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VOLUME CHANGE AND COMPRESSIVE STRENGTH OF COMPACTED LATERITIC SOIL UNDER DRYING-WETTING CYCLE REPETITION

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ABSTRACT: This study was conducted to investigate volume changes and compressive strength behavior of compacted high expansive soils from lateritic soils (60%) and bentonite (40%) mixture under drying-wetting cycle repetition as a construction materials alternatives. Lateritic soil obtained from waste Nickel mining site in East Halmahera, North Maluku, Indonesia. Laboratory tests of physical properties using ASTM standard test were conducted to lateritic soil, bentonite, and mixture soil, while SEM test for lateritic and mixture soil. The soil samples have optimum moisture content based on Proctor standard compaction test results (28%). Then, samples were treated drying-wetting cycle and repeating four cycles with 25, 50, 75, and 100% series path. The soil suction measurement used the *Whatman #42* filter paper placed at the top, middle, and bottom of each sample, and after that, the unconfined compression strength test was performed based on the ASTM standard. The experimental results showed that the drying-wetting cycle repetition has a significant effect on volume change, suction, and compressive strength of the soil. The increasing number of cycle causing void ratio decrease and degree of saturation increase, and soil suction tend to decrease at the certain void ratio; likewise, soil compressive strength decreases at particular water content. Decreasing soil compressive strength causes a decrease in elastic modulus so that soil failure behavior is more brittle and work-softening. Therefore, the study results provide important geotechnical characteristics data of lateritic soil with high swell-shrink potential. Henceforth, some soil improvement innovations can perform to generate high-quality construction materials more effectively and efficiently.

Keywords: Expansive lateritic soil, Compacted soil, Volume changes, Suction, Compressive strength

1. INTRODUCTION

Naturally, the tropical regions like Indonesia have high rainfall during the rainy season and become arid in the dry season. Seasonal changes continuously cause the soil to undergo continuous wetting and drying, along with these changes [1,2]. Changes in the dry-wet conditions repeatedly affect the geotechnical characteristics of the soil, especially the unconfined compressive strength, negative pore water pressure, and soil volume [3-6]. This phenomenon is increasingly essential if it occurs in swelling soils because of experiences significant volume changes as well as local shrinkage and swelling in soils. Compressive and shear strength changes are essential issues in many geotechnical works, such as bearing capacity of deep and shallow foundations, slope stability, retaining walls, and pavement [7].

Several previous studies related to the drying-wetting cycle effect on expansive soils had widely carried out and well-documented and described as follows. The drying-wetting cycle impacts on bentonite plasticity and swelling behavior, and hydraulic of Geo-Synthetic Clay Liners (GCLs) [2], while soil pore characteristics affect stability and Tensile Strength (TS) of wet aggregate microstructurally during wet-dry cycles [1], there is a significant effect of increasing drying-wetting cycle number on compacted soil failure from steady to weak softening [6]. Soil strength reduced due to the wetting-drying process depends on the drying rate and the ultimate strength [8]. Changes in cement bonds reduced water content and void ratio cause failure behavior of compacted residual soil samples due to drying-wetting [9,10]. Moreover, the suction has a significant effect on the swell-shrink cyclic behavior of compacted expansive soil [11]. Silica fume decrease deformation of modified expansive clay soils during cyclic drying and wetting [12], while void ratio change has more effect than water content changes to the collapse potential of the desiccated lateritic soil samples [13]. The lateritic soil modeling with stabilization as a road foundation layer shows significant results in increasing soil compressive strength and reducing surface deformation [14-17].

Therefore, the possible utilization of compacted expansive soil as a construction material [18,19] has interesting for further investigated.

Finally, the drying-wetting cycle repetition effect on expansive soil of mixture lateritic soil and bentonite is interesting to investigate. The present study is useful to investigate the soil volume change and strength deterioration under drying-wetting repetition of compacted initial conditions as relevant geotechnical data. This paper examines Lateritic soil from Halmahera Island, North Maluku Province, Indonesia.

2. MATERIALS AND METHODS

2.1 Expansive Lateritic Soil

The Lateritic soil supplied from the nickel mining site of Eastern Halmahera Island in North Maluku Province, Indonesia, as seen in Fig. 1. The disturbed soil was obtained by open excavation from the surface to a depth of 1 m. This soil place in plastic bags and transported to the geotechnical laboratory.

Subsequently, Halmahera Lateritic soil was blended with bentonite to make a high expansive soil with mix composition of 60% lateritic soil and 40% bentonite. Bentonite used in this study supplied from *Dwi Karya* Bentonite Factory in Banten (Indonesia). The lateritic soil and bentonite defined as high plasticity soil according to the USCS soil classification system [19].

2.2 Samples Preparation for Testing

The lateritic soil was dried with the air-dried base before a grinding process. The mixtures of lateritic soil and bentonite prepared as follows; the amount of lateritic soil and bentonite was measured based on total sample dry weight and mixed in dry condition; the amount of water added until optimum water content ($w_{initial} = w_{opt}$); and the cylindrical PVC molds of 36.5mm diameter and 100mm high used to prepare mixed soil samples for drying-wetting cycle repetition test.

2.3 Atterberg Limit Tests

The soil consistency determined for lateritic and mixtures soil samples and tested for liquid and plastic limit following ASTM D 4318 (1995) [20].

2.4 Standard Proctor Tests

The standard Proctor tests conducted following ASTM D 698 (1995) [20], to prepare samples for wetting–drying cycle tests then the optimum water contents of lateritic soil and mixtures soil determined.

2.5 Drying-Wetting Cycle Tests

The drying-wetting test conduct to investigate the soil volume change, suction, and compressive strength of expansive soil from lateritic soil and bentonite mixture. The whole samples were cured for 24 hours before the test. The drying-wetting process carried out by reducing and adding a certain percentage of water until it reaches a predetermined water content. In the drying-wetting process, water content reduced from optimum water content to dry levels of 25%, 50%, 75%, and 100% (drying path) and water content adding from dry to optimum water content (wetting path). While in Wetting-drying process, water content adding from optimum to liquid limit (wetting path), and reduce water content from liquid limit to optimum water content (drying path). The whole process repeated for four-cycle. Based on several previous studies, after the fifth drying-wetting cycle, there were no differences in test results [10,12,14]—the drying-wetting process to all compacted samples summarized in Table 1 and Fig.2.

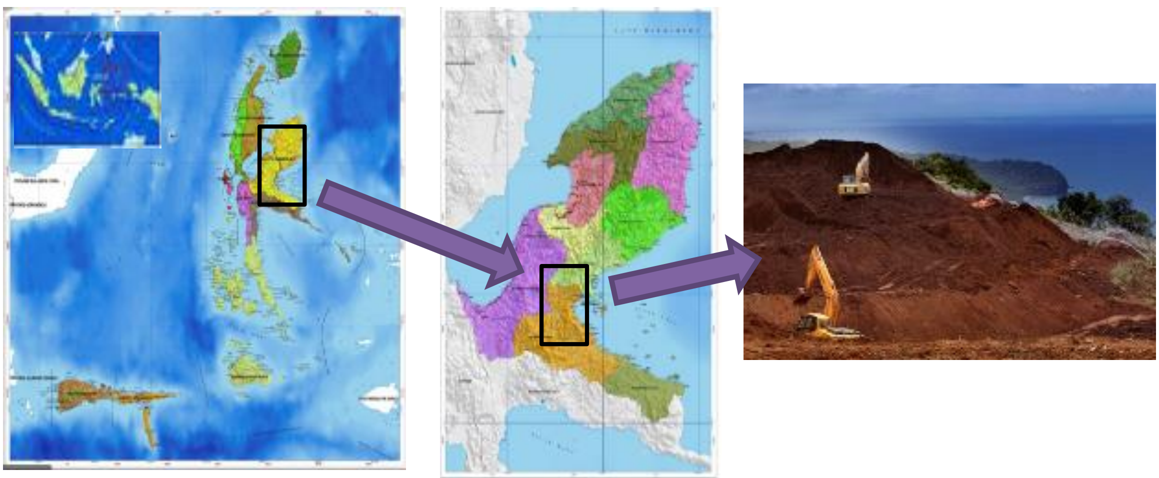

Fig.1 Lateritic soil sampling site

Table 1 Summary of drying-wetting process on compacted samples tests

Stage/process	Drying-Wetting Compacted $w_i=w_{opt}$					Wetting-Drying Compacted $w_i=w_{opt}$				
	Water Content					Water Content				
	w_{opt}	25%	50%	75%	100%	w_{opt}	25%	50%	75%	100
Drying (%)	28	21	14	7	4	28	35	42	49	56
Wetting (%)	4	7	14	21	28	56	49	42	35	28

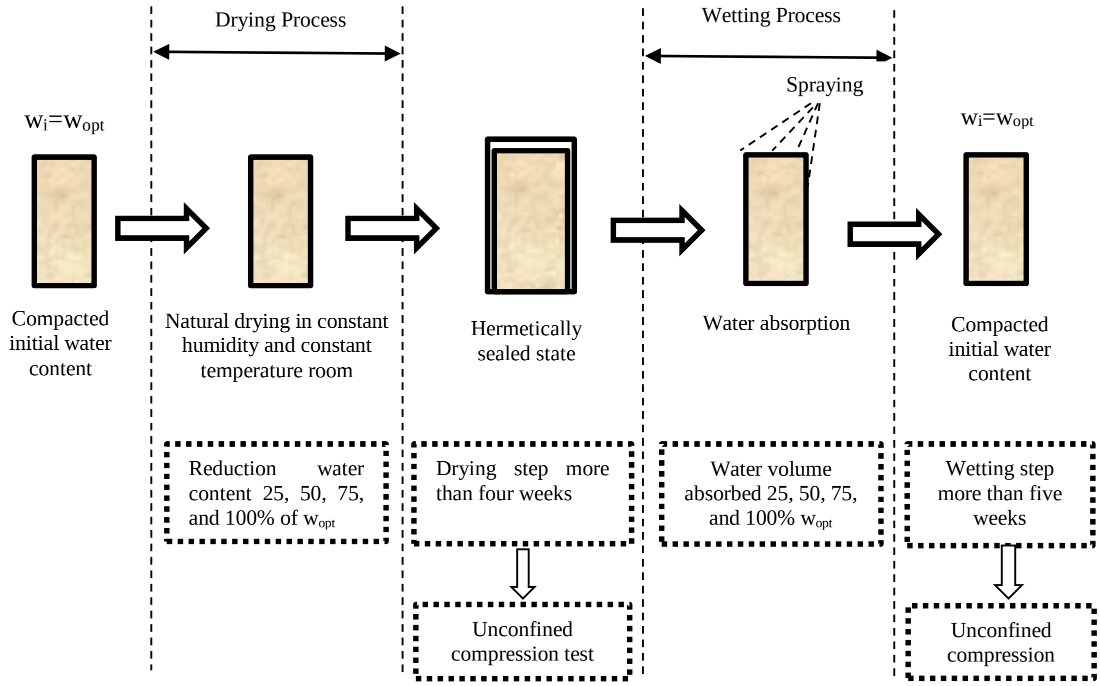

Fig.2 The experimental work of drying-wetting repetition test (modified after Maekawa and Miyakita, 1991)

2.6 Suction Determination Using Filter Paper Method

The negative pore pressure (suction) was measured using *Whatman #42* filter paper. This method has a relatively large measurement range limitation compared to other measurement methods. Each specimen fitted with three filter paper with a diameter of 2.7 cm, and placed in the top, middle, and bottom, to avoid fouling each filter paper is coated on the top and bottom. The filter paper water content calculated to determine soil suction using a calibration graph [21-24].

2.7 Unconfined Compression Test

The unconfined compression test was conducted with a rate of 0.3 mm per minute of axial displacement. The splitting strength measured by applying 74.4N per minute [20].

3. RESULTS AND DISCUSSIONS

The physical properties tests result of lateritic soil, bentonite, and mixed soils are presented in Table 2, while the chemical composition results test as seen in Table 3, as well as the SEM photomicrographs, tests shown in Figs.3 and 4.

Based on physical properties, the lateritic soil, bentonite, and mix-soil classified in high plasticity clay soil under USCS and AASHTO soil classification (Table 2). Based on Table 3, the chemical compounds of lateritic soil dominated by iron oxide (Fe_2O_3) and bentonite dominated by silicon dioxides (SiO_2). Meanwhile, Figs.3 and 4 shows the Scanning Electron Microscope (SEM) test results of lateritic soil and mixture soil, which generally shows the presence of very fine-granules sized (<10μm), in rhombohedral form, cubic, and some elongated tabular forms that are suspected to be calcite. The crystalline grains are generally located on soil fragments surface with a relatively clear shape and scattered in relatively small amounts [25].

Table 2 Physical properties of soil

Soil properties	Lateritic soil	Bento nite	Mixture Soil
1. Grain size analysis			
- Gravel (%)	0	0	0
- Sand (%)	7	0	1.60
- Silt-Clay (%)	93	100	98.40
2. Consistency Limits			
- Liquid Limit (LL), %	81.66	412.21	197.91
- Plastic Limit (PL), %	29.16	37.33	29.86
- Plasticity Index (PI), %	62.50	374.88	168.05
- Shrinkage Limit (SL), %	17.33	52.55	25.34
- Activity (A)	0.54	3.75	1.71
- Swelling Category (Seed et al., 1962)	High	Very High	Very High
3. Specific Gravity	2.68	2.67	2.67
4. Soil Classification			
- USCS	CH	CH	CH
- AASHTO	A-7-6	A-7-6	A-7-6

Table 3 Chemical compositions of Lateritic soil and Bentonite used in this study

Chemical Compound	Lateritic soil	Bentonite
SiO_2 (%)	2.28	55.55
Al_2O_3 (%)	5.37	17.39
Fe_2O_3 (%)	86.55	3.84
MgO (%)	0.83	4.44
CaO (%)	0.25	1.51
Na_2O_3 (%)	-	1.87
K_2O (%)	0.1	0.24

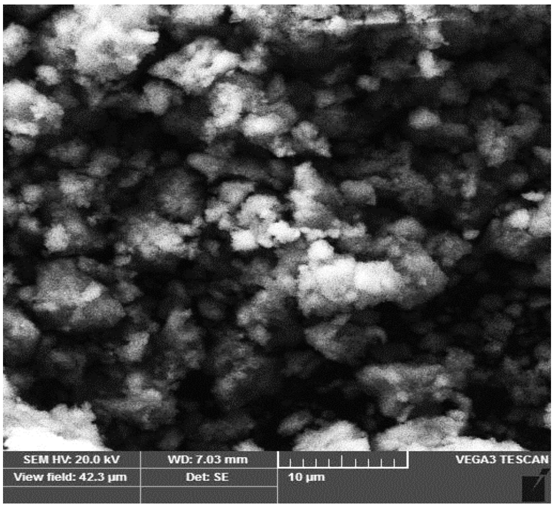

Fig.3 Microphotograph of lateritic soil

Furthermore, the Proctor compaction test was conducted used a *Versa Tester* machine by placing filter paper on sample layer by layer to determine soil suction when compaction test. Proctor compaction test results and their relationship to volume and suction changes presented in Fig.5. Based on Figs.5a and 5c showed that under maximum density, void ratio decreases, and vice versa. The void volume strongly influences the void ratio, so that increasing water content to optimum causes void volume decreases (minimum void ratio) [26-28].

Likewise, void ratio-suction relationship in Figs.5b and 5d show that increasing water content to optimum condition (maximum dry density), suction reaches the optimum condition, whereas water content increase above the optimum causes suction decrease [29-32]. Therefore, the maximum dry density of 1.2001 gr/cm^3 obtained at an optimum moisture content of 28% and an optimum suction of 4500 kPa.

3.1 Volume Change of Compacted Soil under Drying-Wetting Repetition

The drying-wetting path of compacted soil present in Fig.6. Soil volume changes during drying-wetting repetition process on compacted samples show a significant soil-water characteristic curve on suction changes (Fig.6b), this is in line with the findings of Khalili, Habte, and Zargarbashi [33], Tang, Wang, Shi, and Li [34], Wang, Tang, Cui, Shi, and Li [35], and Wei, Hattab, Fleureau, and Hu [36]. In addition, soil suction decrease at a certain degree of saturation. The results are in line with the report of Lourenço, Jones, Morley, Doerr, and Bryant [37], and Sun, Zhang, Gao, and Sheng [38].

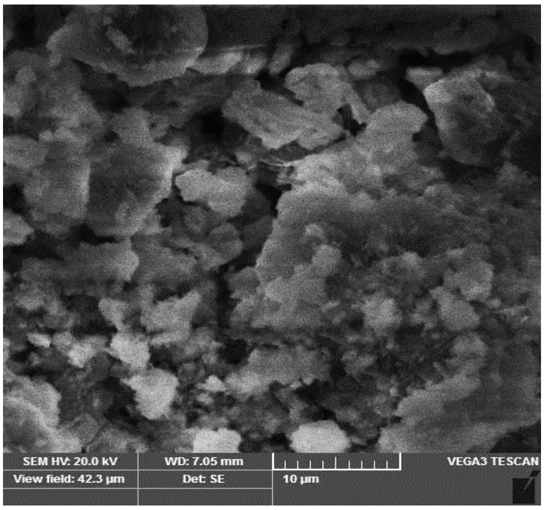

Fig.4 Microphotograph of lateritic-bentonite soil mixture

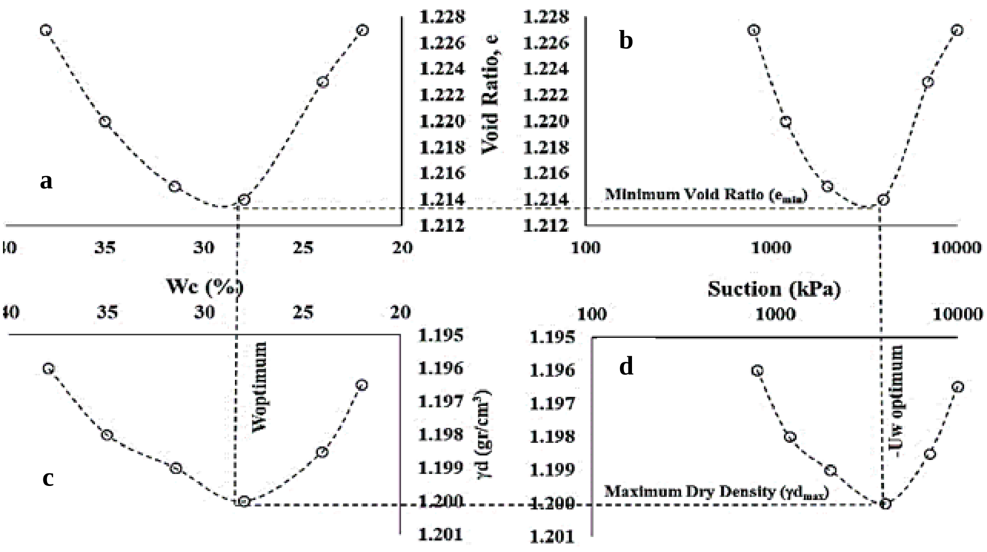

Fig.5 The relationship of soil volume changes, dry density, and suction from standard Proctor compaction tests

Furthermore, based on Fig.6a, during the drying-wetting cycle, the suction value exceeds before the water recedes into the soil pores, similarly with Fredlund and Rahardjo [39]. The degree of saturation on a drying path higher than a wetting path on for two points at the same suction. The soil-water characteristic curve significantly influenced by voids size during the emptying or filling of voids that regularly changed during drying-wetting until it reaches a stable condition. The hysteresis occurs in the drying-wetting paths in this experimental work seen for the first to fourth cycles and similar behavior reported by Tripathy, Rao, and Fredlund [40].

In addition, two swelling components occur; increased water volume-filled voids; and inter-particle force loss from meniscus water causes an increase in void volume during the wetting process [41].

3.2 Unconfined Compressive Strength of Compacted Soil under Drying-Wetting Cycle Repetition

The compressive strength of compacted soil under drying-wetting repetition presented in Fig.7. Soil density and plasticity significantly affect the mechanical behavior, especially compressive strength, elasticity modulus, and permeability. Soil density increases with decreasing water content due to shrinkage, and vice versa during the wetting process in clay soil [42]. The phenomenon seen in soils with high swell-shrink potential.

Furthermore, Fig. 7a shows that the relationship between suction and maximum dry density indicated that increasing drying-wetting cycles cause soil density decreases with decreasing suction. In drying path, shows compacted soil suction changes from 50 - 100,000 kPa.

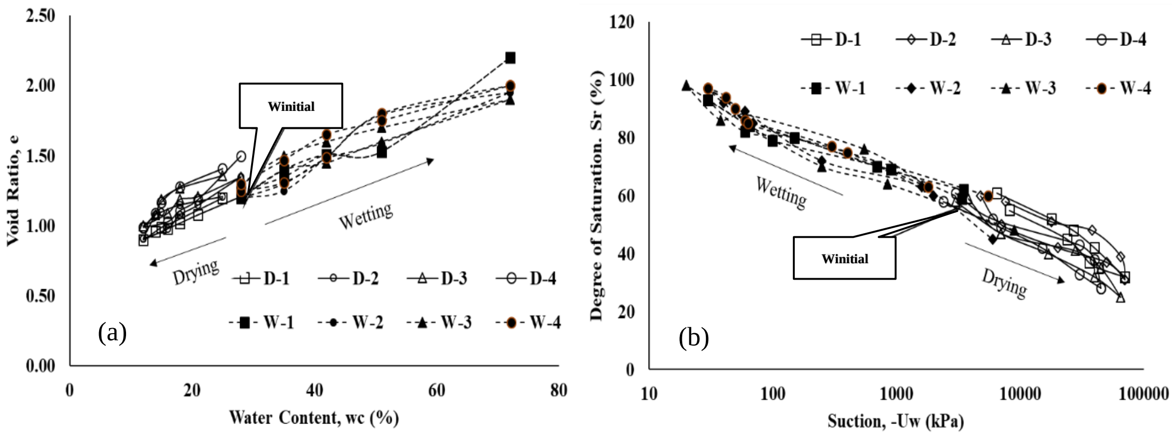

Fig.6 The volume change on compacted soil mixture during drying-wetting cycle repetition

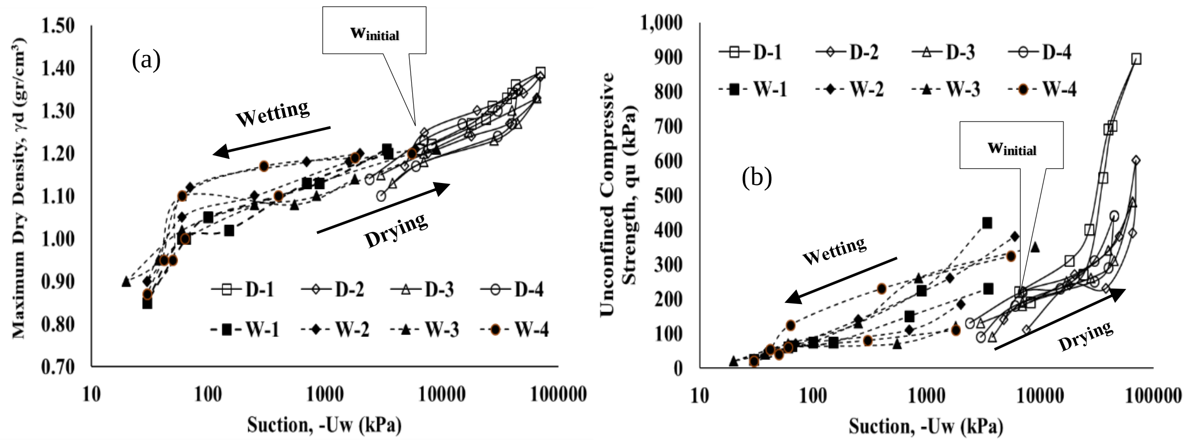

Fig.7 Compressive Strength of compacted soil mixture during the drying-wetting repetition

While soil density increases sharply in suction below 100 kPa, then gradually increases to the maximum suction value. Meanwhile, Fig.7b shows that the phenomenon of increasing and decreasing compressive strength forming peaks in unsaturated conditions. As a result of drying-wetting repetition, soil particle structure, and orientation change due to particle bonds weak, it was causing the strength decreases. Besides, the enlarged pore volume facilitates water discharge, causes the degree of saturation to decrease, and the soil behaves brittle, it is following the results reported by Maekawa and Miyakita [8].

4. CONCLUSION

Unconfined compression tests on compacted expansive soil mixture of lateritic and bentonite under drying-wetting cycle repetition have been conducted—the drying-wetting cycle repetition significant effect on soil volume change, suction, and compressive strength of the soil. The increasing number of cycle, cause void ratio decrease and degree of saturation increase, and soil suction tends to decrease at the same void ratio, likewise, soil compressive strength decrease at the same water content. Decreasing soil compressive strength causes a decrease in elastic modulus so that soil failure behavior is more brittle and work-softening.

Therefore, the study results provide important geotechnical characteristics data of lateritic soil with high swell-shrink potential. Henceforth, some soil improvement innovations can perform to generate high-quality construction materials more effectively and efficiently.

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