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A Review on Critical State Parameters of Residual Soil

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Abstract: The Critical State Soil Mechanics (CSSM) is globally known as useful tool and framework for the behavior of saturated soils such as clay and sand. The importance of knowledge in CSSM of residual soil is needed in Malaysia, since, most of the soil in Malaysia is a residual soil. This study summarizes the critical state parameters of residual soils were obtained by different researchers who have conducted at several location in the world. The critical state parameters such as stress ratio M in q-p' space, Γ as the intercept at v-lnp' space, λ as a slope of critical-state line in v-lnp' space and k as a slope of rebound curve or line in v-lnp' space. Therefore, the information of this summarize study will develop a clear vision and guidance for new researchers and civil engineering activities.

Key words: Critical state parameters, residual soil, guidance, vision, activities, information

INTRODUCTION

More than half or 70% of the land area in Peninsular Malaysia is covered with residual soil (Taha and Asmirza, 2001a, b; Huat *et al*., 2004) make the abudance of this soil types is an advatages to the construction industries such as roads, airports, dam, foundation, slopes and other. Granite and sedimentary residual soils cover most part of Peninsular Malaysia where the rest in coastal area soft clay dominates as refer to Fig. 1. The immense measure of residual soil in Malaysia was contribute by the element of tropical atmosphere with the power of precipitation is recorded between 1778-3556 mm every year and temperature is 25-27°C (Taha and Asmirza, 2001a, b). As weathering process take this factors as an advantage, the residual soil is known as one of the soil with heterogenities.

By definition, the residual soil is delivered nearby or in-situ by the weathering of rock in the region of the tropical climate and sub-tropical. The residual soil is otherwise called the result of the weathering of rock for instance of volcanic, sedimentary or metamorphic rocks and soil adjust is typically rosy or reddish in color because of the presence of iron and aluminum oxides in mineral substance (Rahardjo *et al*., 2012). Residual soil deposited materials generally have a layer of silty clay and clay followed by a layer of silt and sandy soil. In any case, residual soil in Malaysia is comprised of a composite of sand, silt and clay to the rates shift contingent upon topographical part of soil.

Residual soil is not like other sediment transport where the engineering properties and behavior of residual soil might be distinctive and more hard to anticipate and demonstrated in view of numerical counts or mathematical calculations (Rahardjo *et al*., 2012). Residual soil additionally have a tendency to have a porosity and permeability higher than original parents rock. Elements of this is one of a kind that will bring about instability of slope during the infiltration process, especially in tropical regions where the phenomenon of the heavy rain and long-prone (Rahardjo *et al*., 2012). Other than that residual soil also tends to vary due to differences in the percentage of depth or different weathering rates and causes changes in soil properties remaining to be unpredictable (Faisal, 1990; Huat *et al*., 2004). In addition, different depths will produce diverse in mineralogy, soil size distribution and the engineering properties (Rahardjo *et al*., 2012; Huat *et al*., 2004; Taha and Asmirza, 2001a, b).

Critical State Soil Mechanics (CSSM) concept provides an integrated concept relating to the behavior of soil incorporating certain stress value and volume of

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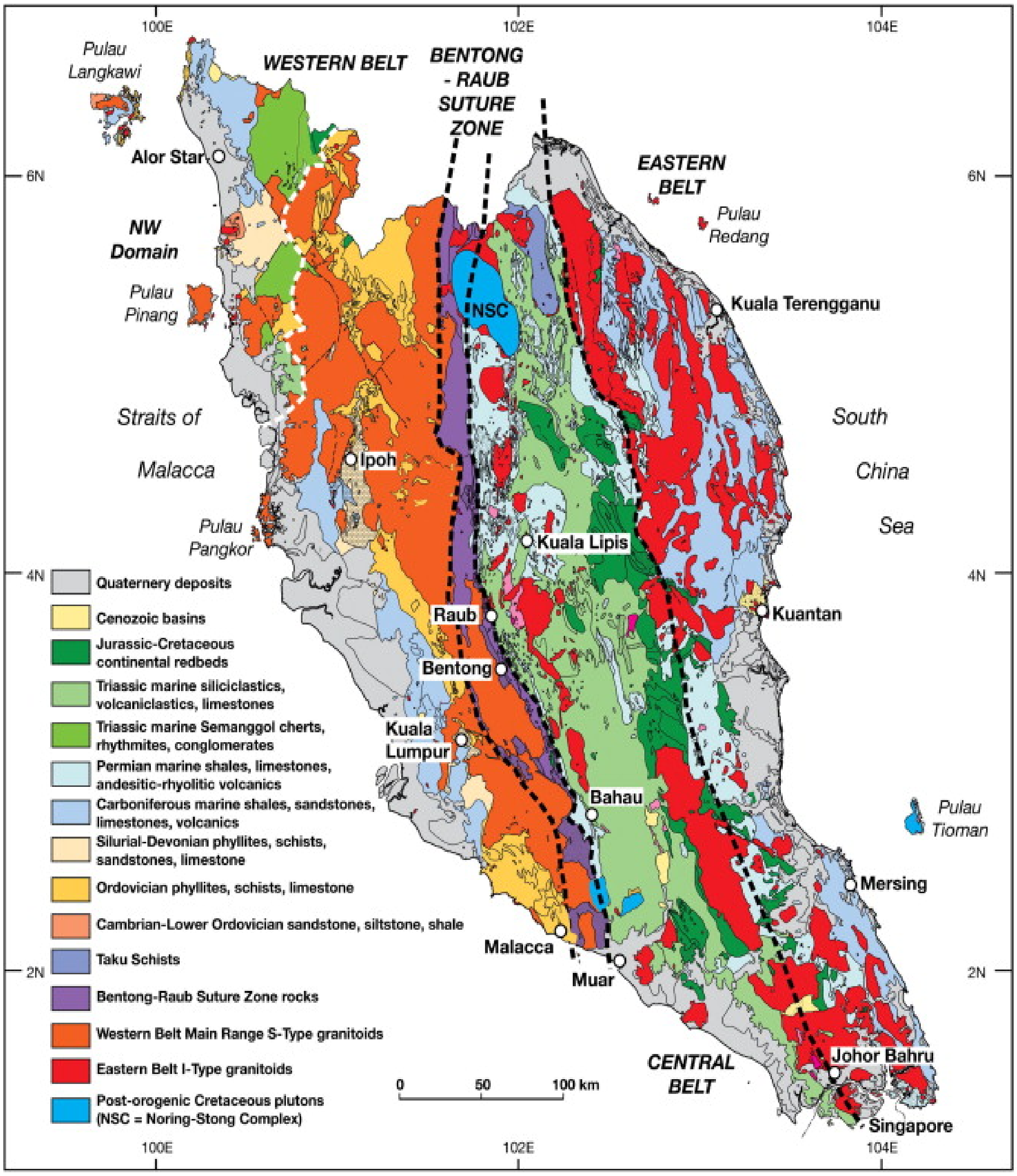

Fig. 1: The distribution types of soils in Malaysia (http://hardrock.earth.ox.ac.ukeconomicimagesMalayMetcalfe, 25 November 2015)

inter-related with each other. This concept initially presented by Roscoe *et al*. (1958) in composing identified with yielding soil. In this study, the soil is said to give strength and achieve critical condition at a certain volume and value of shear stress. At this point, yielding of soil is considered valid at the border point of the three-dimensional surface coverage of failures (Whitlow, 2001). Conduct a critical condition described as soil conditions where the volume of soil has not changed under larger shear strain (Maleki and Bayat, 2012; Toll and Ong, 2003; Kayadelen *et al*., 2007).

Critical state parameters: A soil is said to be in critical state when it experiences large shear deformation at constant volume and constant shear and normal effective stress (Toll and Ong, 2003: Marto *et al*., 2014: Nagendra and Sulochana, 2013: Kayadelen *et al*., 2007). A locus of critical states of all shear tests on a soil is called a Critical State Line (CSL). The CSL is plotted in a three-dimensional space consisting of deviatoric stress, mean normal effective stress and void ratio. Where a particular soil sample will end up on the CSL depends on its starting void ratio, mean normal effective stress and

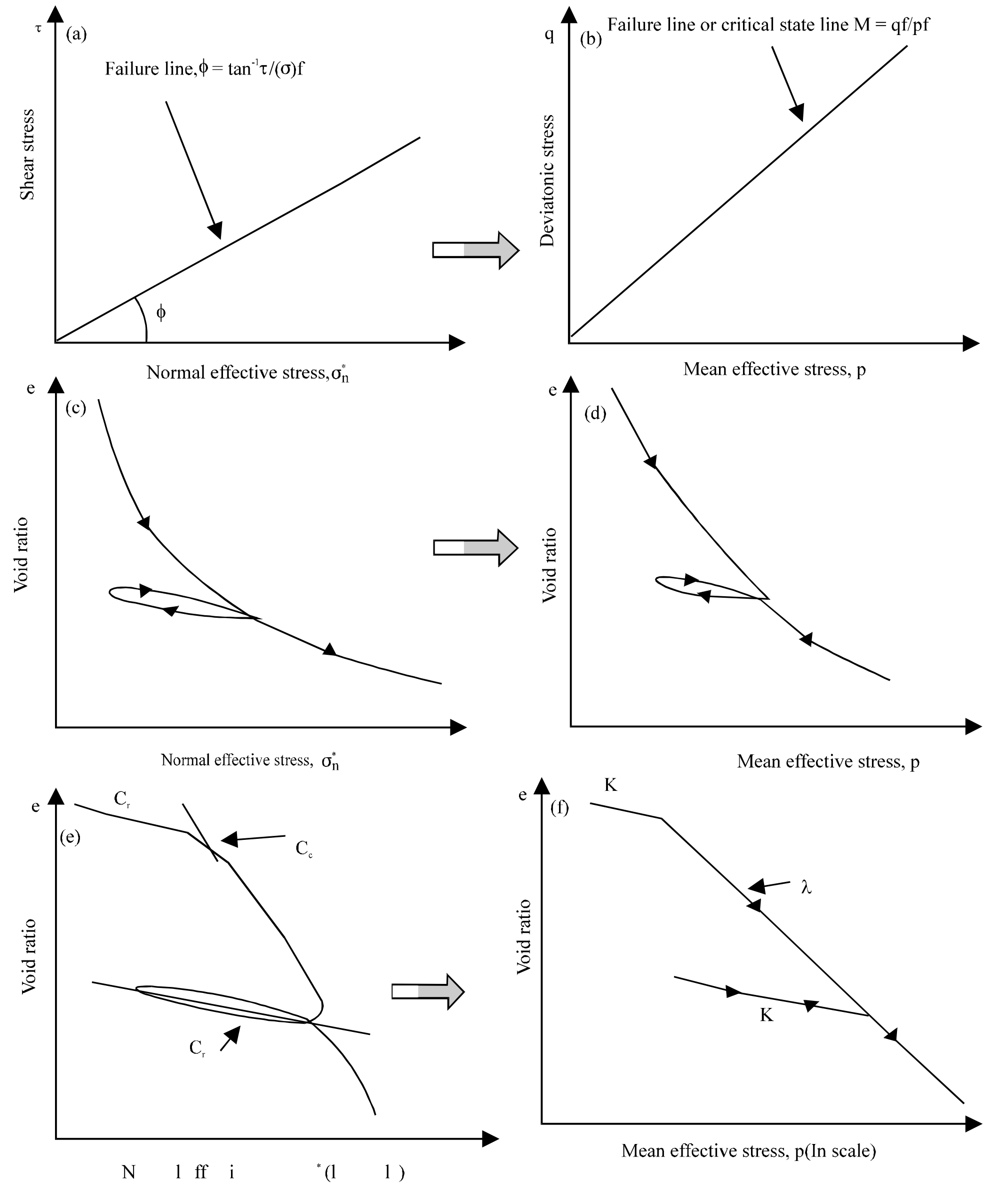

Fig. 2: a-f) Differents between Mohr-Coulomb method and crtitical state method

the stress path. All the elasto-plastic models based on the critical state concept have an all around characterized yield locus that can be either isotropic or anisotropic. These models are not based on the Mohr-Coulomb failure criterion, although, the slope of the CSL can be promptly connected with the critical state angle of internal friction. (Karmakar *et al*., 2004). Figure 2 shows differents between Mohr-Coulomb method and crtitical state method.

The behaviour of saturated soils is controlled by effective stresses and for the saturated case water content and volume are interrelated. In this manner the saturated critical state can be expressed through the deviator stress, q, the mean effective stress, p' and the specific volume, v. At the critical state these variables are connected through three critical-state parameters, M, Γ and λ:

$$q = Mp'$$
$$\nu = \Gamma - \lambda \ln p'$$

Where:

M = The slope of the projection of the critical-state line in q-p' space
Γ = the intercept (at p' = 1 kPa)
λ = Slope of the projection of the critical-state line in ν-ln p' space (Toll and Ong, 2003, Kayadelen *et al*., 2007)

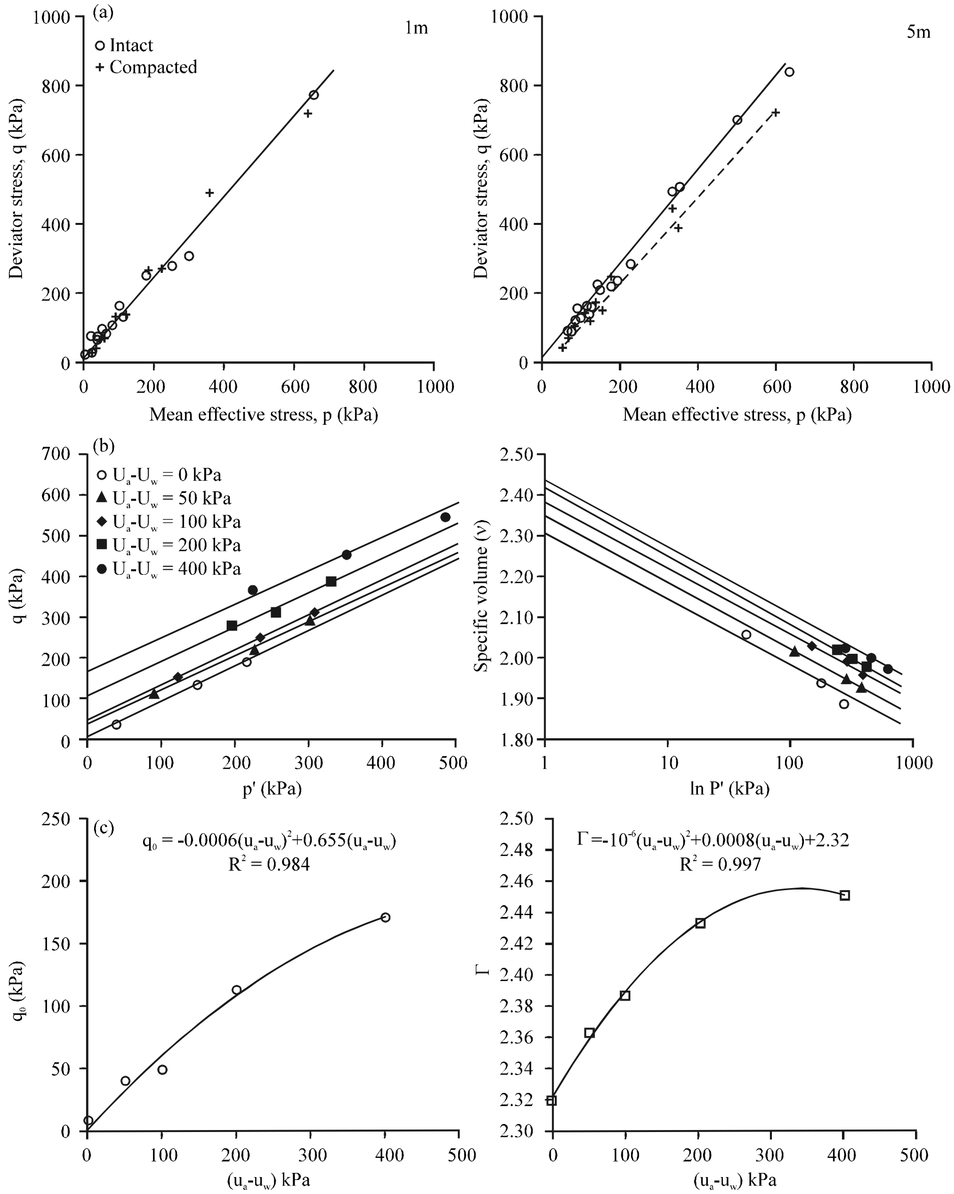

Fig. 3: a) Critical state line in q-p' space of intact and compacted tropical saturated soil for 1 and 5 m depth (Futai *et al*., 2004); b) Critical state line in q-p' space and ν-ln p' space of saturated and unsaturated residual clayey soil from Turkey (Kayadelen *et al*., 2007) and c) Relation between the intercept q_0 and G with matric suction $(u_a\text{-}u_w)$ of unsaturated residual clayey soil from Turkey (Kayadelen *et al*., 2007)

However, unsaturated soils have an extra phase (the air phase) and it is, therefore, no longer conceivable to interpret their behaviour through effective stresses, nor to assume that water content and volume are connected. For unsaturated soils, the stress state can be represented by two stress state variables, the net stress $(\sigma\text{-}u_a)$ and the matric suction $(u_a\text{-}u_w)$ (Fredlund *et al*., 1978) where, u_a is the pore air pressure and uw is the pore water pressure. In addition to specific volume (or void ratio), the phase state of the soil has to be represented by an additional variable. This can be either gravimetric water content (w), volumetric water content (θ) or degree of saturation (S_r). Toll and Ong (2003) suggested that the critical state for unsaturated soils could be expressed in terms of q, $p\text{-}u_a$, $u_a\text{-}u_w$, ν and S_r. The unsaturated critical state requires five parameters, M_a, M_b, Γ_{ab}, λ_a and λ_w:

$$q = M_a(p\text{-}u_a)+M_b(u_a\text{-}u_w)$$
$$\nu = \Gamma_{ab} - \lambda_a \ln(p\text{-}u_a)\text{-}\lambda_b \ln(u_a\text{-}u_w)$$

Figure 3 shows an example of the graph plotted for determination value of M, λ, Γ for various researcher.

Problem statement: The concept of critical state for saturated clay has been successfully produced by Schofield and Wroth in 1968 and up to now many studies have been conducted based on this concept. However, most studies have been made only focuses on the critical parameters for saturated clay and up to now there has been a little study on critical state of residual soil may be because of the uncertain properties and the behavior of residual soil its self.

The aim of research: This summarize study conducted to develop and transfer all the information about the implementation of critical state soil mechanics in residual soil that will develop a clear vision and guidance for new researchers and civil engineering activities.

MATERIALS AND METHODS

Method of research is summarize all the data from the journal and book about the application of critical state soil mechanics in residual soils all over the world. All the types of soil sample with specific location, depth, method approach, value of confining pressure and matrix suction and finally, the results of the critical state parameters were classified accordingly. All the value were then summarize into table and the connection between the data were discussed.

RESULTS AND DISCUSSION

Table 1 shows the summarize value of critical state paremeter from the previous researcher with differences location, method of sampling and others.

Slope of the projection of the critical state line, M: From Table 1, the value of M is in the range of 0.879-3.1 for saturated soil samples while for unsaturated, the value of M is in the range of 0.825-0.866. The value of M can be calculated from the graph of deviator stress, q versus mean effective stress, p' by ploted the value from the origin of the axis. Toll and Ong (2003) reported that the critical state stress ratio, for unsaturated soil is a function of the degree of saturation, S_r. This findings is supported the report by Zakaria *et al.* that, the slope of the critical

Table 1: Critical state parameters of residual soil obtained by previous researchers

Resources	Locations	Type of residual soil	Depth (m)	Method/approach	Matrix suction (ua-uw)	Confining pressure	Critical state parameters M	λ	Γ	κ
Nagendra and Sulochana (2013)	Vinyaka Nagar Gayathri Nagar	Sedimentary residual soil	1.8-3.5	Undisturbed and remoulded saturated sample (Consolidation Drained test-CD test)	-	50	2.8	-	-	-
						100	1.5	-	-	-
						50	3.1	-	-	-
						100	1.4	-	-	-
Kayadelen *et al.* (2007)	Turkey	Residual clayey soil	2.5	Undisturbed saturated and unsaturated sample (Consolidation Drained test-CD test)	-	-	-	-	-	-
				Saturated	-	27-700	0.879	0.074	2.320	-
					50		0.843	0.074	2.363	-
					100		0.866	0.074	2.386	-
				Unsaturated	200		0.84	0.076	2.432	-
					400		0.825	0.075	2.450	-
Toll and Ong (2003)	Curzon Hall, Dhaka Bangladesh	Tropical swdimentary clay soil	1.1-6.4	Undisturbed saturated sample (Consolidation Drained test-CU test)	-	50-800	0.95-0.96	0.060	1.830	-
Azevedo *et al.*	Vicosa City, Minas Geris, Brazil	Young Gneiss residual soil	12.0	Disturbed saturated sample (Consolidation Drained test-CD test)	-	50-400	2.173	0.240	-	-
Mofiz *et al.*	UKM, Bangi, Malaysia	Granite residual soil	1.0	Disturbed saturated sample (Consolidation Drained test-CD test)	-	100-600	1.11	0.039	2.010	0.011
Futai *et al.* (2004)	Ouro Preto City, Minas Gerais, Brazil	Gneiss residual soil	1.0-7.0	Disturbed saturated sample (Consolidation Drained and undrained test-CD and CU test)	-	50-400	-	-	-	-
			1.0				1.14	0.176	2.890	-
			2.0				1.03	0.182	2.930	-
			3.0				1.2	0.151	2.510	-
			4.0				1.36	0.104	2.270	-
			5.0				1.01	0.150	2.500	-
			6.0				1.25	0.183	2.700	-
			7.0				1.08	0.182	2.800	-
Toll and Ong (2003)	Jurong, Singapura	Residual sandy clay soil	4.0-5.0	Disturbed saturated sample (Consolidation Drained-CD test)	-	50-150	1.23	0.080	2.000	-
Taha and Asmirza (2001a, b)	UKM, Bangi, Malaysia	Granite residual soil	1.0	Disturbed saturated sample (Consolidation Drained test-CD test)	-	100, 300 and 600	1.2879	0.040	-	0.014

state line for unsaturated soil sample increased as suction increase. Kayadelen *et al.* (2007) proved that by increased the value of matrix suction, the M value will be increase too.

Slope of the projection of the critical-state line in ν- ln p' space, λ: The value of λ can be calculated from the graph of specific volume, ν versus mean effective stress in log scale, lnp'. From Table 1, the value of λ is in the range of 0.08-0.183 for saturated condition and 0.074-0.076 for unsaturated condition of soil sample. From these data, it is shown that the value of λ is inversely propotional with the value of confining pressure. High confining pressure will lead to low value of void ratio, thus, the specific volume too and this will produce low value of λ.

Intercept value of the critical-state line in ν- ln p' space, Γ: This value can be determined by referring to the intercept of the graph when the value of mean effective stress is equal to 1 kPa (p' = 1 kPa). For saturated soil sample, the range value is between 1.83-2.93 while for unsaturated soil, the range is 2.363-2.45.

Slope of the rebound curve, κ: The value of κ can be calculated from the same graph of the critical-state line in ν-ln p' space but the value is represented the rebound or unloaded curve. From the data in Table 1 only, Taha and Asmirza (2001a, b) and Atkinson (1993) show the value of κ. The value is in the range of 0.06-0.014.

CONCLUSION

The stress-strain behaviour of soils could be interpred through established plasticity model such as Mohr-Coulomb and Critical State Soil Mechanics (CSSM), in the mean time CSSM develop by Schofield and Wroth is the most intense framework to explain and clarify the fundamental behaviour of different types of soils. It is notable that the critical state for sand and clay are both well established. Nevertheless, the usage of CSSM in saturated and unsaturated residual soils is still lacking as yet inadequate.

Researchers found that, different types of residual soil with differents depth will experiences distinctive estimation of critical state parameters. This is because of residual soil characteristic such as original parents rocks, mode of formation, degree of weathering and the location of the the sample at the site such as depth are interlinked with each others. For instance, soil formed from granite has high clay content than soil that formed from the sandstone rocks. The information gathered in this study hopefully required to help researchers to enhance research in the future and makes the information displayed as a kind of perspective in their exploration.

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