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Optimizing the Embankment Fill Reinforcement for Rest Area on the Semarang-Solo Toll Road with Geoframe System

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ABSTRACT On KM 456 Semarang-Solo Toll Road, a rest area which was predicted to be the grandest in Java was built. The rest area covered both sides of the toll road, which is in zone A (heading to Solo) and zone B (heading to Semarang). The rest area is built with remarkable view and unique traditional design with five roofs that represented five surrounding volcanoes. With all its philosophy, the owner sought the best option for all its structures, not only from the most economic, efficient, robust, but also the greenest option for the design. The rest area will be built on embankment with the highest being 11 meters. The embankment's subgrade is rice field with 2 meters of soft silty clay. The initial design is to reinforce the embankment with 7-meters-tall concrete retaining wall and 2 rows of bore pile with 80 cm diameters and depth of 18 meters. This option was deemed to be very budget consuming, time consuming, and not very green. The Geoframe system, which is a combination of Geosynthetic materials, and wire mesh as facing was then chosen as the reinforcement for the embankment. The geogrid as reinforcement has proven to be very easy to install yet it's very strong as the tensile capacity can be adjusted to the embankment's needs. The Geoframe system can be constructed almost vertically (with a slope of 85°). Topographic data, SPT, CPT and laboratory test results were used to design a safe and efficient Geoframe system. Slope stability was analyzed using the Finite Element Method with PLAXIS 3D software. The construction carried out from 2019 to 2020 has proven that this method can be a safe, efficient, environmentally friendly option and still followed the articles stated in Indonesian National Standard for Geotechnical Design Requirements 8460: 2017.

KEYWORDS Rest Area; Geosynthetic; Geoframe; Geogrid; Slope stability

1 PROJECT INTRODUCTION

1.1 The Rest Area

The KM 456 rest area on Semarang-Solo Toll Road is located on Semarang Regency, Central Java. In 2019, the design process for the construction of the rest area that is predicted to be the most magnificent on the Semarang-Solo Toll Road, perhaps even in Indonesia, has begun. This rest area has 2 sides of building, namely zone A (towards Solo) and zone B (towards Semarang) and is connected by a sky bridge. The rest area was constructed next to the toll road which position is higher than the surrounding area. The difference in height between the rest area and the surrounding area varies from 3 meters to 11 meters. For maximum land use, the rest area required an embankment system that can be constructed almost upright. The embankment area of the KM 456 Semarang-Solo Toll Rest Area also supports buildings such as canteens, toilets, workshops and water tanks.

The initial design of the embankment reinforcement of the rest area involving the use of concrete retaining wall reinforced with 2 rows of 80 cm in diameters bored pile foundation to a depth of 18 meters. The upper part of the embankment also reinforced with layers of geotextiles. With all these reinforcement combinations, the system will be indeed very strong, but in terms of the construction cost will be huge. Looking at the rest area's distinct location between five mountains which are

Merbabu, Merapi, Sumbing, Sindoro, Telomoyo and deep philosophy of union with nature surrounding makes the use of huge concrete retaining wall defeats the main purpose. To overcome these challenges, the rest area developer searched for the most optimal retaining wall that supports the construction cost efficiency, environmentally friendly, and can be installed quickly to make sure the rest area can cater the travelers before new year holiday. This is where Geoframe system played as a great alternative of embankment reinforcement.

Below is the depiction of the rest area in full operation.

Figure 1. KM 456 Semarang- Solo toll road Rest Area

1.2 Geoframe System

The Geoframe system adopted in the design of embankment slope stabilization is a method of embankment reinforcement using a combination of geosynthetic materials, namely geogrid which is given per layer of compacted fill with a facing in the form of wire mesh and non-woven geotextile as filter. In this system the geogrid acts as the main reinforcement of the embankment and is installed every 50 cm of compacted soil layer. The required geogrid tensile strength and length are calculated based on the design-by-function concept as a determination of the safety factor, according to Equation. 1:

$$FS = \frac{T_{allow}}{T_{reqd}} \quad (1)$$

where FS is the safety factor, T_{allow} is allowable tensile strength and T_{reqd} is the required tensile strength.

Allowable values are obtained from laboratory tensile strength tests which must be compared with field conditions. One way to achieve this is to provide a reduction factor for each condition that is not modeled in laboratory testing. Therefore, the allowable tensile strength must comply with Equation (2):

$$T_{allow} = \frac{T_{ult}}{RF_{ID} \times RF_{CR} \times RF_{CD} \times RF_{BD}} \quad (2)$$

where T_{ult} is the ultimate tensile strength, RF_{ID} is the reduction factor for installation damage, RF_{CR} is the reduction factor for creep, RF_{CD} is the reduction factor for chemical degradation, and RF_{BD} is the reduction factor for biological degradation.

In addition to the tensile strength parameter, the geogrid anchorage length must also be considered for internal and external stability. As a note, Indonesian National Standard for Geotechnical Design Requirement stated that the anchorage length must be $\geq 0.7\ H_e$ (where H_e is the effective height of the wall). The standard also requires that the minimum safety factor for the stability of the embankment is 1.50.

To model the geogrid in software using the Finite Element Method, the tensile strength needs to be converted into stiffness values (EA) and allowable tensile strength. The stiffness value is influenced by the elongation of the material obtained from the isochronous curve or creep curve. For this embankment reinforcement, an elongation value (ε) of 5% was used. The stiffness value can then be written in Equation (3):

$$EA = \frac{T_{allow}}{\varepsilon} \quad (3)$$

where EA is geosynthetic material stiffness and ε is the geosynthetic elongation value.

The facing of this system is a combination of non-woven geotextile and galvanized iron wire mesh, where the non-woven geotextile plays a role in filtering the soil inside the Geoframe layer so that it does not come out of the wire mesh gap. The key to the Geoframe's robustness also lies in the compaction of the soil layer. After the compaction of each layer is complete, a sand-cone test is carried out to obtain a density value that is in accordance with the results of laboratory tests. In addition to the base reinforcement of the Geoframe system, 2 layers of gabions were added. The advantage of Geoframe system is that it is relatively easier and faster to install. Moreover, the facing of the Geoframe system can be planted with plants to add aesthetic value and give a natural impression so that it blends in with the surrounding nature. Below is the image of Geoframe's facing detail and Geoframe application as shown respectively in Figure 2 and Figure 3.

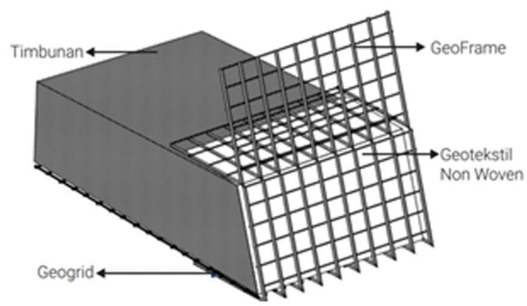

Figure 2. Geoframe's facing detail

Figure 3. Geoframe application

2 DESIGN METHODOLOGY

2.1 Geotechnical Investigation

Field soil investigations in the form of SPT and CPT testing were carried out in several stages. The initial SPT tests were carried out in 4 points and the CPT tests were carried out in 16 points spread in zone A and zone B. The area around the bottom of rest area mainly consists of rice field soil and on the slope of the toll road were uncompacted fill that were dumped during the toll road construction. The results of the SPT and CPT tests indicated that the existing slope is a soft clay soil. The soft soil was then excavated to achieve a stable base for the Geoframe system and accommodate geogrid anchorage. An example of CPT and SPT data result is illustrated in Figure 4 and Figure 5.

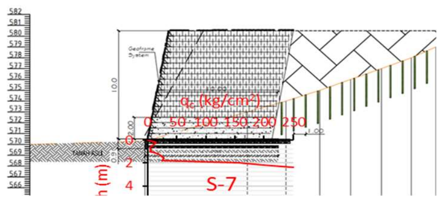

Figure 4. CPT result as accordance to section 15 cross section

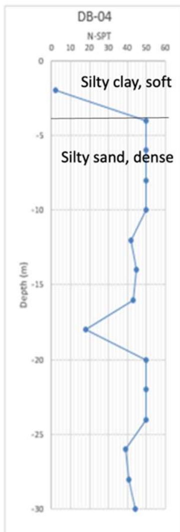

Figure 5. SPT result as accordance to section 15 cross section

The results of the SPT, CPT drill tests and laboratory tests conclude that the bottom layer of the Geoframe system is dominated by very dense silt-fine sand. This base layer then became the bottom of the gabion reinforcement. The subgrade condition is illustrated in Figure 6.

Figure 6. Geoframe's subgrade condition

2.2 Parameter and Geometry

Prior to stability analysis, soil property from field and laboratory tests were then interpreted to obtain design parameters. For Geoframe's fill material, gravelly soil was taken from the quarry in Bawen area, Semarang Regency. The compacted soil has good shear strength characteristics and is dominated by sand, gravel, and silt fractions, so it is a good fill material compared to local clay soil which has smaller shear strength. Below is the laboratory test result's parameter for Geoframe's backfill material listed in Table 1.

Table 1. Backfill laboratory test results

Properties	Value
Wn (%)	23.15
γ_{wet} (kN/m^3)	16.8
γ_{dry} (kN/m^3)	13.6
e	0.98
n (%)	49.64
Specific Gravity	2.7073
φ'	25
c' (kPa)	60

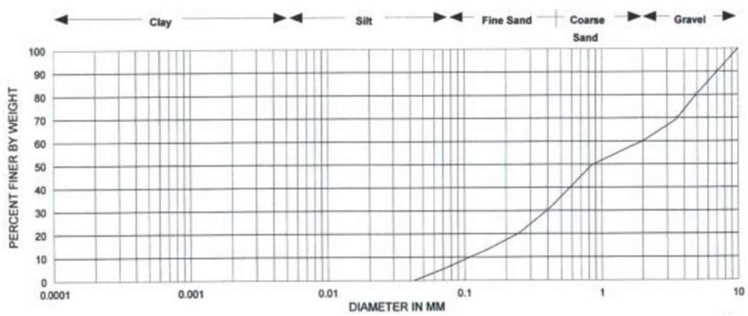

Figure 7. PLAXIS 3D modelling cross section of section 15 KM 456 Semarang-Solo Rest Area

For the shear strength input parameter in PLAXIS, the laboratory test results were used with reduction. For the rest of the parameter, correlations from Budhu (2015) and Kulhawy (1990) were used. The soil model used for the modelling is Mohr-Coulomb, except for the Silty Clay which used Soft Soil Model. The parameter interpretation is listed in Table 2.

Table 2. Soil parameter for numerical modelling

Material	$\gamma_{unsat}/\gamma_{sat}$ (kN/m^3)	E (kN/m^2)	v'	c' (kN/m^2)	ϕ' (°)	Cc/Cs
Geoframe Fill	14/17	10000	0.32	40	23	
Rest Area Fill	14/17	10000	0.32	40	20	
Gabion	21/21	80000	0.2	50	50	
Silty Fine Sand	15/18	60000	0.28	15	33	
Gravel-Sand	17/20	25000	0.28	5	33	
Silty Clay	14/17	-	0.35	25	13	0.4/0.04

In this case study, the analysed geometry is considering the Geoframe in section 15 of the rest area which is used as the land supporting the Ground Water Tank (GWT). There are two tanks above the Geoframe area which are Raw Water Tank (RWT) and Chilled Water Tank (CWT). The Geoframe's height is 10 meters with 1 meter of gabion as reinforcement. The reinforcement of the Geoframe system relies on the tensile strength and anchorage length of the geogrid used. In this case, considering the internal and external stability of the embankment slope, a biaxial geogrid with a tensile strength of 60 kN/m was used with an anchorage length of 10 meters for every 0.5 meter vertical spacing.

To model Geogrid materials in PLAXIS software, we need a parameter that can represent the tensile strength of the Geogrid. In PLAXIS, Geogrid tensile strength is represented by stiffness (EA) and allowable tensile strength (N_p). The parameter values are summarized in Table 3.

Table 3. Geogrid parameter for numerical modelling

Material	EA (kN/m)	Np (kN/m)
Geogrid Biaxial (60 kN/m)	720	36

The anchorage length of the Geoframe system is influenced by the type of embankment fill material, subgrade condition and working load. The Geoframe system in section 15 must be able to withstand the load of the rest area's Ground Water Tank. To represent the GWT load, 25 kPa distributed load was applied in the cross section.

2.3 Modelling

Modeling is done using PLAXIS 3D software with the principle of calculation using the finite element method. This software is used to analyze the settlement and stability of reinforced embankment. The modelling is illustrated in Figure 8.

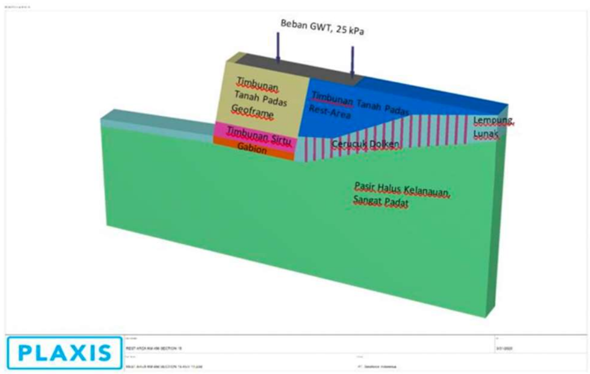

Figure 8. PLAXIS 3D modelling cross section of section 15 KM 456 Semarang-Solo Rest Area

In the modelling, only the reinforcement which is in the form of Geogrid was modelled. The frame in Geoframe and Non-Woven Geotextile for filter weren't modelled as they were merely facing and not the main reinforcement.

The stratification of the existing soil from the slope on the side of the toll road is in the form of a layer of soft silty clay with a thickness of up 4 meters. Then at the bottom there is a very dense layer of fine silty sand. The groundwater table was found at a depth of 2 meters from the surface of the testing level, namely at the base of the slope. This is also due to the fact that the layer in front of the Geoframe system is a rice field which often experiences saturation and fluctuations in the groundwater level.

From the geometry modeling and soil data, the construction phase is then modelled. In the initial conditions there are only layers of subgrade. Then, the process of cutting soft clay is modelled until it reaches the hard soil layer. After that, the installation of 2 layers of gabions was modelled as the base reinforcement of the Geoframe system. Backfilling is then continued with gravelly-sand material up to a height of 2 meters. After that, proceed with backfilling of soil up to a height of 10 meters. At each stage of the embankment construction, the geogrid with a tensile strength of 60 kN/m which has an anchorage length of 10 meters is then activated. After the backfilling phase has been completed, it's continued with the loading phase and long-term settlement and stability checking.

3 RESULTS

The geoframe section which supports the GWT structure is very sensitive to settlement. Geoframe settlement was then reviewed for the condition immediately after the loading and long term. Below is the settlement result.

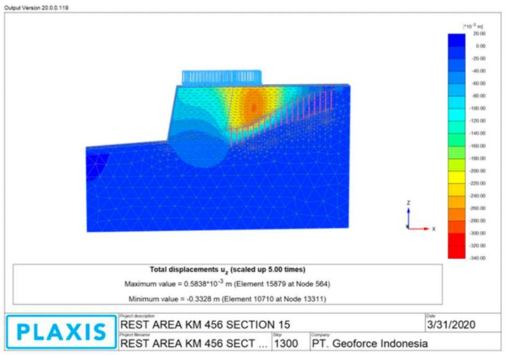

Figure 9. PLAXIS 3D section 15 global settlement estimation after loading

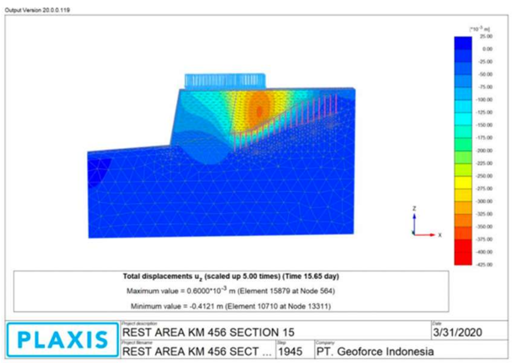

Figure 10. PLAXIS 3D section 15 global settlement estimation for long term

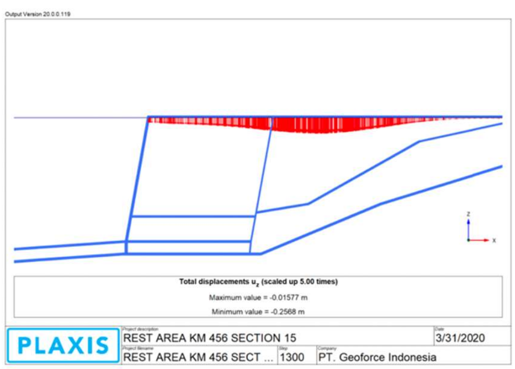

Figure 11. PLAXIS 3D section 15 surface settlement estimation after loading

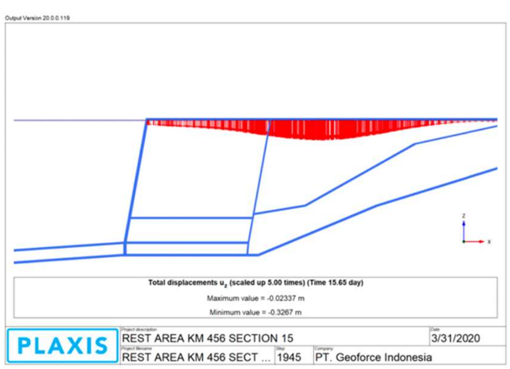

Figure 12. PLAXIS 3D section 15 surface settlement estimation for long term

Based on the estimation of global settlement as shown in Figure 9 and Figure 10, the settlement difference is 79 mm. To consider the settlement estimation on the surface, the data is shown in Figure 11 and Figure 12 which can be seen that the settlement difference is 69 mm.

From the geometry, it is shown that the GWT structure is sitting very near the edge of the embankment slope. Hence, global stability needs to be assessed. Below is the global stability safety factor estimation.

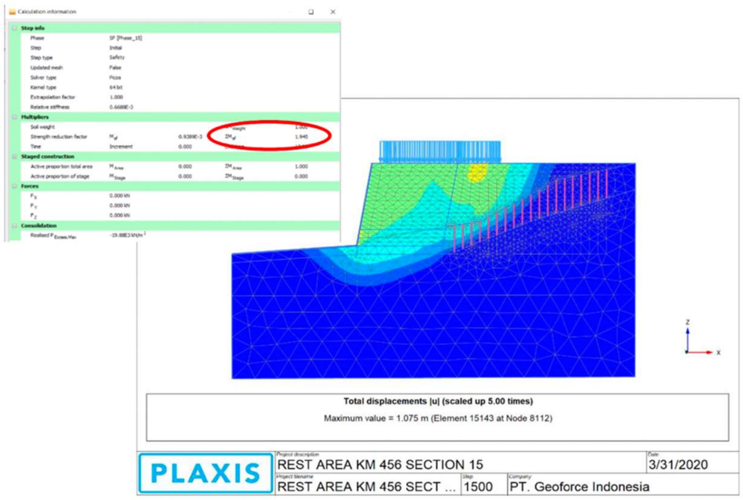

Figure 13. PLAXIS 3D section 15 global stability safety factor estimation

From Figure 13 it is shown that the safety factor estimation of the global stability analysis after the loading application is 1.945. This indicates that the embankment is safe and meets the safety factor criteria for embankment in static condition which is >1.50 as stated in Indonesian National Standard for Geotechnical Design Requirements 8460: 2017.

4 CONSTRUCTION PROCESS AND MONITORING

The construction process of the rest area involving five main works. The works including subgrade preparation, the soft clay cut process, gabion installation, Geoframe facing and reinforcement installation which follows by backfilling and compaction process, lastly the load application. During the transition from the Geoframe final topping process and full operating loading, it is crucial to monitor the settlement.

Figure 14. GWT structure in section 15 of KM 456 Semarang-Solo Rest Area

For the GWT structure, after the installation of shallow foundation until it is full operating, the settlement was monitored. Below is the monitoring points layout and graph around the time it's shallow foundation finished, the initial empty tank condition, and when it was slowly filled with water until its full capacity.

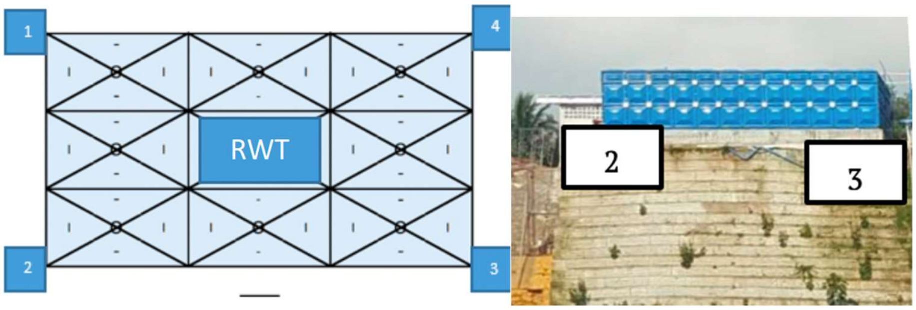

Figure 15. Monitoring observation points layout for GWT structure in section 15

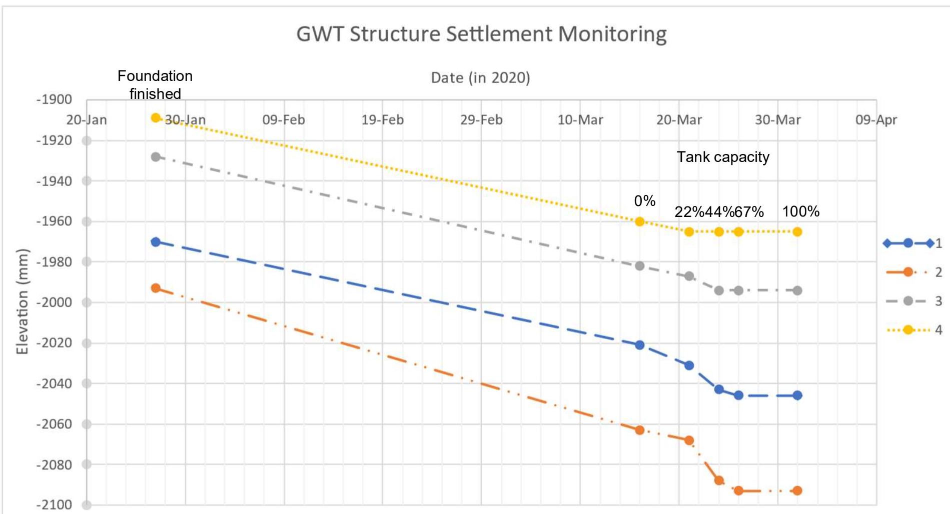

Figure 16. Settlement monitoring graph for GWT structure in section 15

5 DISCUSSION

From the modelling result and the monitoring graph it can be seen that there's similarity on the settlement estimation. The result from PLAXIS 3D global settlement and surface settlement until the long term condition yields the estimation of 69-79 mm. Comparing to the monitoring result, there is similarity as the total settlement from point 1 is 76 mm, point 2 is 100 mm, point 3 is 66 mm and point 4 is 56 mm. The settlement recorded in the monitoring has similar value, but also has some differences to it due to many controlling factors but mainly because of the compaction effort. Due to the GWT structure sitting on the edge of the L-Shape of the Geoframe system, the compaction effort on point 2 would normally be the need to be the highest. Hence making it the hardest to compact and resulting in it being the point with the biggest settlement. The nature of the fill material which is mainly gravel-sand also plays the important factor that makes the settlement happen immediately. Overall, considering the immediate settlement from the fill material and the global safety factor being > 1.50, the construction of Geoframe system is considered success from the quality of the design perspective and cost saving perspective.

6 CONCLUSION

From the construction of the Geoframe system on the Semarang-Solo Toll Rest Area KM 456 itc an be concluded that the Geoframe system can be a safe alternative for stabilizing high embankments if it is designed according to standards and handling according to conditions in the field. The Geoframe system can be an alternative to embankment stabilization which is much cheaper than conservative retaining walls if the bearing capacity of the subgrade is sufficient. The use of fill material with good shear strength with immediate settlement characteristic is very important in Geoframe system. the optimization of the rest area's retaining wall is considered success.

DISCLAIMER

Hereby I declare that I have no conflict of interest.

AVAILABILITY OF DATA AND MATERIALS

All data are available from the author.

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