Rock Slope Stability Evaluation on The Construction of New Road Shortcut 4 Border City of Singaraja – Mangwitani, Bali

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Abstract. Shortcut 4 new national road development project on Singaraja - Mangwitani section Bali found a potential rock slide slope problem. An outcrop of igneous rock with an intensive joint was not expected to be encountered previously. The excavation work in road construction had to pay attention to the stability of the resulting rock slope considering that apart from the potential for slope failure, rock slope could also threaten the bridge abutment building in front of it. The location of the rock slope was on the edge of Lake Bratan which is geologically part of the early Holocene volcanic rocks, namely mountain rocks composed of tuff, lava and volcanic breccia. Anisotropic andesite slope was controlled by a discontinuous plane with a certain pattern. Rock Quality Assessment was carried out by the Rock Mass Rating (RMR) method and Slope Mass Rating (SMR) for slope stability evaluation. The planar, tople and wedge potential slope failure were evaluated. The potential for planar slope failure has a value of SMR 30.18 (Unstable), 57.6 (Partially Stable) for wedge slope failure potential and 47.6 (Partially Stable) for tople slope failure potential. The SMR value indicated that the rock slope requires engineering treatment to become stable.

1. Introduction

National road development on Bali was carried out to support economic and tourism connectivity and reduce travel time from North Bali to South Bali or vice versa. The construction was executed to improve the geometry of the existing road by making shortcuts. Shortcut 4 was one of the road construction projects located in the Singaraja – Mangwitani City Boundary road section. The founding of rock slopes composed of andesite with intensive joints became one of the geotechnical problems that occurred in the construction of this road (shortcut 4). The rock slopes was found locally, and was not expected to be encountered in a road construction project using the Design and Build method so that the analysis of rock slope stability had never been done before.

Assessment of rock slope stability is very important in order to ensure the safety of workers and road users during operations as well as saving the road asset itself considering that the rock slope is right in front of the abutment of the bridge. Rock Mass Rating (RMR) method was conducted as an empirical approach for an assessment of the rock slope stability analysis. The rock mass quality score then was used as the basis for determining the Slope Mass Rating (SMR) score.

Geological Map Sheet of Bali [1] showed that generally the construction of the existing route on the Singaraja – Mangwitani City Boundary Road Section (Shortcut 4) and its surroundings was located in a volcanic area (Figure 1.)
The volcanic formations of the regional geological map of this construction are namely:
1. Quaternary alluvium (Qal) in the form of alluvium units in the form of lake deposits located on the north side of Lake Beratan, the lithology of these deposits is in the form of gravel, gravel, sand, silt, and clay.
2. Formation Qv (l, p, s) of late Holocene age, namely volcanic rocks of the Lesong-Pohen-Sengayang group which are composed of sub-recent volcanic rocks; Mount Lesong mainly produces lava, breccia, lava and tuff (Qvl), Mount Pohen produces volcanic breccia (Qvp) and Mount Sengayang activities produce tuff (Qvs).
3. The formation (Qpbb) is of early Holocene age, namely volcanic rocks of the Buyan-Bratan and Batur groups which are composed of tuff, lahars and volcanic breccias.

Regional Geological Conditions show that the influence of Quaternary volcanism activity was very strong in the stratigraphy of the construction location. This condition was supported by morphological data indicating that the survey location was in the volcanic caldera area (Figure 2). The survey area was on the southern side of the volcanic caldera which can be shown from the semicircular morphological appearance which is the remnant of the volcanic body.

Figure 1. Construction area on regional geological map
Figure 2. The morphology of the study site seen from the DEM map shows the morphology of the caldera

2. Method
The following methods was generally carried out as rock slope stability analysis:
1. Conducting local geological mapping to determine rock types
2. Taking measurements in the field by scanning the location of rock outcrops.
3. Calculating the value of rock mass quality using the RMR method
4. Determining the potential type of rock slope failure
5. Determining score of Slope Mass Rating (SMR) as stability level of the slope
6. Providing advice on slope management based on the SMR score.

2.1. Rock Mass Rating (RMR)
Andesite outcrop has a tendency to collapse in a certain direction which is controlled by the existing discontinuity plane or was referred to as anisotropic rock. RMR is an approach to determine the quality of rock mass based on anisotropic rock. RMR is a method for assessing rock mass quality that is used as a reference throughout the world. Modifications to the basic RMR have developed as of RMR14, but both RMR and RMR14 are all used and for practical needs in the field [2]. Basic RMR calculation using the measurement results of five main parameters including Uniaxial Compressive Strength (UCS) intact rock material, Rock Quality Designation (RQD), discontinuity field spacing, field conditions and discontinuities and groundwater conditions are still effectively used for various research needs [3]. The rock mass classification of the RMR method uses five main parameters [4], the parameters mentioned
above can be obtained by measurement in the field. Measurements were made along the outcrop of rocky slopes.

2.2. Slope Mass Rating (SMR)

Slope Mass Rating (SMR) is the development of RMR as an empirical evaluation method for slope stability [5]. SMR is obtained based on the RMR value by providing an adjustment factor that depends on the relationship between the orientation of the discontinuity plane and the orientation of the slope to be analyzed (Table 1) and added adjustment factors to the excavation method (Table 1). This relationship can be seen in the following equation

$$SMR = RMR + (F1.F2.F3) + F4$$

(1)

Slope Mass Rating (SMR) values are classified into five classifications from very unstable to very stable [6] (Table 2).

| Table 1. Adjustment factor SMR [5]. |
|-------------------------------------|
| Slope Failure Potential | Highly favorable | Favorable | Fair | Unfavorable | Very Unfavorable |
| Planar | I αj - as I | > 30° | 30 - 20° | 20 - 10° | 10 - 5° | < 5° |
| Toppling | I αj - as - 180 ° I | 0,15 | 0,4 | 0,7 | 0,85 | 1 |
| Wedges | I αi - as I | Planar/Wedges/Toppling | F1 | 0,15 | 0,4 | 0,7 | 0,85 | 1 |
| Planar | βj | < 20° | 20 - 30° | 30 - 35° | 35 - 45° | > 45° |
| Toppling | βi | Planar/Wedges | F2 | 0,15 | 0,4 | 0,7 | 0,85 | 1 |
| Wedges | Planar/Wedges | F3 | 0 | -6 | -25 | -50 | -60 |
| Excavation Method | Natural Slope | Blasting with Pre-splitting | Smooth blasting | Normal blasting or mechanical excavation | Poor blasting |
| F4 | 15 | 10 | 8 | 0 | 8 |

| Table 2. Determination of SMS class [6]. |
|----------------------------------------|
| Class Number | V | IV | III | II | I |
| SMR Value | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 |
| Rock mass description | Very Bad | Bad | Fair | Good | Very Good |
| Stability | Completely unstable | Unstable | Partially stable | stable | Completely stable |
| Failure | Big Planar or soil - like or circular | Planar or Big Wedges | Planar along some joint and many wedges | some block failure | No failure |
| Probability of failure | 0,9 | 0,6 | 0,4 | 0,2 | 0 |
The SMR value can then be used as a reference in determining slope engineering with additional reinforcement (Table 3) [7].

| SMR Classes | SMR Value | Support System Recommendation |
|-------------|-----------|------------------------------|
| Ia          | 91 to 100 | No Need Support system       |
| Ib          | 81 to 90  | No Need Support system, Scaling is required |
| II a        | 71 to 80  | (No Need Support system, toe ditch or fence) Spot bolting |
| II b        | 61 to 70  | (Toe ditch or fence nets), spot or systematic bolting |
| III a       | 51 to 60  | (Toe ditch and/or nets), spot or systematic bolting, spot shotcrete |
| III b       | 41 to 50  | (Toe ditch and/or nets), spot or systematic bolting, systematic shotcrete, |
| IV a        | 31 to 40  | Anchor, Systematic shotcrete, toe wall and/or concrete (or re - excavation), drainage |
| IV b        | 21 to 30  | Systematic reinforced shotcrete, toe wall and/or concrete (or re - excavation), deep drainage |
| Va          | 11 to 20  | Gravity or anchored wall, re-excavation/ change Geometry |

3. Results and Discussion

3.1. Lithology

The lithology of the survey site corresponds to regional conditions. The excavation slopes of the shortcut 4 construction resulted in andesite (Figure 3), scoria, unconsolidated lava breccia and unconsolidated tuffan sand.

The abutment I (Bridge) is located in front of the unconsolidated breccia, while abutment II is in front of the andesite slope. In this study, the discussion focuses on the stability of the andesite which is strongly bonded in abutment II. Highly jointed andesite was indicated as a columnar joint that had a porphyroaphanitic texture, degree of hypocrystalline crystallization and granular hypidiomorphic intercrystal relationships. The genesis of this rock was interpreted as being formed from a shallow intrusion (volcanic neck). The intact rock strength of this rock is estimated to be > 20 Mpa [8].

Scoria was also found at location abutment 2. Red scoria, the product of the freezing of a volatile-rich solution from magma solution, consolidated and isotropic, was interpreted to have a compressive strength of < 5 MPA. Andesite is indicated to come last and break through pre-existing rock units such as scoria and laharc deposits which causes the scoria and laharc layers around it to tilt (Figure 4).

3.2. Rock Mass Quality

The Road Construction of Singaraja City Border – Mangwitani Bali section (shortcut 4) was focused on andesite outcrops which had the potential for kinematic landslides and have the greatest impact. The potential for instability was controlled by the structure (joint) with a certain direction pattern. Because
of these properties, the approach to observe or determine the quality of rock mass was carried out by identification of each discontinuity plane within RMR method [4]. The measurement method was carried out with a 47 meter long scanline. The andesite slope was determined as of a good rock mass quality (Good Rock) based on the RMR assessment of rock mass quality. SMR score was produced by some adjustments of the RMR analysis which has been carried out before. Geological Strength Index (GSI) was not conducted in this study because the andesite slope is an anisotropic rock and GSI is more suitable to be applied to isotropic rocks [9].

3.3. SMR Analysis of Planar failure Type

Analysis of the planar type failure was based on field observations that show the straightness of the joint (major) plane (Table 4). The structure was interpreted as the dominant pattern in planar type failure at the slope location. The dominant direction of the discontinuity plane as the basis for the analysis was as follows: N265°E/68°.

The direction data of the discontinuity plane, which is interpreted as the main controlling plane of the planar type of failure, was analyzed with the value of rock mass quality (RMR) and the existing slope data to obtain the SMR score (Table 4). From the results of the SMR analysis for the type of planar failure, it can be seen that the slope belongs to a bad and unstable slope with a probability of failure of 0.6. Based on the results of the SMR analysis above, the slope need improvement of geometry to stabilize the slope or it required very strong reinforcement (Table 4).

3.4. SMR Analysis of wedge-type failure

The wedge-type failure analysis was based on the measurements and directions of two intersecting dominant joints (Table 5). This structure was interpreted as the dominant pattern of wedge-type failure at the abutment slope location 2. The two joint structures are N222E/86 and N337E/78. The intersection between the two discontinuity planes was on an imaginary line which is a weak line controlling wedges type slope failure for the abutment slope location, the direction of the line is N024E/64° as the basis for the analysis.
The 2-way intersection data of the discontinuity plane, which is interpreted as the main weak plane controlling wedges-type failure, was analyzed with rock mass quality (RMR) values and existing slope data to obtain SMR values (Table 5). From the SMR score of wedges failure kinematic analysis, it can be seen that the slope is a partially stable slope with a probability of failure of 0.4 (Table 5).

### Table 5. Details of determining the SMR score for the potential for wedges failure.

| RMR | Slope Plan excavation data | Discontinuity data of slope | Weighting Factors (Romana, 1985) | SMR |
|-----|---------------------------|-----------------------------|----------------------------------|-----|
|     | (SLOPE DIRECTION) (A) | Main Strike of slope (B) | DIP of slope (C) | strike (D) | dip (E) | F1 (D - B) | F2 (E) | F3 (E - C) | F4 |
| 65.18 | 15 | 285 | 70 | 69 | 24 | = 1.24 - 285 1 | 69 | -1 | 0 | 57.69 |

3.5. SMR Analysis of topling-type failure

The topling-type failure analysis was based on field observations that showed the straightness of the joint (major) plane (Table 6). This structure was interpreted as the dominant pattern of topling-type failure at the abutment slope location 2. The dominant direction of the discontinuity plane as the basis for the analysis was as follows: N090 °E/56°.

### Table 6. Determination of Slope Class from potential topling failure. [7]

| Romana (1985) | Sighn & Goel [7] |
|---------------|------------------|
| Class III (Partialy stable, Planar along some joint and many wedges, PROBABILITY OF FAILURE 0.4) | III b | SMR 47.68 | spot or systematic bolting, systematic shotcrete, (Toe ditch and/or nets), toe wall and/or dental concrete |
toppling failure, it can be seen that the slope belongs to partially stable with a probability of failure of 0.4 (Table 6).

4. Conclusion
The volcanic intrusion of the andesite could produce some kinematic failure potential. RMR and SMR could be conducted as effective methods for assessing anisotropic slope type like columnar joint andesite slope. From the assessment, we found that the RMR score for this slope was 65.19 (Good Rock) and SMR score of the biggest potential failure (planar) was 30.19 which is classified as slope class IVA or unstable. Based on empirical analysis of this location, we have to conduct some treatment to counter the kinematic failure potential, especially planar failure.

The numerical analysis will be conducted in the future study to be compared with empirical analysis, and the numerical analysis have to be supported by some appropriate parameters which exactly represent the real parameter of the slope. Geological Strength Index will be conducted to prove the effectiveness of this method to assess the rock slope stability in addition to the RMR and SMR.

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