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Type of Rockslide along the Ponorogo – Pacitan Roads, East Java, Indonesia

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ABSTRACT The Pacitan Regency, located in the southwestern part of East Java Province, is one of the areas with low economic growth. Difficult accessibility is one of the reasons for the slow development of this region. To reaching the Pacitan Regency it can take through the Ponorogo – Slahung – Arjosari - Pacitan roads. Based on the geological condition most of roads are built on geologic formations composed of Oligocene - Miocene volcanic and intrusive rocks. Mass movement often occurs along roads and disturbs the transportation of goods and people. This paper discusses the types and mechanisms of slope failure along roads. Recognizing these two aspects of slope failure plays important role to treat them. The field survey identified 13 landslide zones with a 50–200 m bright. Based on rock type, weathering and alteration levels, and geological structure, slope failure can be classified into three types. First, the wedge rockslide occurred on the low-altered dacitic lapilli tuff. The planar – toppling type of rockslide occurred in the residual soil of the andesitic basalt lava with columnar and sheeting joint. Third, complex circular debris slides occur in highly jointed and altered dacitic intrusive rocks, which contain a large amount of clayey material. The third slide type that occurred at km 226 requires further research with an interdisciplinary approach because of moving the 200-meter-long road mass.

KEYWORDS rockslide, debris material; geologic structure, and alteration

1 INTRODUCTION

The Pacitan Regency is in the southwestern part of East Java Province, Indonesia. It is also known as one of the regions with low economic growth, although in the region, there are high economic resources, such as agricultural products, capture fisheries, metal and non-metal minerals, and tourism. The main problem with economic development is the availability of transportation infrastructure. The only available transportation infrastructure is roads.

The first route passes through Ponorogo – Slahung – Arjosari - Pacitan road. Almost two-thirds of the tracks in this route are parallel to the Grindulu River. Second, the South Coast Road of Java Island takes the Trenggalek – Panggul - Lorog - Pacitan road. The third is the route that crosses Surakarta – Wonogiri – Punung - Pacitan. Among these routes, the first route is frequently passed and managed by the Government of East Java Province. Along the Ponorogo - Pacitan road there are many rockslides because the location coincides with the Grindulu fault which is trending Southwest - Northeast. The rockslide countermeasures have been carried out by the Highways Office of East Java Province, but only to prevent rockslide material to block the road. This study aims to determine the type of rockslide and the main contributor factors. By knowing the main contributing factors, rockslide suitable countermeasures can be planned.

Slope failure occurs in many forms and occurs in many places in Indonesia. There is a wide range in their predictability, rapidity of occurrence and movement, and ground area affected, all of which are transmitted directly to the consequence of failure (Hunt, 2007). Understanding the factors, types, and mechanisms of slope failure plays an important role in the analysis of slope stability and treatment plans (Cheng and Lau, 2014). Slope failure that occurs within the rock mass is generally associated with the level of weathering; the geological structure that is present in the rock mass, such as faults, joints, and bedding; and groundwater seepage. The geological structure can be the slip plane of rock mass movement. In addition, the geological structure can cause changes in the physical-mechanical characteristics of the rock mass and accelerate weathering and hydrothermal alteration processes. All these parameters decrease the stability of the rock slope (Chen et al., 2015).

The discontinuity orientation of the rock forms four types of failures: plane, wedge, and toppling, also circular. However, under certain conditions, a combination of several major types of rock failures may occur. In this case, an irregular form of failure was found, which is also known as a complex type of failure. Determining the sliding type of the cutting rock slope and mapping the orientation of the discontinuity both before and after the rock slope cut is necessary to plan engineering protection against slope failure (Romana, 1985).

Analytical methods are commonly used to calculate soil slope stability. However, these methods are often ineffective in predicting the potential for rock slope failure and its treatment because the rock slope stability is influenced by more factors than the soil slope. Hence, using empirical designs based on rock mass classification is more important than using analytical (Rahman et al., 2023).

Several researchers have proposed rock mass classifications such as the geological strength index (GSI) proposed by Barton (1974), rock mass rating (RMR) by Bieniawski (1973, 1989), and slope mass rating (SMR) by Romana (1985). Slope Mass Rating (SMR) is a classification system developed based on the Bieniawski Rock Mass Rating (RMR) theory, which was originally proposed for tunneling. SMR is also known as a further classification of RMR, which is intended for the probability of rock mass failure. These three rock mass classifications are calculated based on the mechanical properties of the rock, the uniformity or density of the geological structure, the level of weathering or alteration, and the presence of groundwater (Romana et al., 2003; Marinos et al., 2007; Hoek et al., 2013, Abbas & Konietzky, 2015).

2 LOCATION AND METHOD

The study of slope failure took place along the Ponorogo-Slahung–Arjosari-Pacitan road. Geographically, this route is located at 7°58'20.0" S and 111°25'50.6" E to 8°06'14.4" S and 111°09'50.2" E. This route is one of the longest lanes, located 220–275 km from Surabaya, the capital of the East Java Province. Almost two-thirds of the routes are on the banks of the Grindulu River, which is formed by the southwest-northeast shear fault (Figure 1 and Figure 2).

Figure 1. Study Location on map of the highway and railway network in East Java Province, Indonesia

This field survey was conducted by observing landslides and their controlled parameters. Parameters such as rock type, joint intensity, weathering or alteration level, groundwater seepage, and other parameters expected to affect the landslides were observed. Documentation was also performed to visually record the data. Rock and soil sampling was also performed for laboratory testing. The slope stability of the rock mass has been analyzed using numerous methods, such as the Geological

Strength Index (GSI), Rock Mass Rating (RMR), and Slope Mass Rating (SMR) (Singh and Goel, 2011; Abbas and Konietzky, 2015; Wyllie and Mah, 2017).

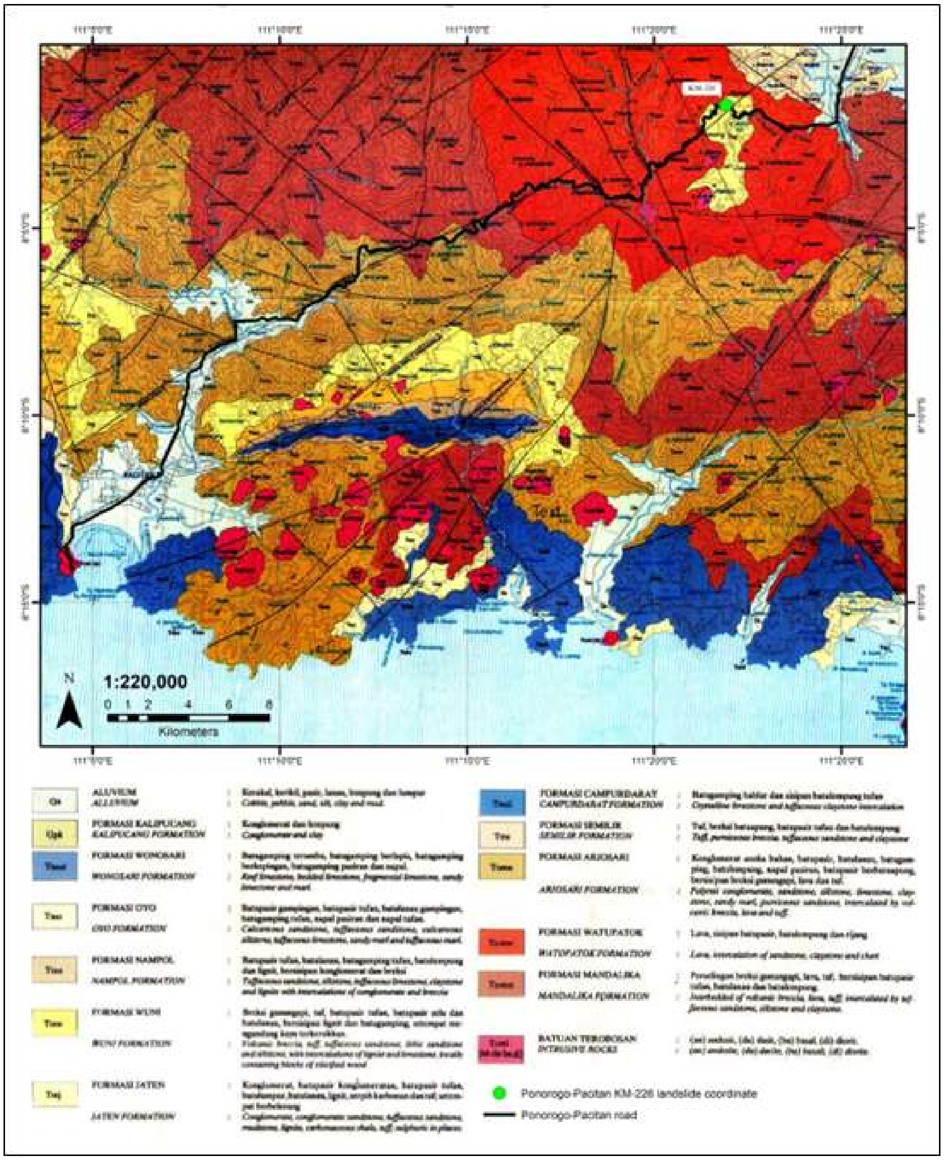

Figure 2. Map of the route of Ponorogo - Pacitan road ploted on the Geological Map of the Pacitan (Samodra et al., 1992)

GSI is a simple and fast rock mass classification, the parameters used are rock type, geological structure, and surface conditions of the discontinuity of the rock mass (Marinos et al., 2005). The determination of the GSI value is carried out by observing the general condition of the rock mass and observing its geological structure which includes the number of sets of geological structures/discontinuity and its surface conditions.

Rock Mass Rating (RMR) is a rock mass classification based on 6 parameters, namely : (a) the unconfined compressive strength (UCS) of intact rocks; (b) the Rock Quality Designation (RQD) of the rock mass; (c) spacing of discontinuities; (d) condition of discontinuities; (e) groundwater, and (f) the orientation of discontinuities, and the rock masses can be grouped into 5 classes (Bieniawski, 1989). Apart from being based on field investigations and laboratory tests, the RMR value can be calculated by equation (1)

$$GSI = RMR - 10 \quad (1)$$

In this study, the RMR value was also calculated based on the two methods. RQD values are not obtained from observations of drill core, but from field observations along 1 pole meter at 3 points at each observation point.

The Slope Mass Rating (SMR) developed by Romana (1985) is based on the RMR value (Bieniawski, 1989). This classification system uses a correction factor that is based on the orientation of discontinuities and slopes, as well as the excavation method applied.

3 GEOLOGY

Based on the physiography of the eastern part of Java Island, all Ponorogo – Pacitan roads are located in the southern mountain zone. This zone is a transition between the Mesozoic paleo-subduction pathway (northeast-southwest) and tertiary subduction (east-west) that formed a tertiary magmatic arc.

All these routes are often meandering, uphill, and downhill. Based on the Geological Map of the Pacitan (Samodra et al., 1992), most of the Ponorogo-Pacitan road was built on rock formations that were composed of volcanic and intrusive rocks of the Oligocene–Miocene age. Generally, these rocks have high stability because they have high uniaxial compressive strength and are resistant to weathering. The road was built on three rock formations (Figure 2), called the Arjosari Formation, the Mandalika Formation, and the Watupatok Formation.

The Arjosari Formation (Toma) is composed of andesitic lava, tuff, polymic conglomerates, and sandstones. The Mandalika Formation (Tomm) is composed of volcanic breccias, basaltic andesite lava and tuff, tuff sandstones, siltstone, and claystone. In the western southern mountains, the Mandalika Formation is aligned with the Nglanggran or Old Andesite Formation of the Kulonprogo. The Watupatok Formation (Tomw) is composed of dacitic lava intercalated with sandstone, claystone, and chert. These three formations formed during the Oligocene to Early Miocene (Samodra et al., 1992).

The geological structures that develop along the path of Ponorogo - Pacitan and its surroundings are normal faults, shear faults, and joints. Some faults have a northwest–southeast or the northeast-southwest. The northeast-southwest direction fault has a type of left horizontal movement, while the northwest-southeast direction fault moves to the right. The shear fault system in this research location intersects and forms a "V" pattern, with northwest-southeast and northeast-southwest directions (Hidayat et al., 2021). Primary structures, such as columnar and sheeting joints, are often found in igneous rocks. A folding structure with an east-west trending axis can also be found (Samodra et al., 1992).

Based on the geological map, two-thirds of the Ponorogo–Slahung–Arjosari–Pacitan road is located in the shear fault zone, called the Grindulu Fault. This zone includes the Tegalombo Arjosari-Pacitan Fault and the Kayuwayang Fault on the Slahung–Tegalombo line. The presence of these faults is a major cause of rock slope failure in this region (Hidayat et al., 2021).

4 RESULTS AND DISCUSSION

Along the Ponorogo - Pacitan road, there were at least 13 landslide points with widths of 50–100 m. Based on the material, geological structure, and slide plane, they can be grouped into three types: Wedge Rockslide, Planar – Toppling Rockslide, and Complex Circular Debris Slide (Figure 3 and Table 1).

4.1 Wedge Rockslide

This type of slope failure happened at km 259 to 262 of the Ponorogo - Pacitan road. The height of the slope varied between 8 m and 10 m. The average dip of the slopes ranged from 60° to 75°. The debris material consisted of a mixture of angular gravel of lapilli rock, tuff, and clayey soil. Lapilli, tuff, and lapilli tuff are parts of the Arjosari Formation. The existence of clay in the rock indicates that the alteration process occurred. Based on Terzaghi's Rock Mass Classification, the rock mass was classified as crushed rock.

Based on geological descriptions, it had an estimate of GSI = 45, whereas the RMR analysis obtained a value of 54. The RMR value can be classified as a fair rock mass (class III). In addition, from the SMR analysis, it was included in Class IV. This class is normal and unstable slope. The probability failure of planar or big wedges are more than 0.6. The recommended slope support methods that can be used in this case are shotcrete and dental concrete.

4.2 Planar – Toppling Rockslide

This type of mass movement occurs on basaltic andesitic rocks. This lava volcanic rock has a columnar and sheeting joint structure, and the thickness of the weathered zone is 30–150 cm. After Terzaghi's Rock Mass Classification, the material can be classified as moderately jointed rock, which occurs between 232 and 256 km. The dip of the slope was 75–85°. The planar rockslide begins by the movement of weathered rock, then is followed by the collapse of the rock mass. The direction of rock toppling failure is like the dip of the slope.

Based on the results of the GSI and RMR analyses, the values obtained sequentially were 83.25 and 74. Based on this RMR value, the rock mass is categorized as a good rock class (class II). In addition, based on the SMR method, the slope was classified as Class III. This implies that it is a normal and partially stable slope. Some joints may be observed in this typical slope failure, with a failure probability of approximately 0.4. Bolting and anchoring can be used as the recommended slope support method in this case.

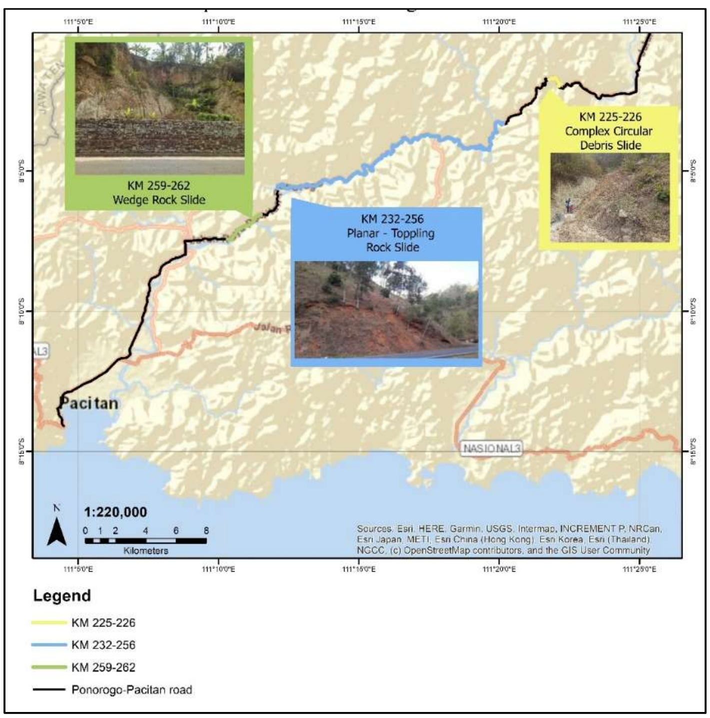

Figure 3. Type rock slide on the Ponorogo – Pacitan road and its distribution

4.3 Complex Circular Debris Slide

This type of slope failure occurs at kilometers 225–226, and the dip of the slope is between 65° and 75°. Rock mass materials are composed of highly jointed and altered dacitic intrusive rocks; there are many clay minerals as product of pyrophyllite alteration. Some outcrops of unaltered dacitic rocks were still found. According to Terzaghi's Rock Mass Classification system, the material can be classified as blocky or steamy rock. Among these three types of landslides, this complex debris slide has the widest distribution and causes road damage.

The results of the rock mass analysis showed that this type of failure has a value of GSI = 31.5 and RMR = 39. The rock mass of this slope was categorized as a poor rock class (class IV) since its RMR value. For the SMR analysis results, the slope was included in Class V. The presence of faults or rock formation boundaries also contributed to the collapse at this location. The slopes in this class were completely unstable and in very poor conditions. The probability failure of a complex circular debris or soil-like is up to 0.9. The recommended slope support methods used in this case were re-excavation walls and drainage installation (both surface and deep drainage).

5 CONSLUSION

Almost two-thirds of the Ponorogo–Slahung–Arjosari–Pacitan road is located on the Grindulu strike-slip fault zone, which has southwest–northeast directions. This fault results from several joints in a very diverse direction and is followed by an alteration process in the volcanic rock. The alteration process produces clay minerals that contribute to the decreasing slope stability. Along this road, 13 slope failures were identified, which can be classified into three types: wedge failure, planar - toppling failure, and complex circular debris slide.

The complex circular debris slide which located at kilometer 226 needs to be further researched using various methods, to determine the depth of the slip plane, the presence of geological structures and groundwater. This complex debris slide causes road damage along 200 meters, and also has the potential to cut off the Ponorogo - Pacitan road.

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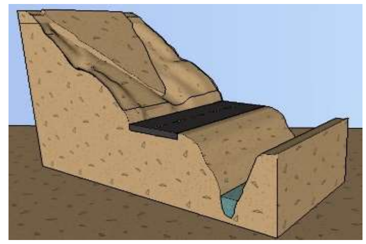
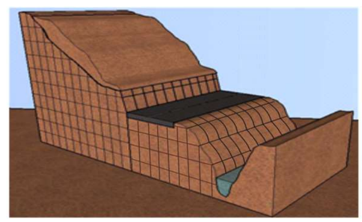
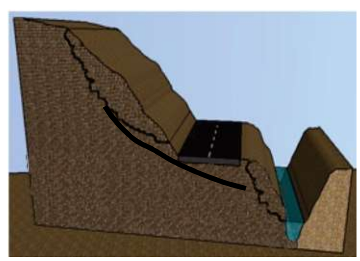
Table 1. Identification and Rock Mass Classification of slope along Ponorogo – Pacitan road, East Java, Indonesia

No	Field Condition	Discription of Material	Type and Model of Slope Failure	Rock Maas Classification of Slope
1	 	The slope failure occurs on low altered of dacitic lapilli tuff rocks. There is clay material as alteration product. Based on Terzhagi's Rock Mass Classification, the rock mass materials classify as crushed rock.	*Wedge Rock Slide* 	GSI = 45 RMR = 54 (Fair Rock) SMR = IV (Bad, unstable, big wedges failure, failure probability 0.6)
2	 	The slope failure occurs on the high weathered zone of basaltic andesite lava with columnar joint structure. After Terzhagi's Rock Mass Classification, the material can be classified as moderately jointed rock.	*Planar Soil Slide – Toppling Rock Slide* 	GSI = 81.25 RMR = 74 (Good Rock) SMR = III (Normal, partially stable, some joint failure, failure probability 0.4)
3	 	This type of slide occurs on phyrophilic alteration of intrusive dacitic rock. Dacite is high jointed with close spacing. Based on Terzhagi's Rock Mass Classification system, the slide material can be classified as blocky and steamy rock.	*Complex Circular Debris Slide* 	GSI = 31.5 RMR = 39 (Poor Rock) SMR = V (Very bad, completely unstable, soil like failure, failure probability 0.9)

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