Analysis of Slope Stability Using Gabion Reinforcement in Dawuhan Sengon Village Purwodadi District Pasuruan Regency

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Keywords: Slope Stability, Gabion, Geo5 2024.

Abstract. The Dawuhan Sengon Village area, Purwodadi District, Pasuruan Regency, is a landslide-prone zone located on a roadside slope characterized by steep topography and high rainfall intensity. This study aims to identify the characteristics of slope failures, analyze the stability of the existing slope, and evaluate the effectiveness of gabion reinforcement in improving slope stability. This research employed a quantitative method with descriptive analysis based on field measurement data and laboratory test results. Undisturbed soil samples were collected from three slope locations, with average soil parameters including a unit weight of 13,25 kN/m³, cohesion of 7,88 kPa, an internal friction angle of 27,96°, and soil classification as SC according to the Unified Soil Classification System (USCS). Slope stability analysis was conducted using GeoFive software with the Limit Equilibrium Method (LEM) based on the Janbu method, considering slope geometry and soil mechanical parameters. The analysis results indicate that the existing slope has a safety factor (SF) value of 1,01, which is below the safety criterion specified in SNI 8460:2017 (SF ≥ 1,5), indicating that the slope is unstable. After reinforcement using gabions variation 2 at the slope toe, the SF increased to 1,85, meeting the slope stability criteria. These findings demonstrate that gabion reinforcement is effective in enhancing slope stability and can be recommended as a landslide mitigation solution for the study area.

Introduction

Indonesia is one of the countries with a high level of vulnerability to geological disasters, especially landslides. This is due to the topographic conditions which are mostly in the form of mountains and hills with quite steep slopes, as well as high rainfall throughout the year. According to Soedarmo & Purnomo (2010: 25), "A slope is a land surface that slopes from a horizontal position as a result of natural or non-human processes, which connect two different elevations.", A landslide is a movement of soil and rock masses that move abruptly towards a lower slope that is controlled by the force of gravity and slides from above a watertight layer (slide plane) [2]. Some of the factors that contribute to slope susceptibility to landslides include rainfall, thick but less dense soil structure, low rock strength, and land use patterns [3]. The pressure of the pore water in the soil also has a great influence on the stability of the slope. When the groundwater level increases due to rainfall or seepage, the effective stress of the soil will decrease so that the shear strength decreases [4].

According to data Badan Nasional Penanggulangan Bencana (BNPB) (2023), landslides rank third the most frequent disasters in Indonesia after floods and tornadoes. Pasuruan Regency, East Java, is an area with a high landslide potential because it is located on Mount Bromo, which has a steep contour and a type of soil that is relatively susceptible to weathering. Efforts to mitigate landslide disasters can be carried out through strengthening slopes. One of the commonly used reinforcement methods is gabions. Gabions are constructions made of galvanized or PVC coated steel wire filled with split stones. Its function is to withstand the lateral pressure of the soil, slow down erosion, while improving the stability of the slope. The advantages of using gabions are relatively easy to obtain materials, more economical implementation costs, and simple maintenance.

To understand the mechanism of avalanches that occur on slopes, it is necessary to evaluate and conduct a technical study of the factors that cause landslides. Based on the results of observations in the field, although previously there was no technical data related to the test of volume weight and soil shear parameters, the test results were obtained with a content weight value (ɣ) = 13.25 kN/m³, cohesion (c) = 7.88 kPa, and deep shear angle (φ) = 27.96°. From the results of preliminary testing at the landslide site, it is known that the percentage of soil granules that passed the No. 200 filter reached 26%, the liquid limit (LL) was 53.38%, the plastic limit (PL) was 17.27%, and the plasticity index (PI) was obtained at 36.10%. Based on the USCS (Unified Soil Classification System) soil classification system, this type of soil is included in the SC group, which is sandy soil with a mixture of clay.

In the planning and analysis of slope stability, a geotechnical approach is needed that can describe real conditions in the field. Geo5 software is one of the software that is often used in slope stability analysis. Through the limit equilibrium and finite element analysis method, Geo5 is able to calculate the value of the safety factor of slopes with various variations of conditions, both before and after reinforcement. Thus, the results of this analysis can be used as a basis for more accurate technical planning for landslide mitigation.

Based on this description, research on the analysis of landslide stability on slopes with gabion reinforcement in the area of Dawuhan Sengon Village, Purwodadi District, Pasuruan Regency using Geo5 software is very important. This research is expected to provide technical solutions to reduce landslide risk, improve infrastructure security, and support the sustainability of community activities around landslide-prone areas.

Research Methods

This study applies a quantitative approach with descriptive analysis as a data processing technique. Slope stability evaluation was carried out using Geo5 software with the Janbu analysis method to obtain safety factor (SF) values on existing conditions, modeling of existing slopes can be seen in Figure 1. The resulting SF value was then analyzed to determine whether the slope at the research site that had been reinforced with gabions was in a stable or unstable condition.

Analysis of slope stability with reinforcement is carried out by adding gabion structures as retaining elements. The technical data of gabions used in the planning process refers to SNI 03-0090-1999. This analysis includes several variations of slope slope modeling, which are further used to determine the safest configuration based on the calculation results. Some forms of variation of slope modeling are shown in Figure 2 and Figure 3.

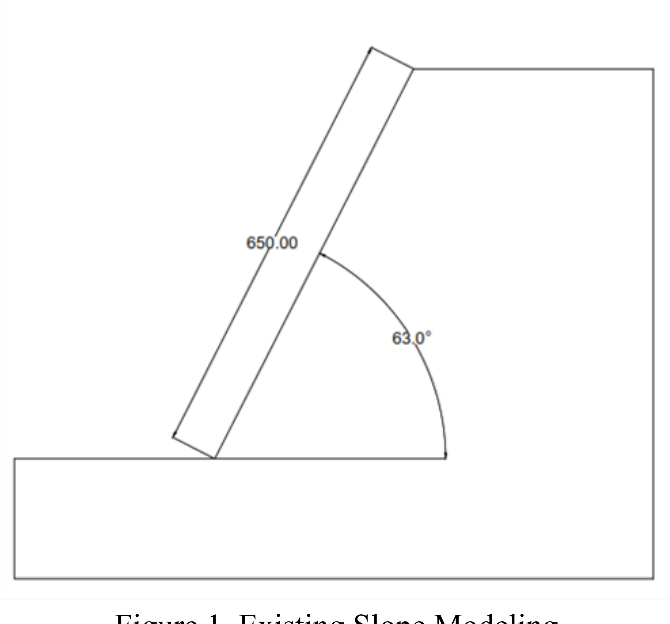

Figure 1. Existing Slope Modeling

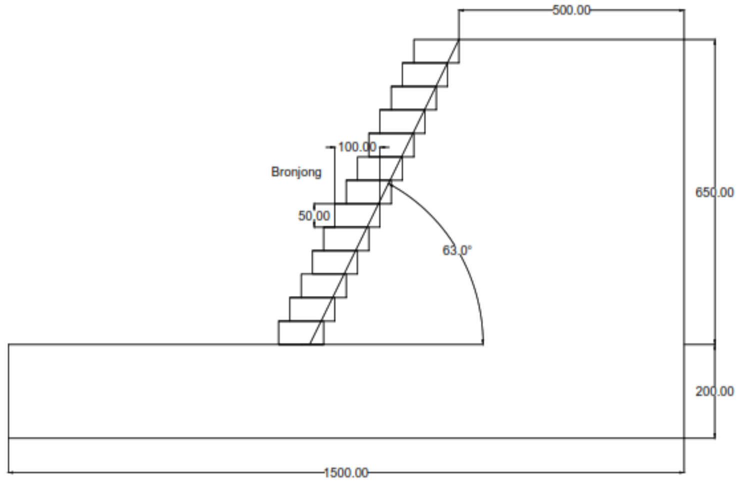

Figure 2. Slope Modeling Variation 1

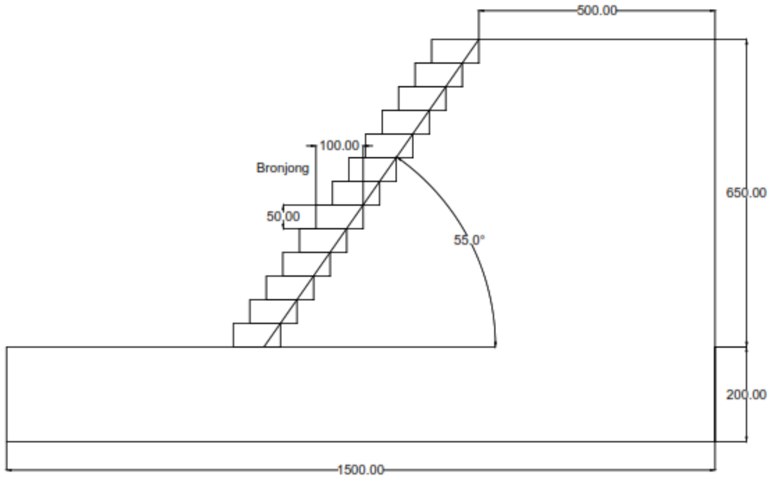

Figure 3. Slope Modeling Variation 2

The data used in this analysis is the same as the data used in the evaluation of the stability of the existing slope. The results of the analysis produced a safety factor (SF) value which was used as the main indicator to assess the effectiveness of gabions. A slope is declared stable if the SF value is ≥ 1.5, while an SF value lower than the limit indicates a potential for instability or the risk of landslides on the slope.

Results and Discussion

An evaluation of the potential for landslides was carried out on slopes that had previously collapsed on Jalan Desa Dawuhan Sengon, Purwodadi District, Malang Regency. This study assesses the magnitude of the safety factor (SF) on the slope. The soil parameters that have been obtained, along with slope geometry data, are then fed into the Geo5 software using the Mohr–Coulomb strength criterion, which is one of the common approaches in slope stability analysis. The results of modeling and the calculation of SF values are shown in Figure 4.

Figure 4. Results of Analysis of Existing Slope Stability

Based on the results of the analysis shown in Figure 4.2, the existing slope conditions produce a safety factor (SF) value of 1.01 Referring to the criteria listed in SNI 8460:2017, the slope is declared stable if it has an SF value of at least 1.5. Thus, an SF value of 1.01 indicates that the slope in its current condition is in the unsafe category, so reinforcement efforts are needed to improve its stability.

Slope stability analysis is carried out by adding gabion type reinforcement through modeling. The gabion data is designed in accordance with SNI 03-0090-1999. Several modeling variations were applied to determine the safest design, including slope slope and gabion configuration. The variation in analysis can be seen in Table 1.

Table 1. Variations of Slope Modeling with Gabions

Variations	**Slope**	**Offset Gabion**
1	63^0	0,25 m
2	55^0	0,35 m

Each design variation that has been determined is then tested to obtain a Safety Factor (SF) value that meets the minimum criteria of ≥ 1.5. Slope variation modeling was carried out using GeoFive software, in particular by utilizing the Slope Stability and Gabion modules. The results of the modeling are shown in Figure 5 and Figure 6, which illustrate the change in slope stability at each reinforcement variation.

Figure 5. Results of Variation Analysis 1 with gabion reinforcement

In reinforcement variation 1, gabions are installed with an offset trap (layer) of 0.25 meters, on slopes with a height of 6.5 meters, and the slope slope is maintained according to existing conditions, which is 63°.

Figure 6. Results of Variation Analysis 2 with gabion reinforcement

The second reinforcement variation uses gabions with a larger offset trap, which is 0.35 meters, on slopes as high as 6.5 meters, but with an adjusted slope slope of 55°. The results of the analysis of the two variations of gabion design showed that all variations produced a Safety Factor (SF) value that exceeded the minimum limit required in SNI 8460:2017. Of the two options, the second variation that used a per-block offset of 0.35-meters and a slope slope angle of 55° yielded an SF value of 1.85. This design is considered the most optimal alternative for gabion applications, because in addition to meeting the stability criteria, it is also more effective than other variations. A complete summary of the results of the stability analysis with gabion reinforcement is presented in Table 2.

Table 2. Recapitulation of Slope Stability Analysis Results After Reinforcement

Variations	**SF (SNI 8460-2017)**	**Safety Factor Results**	**Categories**
1	1,5	1,87	Safe
2	1,5	1,85	Safe

The Safety Factor (SF) value listed in SNI 8460:2017 is the minimum limit that must be met in the structural stability analysis, to ensure that the structure is in a safe condition and does not have the potential to fail. Table 3 shows the results of gabion stability evaluation for two variations, the calculation of which is done manually.

Table 3. Slope Stability Manual Calculation Recapitulation

Stability	**Safety Factor (SF)**	**Variation 1**	**Variation 2**	**Remarks**
Shear	≥ 1,5	1,90	2,01	Safe
Overturning	≥ 2	1,84	2,10	Variation 1 is unsafe
Bearing Capacity	≥ 3	4,22	3,43	Safe
Overall Stability	≥ 1,5	1,87	1,85	Safe

In the design of gabion configurations, the safety and stability aspects of the structure against various loading conditions must be ensured. Based on the results of the stability analysis shown in Table 4, the following results were obtained:

a) The stability of the overturning, with an SF value of 1.84 for variation 1 and 2.10 for variation 2, but for variation 1 did not meet the safety criteria because the value was less than the limit of the safety factor, which was >2.
b) Shear stability, with SF values of 1.90 (variation 1) and 2.01 (variation 2), respectively, which is above the required minimum limit so that it is declared safe.
c) Bearing capacity stability, with an SF value of 4.22 in variation 1 and 3.43 in variation 2, indicating a safe condition against bearing capacity failure.
d) Overall *stability*, with an SF value of 1.87 for variation 1 and 1.85 for variation 2.

The results of this study are in line with the findings from [6], which state that slope slope and loading have a significant influence on SF values, where increased load tends to reduce slope stability. Based on the overall results of the analysis, design variation 2 is recommended as the most optimal configuration, because it is able to provide an adequate level of security from all aspects of stability, and has met the requirements of SNI 8460:2017.

Conclusion

Based on the results of slope stability analysis using Geo5, the existing conditions show a Safety Factor (SF) value of 1.01, which is below the safe limit of SF $\geq$ 1.5 according to SNI 8460:2017. This indicates that the slope is in an unstable state and has the potential for landslides, influenced by steep slopes, high rainfall, and low soil shear strength parameters.

Reinforcement efforts were carried out with gabions in accordance with SNI 8064:2017, resulting in an increase in SF values to 1.87 in variation 1 and 1.85 in variation 2. All variations meet the slope stability criteria, but variation 2 design is recommended as the most optimal solution because it is able to produce SF = 1.85. Thus, gabions have been proven to be effective in increasing slope stability and are suitable for application as a landslide mitigation method at the research site.

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