Slip surface identification based on engineering properties analysis of weathering breccia at landslide occurred in Mount Pawinihan, Central Java, Indonesia

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Abstract Landslide mitigation may be performed in various methods, such as by identifying the weathering degree in order to determine the position of slip surface. Slip surface is an imaginary plane beneath the surface dividing the moving part of the slope mass with the rest. In short, it may also be defined as the weakest zone where the landslide may occur. Therefore, slip surface is the main object of this research which result may be used as a reference for further mitigation step. This research is conducted in the landslide case of Mount Pawinihan, Banjarnegara. The research is conducted by identifying the weathering degree of heterogenic material based on the British Standard EN ISO 14689-1. Engineering properties sampling was conducted after identification of weathering zone and use systematic sampling base on zone of weathering. The research result shows that the landslide soil mass under study may be divided into four weathering zones exposing on surface, while the position of slip surface may be identified in the weathering zone 3 (moderately weathered). This zone is a boundary of rock and soil condition.

1. Introduction
Landslide is a common phenomenon which may result in massive casualties. [1] said some factors causing the landslide are geology soil/rock, water, and human activities. Based on the data recorded by the Indonesian National Disaster Management Agency (Known as Badan Nasional Penanggulangan Bencana/BNPB) [2]. More than 1,000 landslide cases have occurred in Indonesia for almost two centuries in 1815-2012 that approximately 34,000 people died. Landslide phenomenon, may be prevented when the causes may be first recognized. One landslide cause is the presence of slide surface in the slope mass. This research is conducted in Mt. Pawinihan areas considering that recently there are many occurring landslides on the weathered breccia, and the weathering conditions may be well observed (Fig 1). [3]
explain that slip surface is an imaginary plane beneath surface dividing the moving part of slope mass with the rest. The recent research has not studied the shape and position of landslide slip surface in volcanic breccia based on degree of weathering. Even though the position of slip surface may be interpreted based on the development of weathering degree, in this study, occurred in breccia. Weathering is the rock changing process which is directly affected by the atmosphere and hydrosphere [4]. [5] states that the cause of material decay is mainly controlled by the external causes, such as the thermal expansion and unloading. In general, it can be explained as the physical decay caused by the external forces working on rock and resulting in disintegration of mass, crack planes, blocks or sheets into smaller volume. [6] explains that one internal factor in soil mass which also has an important role in weathering is rock decay. [7] shows that physical and mineral changes on several types of weathered rock (Figure 2). The weathering changes may impact on the engineering properties that then may make the materials unstable in the slope.

Some researchers have conducted researches on physical-mechanical properties with the weathering degrees, such as [8] who has found a clear influence on the physical and mechanical properties of different rocks as the result of weathering. [9] has found the relationship between geo-mechanical changes in the weathering degrees, [10] has attempted to form the weathering indexes and found that there is a physical and properties’ strength changes in quartz, granite, and basalt as the result of weathering. [11] has found a change in the engineering properties related to the basalt weathering degree in in Kramu, New Zealand.

Another study on physical properties of weathered rocks is conducted by [12] on granite and gneiss granite in southern Thailand. The tests include the soil physical properties, such as moisture conditions, specific gravity, grain fractions, Atterberg limits, clay content, fill weight, and pore number. The result

![Research Area, Mount Pawinihan, Banjarnegara, Indonesia](image)
shows that there are physical property differences of each weathering degree of. The research on the engineering property changes in the weathered rock has also been conducted. [4] has examined the effective porosity value ($n_e$), density, point load strength index ($I_s$), cohesion ($C$), and internal friction angle ($\phi$) for each different weathering degree.

The result shows that there is a tendency of geometric rise in the effective porosity value, an exponential decrease in the density value, the logarithmic decrease in the point load strength index value, as well as the linear decrease in the cohesion value the internal shear angle. Some researchers state that weathering is an important factor for the landslides like [13] and [14], even as the triggering factor for catastrophic landslide. Changes in physical and mineralogical characteristics of the weathering process may affect the value of UCS, TS (tensile strength), and BPI (block punch strength index) [15].

This research result is similar to the previous researchers for different types of rocks. The weathering process may also affect the decrease of cohesion values and shear angle in the rock shift of to the soil, such as the research conducted by [7] to the Clay-stone Clothes Subang Formation which has undergone weathering. Furthermore, Soil type has the highest effect on the base level location, [16]. [17] also argues that a change in shear strength in granite and granodiorite due to the weathering process. Granite and granodiorite may decrease the value of shear angle in the weathering degree, but cohesion in granodiorite may increase. Ayadat and Hanna explain that the collapsing soils are generally characterized by the large volume and sudden decrease at the constant stress when inundated with water and cause a lateral stress [18]. Decrease in cohesion values and internal shear angle will directly affect the value of slope stability on aparticular slope. Landslide is also influenced by the external factors, such as morphological factor, [19].

![Figure 2](image.png)

**Figure 2.** Degree of weathering profile at several type of rocks in Indonesia(Sadisun et al.,2006)

2. **Method**

The research method based on British Standard EN ISO 14689-1 for heterogenic material developed by [20] (Table 1) and Indonesian national standard for engineering properties test in laboratory. Table 1. The degree of weathering classification based on British Standard EN ISO 14689-1, developed by [20] By using
By using this method, weathering zones may be described, while the position of slip surface may be determined at particular weathering zone.

After the weathering zones are identified, the samples of Engineering properties may be taken using a vertical systematic sampling according to the degree of weathering laboratory work use Indonesian National Standard for moisture content (SNI M – 05 – 1989 – F), specific gravity (SNI M – 04 – 1989 – F), grain size (SNI 03 – 3423 - 1994), hydrometer (SNI 03-3423-1994), and Atterberg limits (SNI 03 – 1967 – 1990), while the slip surface may also be identified in the field. The final result of this research is the changing relationship of engineering property data with the slip surface position.

The research method is British Standard EN ISO 14689-1 for heterogenic material developed by [20] (Table 1) and Indonesian national standard for engineering properties test in laboratory.

| Zone | Description | Typical characteristic |
|------|-------------|------------------------|
| 1    | 100% grades I-III | Behave as rock, apply rock mechanics principles to mass assessment and design |
| 2    | >90% grades I-III, <10% grades IV-VI | Weak materials along discontinuities, shear strength, stiffness and permeability affected |
| 3    | 50% to 90% grades I-III, 10% to 50% grades IV-VI | Rock framework still locked and control strength, and stiffness, matrix control permeability |
| 4    | 30% to 50% grades I-III | Rock framework contribute to strength matrix or weathering product control stiffness and permeability |
| 5    | <30% grades I-III, 70% to 100% grade IV-VI | Weak grade will control behaviour, coarse rock may be significant for investigation and conclusion |
| 6    | 100% grades IV-VI | May behave as soil although fabric may still be significant |

3. Result and Discussion

Based on the field observation, the rock types found in the landslide areas are mainly pyroclastic breccia. In fact, the breccia has changed into the weathered breccia. Fresh rock is rarely found in the research location. The rock unit is exposed on surface around Mt. Pawinihan feet. The characteristics of rock unit may be described on field include: greyish color, fragmented by 3–35 cm in length, mainly composed of andesitic, sandy tuffaceous matrix, well-poorly sorted, poorly rounded, and matrix supported or grain supported.
The mass of breccia has been weathered and may be divided into six weathering zones, i.e.: weathering zone 1, 2, 3, 4, 5, and 6 (Figure 3). The data sampling is conducted in Pawinihan where the landslide occurred in January, 2006 (Figure 4). Each weathering zone has its own characteristics and may be distinguished at the megascopic scale based on its color gradation, soil and rock percentage as well as the structural and textural material.

![Figure 3. Ideal location in the surrounding of Mt. Pawinihan as the weathering zone model](image)

![Figure 4. Location sample in Mt. Pawinihan Landslide, Banjarneagura, Indonesian occured in January, 2006](image)
Figure 5. Graphs of weathering zones versus some engineering properties

Based on the relationship of engineering property (Figure 5). Based on the regression analysis, it changes with the weathering zone, there are some shows that the weight type value is mostly different results on each engineering value stagnant with the value of $R^2 = 0.0006$. So, it can be said that the specific gravity does not significantly increase or decrease. The water content linearly increases with $R^2 = 0.66$. The density is significantly decreased by the polynomial with $R^2 = 0.6$ occurred in zone 3 to 4 until zone 6. The liquid limit
has linearly increased yet not significantly with the value of $R^2 = 0.034$. The plastic limit has linearly increased, yet not significantly with the value of $R^2 = 0.04$. The plasticity index linearly increases with the insignificant value of $R^2 = 0.032$. Among the value of liquid limit, plastic limit, and plasticity index, it is difficult to correlate since there are some similar values, especially between zone 5 and 6. Clay particles are significantly increased by the polynomial from zone 3 to zone 5 and then not significantly decreased to zone 6 with the value of $R^2 = 0.4$. the cohesion has significantly decreased by moving the average from zone 3 to zone 5, then insignificantly rises to zone 6 with the value of $R^2 = 0.87$ and different values in zone 3. The internal friction angle linearly decreases from zone 3 to zone 5 then increases to zone 6 with $R^2 = 0.14$. Each engineering property shows different results due to the relationship with the weathering zone, indicating the breccia weathering system pattern which causes the engineering value changes to support the formation of a weak zone resulted in the breccia weathering internal soil. Due to the significant changes of cohesion in zone 3 to 4, the presence of hazardous zones in its boundary is due to the significant decrease in cohesion in this section. At the research location of Mount Pawinihan, the slip field stop is found at zone 3 and then follow at zone 3.

The density result shows a significant value in zone 3 to zone 4, characterized with the material characteristic changes of dominant stone and soil material in this section. From the Atterberg limit test, there is a linear rising change in zone 4 to 5 as well as zone 6, yet there is a similarity of plastic boundary value and liquid limit between zone 5 and zone 6 as in the plastic and liquid boundary cluster graphs. It proves that the weathering zone 5 and 6 may be distinguished in the field, but not in the laboratory. The increasing Atterberg limit in zone 5 and 6 explains that the rocks are increasingly weathered and converted into soil material. Then the clay particle is dominated in zone 5 as an accumulation zone for clay minerals. This research focus is to explain the significant changes of rock material to the soil at the boundaries of zone 3 and 4 possibly due to the accumulation of water.

Figure 6. Correlation between degree of weathering with landslide [21]
Figure 7. The relationship of each zone with the slip surface in Mt. Pawinihan

Due to the field condition, the position of slip surface shown above rotates through zone 6, 5, and 4 then translationally follows zone 3 (Figure 7). The figure above is the combination of geoelectric data, test pit, field geology mapping, and results of laboratory analysis. The slope field model in Pawinihan mountain area is different from that found by [21] (Figure 6) stating the forms of landslides are different and depends on each zone’s systems. Due to the model found in Pawinihan mount, one landslide system may affect all ones and its response depends on the weathering zone.

4. Conclusion

The slip surface zone is found at the boundary between zone 3 and 4 since there is a composition change of the rock material dominating the soil in zone 4. It is assumed that as there is a groundwater accumulation site, the weathering process is very intensive in this zone boundary. It is proven that the correlation between the cohesion in zone 3 may continuously and significantly decline until zone 4 and also relatively but not significantly decline to zone 6. Due to the results of analysis, the liquid and plastic limit test also shows that the material may become more plastic in zones 5 and 6 due to its more intense rock and soil material changes, proven by the increasing clay particles in zone 5. So, it is included into the landslide slide zone. In fact, it can be quantitatively and scientifically explained from the research result in the form of rotational and translational combinations. The slip surface zone passes through zone 6, 5, and 4 by rotation, and then through zone 3 by translation.

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