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

Existing Design Analysis of Slope Reinforcement on Clayey Soil and Its modified Alternatives (Case Study : Awunio – Lapuko National Road, Southeast Sulawesi)

Zahrial Firman R[1,a], Mohamad Khoiri[2,b] & Freddy Siagian[3,c]

[1]*Master Degree Student, Civil Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia*

[2]*Departement of Civil Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia.*

[3]*The National Road Construction Agency (BPJN) for Southeast Sulawesi, Directorate General of Highways, Ministry of Public Work and Housing (PUPR), Kendari, Indonesia*

Correspondent : [a]fisipits@gmail.com, [b]mkhoiri@ce.its.ac.id & [c]fsiagian70@gmail.com

ABSTRACT

The slopes of the Awunio - Lapuko national road section are prone to landslides, which pose a threat to the road asset management. Hard soil layer with an NSPT value >60 is found at a depth of 4 metres. The slope has been reinforced with cantilever walls (CW) and caisson as well as retaining walls and bored pile. In this research, the problem that needs to be studied is the stability of the existing slope with and without reinforcement using the cracked soils approach to obtain the factor of safety (FS) for critical conditions with the Limit Equilibrium Method (LEM). The CW is calculated for overturning stability, shear stability, foundation bearing capacity and overall stability. In addition, bored pile should also be evaluated when considered as a lateral pile based on NAVFAC, bearing capacity within the group, max & min stress and deflection capacity. The result of LEM program analysis shows the slope failure mechanism due to the existence of slip plane between weak soil layer and strong soil layer. Furthermore, the stability of existing reinforcement such as CW only or CW combined with caisson is insufficient. While the stability of reinforcement CW combined with bored pile or alternative modification such as subdrain combined with geotextile meets the requirements.

Keywords : road asset management, slope stability, cracked soils, bored pile, subdrain - Geotextile

INTRODUCTION

Road infrastructure is a key factor in economic and community movement because most transportation in Southeast Sulawesi Province relies on land transportation. good road conditions will facilitate population mobility in carrying out their daily economic and social activities (Effendi et al., 2022). When road infrastructure is disrupted, such as by landslides, the incident has an impact on economic and community activities. Therefore, road infrastructure is an asset that needs to be managed to keep it functioning properly. Public Works Infrastructure is capital for the good life of a region and more of the country. (Soemitro & Suprayitno, 2020), Moreover, the main objective of the Infrastructure & Facility Asset Management (IFAM) is to ensure that the infrastructure and facility can sustainably well function,economically, efficiently, effectively, while still following the green principle (Soemitro & Suprayitno, 2020).

The Awunio-Lapuko National Road, a section of the Trans Sulawesi Road that supports economic and community activities in Southeast Sulawesi Province, was reported to be subject to frequent landslides **(Figure 1)**. Some of the landslides have even eroded half of the roadbed, posing a risk to road users **(Figure 2)**. As an asset management Stakeholder, the Southeast Sulawesi National Road Implementation Bureau (BPJN Sultra) carried out reinforcement works on a section of the embankment with a 5 m high cantilever wall (CW) combined with 4 m deep caisson foundation in 2022 as shown in **Figure 3**. The projects are located at Sta. 7+940 - Sta. 8+040 and are included in the scope of the Road Preservation Contract. In addition, next to CW combined with 4 m deep caisson foundation, a 3m high CW and an 8 m deep bored pile foundation is constructed in 2023.

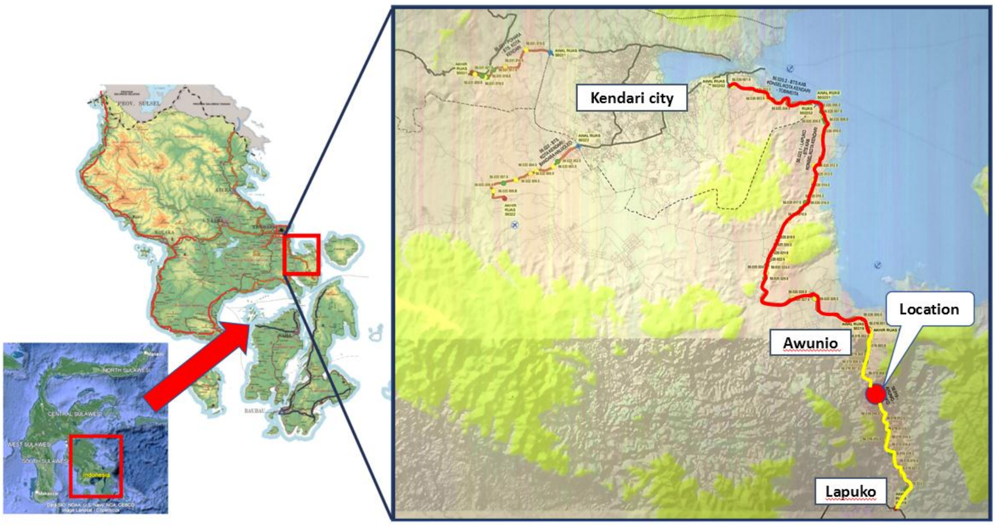


Figure 1**.** Awunio – Lapuko National Road
(Satker P2JN Provinsi Sulawesi Tenggara, 2022)

There were problems on the slope that led to the reinforcement work. First, the test results showed that the depth of hard soil was 4 metres below the surface. In theory, the slope is safe, in the other hand, the slope experienced a landslide to the roadbed. Second, based on Statistic Center Agency (BPS) of Southeast Sulawesi Province's data, the monthly rainfall is high, reaching 1,111.9/mm in 2017. It can be said that the slope location often experiences heavy rains. The condition of slopes that experience collapse can be analyzed for stability first so that soil improvement is appropriate (Wardani et al., 2019). To answer this phenomenon, the slope stability analysis will be carried out with the *cracked soils* approach. Mochtar (2014) came up with the theory of *cracked soil approach* by assuming that cracks already exist in the soil and slopes, and these cracks are the main factor that causes very heavy rains to be able to loosen the slopes. Furthermore, by using the cracked soil approach to obtain the most effective slope reinforcement alternative. it is expected that landslides in the future rainy season can be minimized (Tarigan & Mochtar, 2021).

Figure 2. Slope before reinforcement
(Satker PJN Wil. II Provinsi Sulawesi Tenggara, 2020)

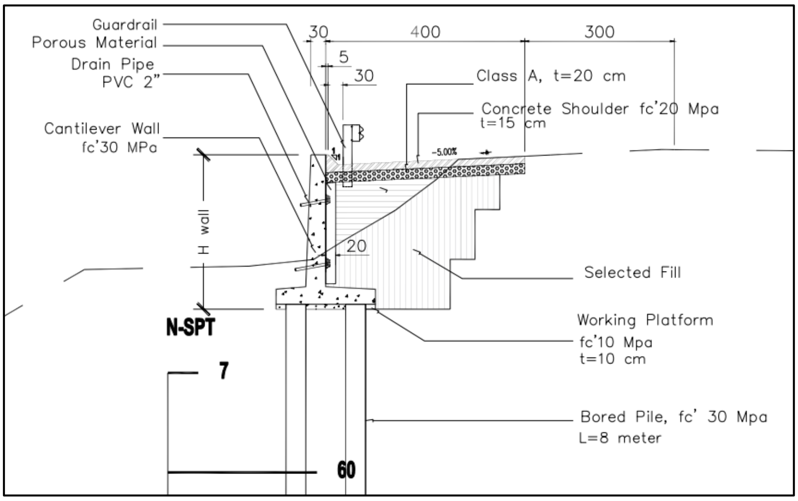


Figure 3. Cross Section of CW + Bored pile on Awunio – Lapuko Road
(Satker P2JN Provinsi Sulawesi Tenggara, 2022)

In this study, if the results of slope modeling and existing reinforcement show that the safety number does not meet the requirements, then the slope reinforcement will be designed with alternative modifications so that later sufficient reinforcement is obtained.

LITERATURE REVIEW

Cracked Soils Theory

The concept of cracked soil was developed and applied to overcome the phenomenon of discrepancy between the results of slope stability analysis and the conditions in the field (Amalia, 2018). Cracked Soils Theory assumes that cracks are already exist in the soil. Cracks are the main factor that causes slope failure when very heavy rainfall occurs. Cracked Soil Theory accommodates the presence of cracks on the slope and the influence of rain intensity where cracks infiltrated by rainwater during very heavy rainfall will determine the stability of the slope.

To accommodate the property of cracks that can drain water easily, the soil strength along the cracks should be assumed to be equal to the soil shear strength under flowing conditions, where the cohesion value (c) = 0 and the angle of internal friction (ϕ) $\neq$ 0; regardless of the original soil conditions. The soil shear strength condition should be assumed to always be under flowing conditions, similar to the shear characteristics of sand, so that the soil is considered behaving like sand.

Bored pile Reinforcement

Bored piles are installed into the ground by drilling the soil first, then filled with reinforcement and casted in concrete. The piles serves as a wedge to resist sliding along a circular sliding plane (Manudianto et al., 2023). Moreover, the *bored pile* installed on the slope serves as a wedge, where the length of the *bored pile* must intersect the landslide plane (Brena et al 2020).

Cantilever Wall Reinforcement

Measure of infrastructure stability is determined by safety factor which compares resistance and load (Satrya et al., 2019). Therefore, CW must be designed to remain safe against overturning stability, slip stability and soil bearing capacity. In addition, it is necessary to consider the soil conditions at the retaining wall location whether there is a potential for the retaining wall as a whole to experience rotational/translational sliding (global stability). The required safety factor for cantilever walls (SNI 8460:2017) are shown in **Table 1.**

Table 1. Required SF for Cantilever Wall

No	Safety Factor	Required Value
1	Overturning	≥ 2
2	Slip	≥ 1,5
3	Bearing Capacity	≥ 3
4	Overall Stability	≥ 1,5

Subdrain – Geotextile Reinforcement

Subdrain design is used to drain groundwater on slopes. Previous studies have shown that ground water level on very high slopes will result in a very large reduction in SF. Therefore, a subdrain system is needed to drain the groundwater and dispose it to the drainage on the left side of the slope. In this study, subdrain with a layer thickness of 20 cm is used with gravel material and *non-woven geotextile* as a coating to prevent soil grains from clogging the subdrain layer.

Geotextile reinforcement is combined if the subdrain is unable to achieve the required SF. When designing the geotextile, it is necessary to take into account the tensile strength of the material in absorbing or resisting the shear force when the landslide occurs (T allow). The number of geotextile layers depends on the difference in the value of the moment of resistance in the embankment soil, so that a sufficient SF is achieved. Calculation of the number of geotextile requirements is carried out in stages until the total moment of the geotextile (Δ Mgeotextile) is equal to or greater than ΔMR (Shoffiana et al., 2022).

DATA COLLECTION

Soil Investigation

Based on the bore log data shown in **Figure 4**, it was found that there are 4 types of soil layers under the road body. The first soil layer is an old backfill with a yellowish colour type that is slightly sandy and gravelly with a soft - medium consistency starting from a depth of 0 meters to 2 meters. The second soil layer is a gray clay type with a soft - medium consistency ranging from a depth of 0 meters to 2 meters. The third soil layer is a dark gray clay with a stiff consistency starting from a depth of 2 meters to 4 meters. The third layer at a depth of > 4 meters is dark gray clay with a hard consistency. Meanwhile, the groundwater table is found at a depth of 2.45 meters from the ground surface. Soil classification table can be seen in **Table 2**. Soil stratigraphy based on secondary data obtained can be seen in **Figure 5.**

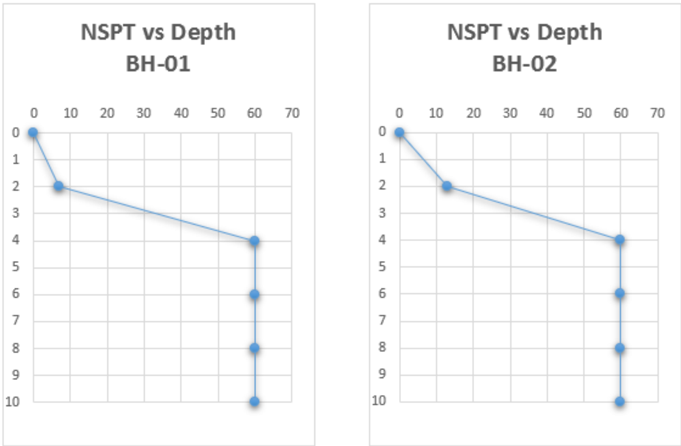


Figure 4. Bor Log Test Graph

Table 2. Soil Layer Classification at Sta. 7+940 - Sta. 8+040

Layer	Thickness	Soil Class. (USCS)	Consistency	γ_{sat}	C	ϕ	μ	E
	(m)			(kN/m^3)	(kPa)	(^{o})		(kN/m$^{2)}$
Fill Material	2		Medium	20,00	5,00	30,00	0,35	27500
Clay 1	2	CL	Medium	19,80	0,00	27,33	0,30	15000
Clay 2	2	CL	Hard	19,80	0,00	68,82	0,25	30000
Clay stone	-	CL	Hard	17,90	23,10	23,02	0,25	50000

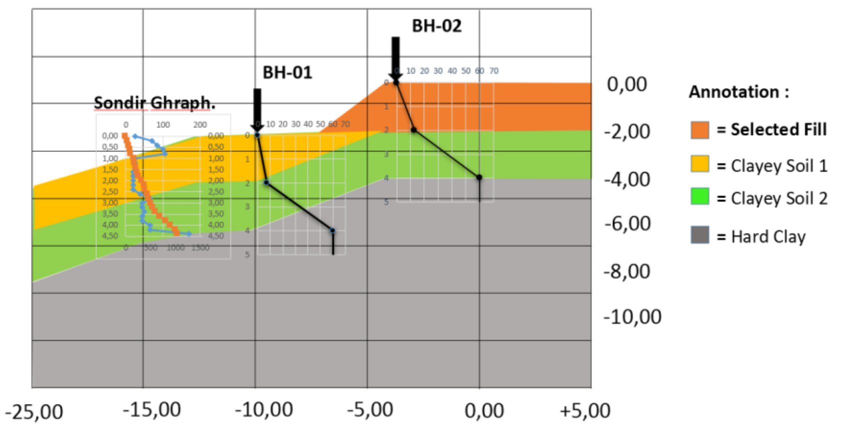


Figure 5. Stratigraphy soil at at Sta. 7+940 - Sta. 8+040

RESEARCH ANALYSIS

Evaluation of bored pile calculation as lateral force retaining pile

Bored piles reinforcement should be evaluated for bearing capacity within the group, capacity to withstand maximum stress & minimum stress, capacity of bored pile as lateral retaining pile based on NAVFAC & lateral capacity (Zf) and deflection capacity due to working load. The results of the calculation resume are shown in **Table 3 & Table 4**.

Table 3. Resume of bored pile bearing capacity calculation

No.	Description				Requirements	Info.
1	Q Allow	=	195,95	tons		
2	Q Allow in the group	=	117,37	tons	Working normal force ≤ bearing capacity of bored pile	
					3,555 tons ≤ 117,374 tons	(Ok)
3	Pmax	=	7,744	tons	Check Pmax ≤ n. QAllow	
					7,744 tons ≤ 117,440 tons	(Ok)
4	Pmin	=	0,634	tons	Check |Pmin | ≤ |Qsafe revoke |	
					0,634 tons ≤ 117,440 tons	(Ok)

Table 4. Resume of bored pile calculation in resisting lateral force

No.	Description				Requirements	Info.
1	Number of bored piles required as lateral resisting piles	=	1,876	unit	Number of reinforcements installed = 2 unit	(Ok)
2	Pole max lateral (Zf) 1 pole	=	9,08	tons	Working lateral force ≤ lateral capacity of bored pile /m	
					3,23 tons ≤ 18,16 tons	(Ok)
3	Lateral max. NAVAC 1 pole	=	17,136	tons	Working lateral force ≤ lateral capacity of bored pile /m	
					3,23 tons ≤ 34,272 tons	(Ok)
4	Deflection due to load	=	0,287	cm	Working deflection ≤ maximum deflection requirement of pile =1.2 cm	
					0,287 cm ≤ 1,2 cm	(Ok)

From the data above, it can be conveyed that bored pile reinforcement has met the requirements in resisting axial forces, maximum & minimum stresses that occur, lateral forces, and deflections. The capacity of bored pile is very safe in resisting axial force, maximum & minimum stress, lateral force and deflection. The number of bored pile reinforcement installed, which is 2 unit/m, is considered sufficient to resist horizontal loads with a calculated result of 1,876 unit.

Slope Model

In order to accommodate the cracked soils theory, slope modeling was conducted with 2 (two) variations of the groundwater table (GWT) and assumed clay layer 1 and clay layer 2 *behaving like sands*. GWT at -2.45 m deep from the road surface elevation was considered to model the non-rainy condition. GWT at -0.00 m deep from the road surface elevation is considered to model heavy rain conditions where the water table rises to the surface as shown in **Figure 6**. Furthermore, the Cohesion value in clay layer 1 and clay layer 2 is equal to zero (0).

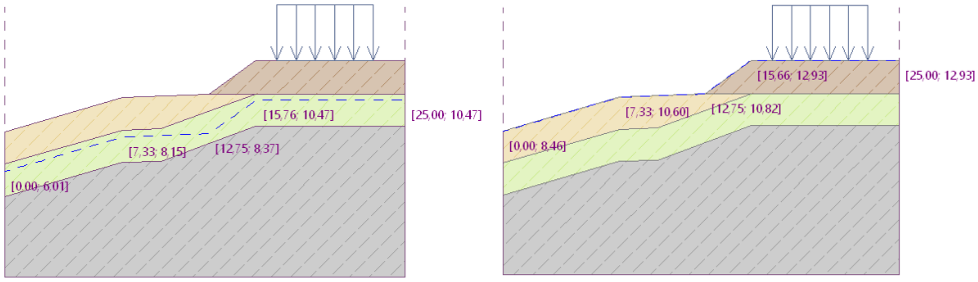
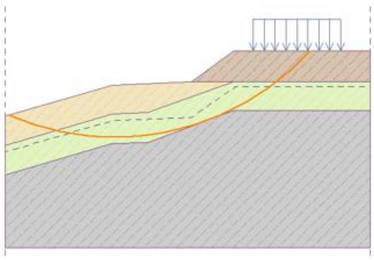


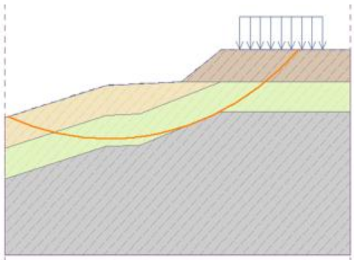
Figure 5. Slope model with GWT elevation -2.45 m (left) and GWT elevation 0.00 m (right)

Slope Stability Analysis Without Reinforcement using LEM Program

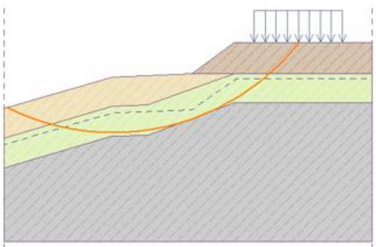
The model is loaded according to the size and class of the road. The Awunio - Lapuko road section is a class I national road with a pavement width of 6 meters. The existing loading is traffic load and pavement load which is 18.3 kPa or 1.83 tons/m^2 according to the Design Requirements SNI 8460-2017. The load in the reinforced condition is the traffic load and the pavement load plus 4 metres of concrete shoulder which is 4.8 kPa or 0.48 tons/m^2.



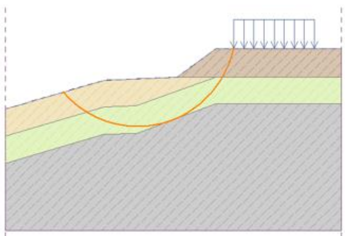
GWT. -2,45 m (FK = 1,67)



GWT.. -0,00 m (FK = 1,48)



GWT. -2,45 m; *Cracked soils Approach*
(FK = 0,43)



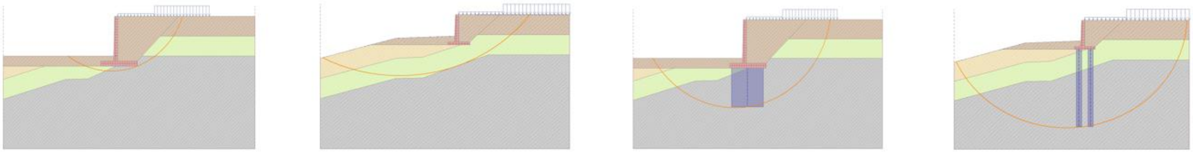
GWT. -0,00 m; *Cracked soils Approach*
(FK = 0,10)

Figure 7. Safety Factor of Slope Model Without Reinforcement

From **Figure 7** we can see that the slope is in good condition if we use the original soil parameters. But, It does not match the condition in the field, where the slope has experienced landslides. Therefore, in order to get the most critical condition, the cracked soil approach is used in the modelling. The SF value obtained by using cracked soils is 0,10. Furthermore, the results of the analysis of the LEM program show that the slope failure mechanism on the Awunio - Lapuko road section is due to the existence of a sliding plane between the weak soil layer and the strong soil layer.

Slope Stability Analysis With Reinforcement using LEM Program

The authors have analysed the overall stability of the slope with existing reinforcement and using the cracked soils approach. The existing reinforcement analysed is CW combined with caisson foundation and CW combined with bored pile foundation. In addition, the author also analysed the overall stability of the slope with CW only to obtain the appropriate reinforcement. The results of the stability analysis of each reinforcement are shown in **Figure 8**.



SF = 1,05 **SF = 0,07** **SF = 1,93** **SF = 2,67**

Figure 6. SF of Slope Model With Reinforcement

From the picture above, we can see that the slope is in good condition if we use CW reinforcement combined with caisson and CW combined with bored pile in terms of overall stability. Based on SNI 8460:2017, Cantilever wall reinforcement needs to be analysed for overturning stability, lateral shear stability and soil bearing capacity. The results of the analysis that has been carried out by the author are shown in **Table 4**.

Table 4. SF value of Reinforcement

Reinforcement	**Safety Factor (SF)**			
	Overturning	**Slip**	**Bearing Cap.**	**Overall stability**
Cantilever Wall 3 meter	1,24	0,07	0,21	0,07
Cantilever Wall 5 meter	1,70	0,80	0,57	1,05
Cantilever Wall 5 meter + Caisson 4 meters	1,15	1,10	1,87	1,93
Cantilever Wall 3 meter + Bored Pile 8 meters	2,44	1,57	10,08	2,67

From the table above we can see that only the CW combined with bored pile reinforcement meet the safety requirements of overturning, slip, bearing capacity and overall stability.

Slope Stability Analysis with Subdrain - Geotextile Reinforcement using LEM Program

The subdrain was placed 4.00 meters below the road elevation throughout the design area. The subdrain is located up to 4.50 meters from the toe of the slope to secure areas of potential slope failure as shown in **Figure 9**. The FS obtained is 0.33 which is less than the requirement. Therefore, it is necessary to add reinforcement such as geotextile. Global stability calculations were carried out using LEM program to obtain the required SF.

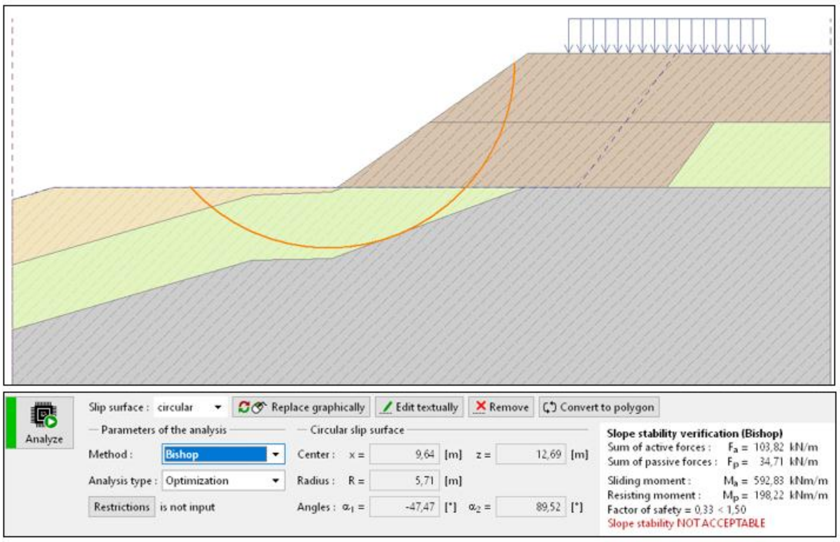


Figure 9. Safety Factor of Slope Model With Reinforcement

Subdrains combined with geotextiles are shown in **Figure 10,** conducted to improve SF. The application of geotextile influences the condition of the subgrade (Septiandri et al., 2021). The author uses geotextiles that have ultimate tensile strength of 100 kN/m and the distance between layers (Lift) at 0.3 m. Geotextile is placed at the base of the embankment to separate the embankment and the soil layer below. Based on the author's calculations, geotextile was installed in 5 layers. The calculation of global stability is evaluated using the LEM program. This evaluation is carried out to prove that the slope with the reinforcement does not experience landslides. If landslides still occur, the reinforcement must be redesigned. The output result of the LEM program is SF = 1.61 (meets SNI requirements).

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

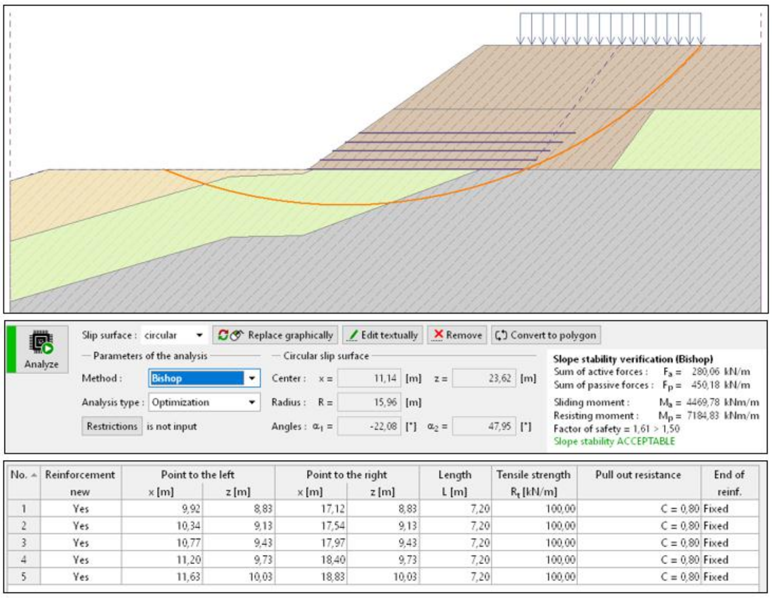


Figure 10. SF value of Subdrain - Geotextile Reinforcement Model

CONCLUSION

Based on the result of modeling analysis, it can be concluded that:

1. The results of the analysis of the LEM and FEM auxiliary programs show the mechanism of slope collapse on the Awunio - Lapuko road section due to the existence of a slip field between the weak soil layer and the strong soil layer. Slope models without reinforcement are at unstable condition based on safety factor of slope stability generated by LEM, which only reaches 0.10 below the requirements (SF>1.5).
2. Only slope models with Cantilever Wall combined with bored pile foundation reinforcement, as existing reinforcement, meet the requirements (SF=2.69>1.5).
3. Reinforcement alternative such as subdrain combined with geotextile reinforcement could increase the stability of the slope model with SF are 1.71.

REFERENCE

[1] Das, B. M. (1995). *Mekanika Tanah (Prinsip-prinsip Rekayasa Geoteknis).* Jilid 2. Erlangga. Jakarta.

[2] DPU (1987). *Petunjuk Perencanaan Penanggulangan Longsoran, SKBI – 2.3.06*. Yayasan
Badan Penerbit PU. Departemen Pekerjaan Umum. Jakarta.

[3] Effendi, F., Mochtar, I. B., Soendiarto, S., & Zulkarnain, Z. (2022). Evaluasi Alternatif Cross Drain di Ruas Jalan Nasional Selat Lampa–Teluk Depih–Simpang Sekunyam, Kepulauan Natuna. *Jurnal Manajemen Aset Infrastruktur & Fasilitas*, *6*.

[4] Manudianto, D., Endah, N., & Siahaan, H. P. (2023). Alternative of Soil Improvement Methods on Organic Soil Using Preloading and Vertical Piles for Embankment with Varied Heights. Case Study: Construction of Batanjung Port Access Road in Pulang Pisau Regency, Central Kalimantan. *Journal of Infrastructure & Facility Asset Management*, *5*.

[5] Satker PJN Wil. I Provinsi Jawa Tengah. (2020). *Perencanaan Teknik Jalan dan Jembatan Pejagan-Prupuk-Tegal-Ajibarang-Wangon Tahap I dan Tahap II.*

[6] Satrya, T. R., Soemitro, R. A. A., Maulana, M. A., Warnana, D. D., & Soetanto, R. (2019). Assessment of Infrastructures Assets Induced by Water Level Fluctuation along the Bengawan Solo River. *Journal of Infrastructure & Facility Asset Management*, *1*(2).

[7] Septiandri, R. A., Mochtar, I. B., & Lastiasih, Y. (2021). Analisis Kebutuhan Perkuatan Geotextile untuk Tinggi Timbunan Badan Jalan yang Bervariasi di atas Tanah Lunak Pada Kondisi dengan dan tanpa Pemasangan PVD (Prefabricated Vertical Drain). *Jurnal Aplikasi Teknik Sipil*, *19*(3), 283–294.

[8] Shoffiana, N., Lastiasih, Y., & Satrya, T. R. (2022). Comparison of Embankment Reinforcement Requirements with Geotextile on Soft Soil with 2D and 3D Slope Stability Analysis Methods. *Journal of Infrastructure & Facility Asset Management*, *4*(2).

[9] SNI 8460:2017 Persyaratan Perancangan Geoteknik, Pub. L. No. 8460:2017 (2017). www.bsn.go.id

[10] Soemitro, R. A., & Suprayitno, H. (2020). Preliminary Reflection on Basic Principle of Operation Management for Public Work Infrastructure Asset Management. *Journal of Infrastructure & Facility Asset Management*, *2*.

[11] Tarigan, B. A. C., & Mochtar, I. B. (2021). Rekomendasi Solusi untuk Mengatasi Kelongsoran pada Lereng Jalan Akses PLTA Musi (KM 5 dan KM 8) dengan Pendekatan Cracked Soil. *Jurnal Teknik ITS*, *9*(2), C265–C271.

[12] Terzaghi, K. (1925). “Principles of Soil Mechanics”. *Engr. News Record, Vol. 95, pp. 832-836.*

[13] Wardani, M. K., Nuciterani, F. T., & Aulady, M. F. N. (2019). Evaluasi Potensi Kelongsoran Pada Lereng Alam Akibat Perubahan Sudut Kemiringan Menggunakan Metode Fellenius. *Jurnal Manajemen Aset Infrastruktur & Fasilitas*, *3*.