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Evaluation of Soil Replacement and Cement Grout Injection in Soil Settlement

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ABSTRACT

This paper discusses the process of original soil stabilization in Trans Sumatra Bakauheni-Terbanggi Besar Toll Road Project Package 2 Sidomulyo-Kotabaru. The soil replacement process was conducted at approximately 24 kilometers along the toll's main road. At the original soil bearing capacity analysis stage were by performing a Dynamic Cone Penetrometer (DCP) and Sondir test to analyze of the deep of hard soil. A soil replacement was carried out to replace the original soil with soil that has appropriate specification. the piling up process was conducted in stages, which has Sandcone in such of layer. Research did about the landfill sample was retaken and collected at 68 points. The stockpile soil samples collection was then followed by the analysis which was conducted in the laboratory to find the soil bearing capacity. There are 4 types of bearing capacity parameters analyzed, namely specific gravity, water content, aggregate analysis (Sieve Analysis), and consistency limit (Atterberg Limit). Refer to it, then there was classification of soil types according to AASHTO M145 & Casagrande Soil Classification System. A point which has settlement after soil replacement is STA 52+000. So, there need to additional soil stabilization, that is cement grout injection. Reseacher analyzed the soil settlement by interpretation method. Results showed that soil replacement and cement grout injection could decrease a soil settlement about 15,07 cm to became 0,93 cm.

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soil bearing capacity, soil replacement, cement grout injection

INTRODUCTION

Nowadays, many toll road constructions are being carried out. Toll road pavement consists of various layers that is subgrade (soil), base course, lean concrete, and concrete slab (rigid pavement). A lot of road's damage that occurs repeatedly even though have been repairs. That was happen caused to several things, including transportation loads that exceed the design load, pavement materials don't meet specifications, and

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soil conditions don not meet standards.

Many road's repair are limited for the surface or base / subbase layer. Meanwhile, damage can also be caused by poor subgrade soil conditions, so that occurs repeatedly. Soil improvement is divided into 2 groups, that is chemical soil improvement and physical soil improvement (Darwis, 2017). Both methods have similarities in goals and objectives to be achieved, but there are many differences in the methods and additives used.

Soil improvement techniques have the basic principle that poor soil capacity (in various aspects) can be improved through improving the properties of the soil, in accordance with the desired improvement objectives (Darwis, 2017). If what is desired is to increase the soil bearing capacity, then some parameters need to be improved. The study discusses about condition of original soil in the toll road area, which has a low California Bearing Ratio (CBR) value, so that it requires corrective action, namely soil replacement. The research was conducted on Trans Sumatra Bakauheni-Terbanggi Besar Toll Road Development Project Package 2 Sidomulyo-Kotabaru.

Soil replacement used soil removal method with heavy equipment's help, and then soil was replaced with materials according to PT. Waskita Karya (Persero)'s contract specifications. According to (Muchlisin & Roestaman, 2019), soil improvement technique using soil replacement method was one of the oldest and simplest methods which was often applied in improving the condition and soil carrying capacity.

Parameters such as percentage of Water Content, Specific Gravity, Sieve Analysis (Percent loss No. 200) and Atterberg limit which consists of liquid limit, plastic limit , and Plasticity Index is presented regarding the soil bearing capacity to withstand transportation and structure loads. Soil replacement is certainly not an easy thing because it will be associated with cost and time. Researcher analyzes the soil stabilization actions that need to be carried out and impact of soil replacement.

There are several factors that affect the soil bearing capacity, one of which is the Ground Water Level (GWL). Characteristics of land subsidence are identical to the pattern of groundwater subsidence (Yuwono, 2013). There is one location that has undergone replacement, but is still experiencing settlement. It was indicated because the Ground Water Level (MAT) was quite high, so it is necessary to take additional soil improvement measures, that was cement grout injection. Injection of cement-sand columns on soft clay soils can reduce amount of settlement caused by additional loads (Chai & Carter, 2011). It aims to create a soil material that is more impermeable to water, so as to minimize the process of soil infiltration. With this research, is hoped can increase engineers's knowledge regarding stabilization measures.

METHODS

Research flow

The research was conducted by collecting primary and secondary data. Primary data was about Standard Penetration Test (SPT) data, Cone Penetration Test, and soil properties test. While the secondary data consists of hard soil depth data from the Dynamic Cone Penetrometer (DCP) test, Cone Penetration Test (CPT), and Sandcone test. After the soil replacement until the depth of hard soil, results of the Sandcone test are obtained which show the degree of density of the embankment soil. Then carried out sampling the embankment soil in 2 ways, with drill machine and drill hand. In the implementation of a machine drill, was carried out a Standard Penetration Test (SPT) at every 2 meter depth drilling. After obtaining the soil sample, laboratory tests were carried out to review characteristics of the soil. There are 4 types of test, namely Percentage of Water Content, Specific Gravity, Sieve Analysis (Percent Lose No. 200) and Consistency Limit (Atterberg Limit) which consists of Liquid Limit, Plastic Limit, and Plasticity Index. After getting soil parameters, the classification is carried out according to the AASHTO M145 & Casagrande Soil Classification System.

Reviewing evaluation's results in field, researchers focused on locations that experienced settlement, namely STA 52+000. By interpretation method, several other parameters are obtained in the soil embankment at STA 52+000. Furthermore, an analysis of the settlement was occurred. The researcher also compared the condition of soil embankment under 3 conditions, namely the condition without stabilization, the condition with soil replacement action, and the condition with soil replacement action and cement grouting injection. It can be seen the comparison of soil settlement rates between soil stabilization action options.

Research stages

Theoretical studies is not be separated from literature review or literature study because theory can actually be obtained through literature study or study.

Primary and secondary data collection

Primary data

Researchers oversee test directly after the soil replacement, namely:

a) Standart Penetration Test (SPT)
This test is carried out on machine drilling (bore machine) at 59 points every 2 meters in depth. The test shows the density of soil embankment until depth of the soil replacement base.

b) Cone Penetrometer Test (CPT)
The test is carried out at 9 locations and aims to ensure that the depth of the replacement base is equal to the depth of hard soil.

c) Soil Properties Test
Laboratory's tests analyzed several soil parameters, namely Water Content, Specific Gravity, Sieve Analysis (Percent Lose No. 200), and Consistency Limit (Atterberg Limit).

d) Soil parameter numbers is interpreted by previous research, namely soil permeability coefficient, void ratio (e), saturated and unsaturated, Young's Modulus (E), Position Ratio (v), Cohesion (Cu), Angle of Shear (φ), and Relative Density.

Secondary data

Secondary data was obtained from project's data around 2016 to 2018 as many as 68 points, namely:

a) Dynamic Cone Penetrometer (DCP)
Before toll road pavement was held, a Dynamic Cone Penetrometer (DCP) test was carried out to determined the California Bearing Ratio (CBR). There were 68 sample locations of Dynamic Cone Penetrometer (DCP). With this, the depth of hard soil (CBR>6%) can be known. The test was held in every 25 meters. It shows that ±24 km of ±40 km of toll road land does not meet specifications. From this, it was known that the deepest of hard soil depth at STA 64+475, which was ±3.8 meters.

b) Cone Penetrometer Test (CPT)

Prior to earthworks being carried out, Cone Penetrometer Test (CPT) was held at several location to determine the depth of hard soil (qonus value ±120 to 150). In general, that is carried out at points that have a silty subgrade. There are 8 location for the Sondir Test which were held before soil replacement. From this, it was known that the deepest hard soil depth at STA 58+375, which was ±7 meters. The site was previously used as a factory waste disposal pond.

c) Sandcone Test

This test was carried out at the end of each compaction layer in ±20 cm thick stockpiling. The results of the sandcone test show that the minimum density of each embankment layer at least 95%.

Data processing

Data processing in this study was carried out in several stages, namely:

a) Presentation of hard soil depth data according to the results of Dynamic Cone Penetrometer (DCP) test and Sondir test, as well as Sandcone data.
b) Explanation of soil replacement stages.
c) Presentation of soil properties after soil replacement is consist of Water Content (water content), Specific Gravity (Gs), Percent Loss No. 200, Atterberg Limit.
d) Evaluation of post-replacement soil conditions
e) Evaluation of cement grouting injection at soil settlement locations.
f) Evaluation of land settlement according to stabilization measures

RESULTS

The scattered research was carried out at 68 points on Trans Sumatra Bakauheni - Terbanggi Besar Toll Road project package 2 Sidomulyo-Kotabaru.

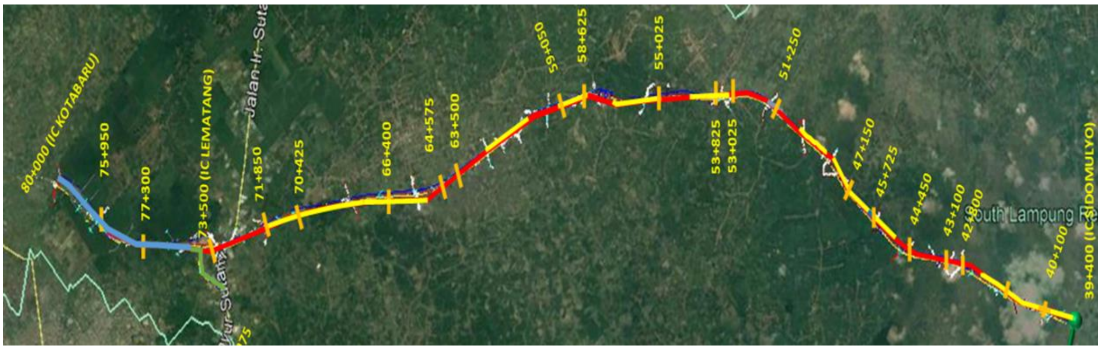

Figure 1. Layout of Bakauheni-Terbanggi Besar Toll Road Project Package 2 Sidomulyo-Kotabaru

Soil replacement has 2 main parts, that is digging bad material until the depth of hard soil and then backfilling with material according to specifications.

Surface evaluation of the post-replacement toll road pavement shows that some damage occurred at research location, namely:

No	Location	Damage Type
1.	STA 52+000	Settlement on the toll road surface
2.	STA 59+900	Transverse and longitudinal cracks on rigid surfaces

3.	STA 68+500	Bumps and holes on rigid surfaces
4.	STA 70+700	Transverse and longitudinal cracks on rigid surfaces

If you look at the type of damages, there is only 1 location that suffered damage to the subgrade layer, that is STA 52+000. If you look at the environment around the location, the Flood Water Level (FWL) at STA 52+000 is quite high, which is at a depth of ± 6.9 meters from finish grade, while soil replacement basis is at a depth of ± 9.3 meters from finish grade.

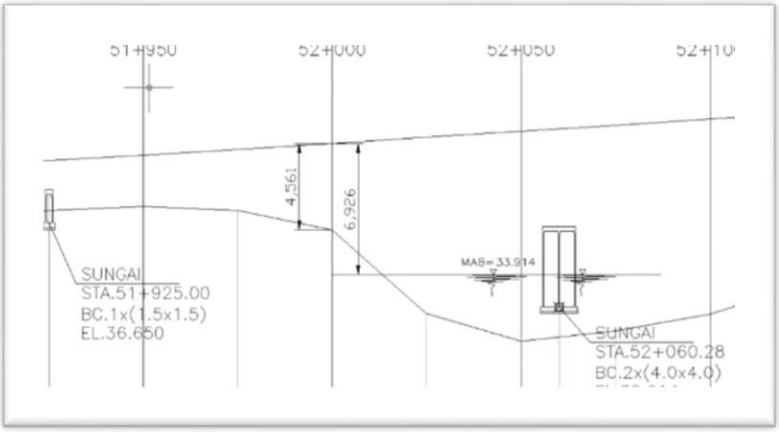

Figure 2. Flood Water Level (FWL) on STA 52+000

This can cause the embankment soil to be inundated by water when the Flood Water Level (FWL) increases. This can changes soil bearing capacity. Preventing infiltration process in the embankment that is caused the increase of Flood Water Level (FWL), it is necessary to carry out repair techniques that reduce soil permeability so as to create a watertight soil layer. Reducing permeability of sandy soils, this is usually applying soil-cement (Darwis, 2017).

According to (Sukiman & Yakin, 2017), consolidation or the process of removing pore water in the pore space due to load on subgrade in the form of embankments or construction loads will makes settlement. Consolidation occurs cause volume or pore voids of low-permeability saturated soils was reduce (Saharuddin et al., 2019). From some opinions, it is necessary to carry out further stabilization measures, namely injection of cement grouting. Interpretation methode research of previous research, compare 3 conditions, namely as follows:

Settlement conditions without soil stabilization measures

With the interpretation method referring to the results of previous research, original soil parameters still have a fairly low carrying capacity, as follows.

Table 1. Soil Parameters without stabilizing action

Depth	0,00 – 6,00 meter	6,00 – 10,00 meter

Empirical data		
Clasification	A (7-5) / ML-OL	A (2-7) / MH-OH
Soil Typical	Fine sandy silt	Organic clay
SPT Value	0 – 12	2
Water Content (%)	48,08	20,33
Specific gravity (T/m^3)	2,53	1,60
Sieve Analysis no. 200 (%)	72,04	32,97
Atterberg Limit		
- Liquid Limit (LL)	48,02	53,43
- Plastic Limit (PL)	35,43	35,90
- Plastic Index (PI)	12,58	17,54
Data interpretation		
Void ratio (e)	0,40	1,40
γ sat (kN/m^3)	20,94	12,5
γ unsaturated (kN/m^3)	10,94	1,25
K permeability	6,89x10^{-3}	9,00x10^{-7}
Modulus Young (E) (kN/m^2)	1,50x10^4	3,00x10^3
Position Ratio (v)	0,30	0,50
Cohesion (Ton/m^2)	25,00	12,50
Sliding angle (φ) (°)	28,00	28,00
Relative Density	Loose	Soft

DISCUSSION

This condition cause a settlement in 12.29 cm for 2 years and consolidation will stop at a settlement in 15.07 cm..

Condition of settlement with soil replacement

this condition shows the soil carrying capacity after soil replacement that occurs in the field.

Table 2. Soil Parameters with Soil Replacement Measures

Depth	0,00 – 6,00 meter	6,00 – 10,00 meter
Empirical Data		
Clasification	A (7-5) / ML-OL	A (2-7) / MH-OH
Soil Typical	Fine sandy silt	Organic clay
SPT Value	0 – 12	12 – 46
Water Content (%)	48,08	20,33
Specific gravity (T/m^3)	2,53	2,45
Sieve Analysis no. 200 (%)	72,04	32,97
Atterberg Limit		
- **Liquid Limit (LL)**	48,02	53,43
- **Plastic Limit (PL)**	35,43	35,90
- **Plastic Index (PI)**	12,58	17,54
Data Interpretation:		
Void Ratio (e)	0,40	0,60
γ sat (kN/m3)	20,94	19,03
γ unsaturated (kN/m3)	10,94	9,03
K permeability	6,89x10^{-3}	4,32x10^{-3}
Modulus Young (E) (kN/m2)	1,50x10^4	3,00x10^3
Position Ratio (v)	0,30	0,10
Cohesion (Ton/m2)	25,00	100,00
Sliding angle (φ) (°)	28,00	30,00
Relative Density	Loose	Hard

This condition causes a settlement in 6.07 cm for 2 years and consolidation will stop at a settlement in 6.16 cm.

Settlement conditions with soil replacement & cement grouting injection

After injection of cement grouting, the Young Elasticity's Modulus will increase from 500 kN/m^2 to 5.26x10^5 kN/m^2 (Yanto, 2015). Refer to the study, Young Elasticity's Modulus (E) was increased 1000 times.

Table 3. Soil Parameters with soil replacement action & cement grouting injection

Depth	0,00 – 6,00 meter	6,00 – 10,00 meter
Empirical Data		
Clasification	A (7-5) / ML-OL	A (2-7) / MH-OH
Soil Typical	Fine sandy silt	Organic clay
SPT Value	0 – 12	12 – 46
Water Content (%)	48,08	20,33
Specific gravity (T/m^3)	2,53	2,45
Sieve Analysis no. 200 (%)	72,04	32,97
Atterberg Limit		
- **Liquid Limit (LL)**	48,02	53,43
- **Plastic Limit (PL)**	35,43	35,90
- **Plastic Index (PI)**	12,58	17,54
Data Interpretation:		
Void Ratio (e)	0,20	0,30
γ sat (kN/m3)	22,50	22,50
γ unsaturated (kN/m3)	12,50	12,50
K permeability	8,38x10^{-1}	8,38x10^{-1}
Modulus Young (E) (kN/m2)	1,5x10^7	3x10^6
Position Ratio (v)	0,15	0,10
Cohesion (Ton/m2)	35,00	150,00
Sliding angle (φ) (°)	38,00	41,00
Relative Density	Dense	Very Dense

This condition causes a settlement in 0.90 cm for 2 years and consolidation will stop at a settlement in 0.93 cm.

CONCLUSION

Some conclusions from the results of the study are as follows:

1. After conducting research at 68 locations, there were 4 damage locations, they are STA 52+000, STA 59+900, STA 68+500, and STA 70+700.
2. The researcher explained that soil replacement consisted of several stages, which consisted of extracting bad soil material, compacting base of the embankment, gradually filling it up, and compacting rolling (proof rolling).
3. After replacement of soil, there are occured Standard Penetration Test (CBR), Sondir Test, and soil characteristics test. The results show that subgrade has met the toll road specification standards.

After evaluating toll road's surface, there is 1 research location that has decreased (settlement), namely at STA 52+000. To overcome this, it is necessary to carry out additional soil improvement, it is cement grout injection. Interpretation method analysing show that the cement grouting injection method is able to reduce the rate of soil settlement from 15.07 cm to 0.93 cm.

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