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The Effect of Drying-Wetting Cycle's Repetition to the Characteristic of Natural and Stabilization Residual Soils Jawa Timur - Indonesia

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Abstract. Indonesia, which located in tropical region, continuously undergoes wetting and drying cycles due to the changeable seasons. An important role in activating the clay minerals on tropical residual soils is the main factor that affects the static and dynamic properties, such as: volume change, soil suction and dynamic modulus. The purpose of this paper is to evaluate the effect of drying-wetting cycles repetition on volume change, soil suction and mechanical characteristics of natural and stabilization of residual soils from Jawa Timur - Indonesia. The natural undisturbed and stabilized residual soil sample was naturally and gradually dried up with air to 25%, 50%, 75%, and 100 % of the initial water content. The wetting processes were carried out with the gradual increment water content of 25 %($w_{sat} - w_i$), 50 %($w_{sat} - w_i$), 75 %($w_{sat} - w_i$), up to 100 %($w_{sat} - w_i$). The Direct Shear test is used to measure the mechanic properties, and Whatman filter paper No. 42 is used to measure the soil suction. The drying-wetting processes were carried out for 1, 2, 4, and 6 cycles. The laboratory test results showed that, the void ratio decreased, the unit weight, cohesion and the internal friction angle were increasing due to stabilization. Drying-wetting cycle repetition reduces void ratio, negative pore-water pressure, cohesion and internal friction angle of natural and stabilized soils. Briefly, the decreased of mechanical soil properties was proven from the physical properties change observation.

1. Introduction

Indonesian geological condition induces residual soil formation over the mountains for more than 53% land coverage region [1]. Due to its proper mechanical soil properties, many types of construction could be built on residual soil [2]. On the other hand, usage of land due to human requirements transforms agriculture area to residential area. Moreover, many residual soil slope instabilities occur rapidly, for example in Tawang Mangu area at Karang Anyar district-Manting, Mojokerto district, and other regions in Indonesia.

Several slope instability shows that residual slope failure occurred during raining or afterwards, for example slope failure in Pacet, Mojokerto, Panti and Arjasa, Jember; failure at several sections in Purbaleunyi toll road, Bandung. Recently, infiltration capacity reaches minimum value since soil pores have already been filled by the water, therefore soil loses its capacity that is usually strengthened by

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the negative pore water pressure [3]. Uncontrolled construction plan activity such as highway, toll road, train railway and dams trigger the residual soil slope clearing, therefore many geotechnical engineering face the residual soil properties problem. Slope clearing also affects the soil which is initially located in the bottom ground become into surface soil and in the following time the drying wetting cycle happens due to changeable season.

Many soil stabilizations have been conducted in order to improve the residual soil characteristics, for instance treated with cement, shotcrete and geogrid. In line with the time, residual soil experiences cyclic drying-wetting due to changeable dry and rainy seasons. This cyclic drying-wetting is predicted to influence the soil volume, soil shear strength and soil negative pore water pressure changes [4].

The purpose of the research is to assess the effect of the drying-wetting cycles on the physic properties, mechanical soil properties (cohesion and internal friction ratio), the negative pore water pressure of natural and stabilized residual soil.

2. Research Methodology

An experimental research was conducted at field and laboratory on Mojokerto residual soils Jawa Timur - Indonesia. Soil sampling was conducted on field and the physical, mechanical soil properties were investigated in laboratory. These investigations were conducted by the standard equipment at laboratory. The flowchart of research methodology could be seen in **Figure 1**.

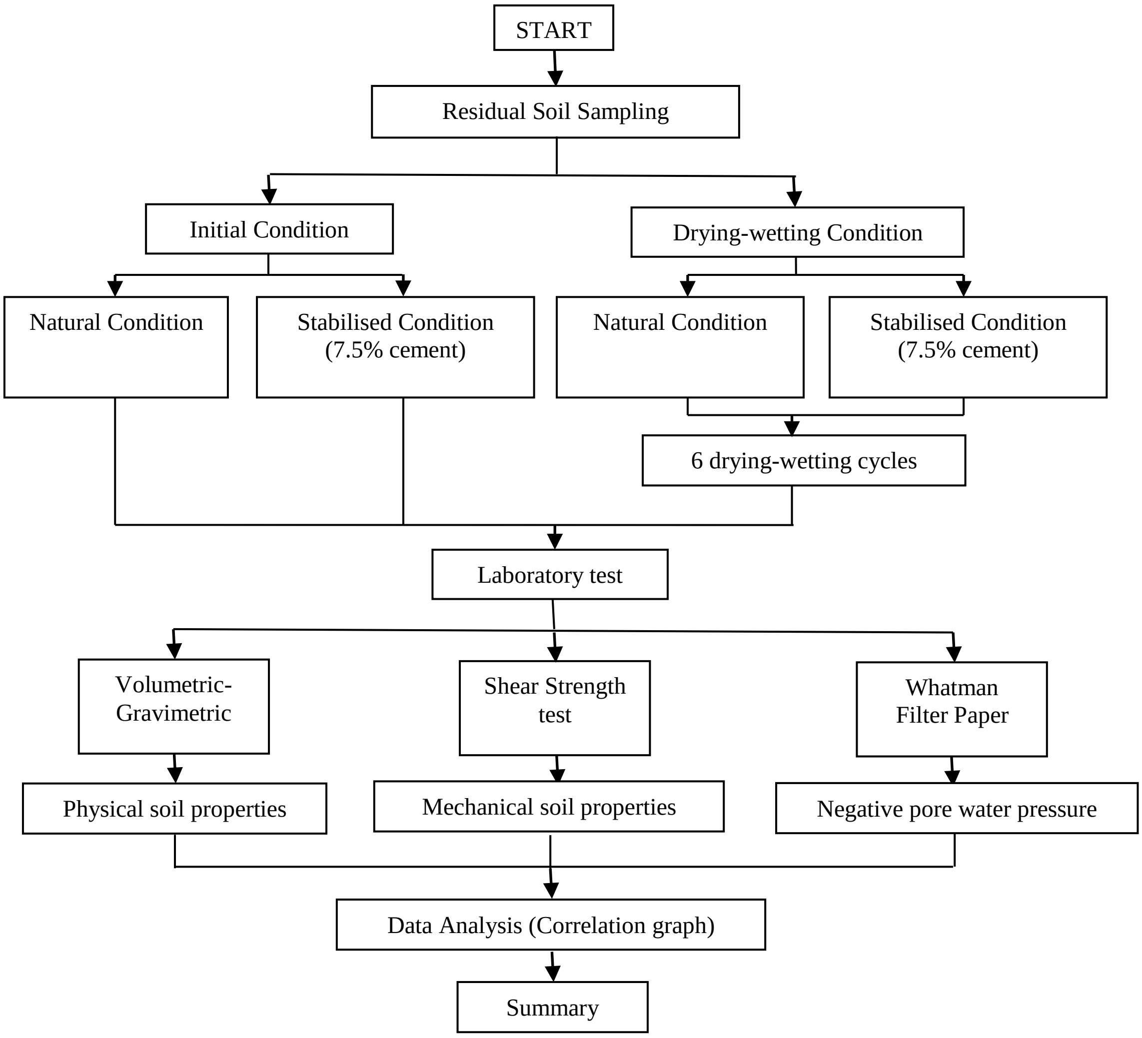

Figure 1. Research flow chart.

Drying-wetting process involves laboratory works to dry and wet the soil samples in cycle generation, and it would be continued with laboratory tests. To determine the drying and wetting model step in each cycle, there is an upper and lower limit of water content range. The upper limit is the saturated soil water content, whilst lower limit is the water content when the sample is dried. Then from the range, step is created by dividing the range into certain value. The degree of saturation would increase during saturation process and decrease during desaturation process [5].

The soil sample starts in initial condition (1^{st} cycle), then it is dried until the lower limit (W_{dry}) and wetted back until the initial condition, this drying-wetting path is regarded as the 1st cycle. Then the next action is wetting the soil sample from initial until upper limit condition (W_{sat}) and continue to dry until its initial condition, this path is regarded as the 2nd cycle. The similar process followed until 3^{rd}, 4^{th}, 5^{th} and 6^{th} cycle [6]. The soil properties tests would be conducted on each step.

Sets of laboratory investigation are then performed to obtain the physical and mechanical soil properties at initial condition and drying-wetting condition (cyclic repetition from 1^{st} cycle to 6^{th} cycle). Physical and mechanic soil properties are proposed to be obtained by performing tests as follows:

- Volumetric-gravimetry (ASTM D 2216-71; ASTM D 854-72).
- Negative pore water pressure by using Whatman paper no. 42 (ASTM D5298-03).
- Triaxial test (ASTM D4767-04), or direct shear test (ASTM D3080).

Laboratory investigation on both initial condition and drying-wetting condition are only conducted at the initial condition point. Therefore, the comparison curves of soil properties are analyzed based on the initial condition point at each cycles.

3. Results and Discussions

3.1. Initial condition

The result of physical, mechanical and negative pore water pressure on natural and stabilized residual soils is presented on Table 1. In order to compare with the initial condition in which the soil was sampled, only the initial condition point was observed in each drying wetting cycles. Then the comparison curves of soil properties could be analyzed at initial condition point during the cycles.

Table 1. Physical, mechanical soil properties at initial condition.

Type of test		Natural	Stabilised
1. Water content	(w, %)	49.67	25.41
2. Degree of saturation	(S_r, %)	97.51	57.45
3. Moisture unit weight	(γ_t, kN/m^3)	15.45	16.23
4. Specific gravity	(G_s)	2.432	2.624
5. Void ratio	(e)	0.963	0.905
6. Cohesion	(c, kPa)	6.5	14.7
7. Internal friction	(ϕ, ^{0})	10.9	14.75
8. Suction	(kPa)	5.85	1815

From Table 1 shows that natural and stabilized soil undergo significant physical soil characteristics changing. Soil moisture unit weight increased 10.33 %, which is followed with specific gravity for about 7.31 %. As well as water content the void ratio also decreased as much as 38.8 %. Similar to mechanical soil and suction properties which the soil cohesion increased from 65 kPa into 147 kPa (55.7 % increment); meanwhile the soil suction increased 99.5 %. Regarding to the analysis, it shows that stabilized soil has higher density rather than natural soil. This phenomenon is predicted due to cement addition into soil that enhance the weight and soil grain volume (W_s and V_s). In line with the soil shear strength, the pore volume reduction affected the lower void ratio, hence the soil effective stress increased. In accordance with results that investigated by Yusdiantoro [7], there is an enhancement of soild grain composition in clay that changes soil physical properties due to soil stabilization.

3.2. Cyclic drying-wetting influence

Laboratory experiments has been conducted in order to assess the influence of cyclic drying-wetting on natural and stabilized soil (initial condition point). **Figure 2** shows the soil-water characteristic curve (1st cycles), **and Figure 3** shows the influence of drying-wetting cycle's to the moisture unit weight and void ratio and soil suction that classified as soil physical properties; mechanical soil properties (cohesion).

3.2.1. Inserting superscripts to link names and addresses.

Figure 2. shows the soil-water characteristic curve (SWCC). At the natural condition, initial water content of the soil specimen was 49.67%. The initial void ratio, e 0.963, moisture unit weight, □$_t$ 15.45 kN/m^3 and the spesific gravity, G_s 2.432. Stabilised soils shows the initial water content soil was 25.41%. The initial void ratio, e 0.905, moisture unit weight, □$_t$ 16.23 kN/m^3 and the spesific gravity, G_s 2.624.

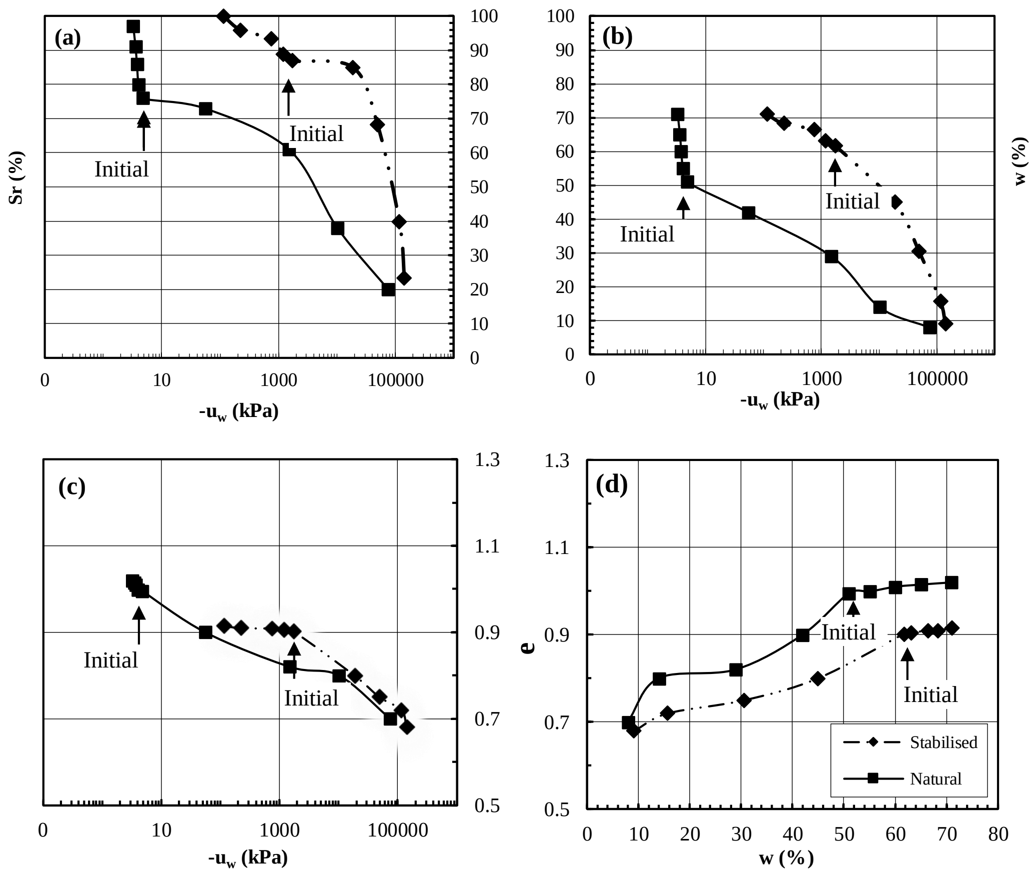

Figure 2. Soil Water Characteristic Curve (SWCC).

During wetting process, for natural and stabilised soils, as water introduced to a relatively nearly saturated soil, it was assumed to be directly taken into the voids. As additional water became available to the soil, the adsorption forces to the clay were attenuated and the voids were gradually and fully filled; resulted in the relatively step increased the water content and the degree of saturation. From the relationship between negative pore water pressure and degree of saturation showed that at the same degree of saturation, the stabilised soil has a value negative pore water pressure higher than natural soils. This happens because the stabilized soil has better density.

Upon drying, for natural and stabilised soils, the water phase within the soil was continued until air entered the soil-water system and the air entry value was reached. On approaching the air entry value, it was assumed that progressively smaller pores were emptied and, were present, the hydrated water layer enveloping clay minerals reduced. It can be obviously seen on the degree of saturation-negative pore pressure curve. Soil water continuity progessively diminished over this range of negative pore pressure as air filled channels began to form within the soil voids.

3.2.2. Cyclic influence on soil physical properties (density).

Figure 3A. shows the relationship between soil moisture unit weight and number of cycles. For instance, in natural soil, soil moisture unit weight increases as much as 5.79 % during cycle that started from initial condition into 1st cycle; meanwhile soil moisture unit weight increased as much as 1.57 % in stabilized soil. From the evidence showed that higher soil moisture unit weight changes occurred in natural soil since the cyclic undergo the higher density.

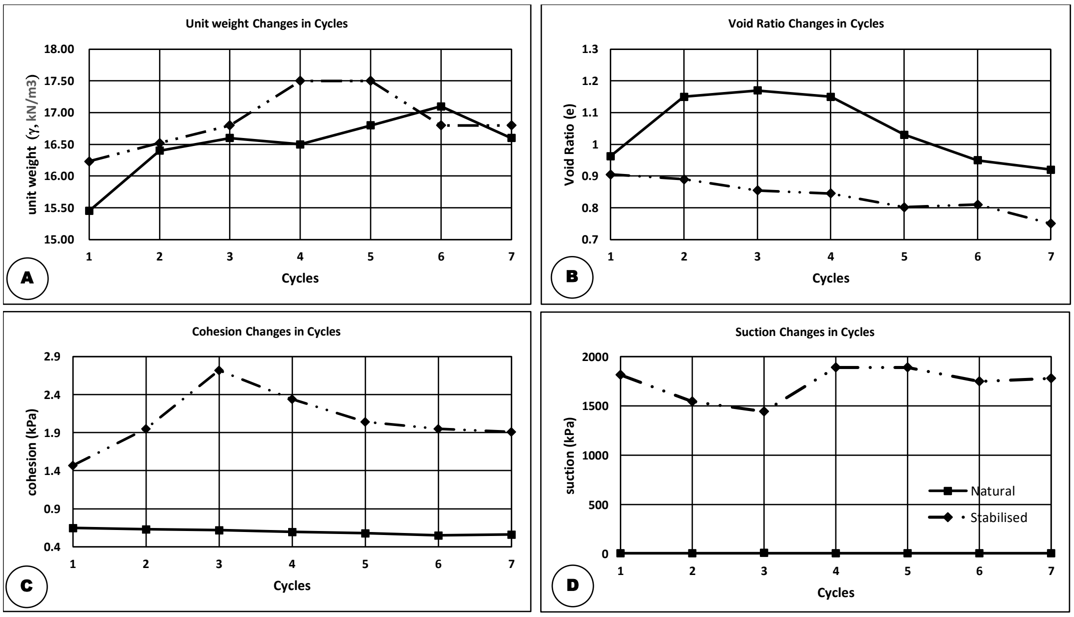

Figure 3. Relationship between void ratio, soil unit volume, cohesion, suction and number of cycles (initial condition point).

Application of the 1st cycle until the 6th cycle on natural soil affected the soil moisture unit weight where γ_t increases as much as 9.6 %; while stabilized soil increased up to 3.39 %. Figure 2A shows that natural soil initial density condition is more affected by the cyclic, compared with the stabilized soil.

Stabilized soil was less affected by the cyclic drying-wetting condition due to higher density. Asmaranto [8] had found that the fly ash added into clay soil induces hydration that triggers the increase of soil volume grain and soil particle orientation as well.

Figure 3B. shows the effects of cyclic drying-wetting of natural and stabilized residual soil on soil void ratio. **Figure 3B.** shows that the 1st cycle until the 6th cycle application induces the decrease of void ratio as much as 25.01 %; while void ratio decreases 18.66 % on stabilized soil. It could be concluded that cyclic drying-wetting induces the void ratio decrease. Muntaha [3] had found that the cyclic drying-wetting induces water between inter particular space and free water in between inter aggregate that comes out from the pore space, hence the soil pore volume will be reduced.

The other phenomenon revealed that void ratio changes on stabilzed soil is tend to be constant in each of cycle. In natural soil, void ratio change for 1st, 2nd, 4th and 6th cycle in consecutive way are 16%, 15,6%, 15,6% and 16,2%, while for stabilized soil are 33,9%, 33,2%, 32,3% and 32,3%. It is caused by the first drying-wetting cycle that the soil re-composed its structure so it is denser and more stable to reduce the soil deformation.

3.2.3. Cyclic influence on soil mechanical properties.

Figure 3.C. shows the relationship curve between soil cohesion and cycle for both natural and stabilized soils. It could be seen that due to cyclic drying-wetting, cohesion for both soils either tend to be constant in the same cycle or decrease in the cycles generation. For example, in natural soil, the soil cohesion consecutively for 1st, 2nd, 4th and 6th cycle are 63, 62, 58 and 56 kPa. These analyses inappropriate with the conventional soil mechanics where due to drying-wetting cyclic generation would reduce the water content and void ratio, it is correlated with the denser and stiffer soil structure. The soil mechanics theory states that as the density and stiffness increase, the soil shear strength will be higher. On the other hand, in this research, the generation of drying-wetting cycle induces soil cohesion reduction for boyh of natural and stabilized soils.

This phenomenon is predicted to be affected by the water content and void ratio reduction that followed by increase of the dry unit weight. However, the degree of saturation is getting higher, it indicates that there is an apparent dry density due to high degree of saturation. The high degree of saturation mostly influences the reduction of soil shear strength. This analysis supports the research conducted by Miyakita [9].

Figure 3.D. reveals that in same cycle and same initial condition point, negative pore water pressure of stabilized soil is higher than natural soil. In same negative pore water pressure during wetting, stabilized soil undergoes increase of solid grain and reduction of pore volume as the cement and water hydration process. As consequency, the soil effective stress will be increased as well. If the cyclic drying-wetting being analogyzed as the loading-unloading during consolidation process, hence the increase of soil effective stress would affect the reduction of void ratio. As it was stated by Yusdiantoro [7], void ratio of stabilized soil with fly ash is much lower than natural soil. Therefore, the stabilized soil with fly ash possesses higher negative pore water pressure rather than natural soil. Paulus [10] stated that lime addition into natural clay soil induces reduction of void ratio, so the degree of saturation increases and negative pore water pressure increases respectively.

4. Conclusion

Test results showed that soil stabilization increased both of the soil density and soil shear strength shown from the reduction of void ratio. Cyclic drying-wetting generation induced the density of natural and stabilized soil. However, the soil density increase is not followed by the soil shear strength increase in stabilized soil. Moreover, the soil density is predicted in the form of apparent density which possesses high degree of saturation. The high degree of saturation mainly induces the decrease of soil shear strength when the density is high.

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