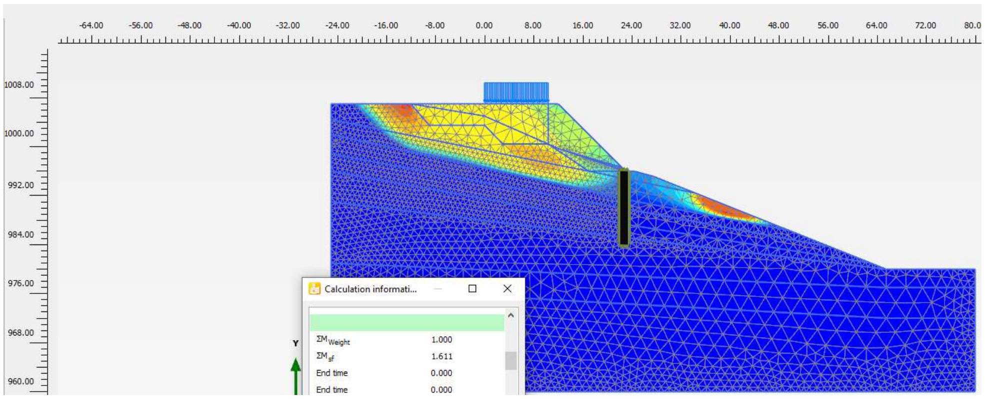

Figure 13. Slope stability analysis, long term SF = 1.6 > 1.50

6 Construction Method

In the context of providing construction assistance, routine site visit and observations are made. The foundation piling works was started in August 2022 by installing square mini pile 25x25 with penetration target of 12 meter length. Piling works is done by using pile drivers and pile hammer equipment.

Figure 14. Pile driving work –August 2022

A visit in September 2022 showed that the minipile installation work was still the main focus of the project. The pile piling work platform is leveled by excavator.

Figure 15. Pile driving work progress –September 2022

The piling works continued to capping beam works in October 2022. Based on observation as shown on Figure 16, the slope area behind the square piles has visibly suffered surface erosion. It was confirmed that the surface material was improperly compacted embankment.

Figure 16. Slope condition on piling works area –October 2022

In November 2022, based on site observation, it is known that the geofoam installation work was not ready yet due to the pile-waste existence that has not been moved away from the geofoam installation area. As shown on Figure 17, It is noticeable that the Contractor utilized a sand bag in order to maintain the degrading area.

Figure 17. Geofoam installation area – November 2022

Based on visit in December 2022, it is seen that geofoam installation work already progressing to 5th layer. According to information from the owner's representative, using geofoam greatly lowers construction costs, especially those linked to the workers hired to install geofoam in the field. It turned out that work in the field was carried out by fellow residents who had received training from the applicator. Elragi (2020) found that with its lightweight property, geofoam blocks can be easily handled after manufacturing, during curing, transportation or placement in the field. Two workers can handle a 0.6m x 1.2m x 2.4 m half size block of an average weight of 35 kg for 20 kg/m3 density EPS geofoam.

Figure 17. Geofoam installation progress – December 2022

Due to the rainy weather, it is noticeable that the slope area above and below the geofoam is covered with tarps. Tarpaulin use is expected for minimizing surface erosion on soil slopes. Based on observation, once geofoam is on site ready for installation, it is easy to move by local labor and place into different bases and works in a shorter time than more conventional embankment material like granular material. Figure 18 shows the geofoam installation area, meanwhile Figure 19 shows the grippers and details of surface cover of geofoam.

Figure 18. Geofoam installation area –December 2022

Figure 19. Gripper for interlocking and details of surface protection –December 2022

In January 2023, geofoam installation work already progressing to final layer and finishing work by install reinforced bar and shotcrete. Figure 20 shows the details of the installation of geofoam which consists of geomembrane, geofoam, reinforced bar and shotcrete.

Figure 20. Geofoam installation area –January 2023

Along January to February 2023, geofoam installation work already progressing to final layer and finishing work by install reinforced bar and shotcrete. Based on site information, it is known that the Contractor took the initiative to install a subdrainage to drain water on the slope behind the geofoam. The walkway or access road has been completed and fenced. Figure 21 shows the access road condition on February 2023.

Figure 21. Geofoam installation area –February 2023

In May 2023, the Contractor carried out finishing work on the slope area around the geofoam by covering the slope with shotcrete. Figure 22 below shows the situation of access road and the surrounding slope.

Figure 22. Access road and slope condition – May 2023

7 Conclusion

One of many advantages of using geofoam material is that the weight of this material is about 1/80 of the conventional material weight. Because of its light weight, geofoam can reduce the additional burden significantly, thus geofoam can be recognized and accepted as a lightweight material alternative for embankment work.

The benefit of using geofoam as an alternative to conventional embankment material in construction results in total project cost savings.

According to information provided by the owner's representative, using geofoam lowers construction costs, particularly those associated with personnel hired to install geofoam in the field, which can be done by locals. However, due to the confidentiality issue, details about this cost cannot be stated.

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