Characteristics and engineering properties of residual soil of volcanic deposits

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Abstract. Residual soil knowledge of volcanic-sedimentary rock products provides important information on the soil bearing capacity and its engineering properties. The residual soil is the result of weathering commonly found in unsaturated conditions, having varied geological characteristics at each level of weathering. This paper summarizes the results of the research from the basic engineering properties of residual soil of volcanic-sedimentary rocks from several different locations. The main engineering properties of residual soil such as specific gravity, porosity, grain size, clay content (X-Ray test) and soil shear strength are performed on volcanic rock deposits. The results show that the variation of the index and engineering properties and the microstructure properties of residual soil have the correlation between the depths of weathering levels. Pore volume and pore size distribution on weathered rock profiles can be used as an indication of weathering levels in the tropics.

1. Introduction
The existence of residual soil on the surface of the land can cause geological engineering problems, especially related to the strength and carrying capacity of the soil. The most frequent land movement disasters have been linked to the residual soil on the hills. Soil movement is the movement of the soil/rock mass down or out of the slope as the material of the slope composition such as soil mass, rocks, or weathering materials were disrupted by the slope stability [1]. This is largely related to several key factors such as the geological, climatic, vegetation and land use conditions. Generally, ground motion occurring on the slopes of soil residue has not been well consolidated. It has been argued that the factor triggering the soil motion can be derived from the slopes such as the weathering of rocks [2].

The ground motion generally occurs in rainy season when rain triggers landslide due to its certain size so that rainwater seeps into the slope and push the ground to move. The rains which triggers ground motion are heavy rainfall and longer normal rain. Heavy rain, for example, is rain that can reach 70 mm per hour or more than 100 mm per day. This will only effectively trigger an landslide on slopes whose soil easily absorbs water [2], such as in clay and sandy soil. It has been concluded that rain absorbed into the soil may cause an increase in pore water pressure, which disturbs the slope stability especially when the residual soil formed [3].

Residual soil research has been undertaken by some former researchers, among which are [4-8], that provide restrictions for residual soil engineering from grade VI, V and IV. The results of the study have discussed the characteristics of soil properties related to the properties of the index (index properties), the properties of soil properties (engineering properties) and the soil development index. However, there are not any researches on the soil of tropical volcanic rocks associated with the movement of the soil. Reference [4], in his research from several samples in Java, gave an illustration that the laps of breccia had higher triaxial test values than sedimentary rocks.
2. Weathering profile

There are various definitions of residual soil from several researchers. Residual soil is defined as a soil material which is derived from rock bedding and has not undergone transportation, usually found in tropical climates with relatively high temperatures and rainfall. McLean & Gribble said that residual soil is a rock material that has been turned into soil which loses both structures of rock texture, changes in the weight of the soil content, and has not experienced transportation. In general, residual soil can be defined as a soil material which is the result of weathering and decomposition of rocks that has not been transported from its original place.

Residual soils from Quaternary volcanic breccia weathering and lapilli tufts generally have texture of a mixture of clay, silt, and fine sand [6,9]. The hilly area is occupied by volcanic sediment with soil classified in CH group that is clay with high plasticity properties and classified as heavy clay. Also, the level of development in residual soils of this type is high; the higher growth rate causes the decrease of parameters of soil resistance (strength parameters).

![Figure 1](image)

Factors that control weathering include rock characteristics, climate, topography, hydrology, and vegetation (biology). Moreover, the influence of human cultivation in the process of land for agriculture/plantation can encourage weathering. Taha says that tropical climates have very important role to the formation of residual soil. In this case, rainfall, temperature, and chemical process cause the formation of relatively thick residual soil compared to mechanical weathering. In the weathering process, there is a gradual shift from the rock to the ground, and it is difficult to determine the change of stone to the soils. In the weathering profiles shown in Fig. 1, the upper three layers (grade VI, V and IV) are more likely to be soil, while the three layers down are more likely to be rock. Residual soils are weathered rocks and the soil for engineering purposes is in degrees VI, V and IV [10]. Residual soils have different engineering properties compared to sedimentary soil deposits and uniformly distributed grains. The differences in residual soil characteristics varied both laterally and in depth due to the differences in weathering intensity. Land movement often occurs in residual soil, especially during the rainy season due to the decreasing strength of soil shear.

Grade I is a fresh rock that has not undergone changes, either in composition or in color. A slight change in the composition is given in grades II and III, where the color change begins and the size of the material becomes smaller. Grade IV and V tend to be classified as soil as it has undergone a change in the composition of more than 50% rock mass. Grade VI is a residual soil group that is the result of weathering both physical and chemical rock. The level of weathering affects the composite material on a residual soil. The higher grade of weathering, the greater the composition of the clay material will be. The degree of weathering is usually proportional to the depth. The greater the depth of a residual soil,
the higher the weathering level it has, and the clay component predominates. Therefore, the grain size will vary greatly due to the influence of saturation level as well as the minerals formed. Sand material decreases along with the increasing degrees of weathering. This affects the value of void ratio and density. Both values decrease with the increasing degrees of weathering. The main rock will contribute to the residual soil composition, while the presence of fine grains is the result of weathering.

Figure 2. Comparison Level (Grade) weathering of some rocks.

3. Quarter volcanic residual soil in Indonesia

As a tropical climate area, residual soil covers more than two-thirds of Indonesia [1]. The residual soil is submerged by the volcanic rock of Quarter in a general textured mixture of clay, silt, and fine sand. The hilly areas occupied by volcanic deposits possess a high-profile nature [6]. This residual soil also has swelling properties. The nature of expanding and shrinking (expansive) is influenced by changes in groundwater content resulting in volume changes.

The effect of soil water content on engineering properties is indicated by the decrease/change in the shear strength of the soil (internal shear angle and cohesion). The cohesion and shear angle in the soil correlate to the size of the clay content and can absorb water. In addition to the increase in clay content, the soil mass will have a lower density, liquid limit and the increased plasticity index with the increase in water content.

There is a problem in geotechnical as the change of the degree of soil saturation causes the occurrence of the small value of shear stress or soil cohesion. The residual soil engineering properties may differ from composite soils and uniformly distributed granules. Its properties can vary greatly, either laterally or in depth, due to the differences in weathering processes.

4. Results

The research results of volcanic breccia residual soil in Cikijing, Majalengka [12] area shows that it has clay mineral content of kaolinite, halloysite with less cohesive properties in organic soil classification. Based on the level of development (swelling), it has a level of development of low-moderate. Research on andesite tuff residues shows that they contain minerals such as montmorillonite, illite, kaolinite, quartz, and pyrite [13]. The presence of montmorillonite and kaolinite characterizes that the underside Tuff is subjected to an interrupt type argillic hydrothermal alteration [6]. Clay minerals, especially montmorillonite, have fluctuating properties in wet conditions [13].
The development process weakens the bond between the clay particles in the andesite Tuff. As a result, the shear strength of the andesite tuffs decreases until there is a glance of the weathering material.

5. Technical properties of volcanic breccias
The result of brick residual soil sampling from several regions obtained cohesion value 0.15 - 27.4 kN/m2, the shear angle in 1.36o - 21.36o while the physical properties test results show that the soil can be classified in inorganic silt (MH) and has low-moderate plasticity properties and low-moderate expansion potential with activity value <1. The test results can be seen in Table 1.

Based on the results of laboratory testing above, it can be seen that the weathering process on the breccia form residual soil, causing easy water infiltration due to the increased porosity value and a decrease in soil shear strength. The data analysis shows significant differences in effective cohesion values as well as the shear angle in the effective soil. This can occur due to several influencing factors such as degrees of weathering and mineral composition of breccia rocks that turn into clay minerals which have different percentages so that it will have varied soil engineering properties. Also, groundwater content, grain distribution and sampling highly affect the shear strength of the soil.

Figure 3. Graph of XRF results of tufa andesite, (a) method of bulk-powder, (b) method of water-Dried, (c) ethylene glycol method [2].
Table 1. Result of soil residue laboratory test [12].

| Engineering Properties | Units | Cianjur | Purwakarta | Majalengka | Majenang | Pangalengan |
|------------------------|-------|---------|------------|------------|----------|-------------|
| Gs                     |       | 2.4 – 2.5 | 2.3 – 3.5  | 2.5 – 3.5  | 2.34 – 2.62 | 2.1 – 2.9   |
| Wc                     | %     | 27.6 – 41.7 | 30.72 – 80.5 | 22.68 – 48.08 | 40.32 – 70.5 | 22.91 – 46.28 |
| LL                     | %     | 58.1 – 87.3 | 81.0 – 95.0 | 59.9 – 98.1 | 40.56 – 71.41 | 32.1 – 66.5  |
| PL                     | %     | 31.0 – 45.0 | 39.6 – 69.5 | 40.36 – 36.86 | 30.21 – 53.33 | 33.1 – 67.8  |
| IP                     | kg/cm²| 26.0 – 42.0 | 15.46 – 38.9 | 30.79 – 40.73 | 14.43 – 26.50 | 25.4 – 57.7  |
| Friction angle (ϕ, °)  |       | 1.41 – 1.55 | 14.4, 28.3 | 9.35 – 18.37 | 1.36 – 1.71 | 12.65 – 21.34 |
| Classified USCS        | MH    | MH       | MH         | MH         | ML        | MH          |

6. Conclusions
Based on the results of the research data above, the following conclusions can be drawn. Research on residual soils associated with the weathering of volcanic rock deposits in Indonesia has not been widely expressed by researchers. Soil mass behavior is a description of the soil material in responding to an activity. The response to be given by the soil mass is influenced by the geological conditions especially the hydrological aspects, the type of soil material, the grain shape, and its distribution. Physical properties of soil mass that most contribute to the shear strength of the soil are grain size, gradation, moisture content, porosity, and permeability. The geological aspects of the role are the type of soil/rock, the direction and slope of soil/rock, rock structure, hydrological conditions, and morphology. Rainfall that seeps into the soil will cause an increase in the water content of the soil, thus causing a decrease in the shear strength of the soil.

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References
[1] Karnawati D 2005 Natural Land Movement Disasters in Indonesia and Its Countermeasures (Yogyakarta: Gadjah Mada University).
[2] Dwi W, Dwikorita K, Hary C, Hardiyatmo and Srijono 2016 Journal of Applied Geology 1 19-28.
[3] Tohari A et. al. 2005 Laporan Research Center For Geotechnology-LIPI (Bandung, Geoteknologi LIPI).
[4] Wesley L D 1977 Soil Mechanics (Jakarta: Public Works Publishing Agency).
[5] Hirnawan F 1993 Environmental Geology Bulletin 26 93-98.
[6] Hirnawan F 1999 Indonesian Technology 22 1-12.
[7] Sadisun I A 2001 Influence of Claystone Clay formation Subang to some engineering properties to support the form of slope reinforcement (Bandung: Bandung Institut of Technology).
[8] Irfan T Y and Dearman W R 1978 Jour. Eng. Geol. 11 233-244.
[9] Hirnawan F 1994 Proceeding PIT IAGI December 1994.
[10] Dearman, W R and Irfan T Y 1978 Proceedings of the Third International Congress of Geological Techniques 2 119-130.
[11] Hardiyatmo HC 2006 Landslide Handling and Erosion (Yogyakarta: Media Universitas Gadjah Mada).
[12] Wibowo Y S 2011 *Geological and Mining Research* **21** 131-139.
[13] Pusch R and Yong R 2006 *Microstructure of smectite clays and performance engineers* Taylor & Francis, London, and New York.