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Rock Slope Stability Assessment Using Kinematic Analysis on Mining Area at Palu, Central Sulawesi, Indonesia

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Abstract
The rock mining industry in Palu is generally carried out using the open pit mining method, which can result in excessive steepness of the slope and has the potential to cause slope failure. This potentially causes huge losses because it can disrupt the production process and even worse it can cause casualties. This research was conducted to assess the rock slope stability using kinematic analysis. Kinematic analysis is used to identify the potential types of slope failure such as planar sliding, wedge sliding, and toppling. The methods used in this research include rock scanline, UAV photogrammetry, and slope failure observation. The kinematic analysis shows that the rock slope has 26.26% for wedge sliding, 10.19% risk for planar sliding, and 2.43% for flexural toppling. Hence, the use of kinematic analysis based on photogrammetric data in rock slope characterization is reliable because it can provide valuable preliminary information on rock slope stability assessment.
Keywords: *Rock Slope Stability, Kinematic Analysis, UAV Photogrametry*

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I. INTRODUCTION

Andesite has been mined for a long time in Palu because it can be used as a basic material for building foundations, concrete mixes, road coatings, and others as it has a high composition of silica (SiO_2) content **[6][7]**. The rock mining industry in Palu is generally carried out using the open pit mining method, which can result in excessive steepness of the slope and has the potential to cause slope failure. This potentially causes huge losses because it can disrupt the production process and even worse it can cause casualties. Field observations show that the slopes are composed of rocks with many discontinuities and weathering effects. The slope angle is steep and there is a history of rockfall in several locations. In addition to rockfalls, there is also the potential for avalanches of the type of flow of debris from the rest of the mining process that is piled up on the slope area. Therefore, it is necessary to conduct an immediate preliminary assessment of other potential collapses that could potentially occur.

1.1 Rock Discontinuity

Discontinuity is defined as a general term referring to any discontinuity in a rock body that has a very low tensile strength or no tensile strength at all. Discontinuities can refer to joints, faults, laminated planes, and weak zones **[3]**. In general, different types of discontinuities have different size ranges.

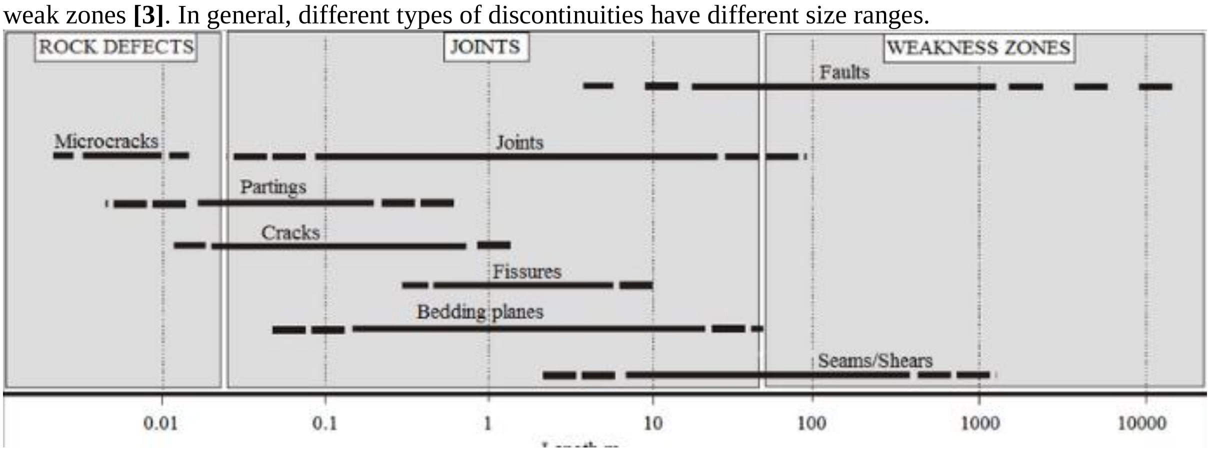

Figure 1: Types of discontinuities defined in engineering geology [5].

1.2 Rock Scanline

Scanline is a technique that is often used in discontinuity surveys. This is because the Scanline utilises simple-to-find tools and an uncomplicated working method. A length of tape is stretched along the face of a rock slope and both ends are attached to the slope face. Any discontinuities encountered along the cross section of the tape are recorded. Discontinuity parameters recorded are orientation, presistence, spacing, roughness, aperture, filling and presence of water. Figure 2 shows the discontinuity characteristics in the rock mass **[2].**

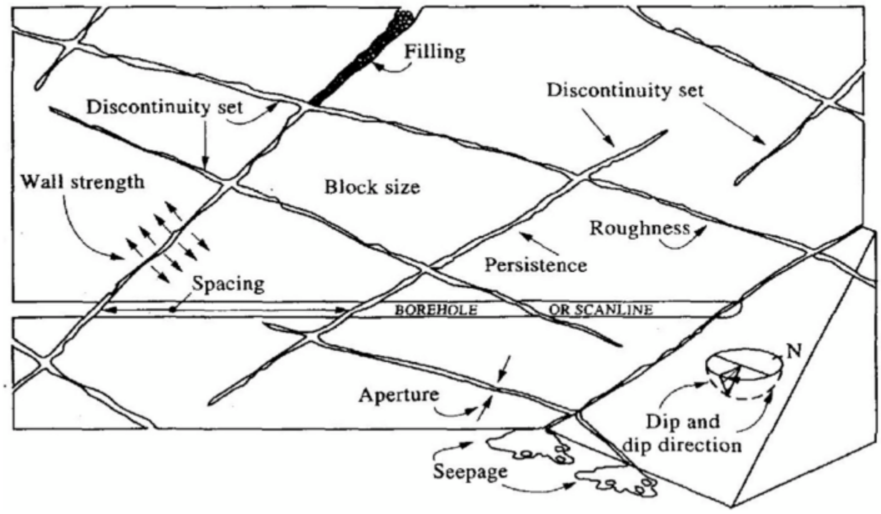

Figure 2: Discontinuity characteristics in the rock mass [2].

1.3 UAV Photogrametry

The photogrammetric method acts as a complement to the scanline technique that has been implemented. It can help analyse discontinuities that cannot be achieved with the scanline method. In addition, a 3D model can also be generated, which helps to measure the size and volume of the blocks more accurately. The method involves taking slope images that overlap at least 60% along the slope. The images are then processed to produce a dense cloud mesh, and elevation model. The resulting photogrammetric 3D model helps identify discontinuity systems that are beyond human reach using scanline techniques. Therefore, this Photogrammetric analysis is more complementary to discontinuity surveys.

1.4 Kinematic Analysis

There are four main types of failure due to discontinuities: circular, planar, wedge and toppling. Analysis of these discontinuity systems, also known as kinematic analysis, uses stereonet projections of equal width. In addition to the discontinuity orientation in the stereonet projection only, potential failures also need to fulfil the general conditions according to the type of failure **[1][8]** as follows:

Planar Failure

- The plane causing the collapse must be parallel or nearly parallel (±20°) to the direction of the slope surface.
- The inclination of the plane must be less than the slope.
- The slope of the collapse plane must exceed the friction angle of the plane.
- The top edge of the collapse plane must intersect the top of the slope (to the surface) or in the form of a tension crack.
- On the failed side of the block there must be a plane that 'releases' the block or there must be circumstances where the block can fail without the aid of a releasing plane.

Wedge Failure

- The two planes must intersect on a line. In stereonet, the line of intersection is represented at the point where two great circle lines meet, and the orientation of the collapse line is represented by the dip direction and dip value.
- The collapse line must be steeper than the slope and steeper than the friction angle of the two intersecting planes.
- The line of intersection must dip towards the outside of the slope surface for collapse to occur.

Toppling failure

- The presence of a near vertical discontinuity plane (Slope >70°) facing the face of the slope can cause rock blocks to topple and fall.

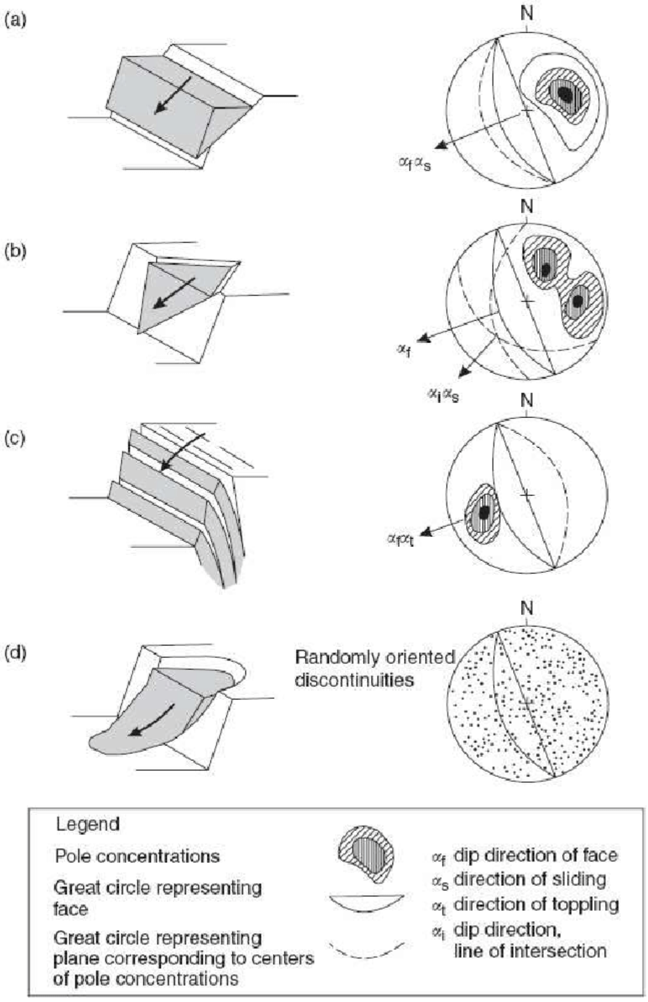

Figure 3: Main types of block failure mechanisms in slopes: (a) Planar, (b) Wedge, (c) Toppling and (d) Circular failures [8].

II. RESULT AND DISCUSSION

The Study area is located in Buluri, Palu, Central Sulawesi, Indonesia. The exact location of the study area is 0°50'29.3"S 119°48'44.5"E. The rock slope has a length of 150 metres and a height of 80 metres with many discontinuities and weathering effects on the slope. Rock slopes excavated for andesite rock mining using the open pit method as shown in Figure 4.

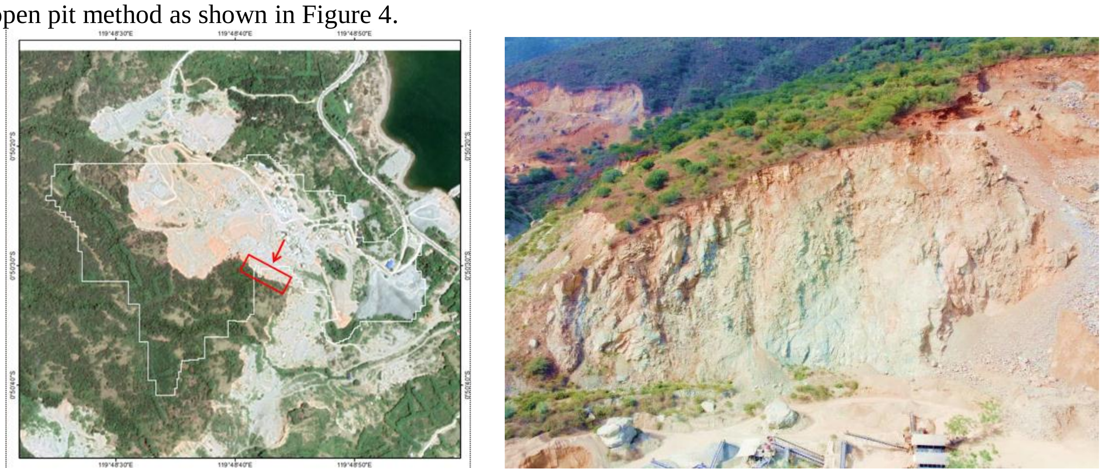

Figure 4: Research Location

A small quadcopter, the DJI Mini 2, mounted with a 12-megapixel camera was used to capture the images. Waypoints were created so that the drone could take appropriate images to cover the required area. The dense point clouds from the photogrammetry process were then imported into a free software called CloudCompare: Compass plugin to identify the orientation of the geological structure which is then combined with rock scanline data for further kinematic analysis using Dips Rocscience software. Kinematic analyses were performed to determine three types of failure modes; sliding, wedge, and toppling. The variables that contribute to the probability of failure are slope orientation, friction angle and lateral limit. The kinematic analysis shows that the rock slope has 26.26% for wedge sliding, 10.19% risk for planar sliding, and 2.43% for flexural toppling. The critical percentage of rock slope failure based on different failure modes is shown in Figure 5, 6, and 7.

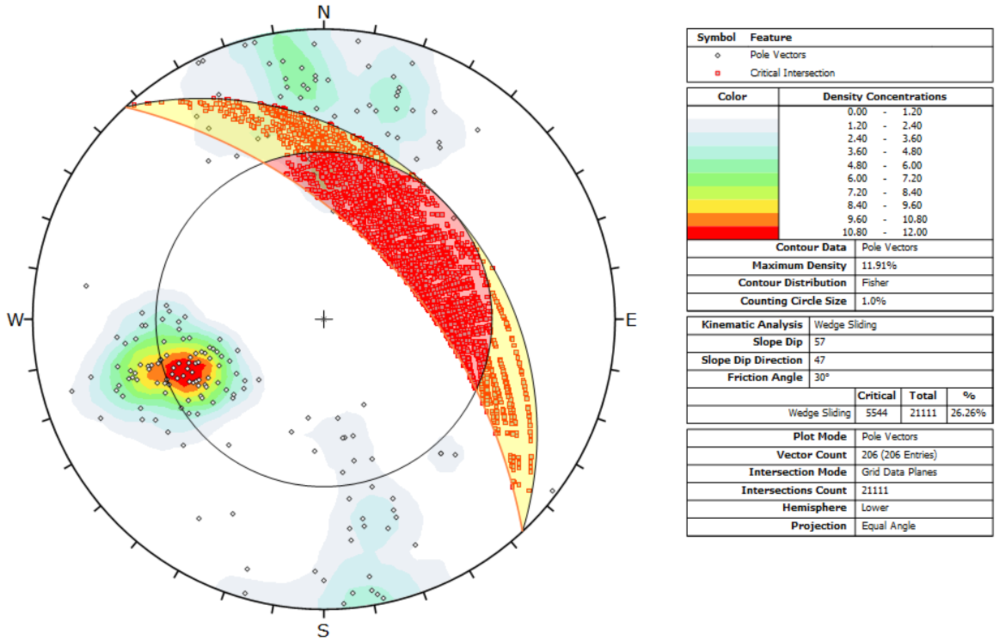

Figure 5: Stereonet of wedge sliding kinematic analysis

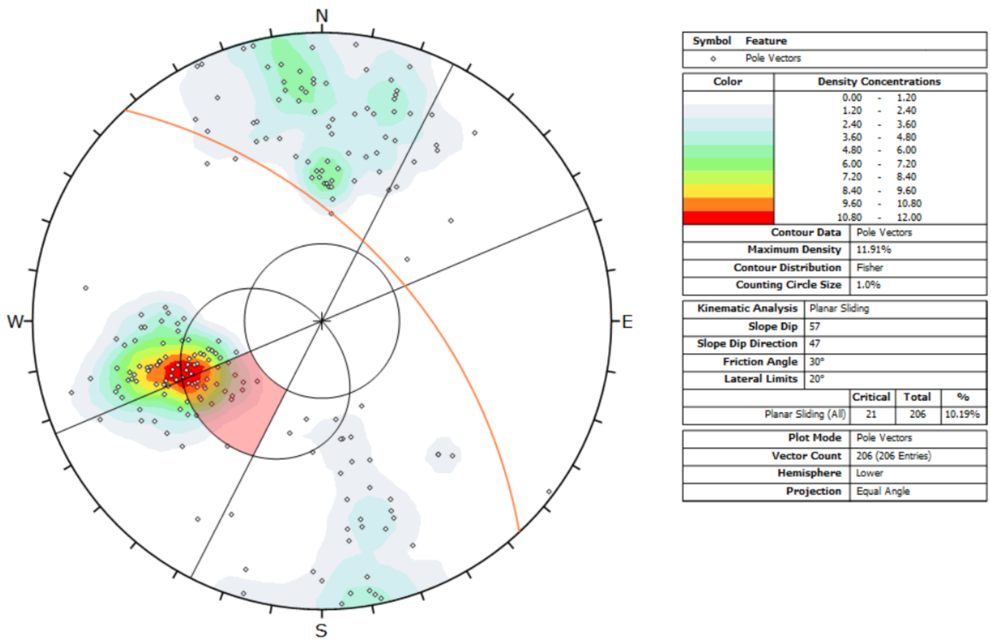

Figure 6: Stereonet of planar sliding kinematic analysis

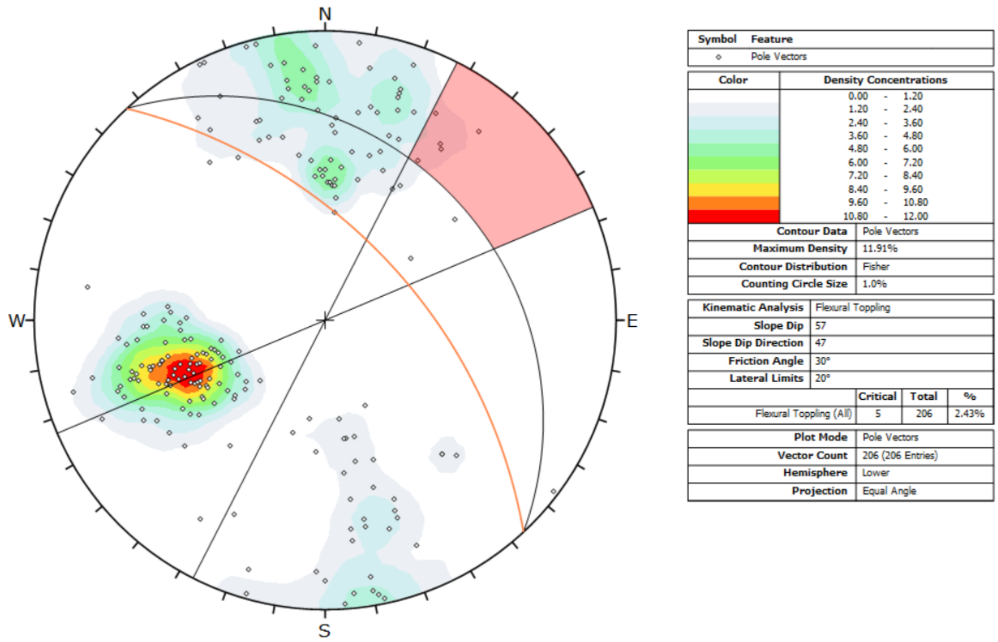

Figure 7: Stereonet of toppling kinematic analysis

III. CONCLUSION

Kinematic analysis is a good tool to conduct a preliminary assessment of rock stability for possible failure especially when aided by photogrammetry methods in data collection. A practitioner will be able to identify possible failures before conducting further detailed assessments. This study can be important to understand the overall slope stability in a short period of time and can provide useful information on possible failures.

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