Rock slope stability analysis using Slope Stability Rating (SSR) method

M U Botjing\textsuperscript{1*}, N R Janat\textsuperscript{1}, T Hilmansyah\textsuperscript{1}, Asrafil\textsuperscript{1}, and Z Saing\textsuperscript{2}

\textsuperscript{1} Faculty of Engineering Tadulako University, Palu, Indonesia
\textsuperscript{2} Civil Engineering Department, Engineering Faculty, Universitas Muhammadiyah Maluku Utara, Ternate, Indonesia

*E-mail: muslimin@untad.ac.id

Abstract. Nupabomba village roads frequently undergo landslides, so that detain transportation access flow pattern as a result of rock slope stability problem, which has become the landslides trigger. Furthermore, to find out landslides prone area slope stability level, an analytical study using a scientific approach is required to reveal this question in the study area. The slope elevation in this area is ±75 meters, with an average slope angle of 60°, where its lithology consists of Schist, Greenschist, Filite, and Granite. Some of these rocks have different weathering levels (e.g., slightly - high weathering), and there are lots of discontinuity. Moreover, its geological strength index (GSI) value showed around 15-75 with the surface shape of blocky and disturbed. Besides, the uniaxial compressive strength (UCS) value was obtained based on the compressive strength carried out in the field, and slope stability rating (SSR) values have gained the range of 9-81.

1. Introduction
Nupabomba village road is often experiencing landslides, which become the obstacle of access and transportation through the road. The slope stability has become the main problem in this area. Currently, the lithology condition in this research field consists of Schist, Greenschist, Filite, and Granite. However, the rocks have been weathering with the result triggered by any occurred-landslide\cite{1},\cite{2}. Geological Strength Index (GSI) applied as the method approach in order to know the quality of rock mass in the field\cite{3}\cite{4}. Furthermore, the GSI result to be used in a method to set the slope stability, which is called Slope Stability Rating (SSR)\cite{5}\cite{6}\cite{7}. Nupabomba village, Trans Sulawesi street, the site where data are collected, has unstable slopes.

2. Literature Review
Earlier research about slope stability has done, which examined rainfall and earthquake effect to the slope stability of the research field\cite{8}, and research of slope stability analysis using the Slope Mass Rating (SMR) method\cite{9}.

2.1. Geological Strength Index (GSI)
The GSI uses the Hoek-Brown failure criteria to quantify rock mass structure and any damage above its strength, assuming that rocks have not been disturbed, in-situ, and induce stress, in which groundwater pressure not considered in MB, \textit{mi} constant calculation. GSI combines two main parameters, which are
the structure of block character and the surface condition in the form of ruggedness, weathering, or alteration and fillers[10]. Sonmez and Ulusay (1999) tried to quantify GSI classification, but it was not noticed having a limitation [11]. This process relates to the rock mass, which eases to be quantified until it concluded that rock mass rating qualitatively using the GSI method is still assumed better than the quantitative method.

2.2. Slope Stability Rating (SSR)
Slope stability rating (SSR) is a classification system on slope stability analysis, which consists of additional five parameters used to the stability of cracked rock slope following the collected data from any location of rock slope. A whole rock mass obtained from the rating calculation of all parameters. In this method, the collected data of different slopes is to get information about dry unit weight, GSI, Intact rock (modulus Young, UCS), and slope geometry design (factor of slope elevation damage and slope angle). The five parameters, as seen in Table 1. Meanwhile, Figure 1 shown the relation chart to find SSR value based on slope angle and slope height.

| Parameter | Rating Range |
|-----------|--------------|
| GSI Modification rating | Refers to Picture 3.9 (0-100) |
| Uniaxial Compressive Strength, MPa | 0-10 | 10-25 | 25-50 | 50-100 | 100-150 | 150-200 |
| Rock Type | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 |
| Rating | 0 | 7 | 18 | 28 | 37 | 43 |
| Slope Excavation Method | Waste Dump | Poor Blasting | Normal Blasting | Smooth Blasting | Presplitting | Natural Slope |
| Rating | 0 | 4 | 9 | 17 | 20 | 25 |
| Ground Water (Ground Water Surface from under slope/slope) | Dry | 0-20% | 20-40% | 40-60 | 60-80 | 80-100 |
| Rating | -11 | -4 | 0 | 6 | 10 | 24 |
| Magnitude Earthquake (Horizontal Velocity) | 0.15 g | 0.20 g | 0.25 g | 0.30 | 0.35 |
| Rating | 0 | -1 | -3 | -6 | -14 | -18 |
| Rating | 0 | -11 | -15 | -19 | -22 | -26 |

3. Research Methods
This study conducted by the survey, measurement, and field test (research area, as seen in Figure 2, and the survey process in Figure 3a). Field survey using the tracking method with several sample points. The coordinate data of each point is plotted using a high accuracy Global Positioning System (GPS)[12]. Furthermore, measurements of weak rock fields are carried out using a geological compass to determine crack strike/slip the direction, as seen in Figure 3b.

Moreover, each point taken rock samples and measurements of slope angle and slope height, as well as geological conditions according to GSI and SSR parameters required. Furthermore, rock samples tested for laboratory uniaxial compressive strength (UCS) to find out the uniaxial compressive strength. All measurement data are processed to obtain parameter values and entered in the SSR criteria table and GSI qualitative analysis to determine the rock slope stability.
Figure 1. The relation chart of SSR Rating and Slope Elevation

Figure 2. The map of Research area

Figure 3. (a) Survey process; (b) Crack measurement.
4. Results and Discussions

4.1. Geological Strength Index (GSI)
The observation result of rock mass classification (GSI), as seen in Figure 4, showed that there are six observed slopes with different GSI ratings.

![GSI Rating based on field data processed](image)

**Figure 4.** GSI Rating based on field data processed

Based on this study, GSI rating obtained on the field is on a very good – bad scale. This due to rocks in location weathered, and their age is qualified as Paleozoikum and classified as metamorph complex [13].
4.2. Slope Stability Rating (SSR)

SSR analysis is applied to know slope stability according to safety slope and its elevation on the field. SSR processing results based on Taheri and Tani’s theory, as shown in Figure 5.

![Figure 5. The slope angle recommended based on SSR Rating analysis](image)

There are some observation points on the recommendation angle regarding SSR Rating and slope elevation. In number three is outside of the SSR curve, based on Taheri research (2009) mentioned that location is including as the landslides prone area. It can prove according to GSI Rating gained in the field, which is on bad to average rating regarding Beinawski (1989)[14]. Observation points on SSR curve, 1a; 2b; 4a; 4b; 5a; 5b, is on stable as to slope angle recommendation of 50° – 65°. Based on the earlier research, the cause of landslide in the research field also lay in the lithology aspect, having become clay, mainly on observation point number six. However, it did not perform XRD and XRF analysis in order to know the type of clay mineral in this area.

5. Conclusions

According to the research that has done, the quality of rock mass in the area is on average – bad scale, while safety slope recommendation points to the angle of 50° – 65°. It is expected to further research to enclose XRD and XRF analysis in order to find out the type of its clay mineral in the field with the result that the interpretation can be more complicated.

References

[1] J. Peng et al., “Heavy rainfall triggered loess–mudstone landslide and subsequent debris flow in Tianshui, China,” *Engineering Geology*, vol. 186, pp. 79–90, 2015.

[2] Raghuvanshi, T. K., Negassa, L., and Kala, P. M., “GIS-based Grid overlay method versus modeling approach–A comparative study for landslide hazard zonation (LHZ) in Meta Robi District of West Showa Zone in Ethiopia,” *The Egyptian Journal of Remote Sensing and Space Science*, vol. 8, no. 2, pp. 235–250, 2015.

[3] E. Hoek, T. G. Carter, and M. S. Diederichs, “Quantification of the geological strength index chart,” in *47th US rock mechanics/geomechanics symposium*, 2013.

[4] E. Osgou, R. R., and Unal, “An empirical method for the design of grouted bolts in rock tunnels based on the Geological Strength Index (GSI),” *Engineering Geology*, vol. 107, no. 3–4, pp. 154–166, 2009.

[5] A. Pain, D. P. Kanungo, and S. Sarkar, “Rock slope stability assessment using finite element based modelling–examples from the Indian Himalayas,” *Geomechanics and Geoengineering*, vol. 9, no. 3, pp. 215–230, 2014.

[6] A. Taheri and K. Tani, “Rock slope design using Slope Stability Rating (SSR)? Application and
field verifications,” in *The 1st Canada-US Rock Mechanics Symposium-Rock Mechanics Meeting Society’s Challenges and Demands*, 2007, pp. 215–221.

[7] M. H. Taherynia, M. Mohammadi, and R. Ajalloeian, “Assessment of slope instability and risk analysis of road cut slopes in lashotor Pass, Iran,” *Journal of Geological Research*, 2014.

[8] I. Oktaviana, “The Effect of Rainfall and Earthquake on the Slope Stability of the Tawaeli-Toboli Road in Central Sulawesi,” 2002.

[9] W. Cakrabuana, H. Gumilar, R. Hastari, and I. A. Sadisun, “Analysis of Rock Mass Slope Stability and Strength Using Slope Mass Rating and Rock Mass Rating on Tawaeli - Toboli Highway Km 52 - 64, Palu, Central Sulawesi,” in *10th National Earth Seminar The Role of Earth Sciences in Infrastructure Development in Indonesia*, 2017, pp. 348–372.

[10] E. Hoek, *Practical Rock Engineering*. 34th ed. Canada: British Columbia, 2007.

[11] H. Sonmez and R. Ulusay, “Modification to The Geological Strength Index (GSI) And Their Application to Stability Of Slopes,” *Int J Rock Mech Min Sci*, vol. 36, pp. 743–760, 1999.

[12] S. Deni, J. Rasai, and Z. Saing, “Public policy analysis on disaster threat due to geo-environmental condition of Tugurara River in Ternate City, North Maluku Province,” *International Journal of GEOMATE*, vol. 17, no. 60, pp. 211–218, 2019.

[13] H. A. Brouwer, * Geological Explorations in the island of Celebes*. North-Holland Publishing Company. Holland: North-Holland Publishing Company., 1946.

[14] Z. T. Bieniawski, *Engineering Rock Mass Classification: A complete Manual For Engineers and Geologist in Mining, Civil, and Petroleum Engineering*. New York: John Wiley and Sons, 1989.