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Determination of Slope Safety Factor Based on Hoek & Brown Collapse Criteria on Ampera-Surumana Road Section

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ABSTRACT (10PT)

Introduction: One way to determine whether a slope is stable or not is by using the safety factor criterion. The method to determine the safety factor using the limit equilibrium method. Administratively the research area is located in the village of Salubomba, Central Banawa District, Donggala Regency, Central Sulawesi Province. The results of the study are also expected to be used as one of the basis for planning the design of stable slopes in the area **Method**: The methods used in this research were qualitative and quantitative. The process in this research was carried out with each method. The process of collecting secondary data and primary data is carried out by Geology and Geological Engineering methods both qualitatively and quantitatively. **Results and Discussion**: Observations in this study were made in the field in the form of observations of bridging on road slopes. The bruises in the study area are grouped on the basis of their shape and genetics. Through the results of observations and measurements on rock slopes at the research site. Based on data processing on the GEOSTUDIO 2018 R2 software application. Then, the value of the slope safety factor at observation station 1 is 2.316. **Conclusion**: Based on testing and analysis of the Hoek & Brown collapse criteria method, it can be concluded that the value of the slope safety factor at observation stations 1, 2, 3, 4, and 5 is 2.316; 2.029; 1.765; 1.658; 2.622 respectively. At station 4 the level of vulnerability is medium (Landslides can occur), at station 3 is at a low level of vulnerability (Landslides rarely occur), while at stations 1,2 and 5 are at a very low level of vulnerability (Landslides very rarely occur).

1. INTRODUCTION

The Ampera-Surumana road section is one of the trans-Sulawesi road sections which plays a very important role in connecting the provinces of Central Sulawesi - West Sulawesi. Part of this road section is located in a mountainous area that has a steep slope angle and there are several slopes that are feared to be unstable due to the weathering of the constituent rocks of the slope due to the weak plane which is the influence of the rock deformation process so that the weak plane can affect the level of slope stability resulting in landslides that can cover the road and can be dangerous.

One way to determine whether a slope is stable or not is by using the safety factor criterion. The method to determine the safety factor using the limit equilibrium method. Calculation of the factor of safety with the limit equilibrium method by dividing the mass of the sliding plane into small slices.

The shear forces acting on the slices are assumed to represent all equal parts of the shear strength of the rock or soil on which these shear forces act.

Rock mass classification is one of the methods to determine the strength of rock masses. Classification of rock mass strength can be known by characterizing the rock mass, this activity can be done on the surface of the slope. In this research, to determine the strength of the rock mass, Hoek & Brown 2002 collapse criteria were used, because Hoek & Brown collapse criteria can be used to estimate the strength, cohesion, and friction angle in the rock mass. Cohesion and angle of friction are parameters to determine the factor of safety in the limit balance method.

This research is expected to know the value of the safety factor contained in the Ampera-Surumana road section based on the Hoek & Brown collapse criteria. The results of the research are also expected to be used as one of the bases for planning a stable slope design in the area.

Administratively, the research area is located in Salubomba village, Central Banawa sub-district, Donggala district, Central Sulawesi province. Geographically, the research area is included in the coordinates 119040'30" East - 119041'30" East and 00043'30" LS - 00045'30" LS.

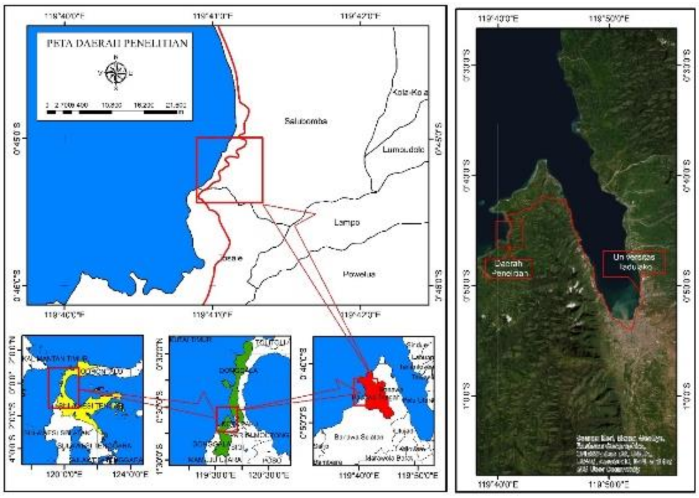

Fig. 1. Location map of the study area

2. THEORETICAL FOUNDATION

2.1. Slope Stability

Slope stability in a job caused by excavation or hoarding activities is a problem that must be considered. This is closely related to the losses that may arise if a landslide occurs.[1].

The level of stability in a slope design needs to be measured using a standard, namely the Factor of Safety (FK). FK is a function between the forces that resist avalanches and also the forces that cause avalanches.[1].

The ratio of the resisting force to the driving force, expressed by the following equation

$$FK = \frac{Gaya\ Penahan}{Gaya\ Penggerak}$$

2.2. Kinematic Analysis

Kinematics analysis is one of the slope stability analysis methods that use the parameters of geological structure orientation, slope orientation, and rock inner shear angle projected on a stereonet. Geological structures projected stereographically can be used to determine the type and direction of landslides. If the slope has discontinuity planes, then the slope has landslide potential because it has weak planes. Weak planes can be bridles, faults, and bedding planes. If water fills the opening of a bridle or weak plane, it will increase the pressure on both sides, which greatly affects the stability of the slope.[2].

Kinematic analysis in this study uses the stereographic method to determine the potential for rock slope collapse. Based on the type of avalanche and its process, four types of rock avalanche types can be distinguished by stereographic analysis [2] namely plane avalanches, wedge avalanches, rolling avalanches, and arc avalanches.

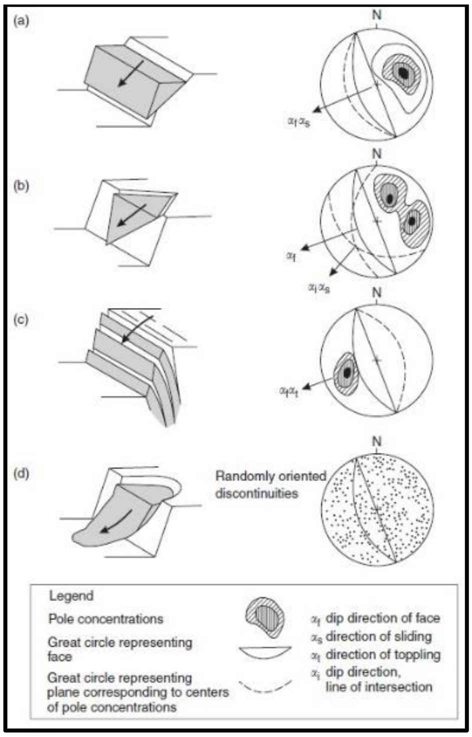

Fig. 2. Avalanche types with stereographic parameters according to Wyllie & Mah (2004): (a) plane avalanches, (b) wedge avalanches, (c) overturning avalanches, (d) arc avalanches

Slope stability analysis requires geomechanical parameters based on the Hoek & Brown (2002) collapse criteria method. The parameters for the analysis of rock mass characteristics are in the form of whole rock mass constants (mi), material constants (s and a), and whole rock strength test data from the field. This method also introduces the relationship between the Geological Strength Index and the subtraction value of the constant mi (mb), and the material constants (a and s). The Geological Strength Index can be calculated based on parameter values that can be seen from the appearance of rock masses through slope observations in the field. [3].

The Hoek-Brown collapse criterion was also developed to estimate the frictional strength in jointed rock masses. This collapse criterion originated from research by Hoek and Brown on the mechanism of intact rock rupture and the behavior of jointed rock masses. Hoek-Brown developed an equation that describes the relationship between the principal stresses in the following equation:

$$\sigma'_1 = \sigma'_3 + \sigma_{ci}\left(mb\frac{\sigma_3}{\sigma_{ci}} + s\right)^a$$

Description:

$\sigma'1$ and $\sigma'3$= Major and minor effective pressures,

σci = Rock compressive strength (UCS) value of intact rock

Mb = Hoek & Brown's rock constant value for rock mass which is the subtraction value of the material constant mi (intact rock), derived from Hoek & Brown's determination

s = Parameter related to the influence of the interlocking force of rock masses in the range $0 \leq s \leq 1$. s = 0 when the interlocking force between rock blocks has disappeared, without cohesion, s = 1 when the rocks are interlocked.

a = Rock linearity parameter related to rock mass competence.

2.3. Determination of Safety Factor Value

After testing between the retaining force and the driving force, the results will be obtained in the form of a safety factor value, experts have conducted many studies for the classification of safety factor values. To determine the stability of the slope in this study based on the value of the safety factor (FK) slope which is a modification of Ward (1976).[4].

Table 1. *Classification of safety factors (FK)*

Safety Factor (FK) Value	Landslide Vulnerability Level
FK ≤ 1.2	High: Landslides Occur Frequently
FK 1.2 - 1.7	Intermediate: Landslides May Occur
FK 1.7 - 2.0	Low: Landslides are Rare
FK > 2.0	Very Low: Landslides Occur Very Infrequently

It can be seen from the table above, that the greater the safety factor value of a slope, the smaller the potential for landslides, if the slope safety factor value is low, the higher the potential for landslides. The slope safety factor value depends on the amount of shear resistance and shear stress, both of which work in opposite directions along the slide plane. The slide plane is the weakest zone in the slope body. Nowadays, there is a lot of software that can help and facilitate calculating slope stability using the Limit Equilibrium method, for example, the most famous is GeoStudio from the GEOSLOPE company with a product called SLOPE/W.

2.4. Geostudio App

This research will use geostudio software to help calculate the factor of safety of the slopes in the study area.

GeoStudio software is an application package for geotechnical and geo-environmental modeling. It includes SLOPE/W, SEEP/W, SIGMA/W, QUAKE/W, TEMP/W, and CTRAN/W, which are integrated to enable the use of results from one product to another.

This feature is quite unique and provides flexibility to be used by both academics and professionals in solving various geotechnical and geo-environmental problems such as landslides, dam construction, mining, and others. SLOPE/W is a software product for calculating soil and rock safety factors by applying the limit equilibrium method in data management. SLOPE/W can analyze both simple and complex problems using one of eight limit equilibrium methods for various sloping surfaces, pore water pressure conditions, soil properties, and concentrated loads in this study using the Spencer limit equilibrium method. In addition, finite element pore water compression, static stress, or dynamic stress can be used in slope stability analysis and can also be combined with probabilistic analysis [5].[5].

Geostudio SLOPE/W 2018 software has been widely applied in slope stability research and analysis, especially by using SLOPE/W and SEEP/W. In this research, slope stability analysis using SLOPE/W by entering Geological Strength Index (GSI) data and the calculation value of Hoek & Brown collapse criteria.

3. Research Methods

The methods used in this research were qualitative and quantitative. The process in this research was carried out with each method. In the process of collecting secondary data and primary data, Geology and Engineering Geology methods are carried out both qualitatively and quantitatively. In the process of analyzing the type of avalanche, the stereographic method was used to analyze the kinematic results. The process of analyzing the quality of rock mass with the Geological Strength

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Index classification is carried out based on the Hoek & Brown (2002) collapse criteria method which will be used to determine the safety factor value using the Spencer analysis method.

4. Results and Discussion

4.1. Geomorphology of the Study Area

Based on observations of satellite imagery and DEMNAS data, the geomorphology of the study area is in a low hilly area with a height difference of 50 - 100 meters above sea level with a slightly steep - very steep slope angle with a percentage of 20% - 140% and, the shape of the valley is shaped like the letter "V". The geomorphology of the study area is determined based on the classification of geomorphology according to Van Zuidam (1985), which includes morphography and morphometry.[6].

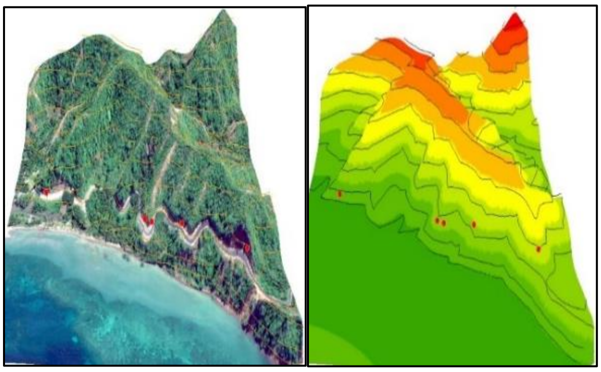

Fig. 3. Geomorphologic landscape features of the study area

The characteristics of natural formations result from processes that change the shape of the earth's face, including the process of weathering on rocks. The predominantly "V" shaped valley is an indication that the vertical erosion process is more dominant than horizontal erosion. In general, the level of weathering in the study area is relatively moderate to high with a soil thickness of ±0.5 - 2 meters. The color of the soil is brownish gray which is residual soil, a type of soil formed from the weathering of previously existing rocks and has not undergone transportation.

The weathering process that occurs in the study area is physical weathering which is the disintegration of rocks into small fragments. The results of physical weathering are found in andesite lithology in the form of loose fragments formed due to the process of geological structures at work. Landforms in the study area are found mass movements as one of the exogenic processes that play a role in controlling the formation of morphology in the study area.

This movement is controlled by relatively steep slopes and generally occurs on hillside cliffs which can trigger an increase in the degree of steepness of the slope.

Fig. 4. The appearance of exogenic processes, namely weathering on andesite lithology at observation station 1.

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4.2. Stratigraphy of the Research Area

The study site is included in the Tinombo Formation on the Geological Review of Palu Sheet, scale 1: 250,000, by Sukamto (1973).[7]. The lithology found in the field on the road section of the research area is andesite lithology.

The lithologic features of andesite in the Tinombo Formation in this study area were observed megascopically. Andesite lithology is found at stations 1 to 5 in the Salubomba Village area (Figure 5). The andesite lithology found in the fresh state is gray, in the weathered state is blackish brown with hypocrystalline crystallinity texture, aphanitic-porphyritic granularity, and subhedral shape, in equigranular relation; massive structure, mineral composition of quartz, plagioclase, orthoclase, hornblende, and biotite. Based on the darkness of the rock's color, mineral composition, and rock texture, the rock's name is andesite (Fenton, 1940).

Fig. 5. Appearance of andesite lithology sample at observation station 1

The age of andesite lithology at the study site was determined based on the stratigraphic position and the principle of comparability to the regional stratigraphy of the study area and the results of previous researchers. Based on previous researchers (Sukamto, 1973) and Hennig, et al (2016), the age of this unit is included in the Tinombo Formation (Tt) as described in this formation consists of andesite lithology at the research site. This unit is of the Middle Eocene - Late Eocene age.[7], [8].

4.3. Regional Geological Structure

Observations in this study were made in the field in the form of observations of bridging on road slopes. The bruises in the study area are grouped on the basis of their shape and genetics. Through the results of observations and measurements on rock slopes at the research location. Based on their shape, the braces in the study area are included in non-systematic braces. This non-systematic bridle is found in andesite lithology characterized by the presence of bridles that intersect with other bridles with various directions and slopes, these bridles are formed due to compression forces so that the rock becomes eroded. Genetically, the braces in the study area are classified as grinding braces (**Error! Reference source not found.**). The type of bridle, namely the grinding bridle in the study area, is a bridle that can cause rock collapse.

Fig. 6. Appearance of scouring bridle structure on the slope of andesite lithology at observation station 1.

Brackets can affect the GSI value of a rock, namely the Structure Rating value, the structure rating affects the GSI value of the rock because at this value there is a measurement of the distance between brackets, the length of the brackets, and the number of brackets which can reduce the GSI value if the distance between brackets is very short with a very large number. This can make the rock quality value poor. A bridle is formed due to a weak plane in the rock mass which can reduce the value of the safety factor on the slope.

4.4. Geological Strength Index (GSI) Analysis

GSI analysis is conducted to obtain the value of rock mass from the observation of the slope surface based on the appearance of discontinuities assessed based on qualitative and quantitative observations in the field. The GSI value of the slope will be used in the slope stability analysis based on Hoek-Brown 4th edition (2004) collapse criteria. Input parameters for the Analysis of rock mass characteristics mi, s, a and rock compressive strength. Hoek and Marinos (2007) also introduced the relationship between GSI and the values of mb, s, and a. The following are the results of the GSI Analysis at the research site[9].

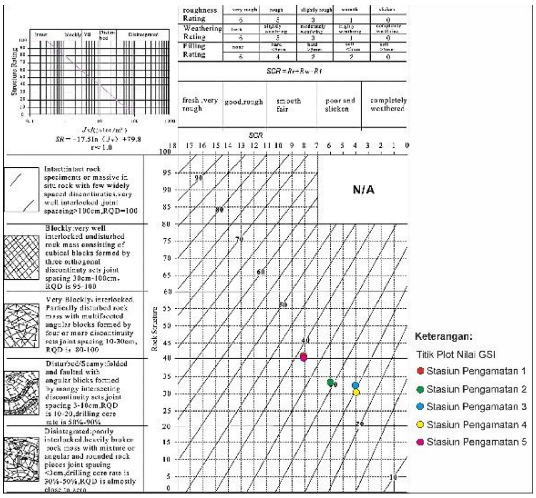

Fig. 7. Plotting GSI of observation stations 1-5

4.5. Hoek & Brown Collapse Criteria Analysis

To analysis of the stability of the slope at the study site is based on Hoek & Brown collapse criteria. To get the safety factor value, the maximum Sigma' 3 value (σ′ 3 max) is used which will be entered into the Hoek & Brown rock material properties using the Geostudio Application (Slope/W). Parameters such as rock compressive strength value, Geological Strength Index (GSI), mi, and D (disturbance factor) value are needed to obtain the maximum stress value on the sliding surface (σ′ 3 max). The results of the Hoek & Brown collapse criteria analysis on the slope of the observation station are as follows.

No. STA	m_i	*GSI*	*D*	σ'_{ci}
1	19	39	0,7	20
2	19	32	0,7	18
3	19	24	0,7	19
4	19	23	0,7	19
5	19	38	0,7	21

Fig. 8. Rock compressive strength values, GSI, mi, and D

4.6. Kinematic Analysis of Avalanche Type Determination

Kinematic analysis was conducted using the stereographic method to determine the type of avalanche potential on the slope at each observation station. The following are the results of kinematic analysis using the stereographic method for each station (0), as follows:

No. STA	Slope Lereng	Set Diskontinuitas 1	Set Diskontinuitas 2	Arah Longsor	ϕ'	Jenis Longsor
1	62°/ N 320° E	72°/ N 358° E	67°/ N 264° E	N 305° E/ 61°	47°	Baji
2	61°/ N 345° E	73°/ N 25° E	72°/ N 308° E	N 343° E/ 68°	48°	Baji
3	60°/ N 230° E	69°/ N 192° E	74°/ N 261° E	N 214° E/ 66°	42°	Baji
4	60°/ N 325° E	59°/ N 8° E	62°/ N 272° E	N 324° E/ 49°	41°	Baji
5	59°/ N 280° E	148°/ N 24° E	51°/ N 42° E	N 283° E/ 62°	47°	Baji

Fig. 9. Results of stereographic analysis of landslide type determination

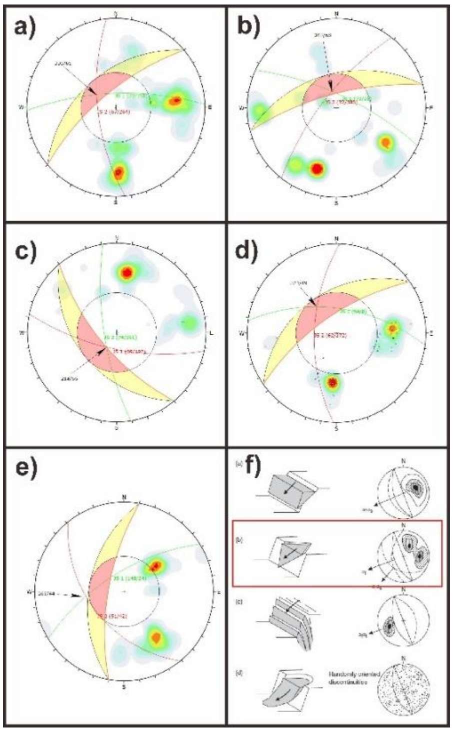

Fig. 10. Stereographic projection of observation station 1

4.7. Analysis of Safety Factor Values

4.7.1. Observation Station 1

Observation station 1 is located at geographical coordinates 0°45'20.31" N and 119°40'58.41" E and is located on the southern part of the research area road in Salubomba village. The direction of the slope is relatively southeast (dip direction) N 320° E with a slope of 62°. The slope at this station has a height of 17.2 meters and a road width of 5.8 meters.

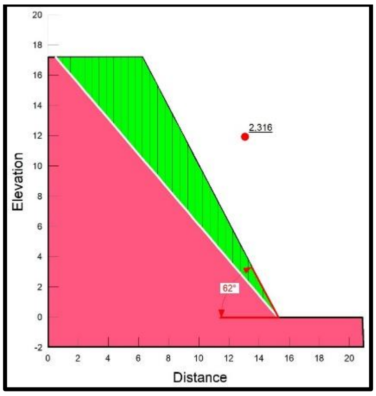

Fig. 11. Slope safety factor at observation station 1

Based on data processing in the GEOSTUDIO 2018 R2 software application. Then, the slope safety factor value at observation station 1 is 2.316 (Figure 11). This slope safety factor value is at the Very Low vulnerability level (Landslides are very rare) based on the landslide hazard classification system according to Ward (1976).

4.7.2. Observation Station 2

Observation station 2 is located at geographical coordinates 0°45'13.10 "N and 119°41'3.52 "E and is located in the middle of the road section of the study area in Salubomba village. The direction of the slope is relatively southeast (dip direction) N 345° E with a slope of 61°. The slope at this station has a height of 18 meters and a road width of 5.8 meters.

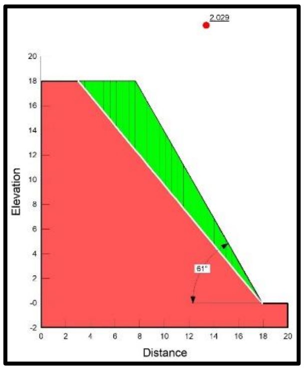

Fig 12. Slope safety factor at observation station 2

Based on data processing in the GEOSTUDIO 2018 R2 software application. Then, the slope safety factor value at observation station 2 is 2.029 (Figure 12). This slope safety factor value is at the Very Low Vulnerability level (Very rare landslides) based on the landslide hazard classification system according to Ward (1976).

4.7.3. Observation Station 3

Observation station 3 is located at geographical coordinates 0°45'9.24 "N and 119°41'5.29 "E and is located in the middle of the road section of the study area in Salubomba village. The direction of the slope is relatively northeast (dip direction) N 230° E with a slope of 60°. The slope at this station has a height of 12.2 meters and a road width of 5.8 meters.

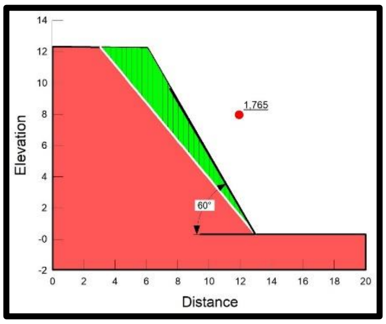

Fig. 13. Slope safety factor at observation station 3

Based on data processing in the GEOSTUDIO 2018 R2 software application. Then, the slope safety factor value at observation station 3 is 1.765 (Figure 13). This slope safety factor value is at the low vulnerability level (Landslides rarely occur) based on the landslide hazard classification system according to Ward (1976).

4.7.4. Observation Station 4

Observation station 4 is located at geographical coordinates 0°45'8.18" LS and 119°41'5.85" East and is located on the southern part of the research area road in Salubomba village. The direction of the slope is relatively westward (dip direction) N 325° E with a slope of 60°. The slope at this station is 8 meters high and has a road width of 5.8 meters.

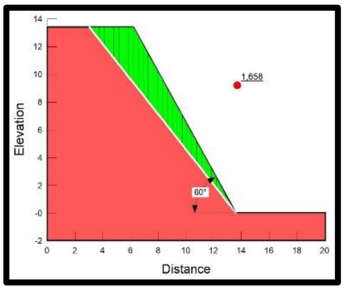

Fig. 14. Slope safety factor at observation station 4

Based on data processing in the GEOSTUDIO 2018 R2 software application. Then, the slope safety factor value at observation station 4 is 1.658 (Figure 14). This slope safety factor value is at the medium vulnerability level (Landslides can occur) based on the landslide hazard classification system according to Ward (1976).

4.7.5. Observation Station 5

Based on data processing in the GEOSTUDIO 2018 R2 software application. Then, the slope safety factor value at observation station 4 is 1.658 (Figure 12). This slope safety factor value is at the medium vulnerability level (Landslides can occur) based on the landslide hazard classification system according to Ward (1976).

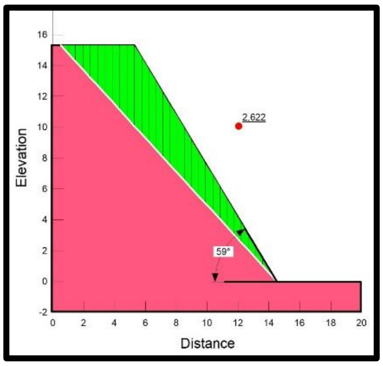

Fig. 15. Slope safety factor at observation station 5

Based on data processing in the GEOSTUDIO 2018 R2 software application. Then, the slope safety factor value at observation station 5 is 2.622 (Figure 15). This slope safety factor value is at the Very Low vulnerability level (Landslides are very rare) based on the landslide hazard classification system according to Ward (1976).

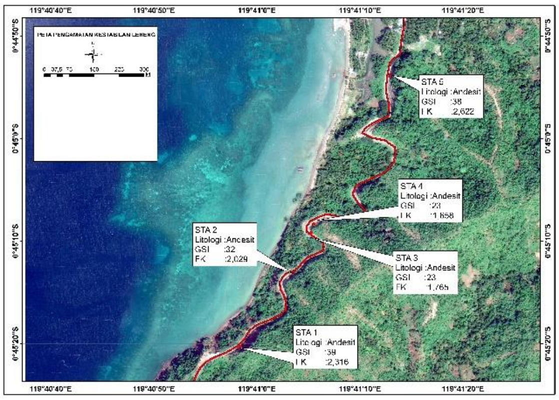

Fig. 16. Slope stability observation map

5. Conclusion

Based on testing and analysis of the Hoek & Brown collapse criteria method in determining the value of the slope safety factor and kinematic analysis on the road section of Salubomba village, Central Banawa District, Donggala Regency, it can be concluded as follows:

1. The types of avalanches that have the potential to occur if the slope is unstable in the research area are wedge avalanches at stations 1, 2, 3, 4, and 5.[2].
2. The slope safety factor values at observation stations 1, 2, 3, 4, and 5 are 2.316; 2.029; 1.765; 1.658; 2.622 respectively. At station 4 the vulnerability level is medium (Landslides can occur), at station 3 is at low vulnerability level (Landslides rarely occur), while at stations 1,2 and 5 are at very low vulnerability level (Landslides very rarely occur).

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