# PRACTICAL EARTH ANCHORING TECHNOLOGY FOR STRENGTHENING SLOPE WALL PROTECTION (CASE STUDY: DG. SIRUA ROAD POST CONSTRUCTION FAILURE WITH SKYHOOK – GRID BEAM TECHNOLOGY IN MAKASSAR CITY – INDONESIA)

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**Abstract:** The application of soil anchoring system and grid beam method of strengthening protection wall post construction failure was observed in this research. The construction of the slope wall protection is situated to suit the existence of barrier made for aqueduct. Based on the numerical simulation on scenario of potential causes of slope failure, it indicates several phenomena such as the stability of barrier foundation experiences drastic drop. Scrutinizing the result of investigation and ideal design criterion for structural element of barriers, the condition function of existing protection wall has the factor of slope stability SF=1.01~1.09, which is categorized as not safe and condition barrier failure. The strengthening method of soil anchoring (Skyhook Earth Anchor, with the capacity of 4 tons) which is combined with grid beam manages to improve the barrier's stability to SF=1.24~1.46 post construction and reduce horizontal displacement of barrier.

*Keywords*: Slide, safety factor, soil anchor, grid beam, protection wall, barrier, SkyHook earth anchor

## 1. INTRODUCTION

The problem of land slide, specifically at slopes area, is one of natural disasters which is commonly occuring in Indonesia, the critical condition usually appears in rainy season. Even though rain is not the only factor of land slide to occur, the infiltration of rain water down to soil is conceded to have the most crucial factor on the reduction of soil's bearing capacity upon slope's strength/deposition. The occurence of slide during the intensive rainy season has been reported by several researchers; Brand (1982), Karhn, et. Al. (1989), Kuwano & Cheng (1990), Widger & Frendlund (1979), dan Wong & Ho (1997). Indarto, e. al. (2000 dan 2001). They cited that there has been dramatic reduction of shear strength when the soil in the phase of pseudo saturated. Thus, the slide occuring in rainy season is one of logical consequences from effective stress of soil deposition.

Deposition/slopes with clayey soil when it is drenched by rain water penetration causes the decrease of soil's bearing capacity parameter such as cohesion and shear strength. This phenomenon surely give an implication to the degradation of the value of slope stability which will potentially induce collapse at the deposition's slope. The effort to anticipate the danger of failure which is commonly executed is the strengthening of barrier's or slope's body. Employing soil achor has attracted attention of the majority of geotechnical engineering practician, empirical approach of soil anchor has been developed by (Neubecker, et. al., 1996; O'Neill. Et.al., 1990; Throne, 1998). The research on the constitutional model has managed to rise an interest from professionals such as Martin, 1994 dan Bransby, et. al., 1998.

The construction failure of protectiocal wall at Jln. Dg. Sirua in rainy season (Zubair, A. et. al., 2011) has become a mass media accomodation in City of Makassar. The road expansion in it became strategic issue to anticipate the problem of traffic jam which has been extremely chronic. It encouraged Makassar Municipality to build alternative roads in order to minimalize the traffic jam from center to eastern part of the city. Because it is hard to obtain available space from the asset of municipality, such alternative roads were constructed along the barrier of PDAM's aqueduct of Makassar Municipality. The pavement is constructed with the barrier of 3-4 meters heights. Physical condition of the road construction, so far, has been completed for 85%, nevertheless some of joints in protection wall experienced slide. Related to such geotechnical structural failure, the series of surveys-investigations and analysis has been conducted to identify the causes of slide. The result of technical examination demonstrated that the slide was occured because the design criteria of structural element of barrier construction was adequate.

This study breakdown the technical analysis on the phenomenon of slide at the protection wall throughout alternative road of Jln. Dg. Sirua, City of Makassar by the approach of nurmerial simulation based on the result of surveys-investigation in order to identify the level of stability and the potential of wall's deformation when the slide was occuring and post construction (with the existence of traffic load). Numerical simulation of achor design for strengthening by Skyhook technology was conducted to observe the performance of soil's anchor which was combined with grid beam and to review the design of barrier strengthening construction.

## 2. THE CONDITION OF SLIDE AND GEOTECHNICAL SURVEY

The failure on the construction of protection wall Jln. Dg. Sirua as alternative route to deal with traffic jam in Makassar from the centre to eastern past of city has become the news headline in mass media. Analysing the condition in field and the technique to mitigate the potential of upcoming disasters along the street, the geotechnical survey of design parameters and analysis on barrier strengthening were conducted by following procedures:

### a. Location and Condition of Slide Spot

Location of slide spot at Jl. Dg. Sirua is situated on Figure 1. The construction of road is supported by protection wall with height of 3-4 meter and length of road ±1.35 km.

Based on the field observation and surveys of the causes of slide barrier (Zubair, A. et. al., 2011), the initial assumption of this slide is the failure of foundation of barrier which is not constructed above the relatively stable soil in the depth of 4.2-5 meter from the surface. Because of the stability of barrier which is disturbed heavily and the huge deformation, it has induced the crack in the river stone masonry barrier which is ductile and even failure on some spot. The barrier which hasn't experienced the slide but has shown the indication of failure can be seen in Figure 2.

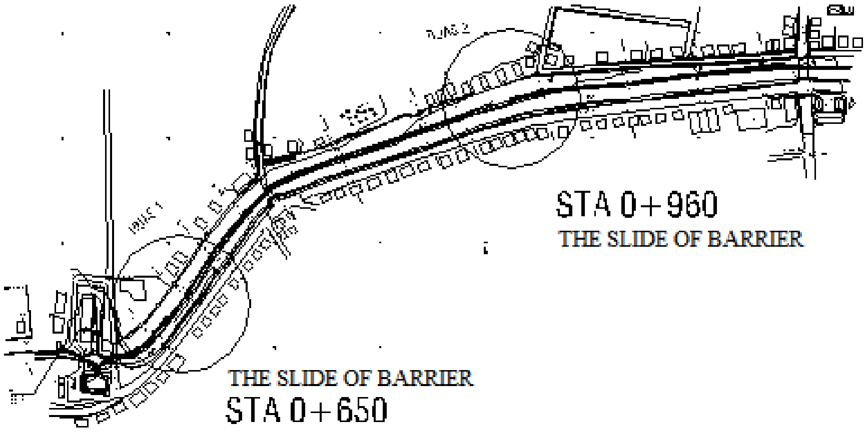


Figure 1. Location of slide potential spot at Jln. Inspeksi Saluran Air Baku PDAM Kota Makassar


Figure 2. The condition of barrier slide (Slide 1, Sta. 0+650) and (Slide 2, Sta. 0+950)

The other important aspects which need to be considered within the design of barrier strengthening are:

- The bad quality of material such as river stone and specie; river stone is easy to be dismember with its specie by hand, the brownish surface layer of stone patches on specie and the wall of barrier is partially minimum with specie.
- The function of pipe of barrier drainage throughout barrier is not adequate in terms of quantity and diameter.
- The red soil has the slope post the failure around 60°, this will decrease the amount of lateral load of active soil which works on barrier.
- The layer of stone lies on the shallow depth.
- The effective width of existing foundation base of 90 cm, as can be seen in Figure 3, is not adequate for the barrier with the height of 350 cm.

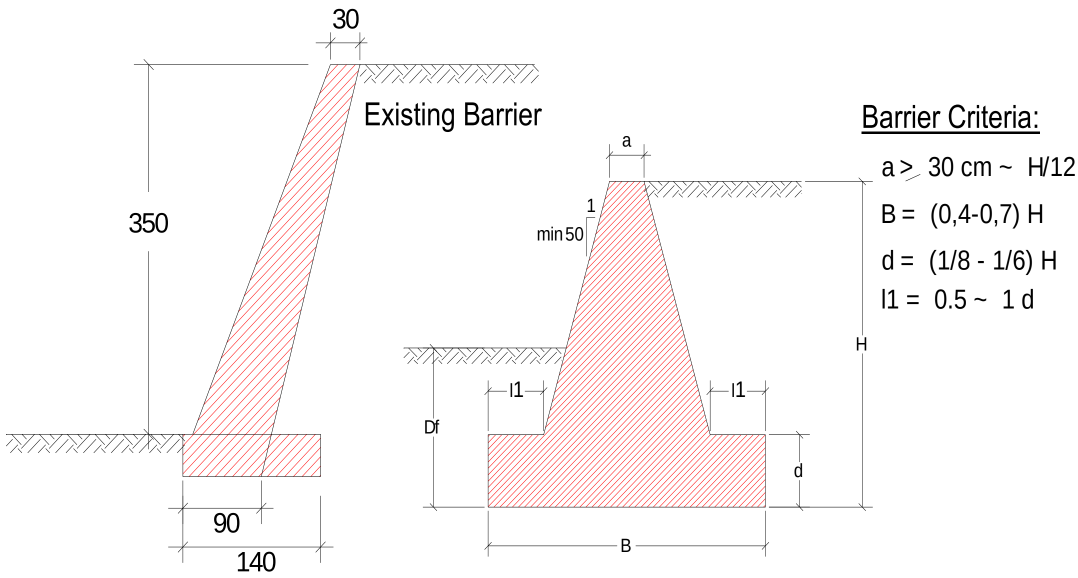


Figure 3. The condition of barrier (Existing Barrier Jln. Dg Sirua) and criteria for stable barrier

b. Visual Illustration of Slide Hue

The preliminary survey to obtain visual illustration of slide hue is conducted after slide was occuring. The initial indication on the causes of failure is the puddle on the pavement due to disfunction road drainage and the muddy content from the construction material. The preliminary visual suvery is described as following:

***The Slide Pattern of Protection Wall***

Based on the survey's documention, the pattern and the condition of slide can be visualized which is shown in Figure 4. The failure of soil protection wall on the pattern of slide on the base of foundation is followed by the crack on the wall of protection wall.


Figure 4. The pattern of failure for both slide spots, Jln. Inspeksi Saluran Air Baku PDAM Kota Makassar.

***The Drainage on the Surface of Slide Zone***

The drainage on the surface of slide which is visualized in Figure 5 is in very bad condition. The potential puddle saturates the layers of survace or high water infiltration table.

***Construction Material for Wall and Embankment***

The drainage on the surface of slide which is visualized in Figure 6 is in very bad condition. The potential puddle saturates the layers of survace or high water infiltration table.


Figure 5. The pattern of failure for both slide spots, Jln. Inspeksi Saluran Air Baku PDAM Kota Makassar.


Figure 6. The construction material for pavement and protection wall at both slide spots.

c. Geotechnical Parameter of Slide Spot

Scrutinizing the existing barrier’s condition which does not meet the stability criteria and the inidication of longitudinal cracks along the street, it can be technically justified that the function of barrier is not as protection wall. This finding is relevant with result of identification on the causes of slide (Zubair, A. et. al., 2011) who technically suggests the barrier reinforcement with soil anchor as an alternative mitigative measure to prevent potential slides along the street.

Table 1. The result of test of soil's index and mechanical properties for both slide spots.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bore Hole No. | | | - | BH-1, Lonsoran 1 | | BH-2, Longsoran 2 | |
| Sample No. | | | - | 1 | 2 | 1 | 2 |
| Sample Depth | | | m | 1.0-1.5 | | 1.0-1.5 | |
| Specific Gravity ($G_s$) | | | - | 2.712 | | 2.804 | |
| Natural States | (Soil Index) | Water Content (ω) | % | 37.87 | | 34.17 | |
| | | Wet Density ($\gamma_{wet}$) | t/m$^3$ | 1.787 | | 1.877 | |
| | | Dry Density (γdry) | t/m$^3$ | 1.296 | | 1.399 | |
| | | Void ratio (e) | - | 1.092 | | 0.939 | |
| | | Porosity (n) | - | 52.21 | | 48.42 | |
| | | Degree of Saturation (Sr) | % | 94.02 | | 98.72 | |
| Direct-Shear | Test | Cohesion (c) | kg/cm$^2$ | 0.099 | | 0.159 | |
| | | Internal Friction Angle (θ') | degree | 31$^o$02' | | 24$^o$08' | |

The geotechnical parameters which are required for strengthening analysis refer to the several geotechnical characteristics. Commonly identified that the material of slide embankment contains sandy clay with following descriptionl Specific Gravity $G_s$=2.712-2.804, water content ω=34.17-37.87%, wet unit weight $\gamma_b$=1.787-1.877 ton/m$^3$, dry unit weight $\gamma_d$=1.299-1.399 ton/m$^3$, cohesion c=0.099-01.59 kg/cm$^2$, shear strength θ=24$^o$08"-31$^o$02". The design parameter is recapped in the Table 1. The level of soil layer as foundation of road embankment is identifed to refer on the geotechnical profile from the sondir examination (Ducth Cone Penetration Test, DCPT).

## 3. STABILITY ANALYSIS OF EXISTING BARRIER

Rain water which has been infiltrated to soil on the slope will be retained by soil or rocks which are more compact and waterproof. The high intensity of rainfall causes water which is retained experiences increase on its discharge and volume. Consequently, the water in this slope presses the soil grains and forces the soil to deform. Thus, in this case, the compact and waterproof rocks functions to retain water as well as the slip medium for slide, whereas water functions to move soil mass which is slipped on the compact soil or rocks.

### a. Existing Model of Barrier Slide

The geometry of barrier which is used on this reinforcement analysis is modelled based on the sectional profile of slide prototype at the slide spot along the road which is illustrated in Figure 7. The mechanism of slide which has occurred is simulated with the packet of numerical simulation and refers to the model of soil profile and the prediction of ground water table when the slide occurred.

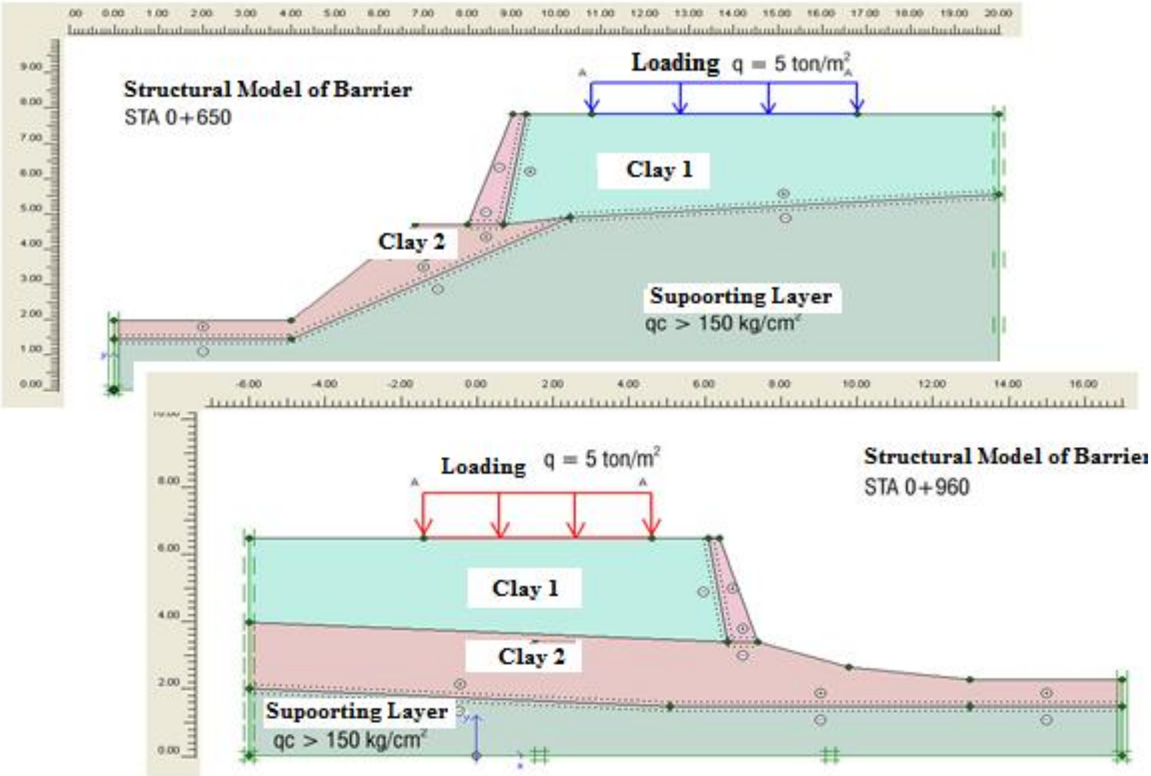


Figure 7 Structural Model of Existing Barrier Jln. Dg Sirua Makassar, Slide Spot 1 (Sta. 0+650) and 2 (Sta. 0+960)

Parameter of soil design and barrier construction which is used in the analysis is recapped in Table 2.

Table 2. Parameter of desain soil design and existing structure of barrier Jln. Dg Sirua Makassar, Slide Spots 1 and 2.

| Location | Material Descrption | Type | Design Parameter for Soil and Barrier | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $\gamma_{dry}$ | $\gamma_{wet}$ | mu | v | E_ref | c_ref | θ | R_inter |
| | | | (kN/m³) | (kN/m³) | - | - | (kN/m²) | (kN/m²) | (°) | - |
| Sta. 0+650 | **River Stone** | Drained | 20.00 | 22.00 | 0.25 | - | 750,000 | - | - | 1.00 |
| | **Clay 1** | - | 12.96 | 17.87 | - | 0.30 | 1,500 | 16.00 | 31°00" | 0.90 |
| | **Clay 2** | - | 12.96 | 17.87 | - | 0.30 | 1,000 | 10.00 | 15°00" | 0.90 |
| | **Hard Soil** | - | 16.00 | 18.00 | - | 0.30 | 45,000 | 20.00 | 35°00" | 0.90 |
| Sta. 0+960 | **River Stone** | Drained | 20.00 | 22.00 | 0.25 | - | 750,000 | - | - | 1.00 |
| | **Clay 1** | - | 13.99 | 18.77 | - | 0.30 | 1,500 | 16.00 | 24°00" | 0.40 |
| | **Clay 2** | - | 13.99 | 18.77 | - | 0.30 | 1,000 | 10.00 | 15°00" | 0.40 |
| | **Hard Soil** | - | 16.00 | 18.00 | - | 0.30 | 45,000 | 20.00 | 35°00" | 0.90 |

**b. Deformation and Stability of Existing Barrier**

The rehabilitation design or barrier slope reinforcement can be considered safe and economical if the value of existing barrier's stability can be measured accurately. This study examines such factors by numerical simulation of potential deformation and barrier's stability under the loading condition;

- Construction Phase (without Traffic Loads)
- Post Construction Phase (Traffic Loads).

The result of simulation on the slide stability value of existing barrier for both slide spots is indicated in the Figure 8.

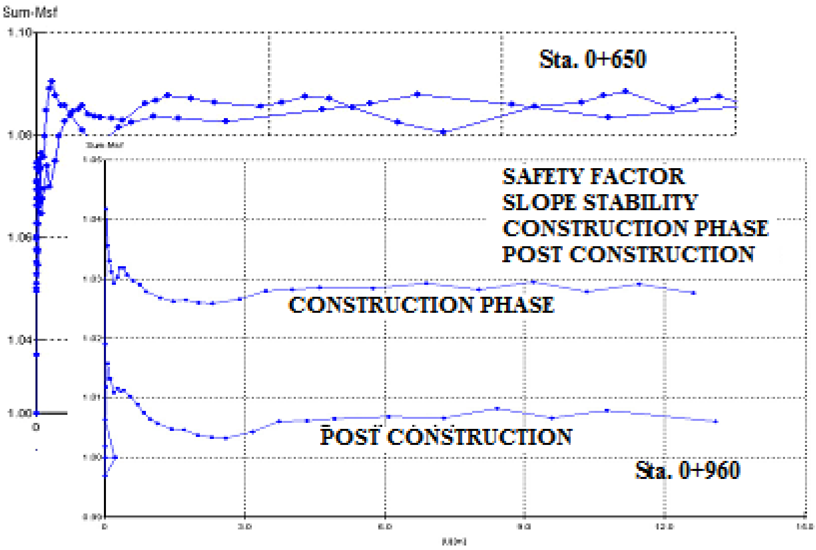


Figure 8. The value of existing barrier's stability Jln. Dg Sirua Makassar, Slide Spot 1 (Sta. 0+650) and 2 (Sta. 0+960)

When the slide occured, the stability factor of slope are $S_F$=1.08~1.09 (Slide Spot 1) and $S_F$=1.01~1.03 (Slide Spot 2). This value of stability is categorized as inadequate, lower than the value of criteria which is $S_F$=1.5 and the value $S_F$ was lower than than the phase of post construction.

Numerical simulation on the potential deformation of existing barrier for both slide spots is illustrated in the Figure 9 and 10.

Based on the numerical simulation, it can be justified that the deformation of existing barrier when the slide occured was 11.056~11.278 cm (slide spot 1) dan 20.85~22.55 cm (slide spot 2) toward the channel of PDAM. Such potential horizontal movement is categorized as critical because it will potentially induce destruction on the structure of existing barrier.

## 4. BARRIER STRENGTHENING DESIGN BY SOIL ANCHORING

Analyzing the analysis result of stability and the potential dislocation of existing barrier, the method of barrier strengthening by the alternative combination of soil anchor and grid beam is considered. The attempt to select the barrier strengthening system which has been constructed but have not experienced slide should consider following technical aspects:

- The sloping on the surface base of barrier foundation which is steep uses material from the fraction of stone in order meet the required stability of soil's bearing capacity. This fraction of stone can function to minimze the erosion of foundation base due to water in the channel.
- The drainage system of barrier which is poor can greatly influence the failure risk of barrier strengthenin. Thus, it should be anticipated before the construction of barrier strengthening commencing
- The barrier which is made of river stone is substantially risky, considering the poor quality of materials, if the re-excavation is conducted at the side of road.

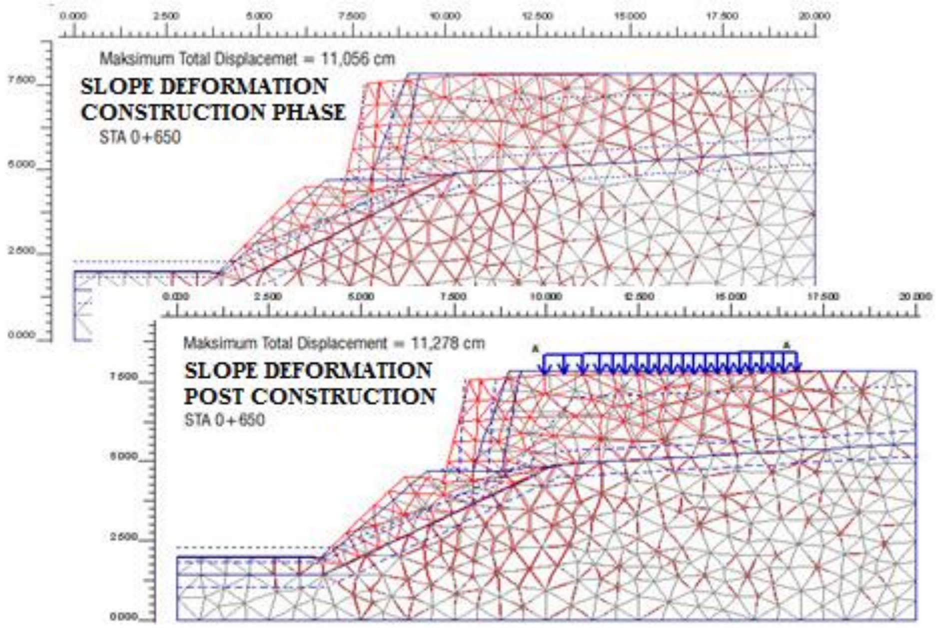

Figure 9. The potential deformation of existing barrier Jln. Dg Sirua Makassar, Slide spot 1 (Sta. 0+650)

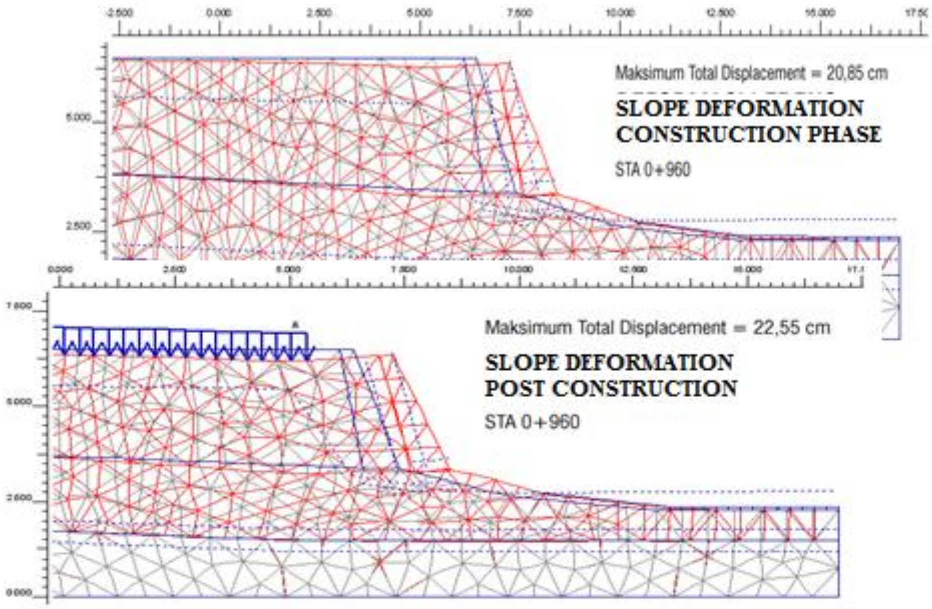

Figure 10. The potential deformation of existing barrier Jln. Dg Sirua Makassar, Slide Spot 2 (Sta. 0+960)

a. Barrier Strengthening Model by Soil Anchor

After obtaining several alternatives, the economical solution to strengthen the barrier is the application of anchor with structural model as described in Figure 11. Such strengthening model is congruent with the suggestion of *barrier strengthening and the rehabilitation of road pavement*, material of subbase embankment with Sirtu selected materials (Samang, L. et. al., 2006).

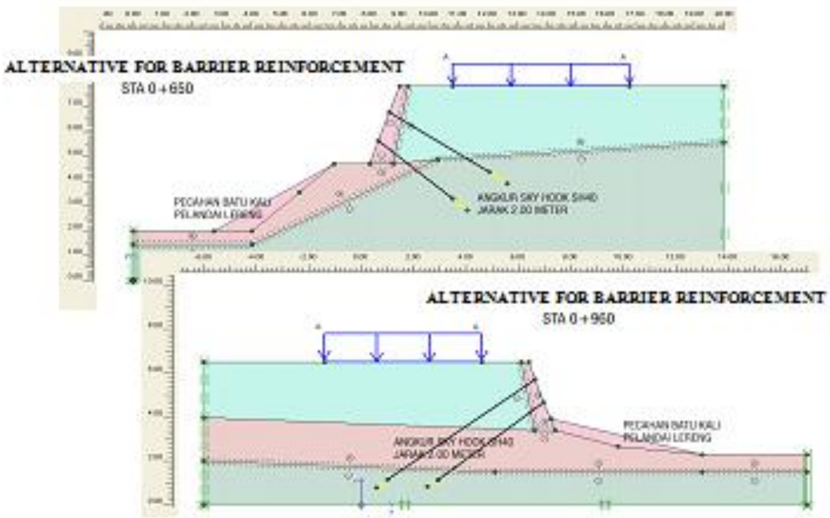

Figure 11. Structural model of barrier strengthening by anchor Jln. Dg Sirua Makassar, Slide Spot 1 (Sta. 0+650) and 2 (Sta. 0+960)

Geometry and design parameter of barrier structure which is used in the analysis of strengthening is modelled according to the existing barrier profile in Figure 7. The mechanism of slide which has occurred with the application of SkyHook Earth Anvhor is simulated with the same packet of numerical application.

The design parameter and barrier construction which is employed in this analysis is the same with the Table 2 and the design parameter for soil anvhor with specification of SkyHook Earth Anchor with the capacity of 4 ton type SH40; the value of stifness EA = 23.700 kN, strain of anchor F_max= 20 kN with the assumption of $S_F$=2, and the distance between installed anchor L_s=2.5 m. The visualization of anchor material and its installation is illustrated in Figure 12

b. Simulation of Barrier Strengthening Anchor

Simulation of barrier strengthening anchor aims to evaluaye the slope stability and barrier's deformation post anchor installation. In addition, the illustration of slide patter post strengthening can be visualized to determine the length of anchor at the time of constrution.

***The performance of Anchor in Slide Zone 1***

The performance of anchor in Slide Zone 1 managed to increase the value of stability from 1.42-1.46 after phase of construction. The deformation post construction at 0+650 is 4.2 cm and the safety factor of slopes as well as the area of slide post construction is illustrated in Figure 13. The use of protection layer of barrier's foundation base without anchor is not effective to increase the barrier's stability.

***The performance of Anchor in Slide Zone 2***

The performance of anchor in Slide Zone 2 managed to increase the value of stability from 1.24-1.27 after phase of construction, the increase of $S_F$ is not significant which can be seen in Figure 14. The deformation post construction at 0+650 is 12.4 cm and the safety factor of slopes as well as the area of slide post construction is illustrated in Figure 15. The redution of horizontal deformation is moderately significant. The use of protection layer of barrier's foundation base withouth anchor is not effective to increase the barrier's stability, but can be considered as the protection layer of potential infiltration.

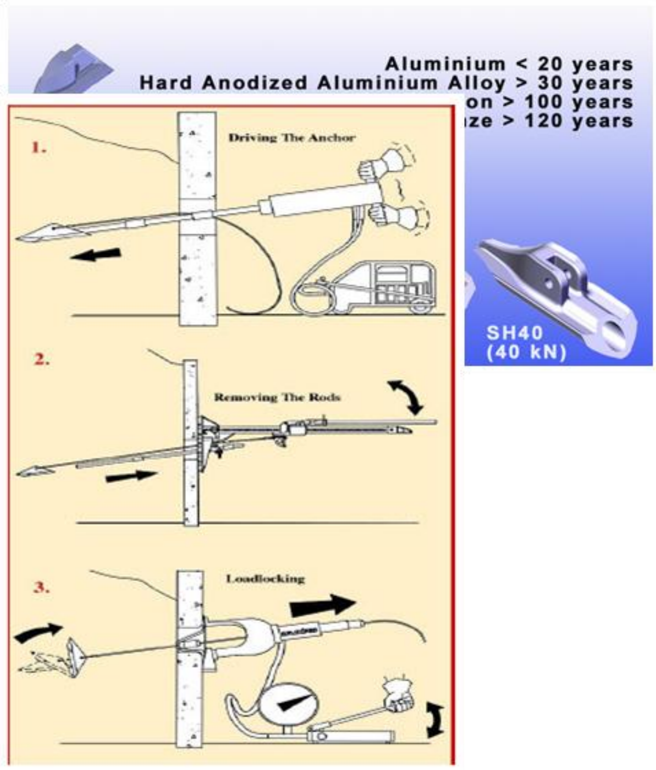


Figure 12. The picture of anchor material and the phase of anchor installation with the strain capacity of 40 kN (type SH40)

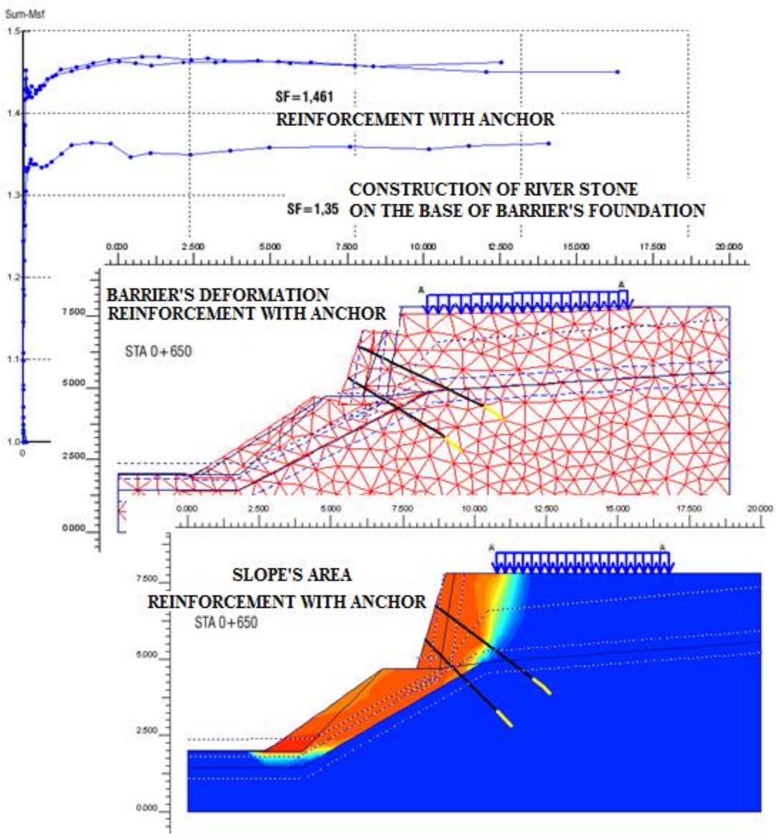


Figure 13. The value of stability, deformation and the pattern of slide area post installation of soil's anchor at slide zone 1.

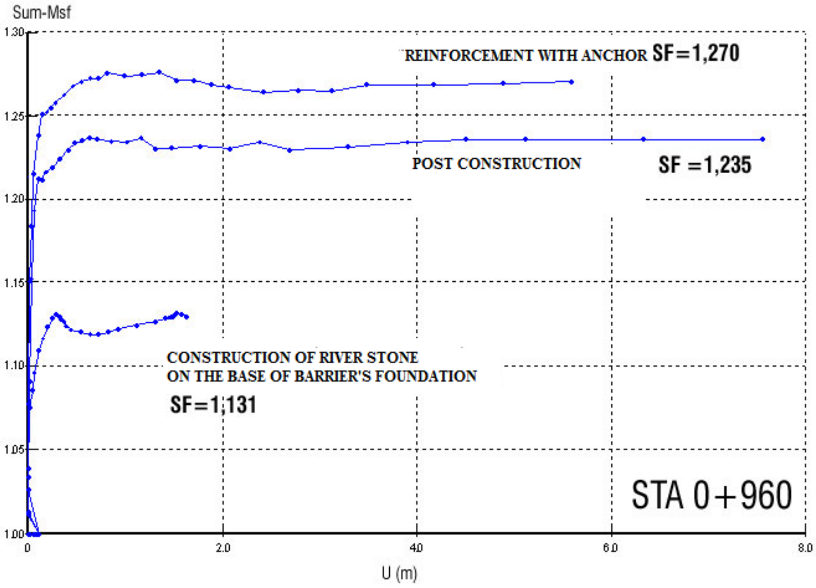


Figure 14. The value of slope stability after the installation of soil's anchor at slide zone 2.

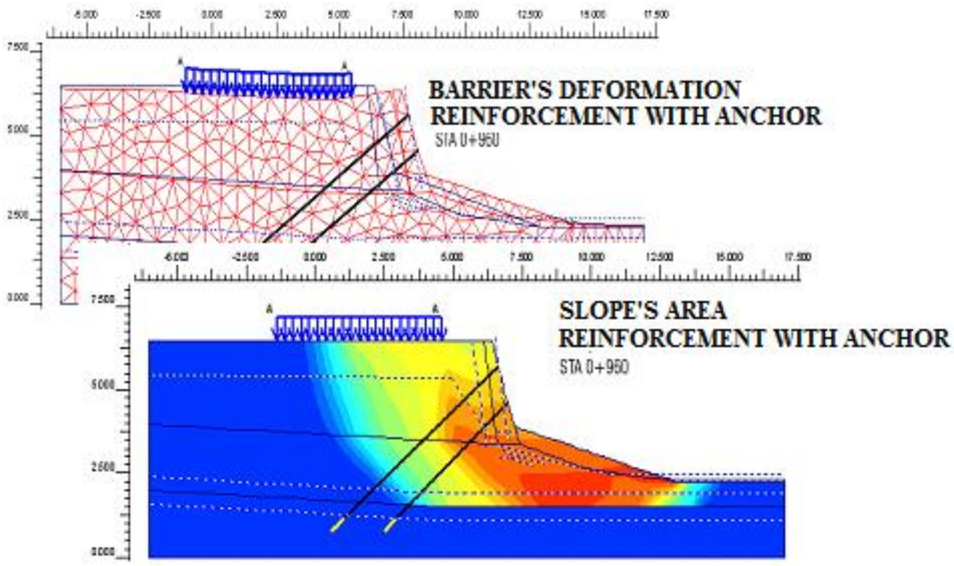


Figure 15. The potential deformation and the pattern of slide area after the installation of soil's anchor at slide zone 2.

The description for the numerical result of stability and the potential barrier's displacement (existing and post anchor installation) is comprehensively provided in Table 3.

Analysing the performance of anchor in strengthening the soil's protection wall, it can be inferred that the application of anchor system manages to increase the value of barrier's stability and reduce the horizontal deformation significantly. The amount of increase for stability and reduction of deformation depends on the design; capacity of anchor, geometry of barrier and soil's parameter. The consideration in using the anchor system of SkyHook in this study, because it has comparative advantage which are measurable performance of anchor's capacity, simple and quick application, flexible anchor's material and can be synergized with the other materials of slope strengthening such as geotextile, beam and many more.

Table 3. The result of numerical analysis for stability and the deformation of barrier (existing and the post anchor installation)

| Location | Loading | Quantity (Unit) | Stability and Deformation | | | |
|---|---|---|---|---|---|---|
| | | | Safety Factor | | Deformation | |
| | | | Existing | Reinforcement | Existing | Reinforcement |
| Sta. 0+650 | Post Construction | 2 | 1.08 | 1.42 | 11.28 | 4.210 |
| | Construction | 2 | 1.09 | 1.46 | 11.05 | 4.210 |
| | River Stone Base | - | 1.09 | 1.35 | 11.05 | - |
| Sta. 0+960 | Post Construction | 2 | 1.01 | 1.24 | 22.55 | 12.400 |
| | Construction | 2 | 1.03 | 1.27 | 20.85 | 12.400 |
| | River Stone Base | - | 1.03 | 1.13 | 20.85 | - |

Analysing the performance of anchor in strengthening the soil's protection wall, it can be inferred that the application of anchor system manages to increase the value of barrier's stability and reduce the horizontal deformation significantly. The amount of increase for stability and reduction of deformation depends on the design; capacity of anchor, geometry of barrier and soil's parameter. The consideration in using the anchor system of SkyHook in this study, because it has comparative advantage which are measurable performance of anchor's capacity, simple and quick application, flexible anchor's material and can be synergized with the other materials of slope strengthening such as geotextile, beam and many more.

This study considers grid beam and protection layer of barrier's foundation base which is synergized with anchor in order to strengthen the road in Jln. Dg. Sirua Kota Makassar. The use of grid beam of 0.2x0.15 cm with space of 2.5 m is functionally and structurally able to anticipate the crack on barrier's body sustainably

## 6. CONCLUSION

The occurrence of barrier's slide at Jln. Dg. Sirua, Kota Makassar technically indicates that the design criterion of barrier's structural element is not adequate. This study analyses the application reinforcement scheme as an alternative to strengthen the barrier by anchoring system combined with grid beam with the conclusion of numerical simulation of strengthening design as follow:

- When the slide occurred, the stability factor of slope are SF=1.08~1.09 (Slide Spot 1) and SF=1.01~1.03 (Slide Spot 2), this value of stability is categorized as not safe and the tendency of barrier's failure is high.
- Based on the numerical simulation, it can be justified that the deformation of existing barrier when the slide occured was 11.056~11.278 cm (slide spot 1) dan 20.85~22.55 cm (slide spot 2) toward the channel of PDAM. Such potential horizontal movement is categorized as critical because it will potentially induce destruction on the structure of existing barrier.
- The performance of anchor in Slide Zone 1 managed to increase the value of stability from 1.42-1.46 after phase of construction. The deformation post construction at 0+650 is 4.2 cm, this indicate that it manages to effectively reduce the displacement up to 70%. Nevertheless, the use of protection layer of barrier's foundation base without anchor is not effective to increase the barrier's stability
- The performance of anchor in Slide Zone 2 managed to increase the value of stability from 1.24-1.27 after phase of construction, the increase of SF is not significant. The deformation post construction at 0+650 is 12.4 cm, it successfully reduces the horizontal deformation up to 50%.

- Analysing the performance of anchor in strengthening the soil's protection wall, it is believed that the application of anchor system manages to increase the value of barrier's stability and reduce the horizontal deformation significantly
- The consideration in using the anchor system of SkyHook in this study, because it has comparative advantage which are measurable performance of anchor's capacity, simple and quick application, flexible anchor's material and can be synergized with the other materials of slope strengthening such as geotextile, beam and many more.
- The use of protection layer of barrier's foundation base without anchor is not effective to increase the barrier's stability, but can be considered as the protection layer of potential infiltration. However, the use of grid beam of 0.2x0.15 cm with space of 2.5 m is functionally and structurally able to anticipate the crack on barrier's body sustainably.

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