(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 6, Special Issue 1, January 2024

Comparison of Three Embankment Reinforcement on Soft Soil, A Case Study of Calang – Simpang Peut Road Section

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ABSTRACT

One of the road damages caused by problematic soil is found on the Calang - Simpang Peut Road Section. Soil testing data shows that soft soil exists at a depth of zero meters, up to five meters. The damage is being repaired using a Modified Chicken Claw (CAM) system. The CAM system is built on a road embankment. Using the CAM on the top of the road embankment has a settlement problem that will cause non-uniform settlement. This study reviews three alternatives that have been proven effective and efficient in fixing road embankment failures on problematic soils. These alternatives are geosynthetic reinforcement, geosynthetic reinforcement with prefabricated vertical drain (PVD), and encapsulated stone columns. This research will analyze the three alternatives based on their efficiency and effectiveness in treating the damage. The results of the calculation analysis show that the geosynthetic-reinforced embankment is the most effective alternative design. The alternative can also reduce the execution time by 42% and cost by 43% compared to the CAM system. However, a subgrade improvement alternative with encapsulated stone columns increases the execution time by 20% and cost by 25% compared to the CAM system, and using a PVD alternative is not recommended to repair the road embankment on this road section.

Keywords : Road asset management, Soil reinforcement, Soft soil, Embarkment, Geotextile

INTRODUCTION

In the case of construction on soft soil, reinforcement, and improvement measures are required to prevent damage and ensure the structure's sustainability. Especially if the road is an Arterial highway that connects activity centres at a national level or activity centres at both national and regional levels. One of the damages caused by soft soil is found on the Calang - Simpang Peut Road Section. Calang - Sp. Peut road section was built using funding from the United States of America (USAID) to repair the road damaged by the tsunami in 2004. The road construction was completed in 2010. This road section is a National Road with arterial road status that connects Banda Aceh City with Meulaboh City. This road section also provides transportation access to oil palm plantations. This road section embankment has a maximum height of three meters above the subgrade. The type of damage in this section is a non-uniform settlement and shear collapse on the shoulder of the road **(Figure 1)**. Indications of road damage due to problematic soils are proven by soil data taken directly from the field. The soil data are field test data (deep borings) and laboratory test data **(Table 1)**. The data shows that at a depth of 0 to 5 meters, the soil has an N-SPT value of 2 and an undrained shear strength value of 5.75 KPa. This indicates that the soil has a clay layer with a very soft consistency at this depth.

Figure 1. Documentation of Road Damage

Table 1. Soil Testing Summary

No	Depth (m)	Field Interpretation	N-SPT	w (%)	LL	PL	γ_t (gr/cm3)	Gs	e	Sr (%)	Clay & Silt	Sand	K (cm/dt)	ø (deg)	C (kg/cm2)	Classification (USCS)
								BH-1								
1	3-0	Embankment and gravel								Not tested						
2	0-5,5	Peat/organic	2							Not tested						
3	5,5-8	Silty fine sand (Medium)	11	35	-	-	1,74	2,6	1,0	90	8,05	92	-	8,9	0,045	Poorly Graded Sand (SP)
4	8-20	Silty sand (Medium)	29	30	-	-	1,82	2,6	0,8	93	7,82	92,2	-	26,5	0,07	Poorly Graded Sand (SP)
			28	29	-	-	1,81	2,6	0,8	89	9,01	91	-	25,1	0,06	
5	20-30	Silty sand (Dense – Very Dense)	52	18	-	-	1,93	2,6	0,6	82	8,92	91,1	-	30,29	0,058	Poorly Graded Sand (SP)
			50	20	-	-	1,90	2,6	0,6	83	7,65	92,4	-	29,1	0,062	
								BH-2								
1	3 - 0	Embankment and gravel								Not tested						
2	0-5	Peat/organic (Very Soft)	2	43	48	24	1,61	2,6	1,3	85	92,57	7,43	8E-08	5,23	0,105	Clay (CL)
3	5-15	Silty fine sand (Medium)	11	29	-	-	1,74	2,6	0,9	83	8,16	91,8	-	9,23	0,062	Poorly Graded Sand (SP)
4	15-21	Silty sand (Medium)	29	26	-	-	1,78	2,6	0,8	82	7,45	92,6	-	25,36	0,07	Poorly Graded Sand (SP)
5	21-30	Silty fine sand (Dense – Very Dense)	53	18	-	-	1,87	2,6	0,6	75	8,96	91	-	28,24	0,075	Poorly Graded Sand (SP)

source: The National Road Implementation Agency for Aceh Region (BPJN Aceh)

This problem can be solved if Infrastructure & Facility Asset Management (IFAM) is appropriately implemented. IFAM is a discipline that involves the management of infrastructure and facility assets throughout their lifespan. It encompasses knowledge, principles, and a systematic approach to effectively oversee these assets (Soemitro & Suprayitno, 2020). The primary goal of the IFAM is to guarantee that the infrastructure and facility can operate sustainable, both economically and efficiently, while also adhering to environmentally friendly practices (Soemitro & Suprayitno, 2020). Based on the IFAM, every infrastructure serves a specific purpose, but the critical factor is that it should possess a sustainable role in the economy, society, and the environment (Soemitro & Suprayitno, 2018). Referring to this statement, the damage must be repaired immediately.

The National Road Implementation Agency for Aceh Region (BPJN Aceh) has tried to repair road damage using the Modified Chicken Claw (CAM) system. The system is installed at the road surface elevation with a width of seven meters. This construction is planned to be installed continuously for one kilometer. However, according to Hardiyatmo 2022, the use of the CAM system installed in embankments on soft soil has the problem of consolidation settlement under the embankment, which will cause the embankment surface to experience a non-uniform settlement in the form of curving downward and causing the bearing capacity of the pavement to decrease in the middle of the road. Referring to Hardiyatmo's statement, the planning design conducted by BPJN Aceh still needs to be revised because the design does not consider the land subsidence that will occur under long-term conditions. In addition, the price per m^2 of the CAM system is One million five hundred sixty-three thousand four hundred thirty-eight rupiah for the estimated year 2022 in Java (Hardiyatmo, 2022), and this cost is expensive when compared to other options in the same region.

Repair of embankment damage on soft soil should be done effectively and efficiently. An improvement can be effective if the design meets the required stability and settlement criteria. Then, reinforcement can be considered efficient if it is quickly executed and affordable. To meet these criteria, three alternatives can be used to repair the road embankment that has been proven effective and efficient compared to the Modified Chicken Claw Method. The three alternatives are geosynthetic reinforcement, geosynthetic reinforcement with prefabricated vertical drain (PVD), and encapsulated stone columns **(Table 2)**.

Table 2. Alternative Road Embankment Repair

No.	Metode	General Description	Benefit	Application
1	Encapsulated Stone Column	Replace the troublesome geomaterial in the ground by driving a solid steel casing into it with a geosynthetic casing and fill.	Increase bearing capacity and stability; reduce settlement; accelerate consolidation	Suitable and economic for very soft soil (undrained shear strength <15 kPa) to a typical depth of 5−10 m; used to improve foundations
2	Geosynthetic-reinforced embankments	To provide tensile resistance, one can incorporate geosynthetics at various elevations in a slope while adding fill materials.	Increase stability	Suitable for low plasticity fill; mainly used for slope stability
3	Geosynthetic-reinforced embankments with PVD	Embedding PVDs in the soil and placing geosynthetics in the embankment.	Releases pore water pressure; accelerates consolidation; increases strength, stiffness, and stability.	Suitable for soils with low permeability; used for roads, retaining walls, slopes, and landfills.

source: Han, 2015

These three alternatives still need to be detailed regarding their efficiency and effectiveness in repairing the damage on the Calang - Simpang Peut Road Section. Therefore, research is required to determine the efficiency and effectiveness of the three alternatives so that the damage occurring on the Calang - Simpang Peut Road Section can be repaired with the most efficient and effective alternative.

LITERATURE REVIEW

Study Literature

Geosynthetics technology has become increasingly popular in solving various geotechnical challenges since its initial use in 1983. This was proven when strong geotextiles were used to stabilize the base of a highway that connects Jakarta International Airport with the city of Jakarta, which was built on soft organic clay deposits. Geosynthetics technology has become increasingly popular in addressing various geotechnical issues mentioned above. For example, using geosynthetics can help stabilize road embankments, reinforce soils for slope stabilization, minimize settlement in soft soils by using prefabricated vertical drains, build containment dykes and breakwater structures with geotextile tubes, and serve various other purposes. (Gouw, 2018). The use of geosynthetics in embankments on soft soils can also reduce the settlement of the subgrade by an average of 7.633% in the short term and 4.113% in the long term when compared to the embankment which not using any reinforcement (Surachmat et al., 2019). Meanwhile, if geosynthetics are added with PVD installation, the number of geotextiles used for embankment reinforcement will be reduced and can save geotextile costs. (Septiandri, Mochtar, & Lastiasih, 2021).

Geosynthetic technology has recently been applied to the use of stone columns. Indeed, this technology has yet to become familiar in Indonesia. However, there have been many applications and research, and their research compared ordinary stone column reinforcement and Geosynthetic Encapsulated Stone Column (GESC). The results obtained from the study show that GESC can withstand more significant loading compared to standard stone columns. The ratio of stress between piles and soil for ordinary stone columns gradually increased from 1.1 to 1.5 as the height of the embankment increased. However, the stress ratio of GESC in the initial backfill phase is 1.5 and it elevates to 1.7 during the backfilling process. The drainage capability of GESC is superior to regular stone columns, and GESC can effectively enhance the overall rigidity to decrease the horizontal movement of soil. Enhancing the stiffness of the geotextile, increasing its wrapping length, and improving the internal friction angle of the gravel can lead to a better bearing performance for GESC. Nevertheless, once the geotextile's rigidity and the extent of wrapping have attained a certain threshold, the impact of its hoisting quantity will diminish (Wang et al., 2023).

Design Criteria

The alternative design that will be made must meet the design criteria by applicable regulations **(Table 3 and Table 4)**.

Table 3. Alternative Road Embankment Repair

Road Grade	Traffic Load (Kpa)
I	15
II	12
III	12

source: Geotechnical Guidance 4, 2002

Table 4. Alternative Road Embankment Repair

Description	Safety Factor
Road construction	1,3
Ultimate bearing capacity of deep foundation	2,5

source: Geotechnical Design Requirements, 2017

The modulus of elasticity of each soil layer can be found; as for the sand soil layer, according to Bowles, it is 6000 times the corrected N-SPT value. Poisson ratio value for analysis is various based on soil type **(Table 5)**.

Table 5. Poisson Ratio Based on Soil Type

Soil Types	μ
Saturated clay	0,4 - 0,5
Unsaturated clay	0,1 - 0,3
Sandy silt	0,2 - 0,3
Silt	0,3 - 0,35
Sand, gravelly sand	0,3 - 0,4
Stone	0,1 - 0,4

source: Bowles, 1996

RESEARCH METHOD

The data used to analyze alternative reinforcement calculations are primary and secondary data. Previously known, the secondary data is in **(Table 1)**. However, there are irregularities in the data at a depth of zero to five meters. BH-02 states that the field interpretation is peat soil. This differs from the USCS classification results, which state that clay is at that depth. Therefore, field data retrieval was done to confirm the data. As for depths below five meters, data retrieval was not done because the field interpretation results were the same as the USCS classification results.

Analysis of the reinforcement alternatives' effectiveness is based on whether the stability and settlement are included in the design criteria. Numerical analysis determines the stability and settlement of the three reinforcement alternatives under review. Due to the availability of settlement plates and inclinometer instruments in the field, the analysis method will use finite element and limit equilibrium methods. The analysis will be done for geosynthetic reinforcement alternatives to review the global shear stability that occurs whether it meets the design criteria or not. Then, for the settlement, it is checked whether the settlement after reinforcement occurs uniformly or not. The same is done for the alternative geosynthetic reinforcement with PVD. As for the alternative using encapsulated stone columns, in addition to reviewing the global shear stability and uniformity of settlement, a review of the analysis of the bearing capacity of the columns to withstand the load above them was also done.

Efficiency analysis on retrofitting alternatives is reviewed from the point of view of ease of execution and cost. Analysis of ease of execution will be reviewed from the time duration of work completed from each of the proposed reinforcement alternatives. The duration of work for each proposed reinforcement alternative will be compared with the duration of work with the CAM method currently implemented in the field. Meanwhile, the cost analysis will be reviewed by calculating the cheapest labor, equipment, and materials among the proposed alternatives. The CAM cost calculation compares whether the proposed retrofitting alternative is more efficient than the existing design. The calculation of work duration and cost is based on the basic unit price of the local province.

RESEARCH ANALYSIS

Repeat Soil Testing

The results of the repeat soil test show that the soil classification is fibrous peat with high organic content **(Table 6)**. This differs from the secondary data, which classifies the soil at a depth of zero to five meters below the ground surface as clay. However, the data from the soil retest agree with the field interpretation that the soil is peat. Given these differences in soil characteristics, the approach to damage repair should also be adjusted accordingly. Therefore, this primary data will be used to analyze repair alternatives.

Table 6. Soil Data Used for Analysis

Depth (m)	Field Interpretation	N-SPT	E (kN/m^2)	v	w (%)	Cc/ Ca/ Cv	γ_t (gr/cm3)	Gs	e_0	Organic Content (%)	Fiber Content (%)	K (m/day)	ø (deg)	C (kg/cm2)	Classification
3-0	Embankment and gravel		75000	0,2	Not tested										
0-5,5	Peat/organic	2	-	0,2	721	7,21 /0,3/ 0,00 908	1,04	1,4	11,5	91,5	46,13	7E-03	26,1	0,05	Fibrous Peat
5,5-8	Silty fine sand (Medium)	11	8347	0,3	35,1	-	1,74	2,6	1,0	-	-	-	8,9	0,045	Poorly Graded Sand (SP)
8-20	Silty sand (Medium)	29	43343	0,3	30,3	-	1,82	2,6	0,8	-	-	-	26,5	0,07	Poorly Graded Sand (SP)
		28			28,7	-	1,81	2,6	0,8	-	-	-	25,1	0,06	
20-30	Silty sand (Dense – Very Dense)	52	63672	0,3	18,4	-	1,93	2,6	0,6	-	-	-	30,3	0,058	Poorly Graded Sand (SP)
		50			20,1	-	1,90	2,6	0,6	-	-	-	29,1	0,062	

Existing Compression Analysis

This road section has been in place for 13 years, so the compression that occurs at the point of failure needs to be analyzed first. Due to the availability of settlement plates and inclinometer instruments, roadway compression can be calculated only by analyzing laboratory data. The currently known embankment's height, top, and bottom width vary. However, the maximum height found in the field is 3 meters. The width of the top embankment is 11 meters, and the width of the bottom embankment is 18 meters **(Figure 3)**.

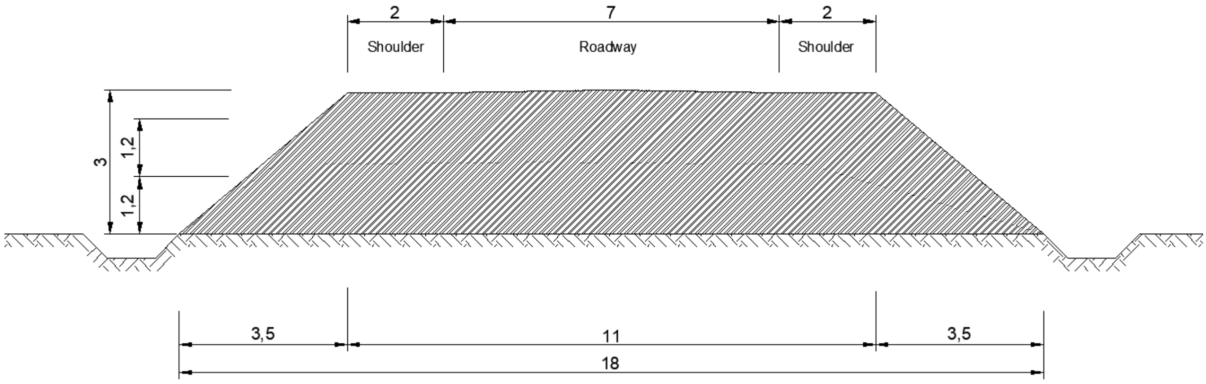

Figure 3. Cross Section of Current Road Embankment

The primary consolidation was calculated first, knowing that the current embankment height was three meters. Since there was no known initial height or history of re-levelling on the road section, Sc was calculated based on the known final embankment height. The primary consolidation that occurred was 2.1 meters **(Figure 4)**.

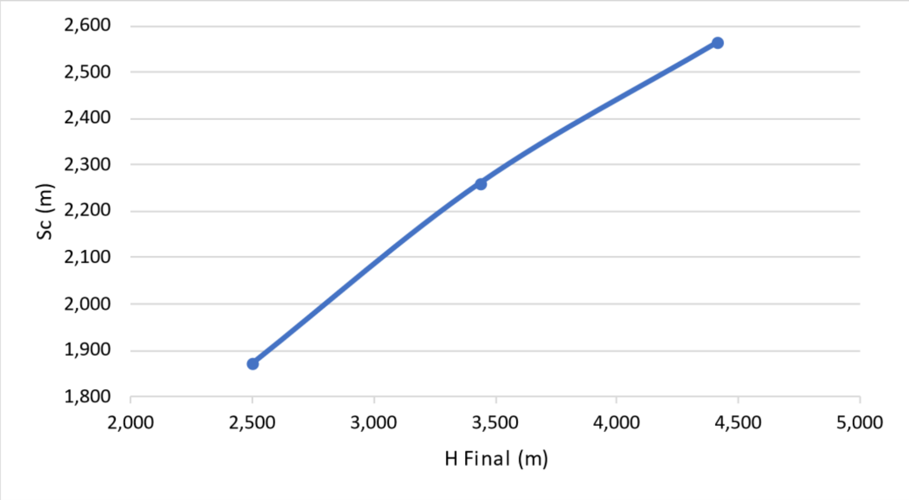

Figure 4. Primary Consolidation

The primary consolidation time must be calculated before calculating the secondary settlement calculation. The calculation is as follows:

Cv = 9,08 x 10^{-3} cm/minute …(1)

T_{50} = 2,782 – 0,944 log (100-U%)

= 0,19635

$t_{50\ field}$ $= \frac{T_{50} x (Hdr)^2}{cv}$

$= \frac{0{,}196\ x\ (275)^2}{9{,}08\ \mathrm{x}\ 10^{-3}}$

= 27246,6 minutes

$t_{100\ field}$ = 27246,6 x 2

= 54493,1 minutes

= 38 days

The result of the primary consolidation duration calculation was found to be 38 days. The secondary settlement that occurs is 0.4 **(Figure 5)**.

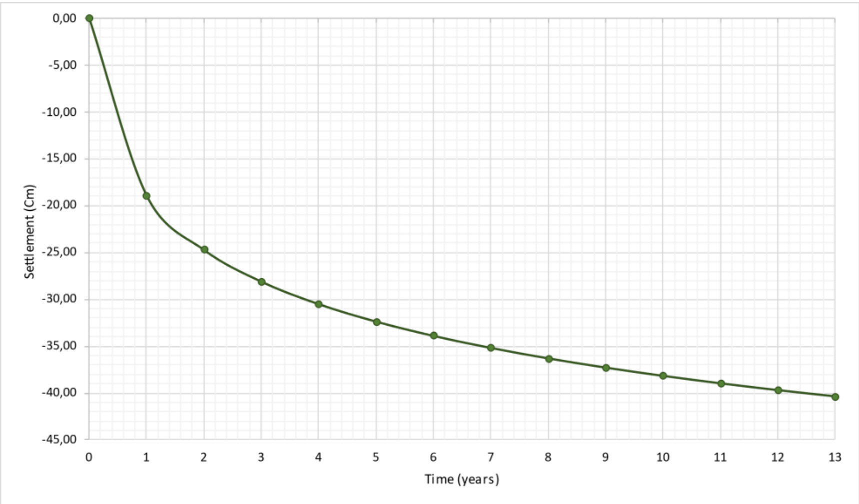

Figure 5. Secondary Settlement

The calculation results show that the road has experienced secondary settlement. Thus, the total settlement that occurred over 13 years was 2.54 meters. Given that PVD construction aims to discharge pore water during primary consolidation, the alternative using PVD is not effective. Therefore, the PVD alternative is not required. This compression value will then be included in the existing stability analysis **(Figure 6)**.

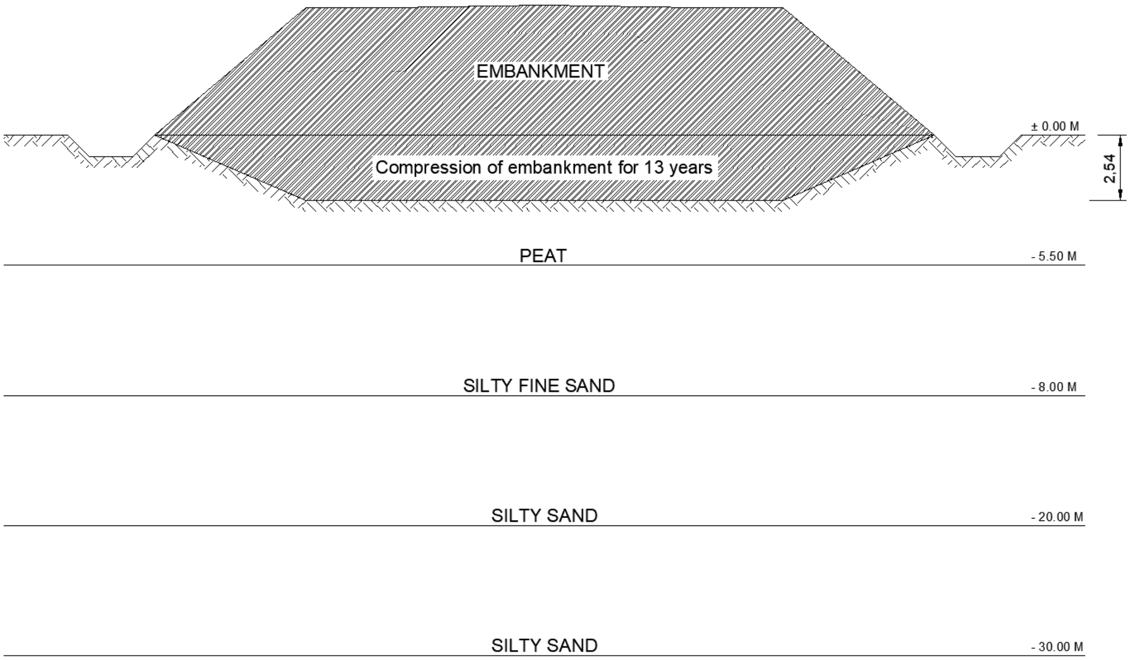

Figure 6. Cross Section of Road Embankment for Analysis (Non-Scaled Drawing)

Global Shear Stability Analysis

The initial stability analysis of the embankment was done to ensure that the visual conditions in the field, as shown in **(Figure 1)** experienced shear collapse or not. Furthermore, the analysis was done using geosynthetic reinforcement and encapsulated stone columns. The ESC modeling method was two-dimensional axisymmetric by converting the ESC diameter into width. The geotextile material used was 450 g/m^2 woven geotextile with an ultimate tensile strength of 100 kN/m and allowable tensile strength of 33.3 kN/m. The geotextile used as the casing of the stone columns had the same material. The gravel used to fill the stone columns was gravel with a maximum size of 2 cm and a shear angle 45^0. The results of the analysis, using the finite element method and the limit equilibrium method, obtained four alternative geotextile reinforcements and one alternative encapsulated stone column that are most effective to be done in the field **(Table 7)**.

Table 7. Stability Analysis Result

No.	Model	Safety Factor			Description
		LE Method	FE Method	Design Criteria	
1	Embankment initial condition	1,07	0,96	1,3	Not ok
2	Geotextille with existing slope (n=5)	1,31	1,34	1,3	ok
3	Geotextille with existing slope (n=7)	1,3	1,33	1,3	ok
4	Geotextille with 45^0 slope (n=6)	1,31	1,35	1,3	ok
5	Geotextille with 60^0 slope (n=6)	1,35	1,4	1,3	ok
6	Encapsulated stone column (n=8)	-	1,45	1,3	ok

(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 6, Special Issue 1, January 2024

The four geotextile reinforcement alternatives obtained have different installation types. The first geotextile reinforcement alternative, namely geotextiles with an existing slope of five pieces, was installed at the bottom of the embankment with a distance between geotextiles of 0.2 meters so that the total height of geotextile installation from the bottom of the embankment was 1 meter. The second geotextile reinforcement alternative, seven geotextiles with existing slope, were installed at a height of 1.2 meters from the bottom of the embankment with the exact distance between geotextiles as the previous alternative so that the total height of geotextile installation was 1.2 meters. The distance from the bottom of the embankment to the topmost geotextile was 2.4 meters. The third and fourth geotextile reinforcement alternatives totaling six pieces were installed with the same stages as the first alternative, but when backfilling was done, the slope was trimmed to 45^0 and 60^0, this was made to save the cost of geotextile procurement **(Figure 7 to Figure 10)**.

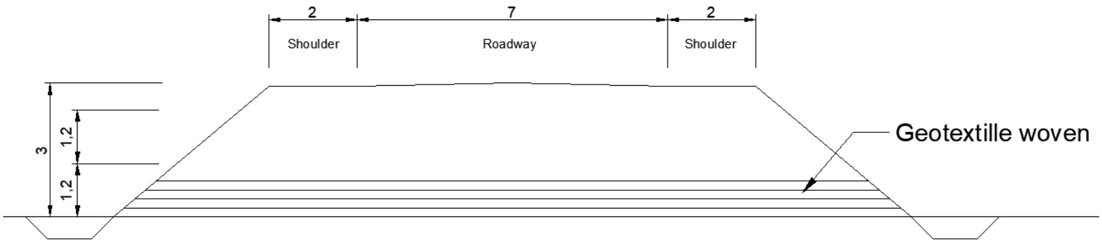

Figure 7. Cross Section Geotextile 1 Alternative

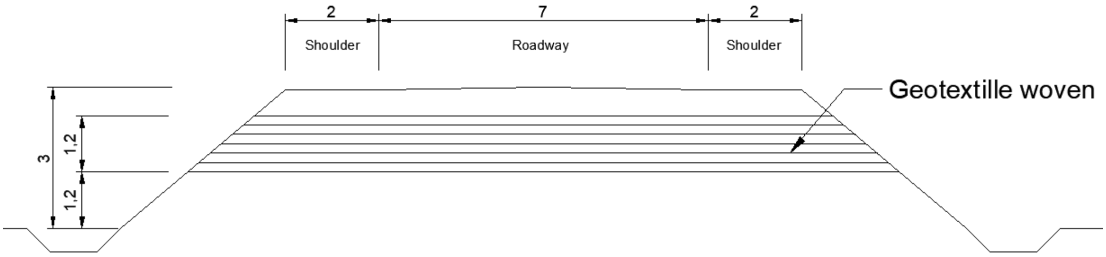

Figure 8. Cross Section Geotextile 2 Alternative

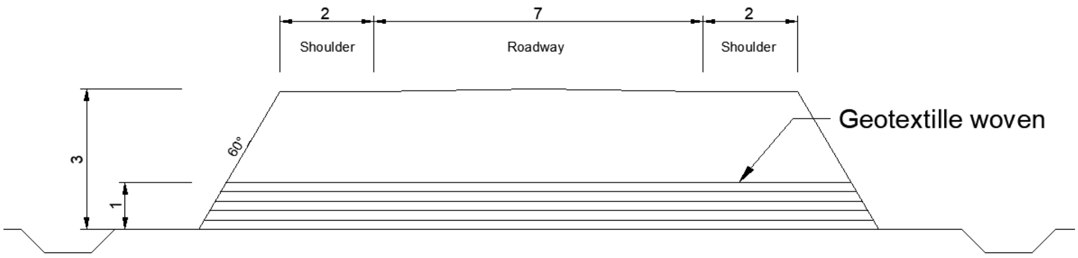

Figure 9. Cross Section Geotextile 3 Alternative

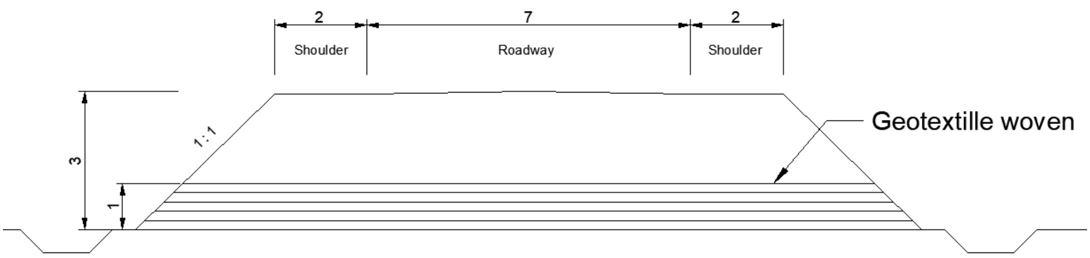

Figure 10. Cross Section Geotextile 4 Alternative

The optimum result for the practical dimension of encapsulated stone columns is eight pieces at the cross-section, a diameter of 0.7 meters, a distance of 1.75 meters between ESCs, and a depth of 5.5 meters **(Figure 11)**.

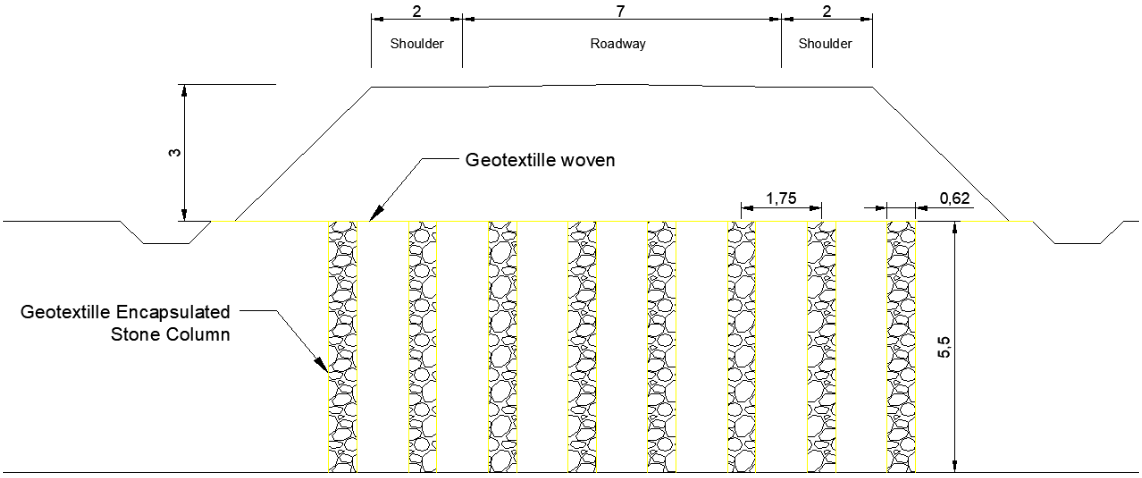

Figure 11. Cross Section ESC Alternative

Compared to the 3 previous studies, the comparison and difference in the safety factor values of the slope stability analysis of the limit equilibrium method and the finite element method in this study are in line. From this study and the previous study, it is found that the safety factor value of the slope stability analysis of the finite element method is always smaller than that of the limit equilibrium method **(Table 8)**.

Table 8. Comparison of Safety Factor Values of FE and LE Method

Safety Factor of Slope Stability Analysis	Analysis Result	Siregar, et. al. 2021	Beyene, 2017	Potgieter, 2016
FE Method	0,96	0,73	2,75	1,72
LE Method	1,07	0,83	2,97	1,82
FE/LE	0,90	0,88	0,93	0,95
FE - LE	-0,11	-0,10	-0,22	-0,10

Settlement Analysis

Calculating the compression during the lifetime plan (next ten years) is needed to see whether the compression on the road body occurs uniformly. The review point is the center point. The results of the compression analysis show that all proposed alternatives have a smaller settlement than the unreinforced embankment. ESC is the reinforcement alternative with the most minor settlement of 22 millimetres at the end of the lifetime plan; this is because the depth of ESC is designed to reach relatively hard soil. Geotextile 2 is the alternative with the highest settlement of 60 millimetres at the end of the lifetime plan, but this is because the installation of geotextile 2 alternatives is not done at the base of the embankment. While other alternatives are geotextile 1 > geotextile 3 > geotextile 4, this is due to the smaller width of the embankment **(Figure 12)**.

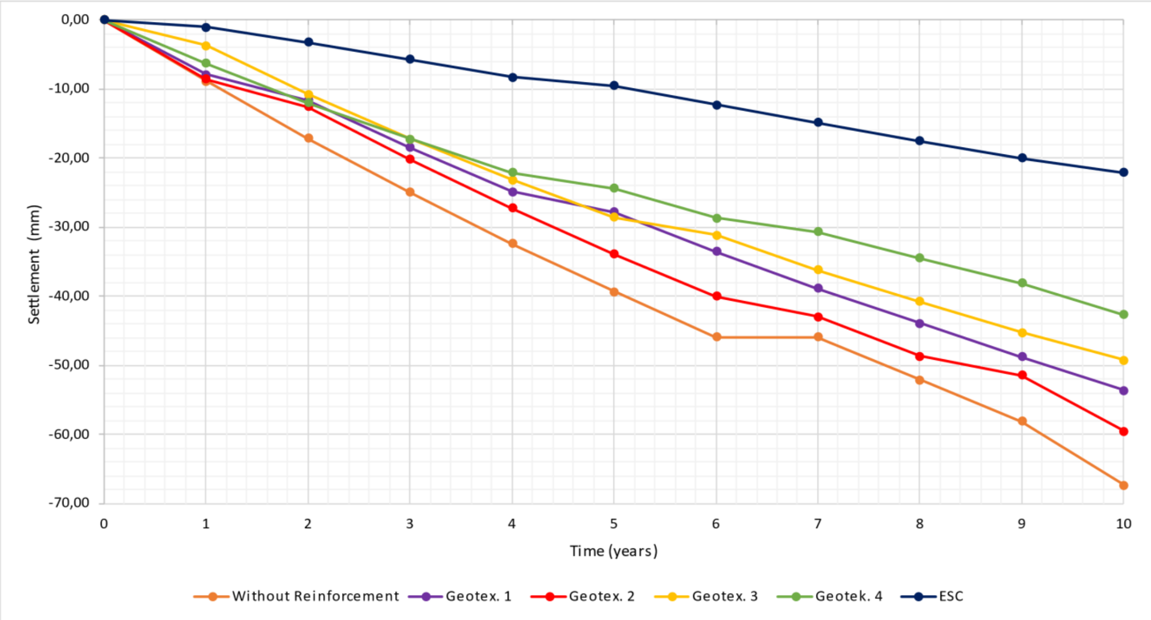

Figure 12. Secondary Settlement (10-year plan length)

All the proposed reinforcement alternatives experienced only slight non-uniform settlement. The highest non-uniform settlement occurred in geotextile 3 with a value of 0.09%, while the most minor non-uniform settlement occurred in the ESC alternative. The percentage of settlement that occurs in the proposed reinforcement alternatives compared to the unreinforced embankment is also much smaller; the geotextile 2 alternative can reduce the settlement by 11.48% during the construction lifetime plan. This result is in line with research from (Surachmat et al., 2019). The encapsulated stone column can reduce the settlement by 70.15% over the life of the construction plan **(Table 9)**.

Table 9. Percentage of Non-Uniform Settlement and Comparison with Unreinforced One

No.	Model	% non-uniform settlement	% Settlement against unreinforced embankment
1	Geotextille with existing slope (n=5)	0,07%	20,25%
2	Geotextille with existing slope (n=7)	0,06%	11,48%
3	Geotextille with 450 slope (n=6)	0,04%	26,88%
4	Geotextille with 600 slope (n=6)	0,09%	36,54%
5	Encapsulated stone column (n=8)	0,00%	70,15%

Bearing Capacity Analysis of Encapsulated Stone Columns

The calculation of the bearing capacity of the ESC is done manually. The calculation stages are as follows:

Vertical overburden stress ($\Delta\sigma_z$) $= (3 \times 18) + 15$ …(2)

$= 69{,}00$ kPa

Stress concentration ratio (n) = 5

diameter stone unit cell (D_e) $= 1{,}13 \times 1{,}75$

	= 1,98 meters
Influence area (A_e)	$= \frac{1}{4}\ x\ \pi\ x\ 1{,}7^2$
	= 3,07 m^2
Cross-sectional area of EC (A_c)	$= \frac{1}{4}\ x\ \pi\ x\ 0{,}7^2$
	= 0,38 m^2
area replacement ratio (a_s)	$= \frac{0{,}38}{2{,}26}$
	= 0,13
Stress reduction factor (μ_c)	$= \frac{1}{(1 + (5-1)\ x\ 0{,}17)}$
	= 3,21
Stress at EC (σ_c)	= 69 x 3,21
	= 221,57 kPa
Lateral earth pressure (k_{ac})	$= tan^2(45^0\ -\ \frac{45}{2}\ )$
	= 0,17
Total lateral stress (σ_3)	= 221,57 x 0,17
	= 38,02 kPa
Tensile strength allowable (T_{allow})	$= \frac{100}{3}$
	= 33,33 kN/m
Load ESC (T)	$= \frac{38{,}02\ \ x\ 0{,}7\ x\ 1}{2}$
	= 13,31 kN/m
Safety Factor (SF)	$= \frac{33{,}33}{13{,}31}$
	= 2,51 Meets a requirement **(Table 4)**

Ease of Execution Analysis

The analysis found that geotextile alternative 2 with the existing slope (n = 7) could complete the work the fastest, with an execution time of 151 days. This is because, in alternative 2, there is no need to excavate the embankment layer until it reaches the bottom of the original ground surface elevation. Geotextile alternative 1 has a longer construction time compared to the other options. This is because, in addition to excavating the existing embankment to its original depth, this option also requires backfilling to the same width as the existing embankment. The execution time of encapsulated stone column works is at least 569 days or 19 months, with a total of two drilling tools **(Figure 13)**.

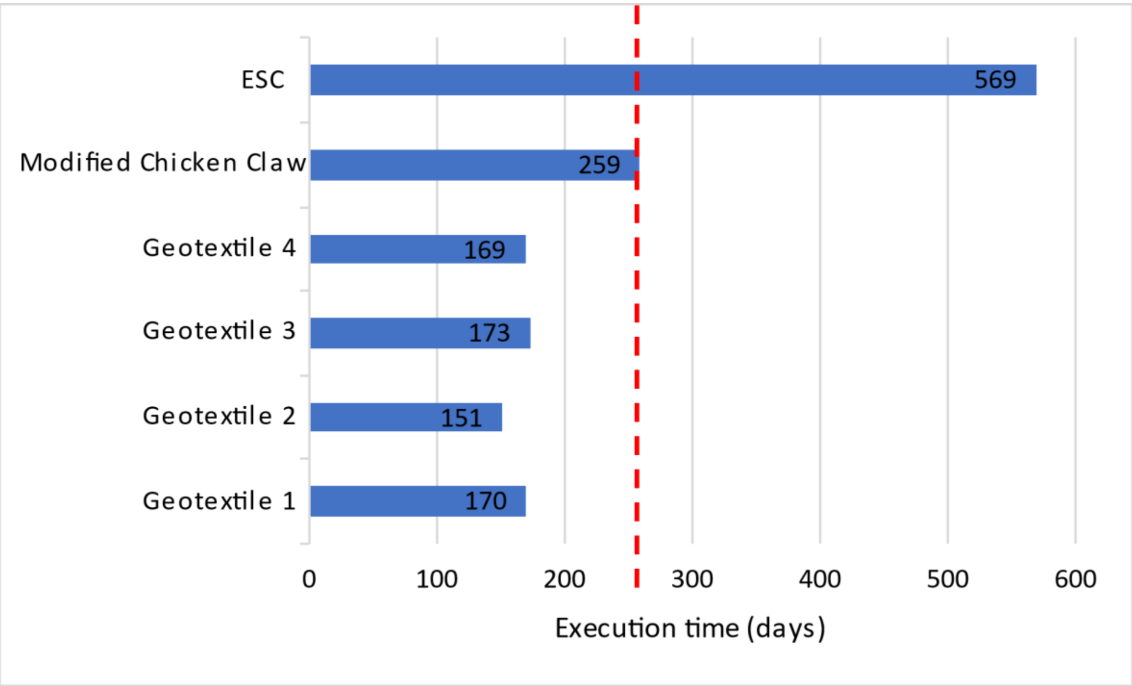

Figure 13. Execution time of Alternative and Initial Design

Cost Analysis

The geotextile alternative that has the lowest cost is geotextile alternative 2; this is because the construction does not require the excavation of the existing embankment as a whole, thus reducing the cost of excavation and embankment. Meanwhile, the alternative with geotextile 3 is the most expensive. This is due to the substantial number of geotextiles installed (n = 6) compared to alternative 1 (n = 5) and the need to excavate the existing embankment as a whole. Meanwhile, the cost of the ESC reinforcement alternative amounted to 28.25 billion **(Figure 14)**.

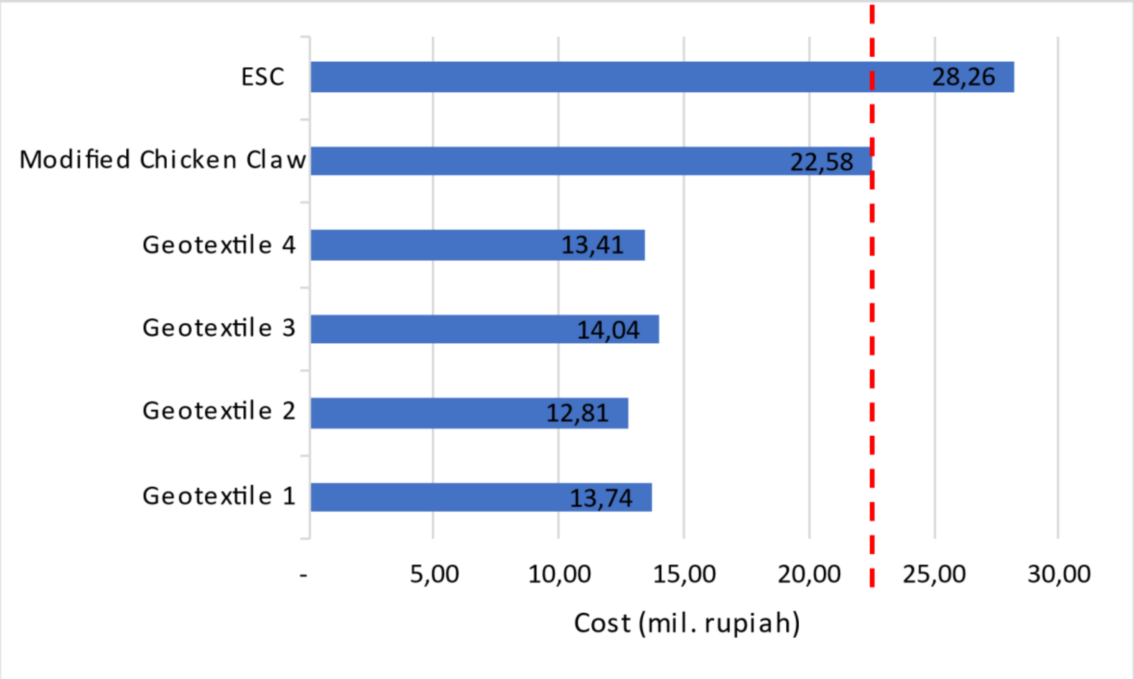

Figure 14. Cost of Alternative and Initial Design

Determining the Most Effective and Efficient Design Alternatives

Four criteria for the effectiveness and efficiency of reinforcement alternatives have been evaluated in the previous subchapters. Two in terms of effectiveness include the safety factor and the settlement. The following two criteria in terms of efficiency include execution time and cost. In determining the best alternative, an assessment is done with each weight. Reinforcement alternatives are ranked first. The highest rank gets the highest points. In this case, the safety factor with the highest value has the highest points. As for settlement, execution time, and cost, the highest points are obtained for the alternative that has the smallest value, then ranked based on four criteria. In this case, the rank point for the safety factor is 0.3, The rank point for compression is 0.2, The rank point for ease of execution is 0.4, and The rank point for cost is 0.6, so the total sum of all ranks is two and the maximum score that can be obtained is 10. A high rank indicates that the criterion is considered the most important.

The analysis showed that the best score was 8.3 and the worst score was 0. The geotextile alternative with existing slope or geotextile 2 scored the highest, while the geosynthetic-reinforced embankments with PVD alternative scored the lowest. Thus, geotextile 2 is the most recommended reinforcement alternative for repairing road embankment failures at Calang – Sp. Peut road section. **(Table 10)**.

Table 10. Score of Alternative Design

No.	Reinforcement Alternatives	Safety Factor			Settlement			Execution time			Cost			Total Score
		LE Method	Point	Point x 0,3	10 year lifetime design (mm)	Point	Point x 0,2	Days	Point	Point x 0,4	Mil. Rupiah	Point	Point x 0,6	
1	Geotextille with existing slope (n=5)	1,42	4	1,2	43	4	0,8	169	4	2,8	13,41	4	3,2	8,00
2	Geotextille with existing slope (n=7)	1,37	2	0,6	59	1	0,2	151	5	3,5	12,81	5	4	8,30
3	Geotextille with 45^0 slope (n=6)	1,41	3	0,9	49	3	0,6	173	2	1,4	14,04	2	1,6	4,50
4	Geotextille with 60^0 slope (n=6)	1,36	1	0,3	54	2	0,4	170	3	2,1	13,74	3	2,4	5,20
5	Encapsulated stone column (n=8)	1,45	5	1,5	2	5	1	569	1	0,7	28,26	1	0,8	4,00
6	Geosynthetic-reinforced embankments with PVD	0	0	0	0	0	0	0	0	0	0	0	0	0,00

CONCLUSION

From the analysis that has been done, there are seven points that can be concluded as follows:

1. There are 4 alternative options for reinforcing embankments using geotextiles and one alternative option for improving subgrade using encapsulated stone columns that can be implemented in the field, including:
   a. Geotextile with existing slope (n=5)
   b. Geotextile with existing slope (n=7)
   c. Geotextile with 45^0 slope (n=6)
   d. Geotextile with 60^0 slope (n=6)
   e. Encapsulated stone column (n=8)

2.

2. The results of the settlement analysis during the lifetime design on the alternative reinforcement show that the settlement occurs uniformly, and the value of settlement is smaller than the value of compression on the embankment without reinforcement. The percentage of difference in compression on the reinforced alternative and unreinforced embankment is 20.25%, 11.48%, 26.88%, 36.54%, and 70.15%, respectively.
3. The alternative design using prefabricated vertical drains is ineffective because the subgrade soil is peat, and the primary consolidation was completed on the 38th day after embankment construction.
4. All alternative reinforcement options with geotextiles have lower construction costs compared to the Modified Chicken Claw system, while the alternative design of soil improvement with ESC is more expensive. The percentage costs of the alternative reinforcement options compared to the CAM system are 61%, 57%, 62%, 59%, and 125%, respectively.
5. The alternative of reinforcement with Existing Slope Geotextile (n=7) is the most effective and efficient alternative, with 39% lower cost and 42% faster execution time than CAM

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