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ROAD EMBANKMENT FULL-SCALE INVESTIGATION ON SOFT SOIL WITH GEOTEXTILE STABILIZATION

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ABSTRACT: When building roads in swampy areas, several problems include soil with low bearing capacity, scarce and expensive embankment materials are often met. Although local materials can be an alternative for backfill materials, this research focuses on the use of local soil as backfills by utilizing geotextile as soil stabilization. The case study was conducted in Tapin, South Kalimantan. The trial embankment method was used; thus, the road performance was observed primarily in a quite long time – not only because of the soil layers but also because of the traffic above it. Two types of embankment models were used. Embankment 1 utilized the ordinary backfill material transported from off-site. Whereas the backfill used for the Embankment 2 was local material. The number of geotextile layers installed was adjusted to the stability analysis of each embankment. A couple of direct observations were done, such as vertical settlement and horizontal deformation using a settlement plate and inclinometer, respectively. The numeric analysis was also performed using a finite element method to learn the influence of the geotextile toward embankment stability. The result shows that the settlement that occurs to the embankment with the usual backfill material is bigger than the one with the combination of the local soil. There is no difference in the visual values of the road between the ordinary backfill material and the local backfill material.

Keywords: Trial embankment, Soft clay, Local material, Geotextile, Settlement

1. INTRODUCTION

There are still difficulties often faced on road constructions that are built on soft soil in swampy areas, even more so if there is no material for strengthener purposes on the road itself. Backfills materials often drowned into the softer ground soil since it is not strong enough to bear the embankment soil [1]. This results in the total volume of the embankment materials needed will be a lot more than the total volume of the embankment materials calculated. Other than that, due to ground movement on the road construction, rainwater will quickly penetrate the embankment and will create puddles on the top of the road. This condition will damage the road [2].

To handle the problem, the soil will be strengthened at first before any construction work is done. One of the ways is to use geosynthetic materials for soil stabilization at the base of the embankment [3-7]. The stabilization will not occur only at the base since a few layers of geotextile can be added [8]. With geotextile, the performance of the road will significantly increase, such as reducing the vertical settlement, increasing the resistance to horizontal displacement, increasing the service life of the pavement, and decreasing the thickness of the base to support repetitive load [9]. The performance of geotextile as soil stabilizer is maximized for soil with undrained cohesion less than 90 kN/m2. More than that, geotextile tends to become separator [6]. According to [10], road construction on soft soil needs the help of geotextile to decrease early damage on the road due to local collapse on soft soil because of its low bearing capacity. Djarwadi [10] researched the implementation of geotextile using selected material on soft soil in the Riau Islands. From the analysis result of the limit equilibrium method with three construction stability mode, the result is satisfying.

At present, field tests of road embankment on the soft soil using selected material have been carried out by several researchers. Research on the performance of embankments reinforced by geotextile using selected materials as fillers on a field scale in Thailand was carried out by [3] by observing settlement, lateral displacement, and pore water pressure. Rowe [11] analyzed embankment without and with geotextile reinforcement using elastoplastic models and large deformations of finite element theory. Then, Rowe and Soderman [12] demonstrated the use of reinforced geotextile or lightweight fillers, enabling improved embankment performance significantly.

Even though the use of geotextile is highly recommended for road construction on soft soil, there is still another difficulty, which is the requirement using soil filler from the usual backfill material or selected material for the embankment. During this time, it has never been thought to utilize as much material available around the construction site. Shahjahan [13] reported that the use of local material includes alluvial sand, silt, mica-contained, clay, and organic with different compositions from the road embankment in Bangladesh. However, the investigation only focuses on the road material and not the condition of the embankment itself. The use of local material as embankment was also reported by [14] for a pool construction project for wastewater shelter before it was filtered to refill the aquifer. However, the embankment material used was compacted sand/marl material, which is relatively stable to be used as an embankment. In South Africa, the use of local material is allowed as long as it fulfills the allowed strength [15].

In Indonesia, the use of non-selected material with geotextile reinforcement has been done on road constructions in Irian Jaya. Soil stabilization was done by using backfill material from a few available street locations wrapped in geotextile, which function well [16]. However, there is no data on broad field supervising on the said embankment. It is necessary to consider using local materials as much as possible and not using selected material that is transported outside of the road construction site [5].

The case study is conducted in the Tapin region, South Kalimantan, where soft soil is frequently found in this area. This paper discusses the embankment field test on soft soil stabilized with geotextile and local soil as an embankment material. Field-scale research was conducted to obtain reliable data to achieve the objectives of this study. The field test itself covers observation on the road construction for a quite long period of time due to traffic and ground movement (i.e., lateral displacement and vertical settlement). A numeric analysis was also performed using the finite element method to know the safety factor of the embankment and qualitative investigation of the embankment.

2. FULL-SCALE TEST EMBANKMENT

2.1 Subsoil Investigation

Subsoil profile, CPT result, and other nature of soil such as water content, volumetric weight, and cu (from the direct shear test) are shown in Fig. 1. Generally, the soil is divided into four layers. The top layer is silt with soft gravel with a value of qc 0.01 MPa. Under it, the second layer is soft organic clay with a value of qc 0.01MPa. Firm clay is found under it starting 8 m with a value of qc 0.5-1.0 MPa.

Meanwhile, the last layer, which is the layer of hard soil, starts around the depth of 11 m or more in-depth. The soil consistency data, which consists of water content (WN), liquid limit (LL), and plastic limit (PL), clearly shows that the soil is on a very soft condition because of the water content more than the LL. Soil volumetric weight is relative constant starting the depth 1 until 8 m. Undrained shear strength varies from 16 to 27 kN/m^2 extracted from the direct shear test, also shown in Fig. 1. The water level is found at varied depth, starting from 1.0 to 1.5 m depends on the season.

2.2 Embankment Construction

Two road embankment constructions were made. The first one was construction with filling material from offsite – usual embankment material. The second one was filled using local material taken from around the road construction area. Construction with the offsite material was made with a total length of 11 m, width 10 m, and thickness 2 m, as can be seen in Fig. 1. 1.5 m of the thickness was filled with offsite material with geotextile woven on the base of the layer. The upper

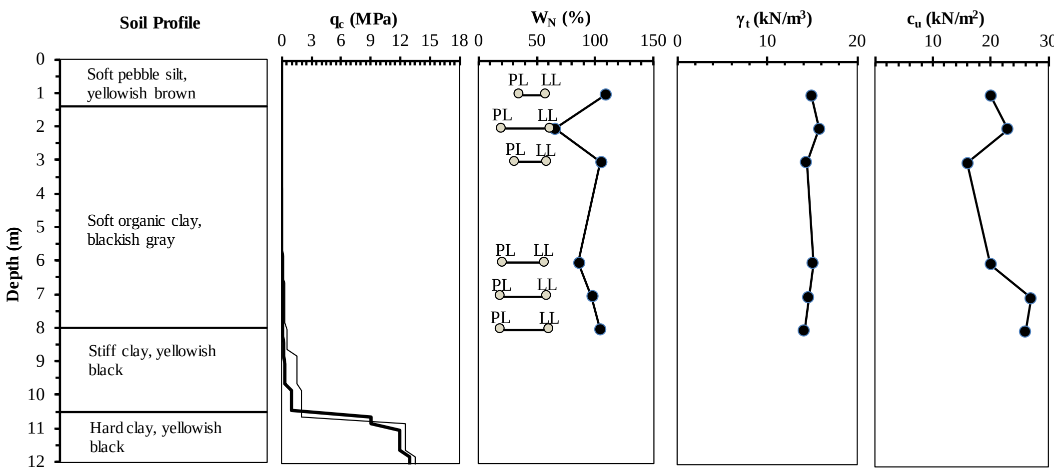


Fig.1 Soil layer profile, CPT result, and other soil nature

material was a 30 cm sand layer. The top material was a 20 cm layer filled with crushed stone. The total time needed for the making of the embankment was 46 days. The embankment construction was performed using excavator, compacted using vibrator roller with a few lines. Generally, the settlement plate is put in the middle of the embankment to obtain the maximum settlement. However, in this research, the settlement plate was put on the left and right side of the road (Fig. 2). This was done because public transport will be passed after the project ends. The inclinometer tube for the horizontal displacement observation was put on the right side of the road, as seen in Fig. 2.

The construction of the embankment with local material as filling material is shown in Fig. 3. The embankment was built with a height of 2 m with total length and width of the road of 11 m and 10 m, respectively. The embankment construction consists of a few layers with geotextile. The first layer is a 30 cm sand layer with woven and nonwoven geotextile. The second to fifth layer each is 30 cm using local soil as filling material stabilized by a woven geotextile. The last one is a 20 cm crushed stone layer. Embankment construction was performed using the excavator, and each layer was compacted using a vibrator with a few lines. The total time taken for the construction work was 39 days.

3. TECHNIQUE AND PROCEDURE

3.1 Observation of Horizontal Decline and Movement

The observation was done on three components (i.e., the vertical settlement, the lateral displacement, and the road surface visual). A water pass device was used to observe the displacement of the settlement plate that was placed in the left and right embankment, as seen in Fig. 2 and 3. Observation time takes place as soon as the actual construction work was done, up until two years and four months. After 7.5 months (225 days) construction was finished, the road has been passed by vehicles such as motorcycles, cars, and trucks.

Observation for the lateral movement was done with the inclinometer device. Observation starts at

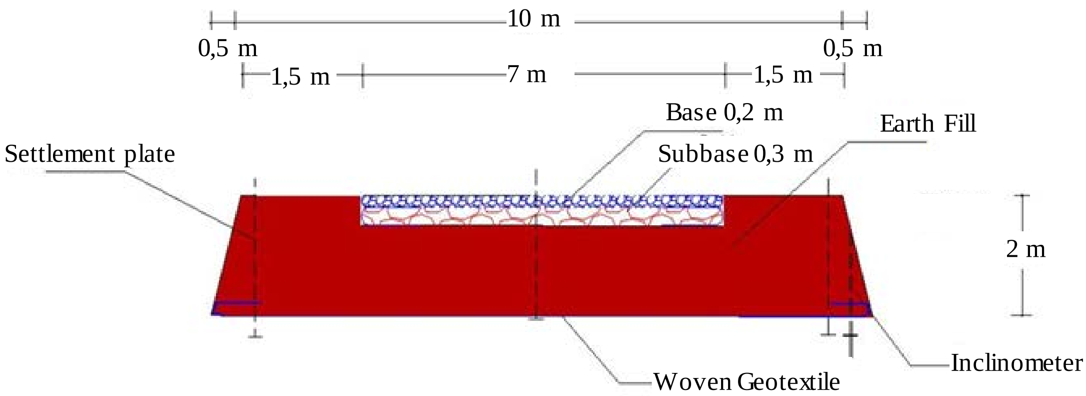


Fig.2 Embankment with Earth fill

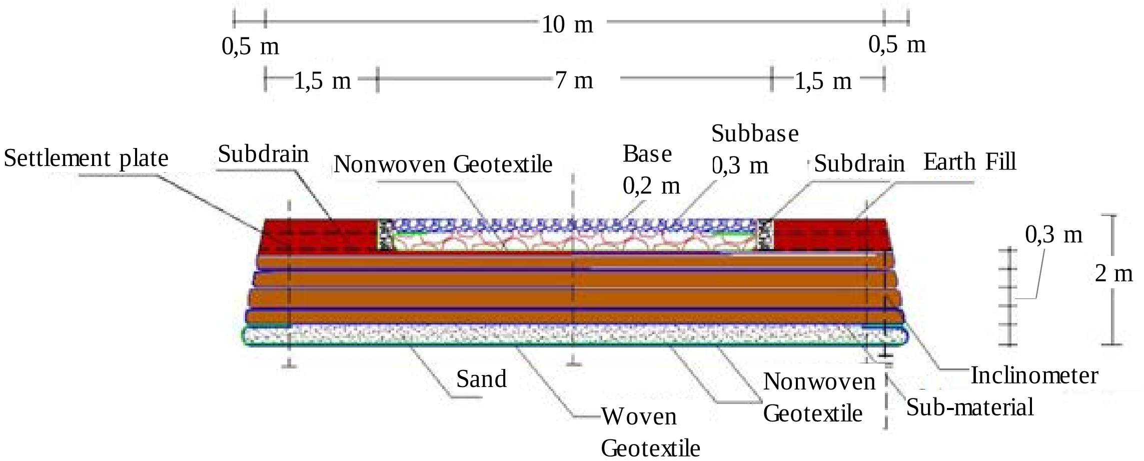


Fig.3 Embankment with Sub-material

the same time with the settlement measurement with the investigation period of two years and four months.

3.2 Visual Observation

Visual observation of the road surface was performed by looking at the relative element of visual observation, such as summarized in Table 1. Visual observation is essential not only to measure the performance of embankment material but also crucial for the satisfaction of the local community who uses the road itself. The observation elements consist of road damage types, the condition of the puddle on the surface of the road, and the comfort of passing vehicles. The visual investigation was also done by many researchers for different interests, such as accomplished by [17] for landscape improvement on a few roads on Malang, East Java.

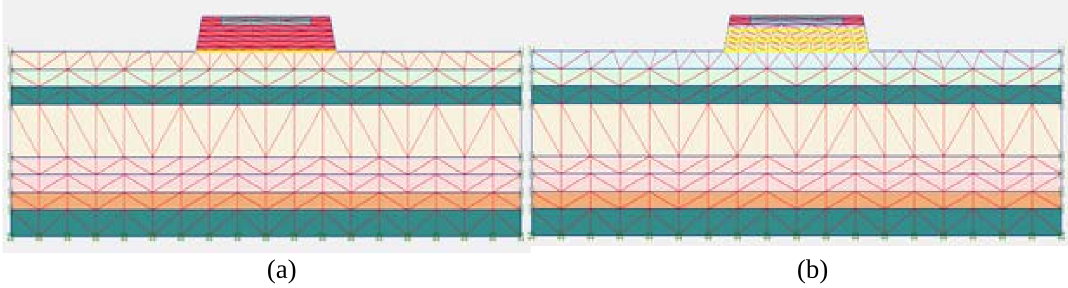
3.3 Finite element analysis and slope stability

Finite element analysis was used to obtain the vertical settlement, the embankment safety factor, and horizontal deformation that happens on the slope. Both embankments were modeled using Plaxis 2D, as shown in Fig. 4. Traffic load was applied on the embankment as a distributed load of 15 kN/m. This program makes it possible for field strain and axisymmetric idealization, including construction sequence simulation. The embankment was modeled as field strain – two dimensions modeling, for finite element analysis. Geotextile can also be applied straight onto the model with a tensile strength of 45 kN/m. Fig. 4 also shows the meshes of the finite element that become six vertices triangle for the embankment and soil layer. Material data used for the full-scale model of Embankment 1 and 2 summarized each in Tables 2 and 3. Mohr-Coulomb (MC) soil model was used in this research, which is also used by other researchers in modeling embankment on soft soil such as [6].

The embankment was modeled with compacted soil layers and ordered by the same time as happened in the field. The type of calculation used also adapts to field processes such as plastic, consolidation, and phi/c reduction types for construction, settlement, and safety factor analysis, respectively. The soil parameters used and shown in Table 2 are parameters that support the MC model in Plaxis.

Table 1 Visual observation elements in the field

Element of observation-	Sub element	Criteria	Measurement
Damage types	Wavy	Light < 2cm, Intermediate 2-5 cm, Great > 5 cm	Impacted area 0, 0-10%, 10-30%, 30-60%, >60%
	Landslide	Light < 5 cm, Intermediate 5-20 cm, Great > 20 cm	Impacted area 0, 0-10%, 10-30%, 30-60%, >60%
	Sinking	Light < 2cm, Intermediate 2-5 cm, Great > 5 cm	npacted area 0, 0-10%, 10-30%, 0-60%, >60%
Condition of puddles on the surface of the road	Water on surface		Impacted area 0, 0-10%, 10-30%, 30-60%, >60%
	Time flooded		1 hour, 1-3 hours, 3-24 hours, >24 hours
Comfort of passing vehicles		Relatively Comfortable	Interview
		Not Comfortable	Interview
		Very Comfortable	Interview



(a) (b)

Fig.4 Finite Element Model for Both Types of Embankment

Table 2 Full Scale Soil Data for Embankment 1

Material	Depth (m)	Model	γ_{unsat} (kN/m^3)	γ_{sat} (kN/m^3)	kx (m/d)	ky (m/d)	c_u' (kN/m^2)	ϕ (deg)	E (kN/m^2)	v'
Foundation soil										
Soft clay 1	0 - 1	MC	14,62	14,62	9,42E-04	9,42E-04	20,0	0	2000	0,30
Soft clay 2	1 - 2	MC	15,50	15,50	6,17E-04	6,17E-04	23,0	0	2000	0,35
Soft clay 3	2 - 3	MC	14,13	14,13	1,00E-03	1,00E-03	16,0	0	2000	0,35
Soft clay 4	3 - 6	MC	14,81	14,81	1,43E-03	1,43E-03	16,0	0	2000	0,35
Soft clay 5	6 - 7	MC	14,32	14,32	6,67E-04	6,67E-04	27,0	0	2000	0,35
Soft clay 6	7 - 8	MC	13,83	13,83	2,59E-03	2.59E-03	26,0	0	2000	0,40
Soft clay 7	8 - 9	MC	13,83	13,83	2,59E-03	2,59E-03	26,0	0	2000	0,40
Soft clay 8	9 - 10,5	MC	13,83	13,83	2,59E-03	2,59E-03	26,0	0	1,50E+04	0,4
Backfill soil										
Cobblers	-	MC	14,52	14,52	2,59E+04	2,59E+04	0	35,00	1,00E+05	0,20
Gravelly sand	-	MC	26,61	26,61	864	864	0	35,00	1,00E+05	0,20
Backfill soil	-	MC	17,76	17,76	1,00E-04	1,00E-04	25,5	14,45	5,00E+04	0,30

Table 3 Full Scale Soil Data for Embankment 2

Material	Depth (m)	Model	γ_{unsat} (kN/m^3)	γ_{sat} (kN/m^3)	kx (m/d)	ky (m/d)	cu' (kN/m^2)	ϕ (deg)	E (kN/m^2)	v'
Foundation soil										
Soft clay 1	0 - 1	MC	14,62	14,62	9,42E-04	9,42E-04	20,0	0	2000	0,30
Soft clay 2	1 - 2	MC	15,50	15,50	6,17E-04	6,17E-04	23,0	0	2000	0,35
Soft clay 3	2 - 3	MC	14,13	14,13	1,00E-03	1,00E-03	16,0	0	2000	0,35
Soft clay 4	3 - 6	MC	14,81	14,81	1,43E-03	1,43E-03	16,0	0	2000	0,35
Soft clay 5	6 - 7	MC	14,32	14,32	6,67E-04	6,67E-04	27,0	0	2000	0,35
Soft clay 6	7 - 8	MC	13,83	13,83	2,59E-03	2.59E-03	26,0	0	2000	0,40
Soft clay 7	8 - 9	MC	13,83	13,83	2,59E-03	2,59E-03	26,0	0	2000	0,40
Soft clay 8	9 - 10,5	MC	13,83	13,83	2,59E-03	2,59E-03	26,0	0	1,50E+04	0,4
Backfill soil										
Cobblers	-	MC	14,52	14,52	2,59E+04	2,59E+04	0	35,00	1,00E+05	0,20
Gravelly sand	-	MC	26,61	26,61	864	864	0	35,00	1,00E+05	0,20
Substandard 1	-	MC	17,76	17,76	1,00E-04	1,00E-04	25,5	14,45	5,00E+04	0,30
Substandard 2	-	MC	17,76	17,76	1,00E-04	1,00E-04	25,5	14,45	5,00E+04	0,30
Substandard 3	-	MC	17,76	17,76	1,00E-04	1,00E-04	25,5	14,45	5,00E+04	0,30
Substandard 4	-	MC	17,76	17,76	1,00E-04	1,00E-04	25,5	14,45	5,00E+04	0,30
Sand	-	MC	19,33	19,33	1,00	1,00	6,0	20,97	1.30E+04	0,30

4. RESULTS AND DISSCUSSIONS

4.1 Settlement of Embankment

Fig. 5 shows the result of the settlement plate measurement on the embankment (the position of settlement plate is as shown in Fig. 1 and 2) for each embankment. At first, the settlement on Embankment 1 is smaller, which is about 25 mm on day 60. At the same time, the settlement of Embankment 2 is around 45 m. Up until day 486, the settlement that happens on Embankment 2 is higher than the one on Embankment 1; each settlement is 90 mm and 80 mm. The change happens on day 500, the settlement on Embankment 1 (i.e., 117 mm) is greater than Embankment 2 (i.e., 104 mm). The settlement that happens to both types of embankments is relatively constant up until the measurement on day 851 as the final measurement in this research. Because this road has been used as a public road, it is not possible to take

measurements any longer.

Even though it has a higher volumetric weight, the materials on Embankment 1 produces a stiffer embankment; thus, the earlier settlement becomes relatively small. However, consolidation settlement is the function of load given; therefore, the

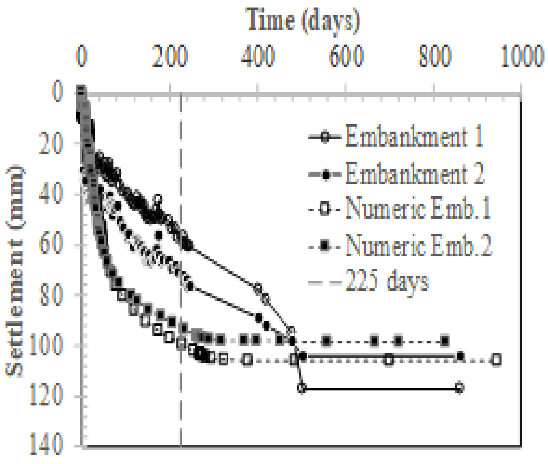


Fig.5 Time-Average Settlement Curves Obtained by Numeric and Settlement Plate Measurement

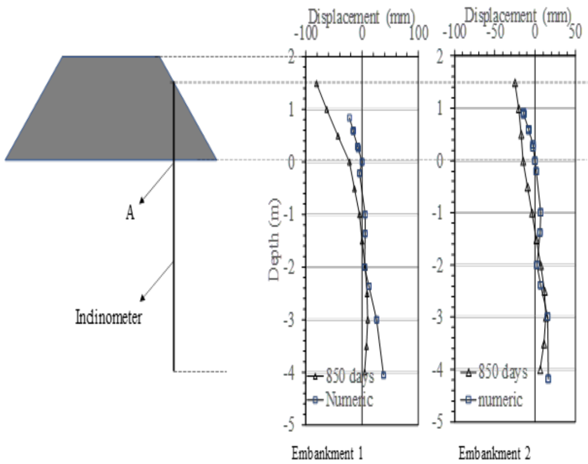


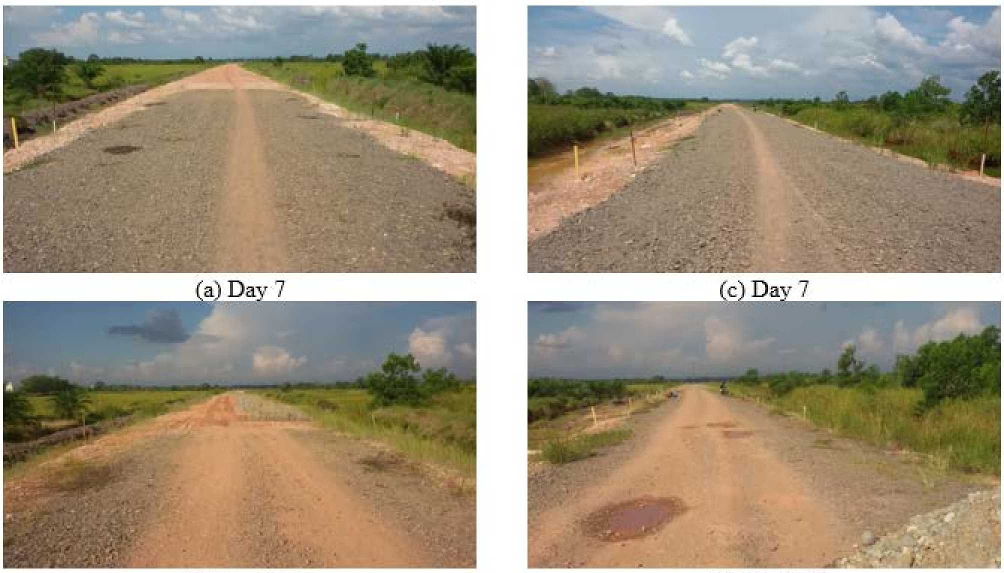
Fig.6 Horizontal Displacement Results

settlement on Embankment 1 is greater than the one on Embankment 2 up until day 861. The final settlement observed on Embankments 1 and 2 is 117 and 104 mm, respectively.

Fig. 5 also shows the results of numerical analysis calculated using the data in Tables 2 and 3. Curves of settlement obtained from calculations and field measurements are not fully fit, possibly because the chosen soil model does not represent the behavior of soft soils. Furthermore, more complex models require specific parameters that are rarely tested for field work. However, the total settlement obtained from the numerical analysis is almost the same as the data from the field.

4.2 Horizontal displacement

Fig. 6 shows the result of horizontal displacement generally obtained from the inclinometer reading on the embankment to the subbase at different times. Even though the measurement was performed periodically, there is only certain time that are shown in this article representing all data recorded. The time is day 850 (i.e., the last measurement day). The total length of the inclinometer used in this measurement was 5.5 m, with details of 1.5 m above the subgrade and 4 meters below. This was done to study the horizontal movement of the soil in both embankments, mainly



(a) Day 7 (c) Day 7

(b) Day 200 (d) Day 200

Fig.7 Photo Visual Field Observation (a, b) Embankment 1, and (c, d) Embankment 2 using local material.

Generally, both types of embankment show a similar horizontal movement. On-field data reading for Embankment 1, the biggest horizontal displacement that happens on day 850 is negative -81.5 mm. Meanwhile, as for Embankment 2, the biggest horizontal displacement happens on day 850 negative -25.5 mm. Even though it uses local materials, the horizontal displacement that happened on the slope of Embankment 2 is smaller than the one on Embankment 1 due to the number of geotextile stabilizers that are a lot more than the one on Embankment 2.

The outline is, the result for the measurement of horizontal deformation with numerical analysis shows the same tendency. The difference due to the stiffness of the inclinometer pole [3]. The negative deformation that is gotten from field observation is because of the tensile strength of the geotextile because of the deformation in the middle of the embankment.

Fig. 6 also shows horizontal deformation obtained from the finite element method. In general, the results for the measurement of horizontal deformation and numerical analysis show the same tendency. The difference is due to the stiffness of the inclinometer tube [3]. Deformation in the negative direction obtained from field measurements is caused by geotextiles being pulled towards the middle of the pile due to vertical deformation that occurs there. This also confirms that no pullout mechanism on the geotextile occurs in the embankment.

According to [3], the pullout mechanism occurs when the collapse process begins. This does not happen in both types of embankments. Soil movement occurs at -1.5 m below the embankment. The amount of horizontal displacement that occurs in the soft soil in both embankments is relatively the same.

4.3 Visual Observation Results

Fig. 7 shows the photos of both embankments that were taken at the age of 7 and 150 days. As shown in the pictures, both embankments show the same surface condition at first (7 days). This happens up until day 200, where Embankment 2 starts getting poor results due to the puddles that are quite large (Fig. 7 (b)). Whereas on Embankment 1, the puddles that happened are small on the day 200. After the roads are open for the public and are passed by heavily loaded trucks, Embankment 1 starts to have puddles. On the 200th day of the embankment, both embankments are showing the same condition with the same observational value. In total, the results of the visual assessment done are shown in Fig. 8.

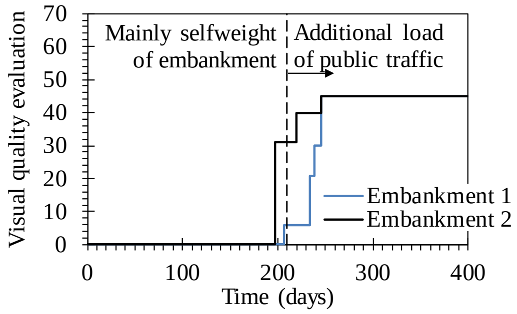


Fig.8 Visual Quality Evaluation by Time

4.4 Slope Stability

Fig. 9(a) and 9(b) shows the deformation result of both Embankment 1 and 2. For Embankment 2, the deformation that happened on the subbase below the embankment. This supports the measurement result of the horizontal displacement for both embankments that are measured straight on the field with the inclinometer (Fig. 6). The safety factors obtained for Embankments 1 and 2 are 1.55 and 1.62, respectively. The smaller shear strength parameters (i.e., c and f) of material on Embankment 2 makes the safety factor a lot smaller than Embankment 1. Until the 800th day on observation, both embankments are showing the stable state, as seen on the FEM calculation result. These results are consistent with the fact that the stable conditions of the two embankments are seen visually in Fig. 7. This also proves that local soil is very suitable for embankment material with geotextile reinforcement.

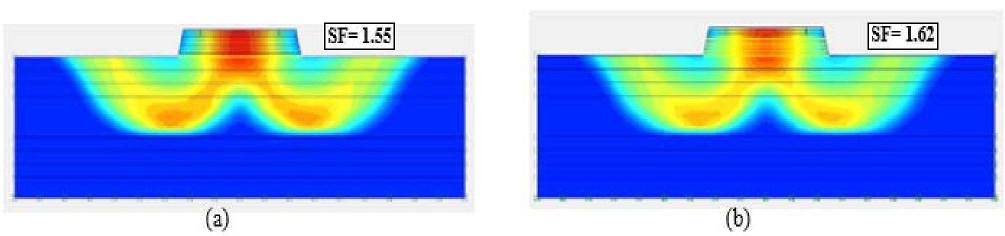


Fig.9 Collapse Pattern and Safety factor obtained by FEM

5. CONCLUSIONS

Investigations on the performance of the pile with local and ordinary materials have been presented. Some points that can be concluded from this research are

1. The settlement on Embankment 1 that uses usual material is larger than the one on Embankment 2 that uses backfill material from local soil stabilized by geotextiles.
2. The magnitude and direction of horizontal movement occurred for both types of the embankments are almost the same.
3. In the initial stage, the results of the visual evaluation of the two types of embankments show different performances. However, both of them showed the same performance after the road was more than 400 days old.
4. In general, FEM results that show total settlement, horizontal deformation, and safety factors are consistent and support the results of field observations. Safety factors of Embankment 1 and 2 are 1.55 and 1.62, respectively.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] Hardiyatmo, H.C., Geosynthetic for Highway Engineering-Planning and Application, 2013.

[2] Yelvi, Design of Modified Bamboo Matting as a Substitute for Geotextile for Separation between Foundation Layers and Subbase Soil, Civil Engineering, Vol. IV, No. 1, 2008.

[3] Bergado, D. T., Long P. V., Murthy S.B.R., A case study of geotextile-reinforced embankment on soft ground. Geotextiles and Geomembranes 20, 2002, pp. 343–365.

[4] Panayides, S., Rouainia, M. and Wood, M.D., Influence of degradation of structure on the behavior of a full-scale embankment, Can. Geotech,, J. 49, 2012, pp.344–356.

[5] Esmaili, D and Hatami, K., Measured Performance and Stability Analysis of Large-Scale Reinforced Model Embankments at Different Moisture Contents, Int. J. of Geosynth. and Ground Eng. 1(22), 2015, pp. 1-16.

[6] Benmebarek, S., Berrabah, F., Benmebarek, N., Belounar, L. Effect of Geosynthetic on the Performance of Road Embankment over Sabkha Soils in Algeria: Case Study, Int. J. of Geosynth. and Ground Eng. 1(35), 2015, pp. 1-8.

[7] Mohan, R. K. and Nair, C. G. R. Geotextile Applications, C. W. Finkl, C. Makowski (eds.), Encyclopedia of Coastal Science, 2018, pp.1-3.

[8] Chu, J., Bergado, D. T., Shin, E.C., and Chai, J. Embankments on Soft Ground and Ground Improvement, Geosynthetics Asia, 5th Asian Regional Conference on Geosynthetics, Bangkok, Thailand, 2012.

[9] Calvarano, L. S., Leonardi, G., Palamara, Finite Element Modelling of Unpaved Road Reinforced with Geosynthetics. Procedia Engineering. Vol. 189, 2017, pp. 99-104.

[10] Djarwadi, D. Road Construction on Soft Soil with Geotextile Stabilization, International Civil Engineering Conf., Surabaya, 2006.

[11] Rowe, R.K. Reinforced embankments: Analysis and Design. ASCE Journal of the Geotechnical Engineering Division, 110(GT2), 1984, pp. 231-246.

[12] Rowe, R.K., Soderman, K.L. Geotextile reinforcement of embankments on peat. Geotextiles and Geomembranes, 2 (4), 1985, pp. 277-298.

[13] Shahjahan, M., Materials Considered for Pavement and Embankment Design, Master Thesis, 2010.

[14] Aiban, S.A., Ishaq, A. M., Al-Suwaiyan, M. S. Utilization of Local Material in the Construction of an Embankment for Recharging Groundwater Aquifer with Treated Wastewater Effluents, Water Sci Technol, , 40 (7), 1999, pp.25-32.

[15] TRH9. Construction of Road Embankments. Technical Recommendations for Highways. Pretoria, South Africa, 1993.

[16] Indrasurya M.B., Road Construction for PT. Pertamina on Salawati Island, West Papua , Research Report, 2013.

[17] Santoso, H., Ernawati, J., Wulandari, L.D. Visual quality evaluation of urban commercial streetscape for the development of landscape visual planning system in provincial street corridors in Malang, Indonesia. IOP Conf. Series: Earth and Environmental Science 126 012202, 2018.