SHEAR STRENGTH PARAMETER CORRELATION OF CRACKED SOILS FROM MODIFIED DIRECT SHEAR

Rosa Irdiana[a*], Indrasurya B. Mochtar[a], Noor E. Mochtar[a]

***Abstract**: Cracked soil is a theory about the landslide due to cracks on the surface of the slope. Several studies about the shear parameters of cracked soil have been carried out. The latest research was about physical and shear strength parameters correlation of cracked soil upon soft to stiff consistency. The soil conditions in that research were less representative of the slope soil consistency that can be very stiff. Therefore, further research for medium to very stiff consistency was conducted. Cracked soil test specimens were tested using the modified direct shear test with the same total pressure and various water pressure. The results showed that water pressure had no significant effect on the cracked soil. Thus, the other cracked soil samples were tested using direct shear without water pressure in the crack to know the shear parameters correlation of the soil. In cracked soils, the cohesion was lost and friction angle was not affected by the void ratio of the soil. The empirical formula of cracked soil shear parameters correlation at medium to very stiff consistency were for LL < 50%; Ø = 22˚ and LL ≥ 50%, Ø = -0.0024 LL^2 + 0.2062 LL + 17.514.*

Keywords: *Cracked soil, modified direct shear, shear strength parameter*

INTRODUCTION

Landslide facts in the field show that landslides occur during the rainy season with high-intensity/heavy rainfall. Many studies have also shown that heavy rainfall is directly related to slope failure [1][2][3]. Besides that, landslides can occur on slopes that have been stable for a long time. Landslides can also occur on the slope composed of rock or stiff clay that has very safe stability. Landslides also occur on sloping slopes and generally do not occur along the side of the slope, although the soil type, slope, and rainfall intensity are relatively the same [4]. Logically and theoretically, the slope should have the same slide along the side of the slope in the same condition.

According to [5], landslides occur due to cracks in the soil surface as a result of soil shrinkage, past soil movements, strong ground movements (vibrations from earthquakes), the presence of a thin layer of sand on a thick silt-clay soil layer (Figure 1), and the weathering of plant roots. Cracks may have appeared since the soil formed[4][6]. When it rains, water will enter the crack and flow out of the crack at a relatively slow speed (dissipate). The water may carry the fine soil fraction, while the coarse soil fraction (fine sand) remains in the crack plane. This causes there to be a thin layer of sand in the crack so it behaves like sand [7].

When the rain is not heavy, the volume of water entering the crack is relatively small and can be easily dissipated so the crack area is not completely filled with water (Figure 1). During heavy rains, the volume of water entering the crack is relatively large, thus the crack is completely filled with water (Figure 2) and causes pore-water pressure build-up; this situation can cause sliding if there is a propagation of the crack [5].

The crack propagation is a function of time, where the propagation can be stopped by rocks or plant roots (Figure 3). The crack propagation that causes landslide depends on the crack direction, as shown in Figure 4 [8]. During heavy rains, crack propagation in the same direction as the landslide potential area might induce landslides.

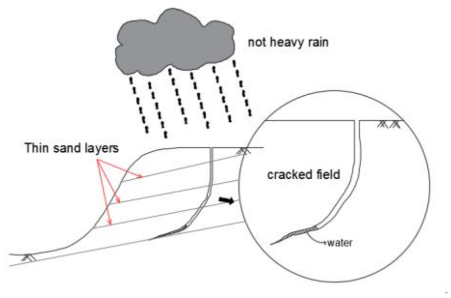

Figure 1 Thin layer of sand and crack is not completely filled with water [5]

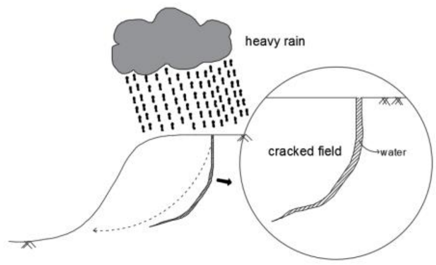

Figure 2 Crack is not completely filled with water during heavy rain [5]

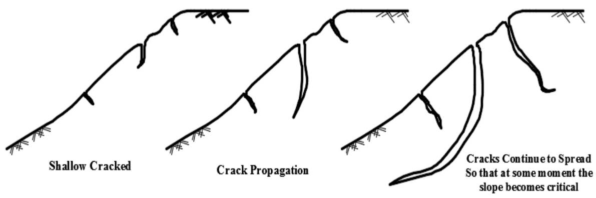

Figure 3 Crack propagation mechanism

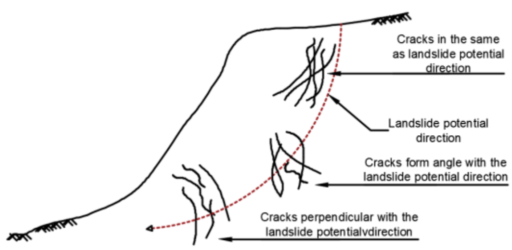

Figure 4 Crack direction and pattern on the potential landslide [8]

[a]Civil Engineering Department, Institut Teknologi Sepuluh Nopember, ITS Campus, Sukolilo, Surabaya 60111, Indonesia. Corresponding author email address: rosa.irdiana@gmail.com

Several studies, including one on cracked soil parameters, have been conducted to develop this theory. The research developed cracked soil testing in the laboratory using a modified direct shear device by adding a water input system; modifications were also made to the shear box, so the water pressure could be given to test object as the conditions in the field as shown in Figure 5 [9]. Besides that, [10] has conducted on the relationship between cracked soil and cohesion, also the shear angle for high plasticity clay (Lok Buntar clay).

From that research, it was found that the soil cohesion would be lost when a crack 100% occurs and the soil only had a friction angle value. However, research that is conducted with the modified direct shear takes a long time and is expensive. Therefore, [11] researched to find another way to obtain the relationship between soil physical parameters with cohesion and friction angle in cracked soil without direct testing in the laboratory. The research was conducted for soft, medium, and stiff consistency soils, where the empirical formula was obtained between the initial soil cohesion and the void ratio. Besides that, an empirical relationship is obtained between the plasticity index and the void ratio to the value of friction angle of the cracked soil. However, the results of this research are not representative of field conditions because slopes are generally formed from medium to very stiff consistency soil.

Based on the above-mentioned research findings, additional research is required to determine the empirical formulation between the physical parameters of the soil and the value of the friction angle in cracked soil for fine soils with medium to very stiff consistency according to the soil conditions in the field.

RESEARCH SIGNIFICANCE

This research was carried out to determine the empirical formula between the soil physical parameters and the friction angle in cracked soil for medium to very stiff consistency fine soils, so direct laboratory testing is not required.

METHODOLOGY

This research used disturbed soil samples to test for various plasticities (liquid limit) and water content variations. The water content was the optimum water content obtained from the modified proctor test. The mixture of the soil and water was compacted to make a soil sample with a design consistency (medium to very stiff) under the C_u value estimated by [12] which was determined using the UCT test. Henceforth, new specimens were made to be tested for modified direct shear and direct shear.

To imitate the condition of the sample in a cracked state for the modified direct shear and direct shear tests, the specimen was cut in half. Before the modified direct shear test was done, the varying water pressure with the same total pressure for each sample was applied to the cracked sample. The variation of the test object with various water pressure is presented in the form of a matrix as in Table 1.

The tests were carried out to ascertain the effect of water pressure on the cracked soil shear strength. If the water pressure in the cracked soil did no effect on the soil shear strength, the test object was subjected to additional tests with a water pressure of 0 kg/cm^2 that presented in Table 2. The modified direct shear test without water pressure is the same as the direct shear test in general.

The value of the cracked soil physical and shear parameters will be obtained as the result. The parameters will then be analyzed to obtain an empirical correlation between the physical and shear parameters of the cracked soil.

ANALYSIS AND DISCUSSIONS

A. SOIL PARAMETERS STUDIED

The soil samples studied in this research were taken from three different locations which had liquid limit (LL) value as follow: low ±30%, medium ±60%, and high ±90%. The classification of the soil samples is shown in Table 3. The optimum moisture contents (w_c optimum) of the samples were determined by a modified proctor test; w_c optimum for each sample was 12.1% (Gresik Soil), 27.0% (Cicadas Soil), and 26.0% (Robotics Soil).

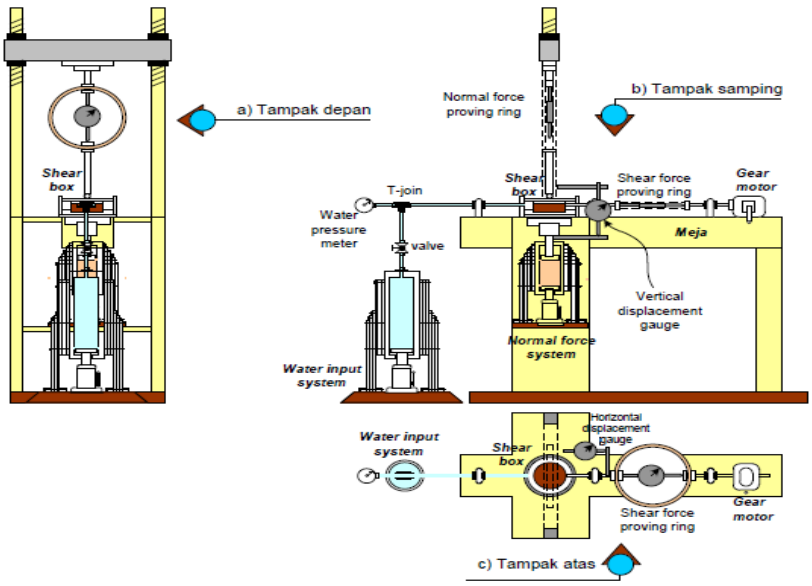

Figure 5 Schematic of the modified direct shear test apparatus [9]

A new sample was made using each sample wc optimum to determine the Cu value using the UCT test to obtain the density of soil samples with different consistency (medium, stiff, and very stiff) as given in Table 4. So, each type of soil (low, medium, and high LL) has 3 samples with different consistencies.

Furthermore, the physical properties and soil shear parameters of the new samples were determined by direct shear and modified direct shear tests. The void ratio of each soil type (low, medium, and high LL) with different consistency (medium, stiff, and very stiff) are given in Table 5. From the results given in Table 5, it is known that the higher the consistency of the soil, the value of the void ratio will decrease, the value of the void ratio will decrease. This is because the pores of the soil are smaller with higher soil consistency.

B. THE EFFECT OF WATER PRESSURE ON CRACKED SOIL SHEAR STRENGTH

To determine the effect of water pressure on the cracked soil shear strength, a modified direct shear test was carried out with the same total pressure ($\sigma = \sigma' + u$) with various water pressure (u) (u = 0.0 kg/cm^2, 0.5 kg/cm^2, 1.0 kg/^{2}) only for some specimens Table 1.

The test results are presented in the form of the relationship between horizontal displacement and shear stress for medium consistency with low LL, stiff consistency with medium LL, and very stiff consistency with high LL soil samples, given in Figure 6, Figure 7 and Figure 8.

The results in the figures show that the largest shear stress value of the cracked soil sample is at water pressure = 0 kg/cm^2. However, the shear stress is not affected by the water pressure in the cracks, especially for soil samples with medium liquid limit and stiff consistency. These results are appropriate with the results of the research by [10][11]. Therefore, it can be concluded that water pressure does not affect the shear strength of the soil. For this reason, further tests were carried out with direct shear without water pressure (0.0 kg/cm^2) on the cracks.

C. RELATIONSHIP BETWEEN PHYSICAL AND SHEAR PARAMETERS ON CRACKED SOIL

The results of the direct shear test with water pressure in the crack = 0 kg/cm^2 for soil samples with LL values and consistency variations based on Table 2 are in the form of the relationship between horizontal displacement and shear stress.

Table 1 Cracked Soil Specimen Matric with Water Pressure Variations

Consistency/ Plasticity	Medium	Stiff	Very Stiff
Low	Water pressure: 0.0 kg/cm^2: 1 specimen 0.5 kg/cm^2: 1 specimen 1.0 kg/cm^2: 1 specimen Note: Same total stress.	None	None
Medium	None	Water pressure: 0.0 kg/cm^2: 1 specimen 0.5 kg/cm^2: 1 specimen 1.0 kg/cm^2: 1 specimen Note: Same total stress	None
High	None	None	Water pressure: 0.0 kg/cm^2: 1 specimen 0.5 kg/cm^2: 1 specimen 1.0 kg/cm^2: 1 specimen Note: Same total stress

Note:
- The test object can be added if the results are irregular
- If the **water pressure did not affect** shear strength, the test will be done with water pressure of 0.0 kg/cm^2

Table 2 Cracked Soil Specimen Matric with Water Pressure of 0 kg/cm^2

Consistency/ Plasticity	Medium	Stiff	Very Stiff
Low	3 specimens for 3 different normal stresses	3 specimens for 3 different normal stresses	3 specimens for 3 different normal stresses
Medium	3 specimens for 3 different normal stresses	3 specimens for 3 different normal stresses	3 specimens for 3 different normal stresses
High	3 specimens for 3 different normal stresses	3 specimens for 3 different normal stresses	3 specimens for 3 different normal stresses

Note:
- Three times tests for each normal stress

Table 3 Initial Soil Classification

Parameters	Gresik Soil	Cicadas Soil	Robotic Soil
Liquid limit (LL)	30%	62%	92%
Plastic Limit (PL)	22%	45%	53%
Plasticity Index (PI)	9%	17%	39%
Sand	13,20%	2,34%	1,10%
Silt	36,75%	17,12%	15,94%
Clay	31,96%	80,33%	82,96%
USCS	CL	MH	MH
AASHTO	A-4	A-7-5	A-7-5

Table 4 Soil density use

LL 30% (GRESIK)			
Consistency	C_u (kg/m^2)	γ (g/cm^3)	γ use (g/cm^3)
Medium	0,27	1,64	1,64
Stiff	0,52	1,76	1,76
Very Stiff	1,01	1,89	1,89
LL 60% (CICADAS)			
Consistency	C_u (kg/m^2)	γ (g/cm^3)	γ use (g/cm^3)
Medium	0,26	1,29	1,30
Stiff	0,52	1,37	1,37
Very Stiff	1,03	1,51	1,52
LL 90% (ROBOTIKA)			
Consistency	C_u (kg/m^2)	γ (g/cm^3)	γ use (g/cm^3)
Medium	0,26	1,25	1,25
Stiff	0,53	1,3415	1,35
Very Stiff	1,06	1,496	1,50

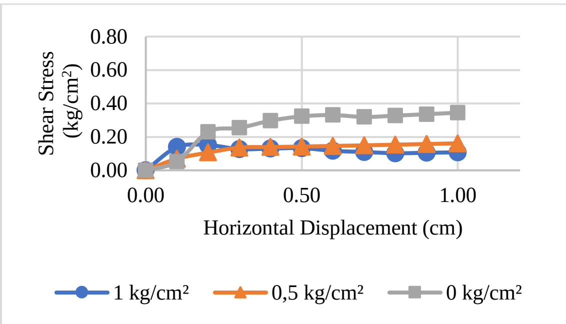

Figure 6 Modified direct shear test results on low plasticity and medium consistency soil

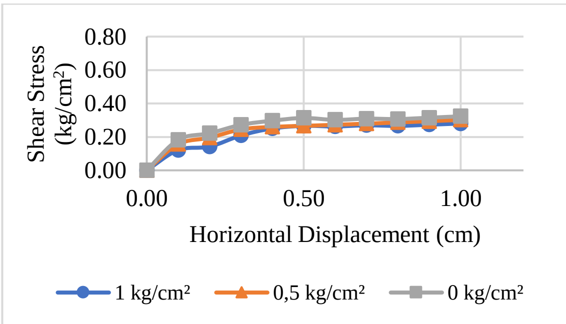

Figure 7 Modified direct shear test results on medium plasticity and stiff consistency soil

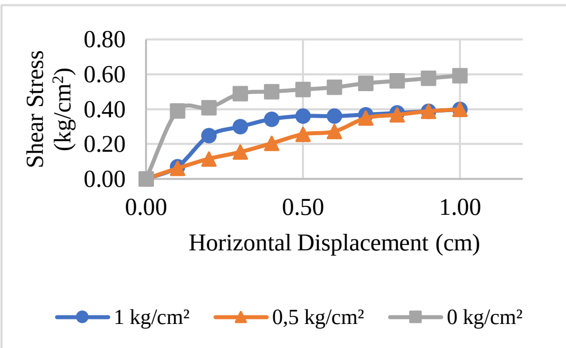

Figure 8 Modified direct shear test results on high plasticity and very stiff consistency soil

Thus, the residual shear stress value is plotted with the normal stress value to get the soil shear strength (cohesion and friction angle) as shown in Table 6. From the shear test results in Table 6, it is known that the cohesion value is very small (close to 0). This means that in soils that have been cracked the cohesion value will be lost because the value is so small and it can be ignored (C = 0). These findings are relevant to previous research [5] [6].

The relationship between liquid limit and friction angle for cracked soil samples is given in Figure 9; while the relationship between the void ratio and the friction angle is given in Figure 10. From Figure 9 it can be seen that the increasing LL is accompanied by a decreasing value of the soil friction angle. This shows that with the finer soil, the value of the friction angle will decrease. Figure 10 shows that the value of the void ratio in cracked soil does not affect the value of the friction angle. This is appropriate with [13], which states that the main variable for cohesion derivatives is the void ratio; if cohesion is lost, the void ratio does not affect the friction angle. Therefore, the empirical correlation that can be made is the relationship between the liquid limit and the friction angle.

Empirical correlation is obtained from cracked soil liquid limit and friction angle data regression (Figure 11). From the regression, it was found that for LL < 50% the friction angle value is constant and at LL 50% the friction angle value will decrease (Figure 11). The empirical formula obtained for cracked soil (C = 0) is as follows:

$LL < 50\%$:

$$\Phi = 22^{o} \qquad (1)$$

$LL \geq 50\%$:

$$\Phi = -0,0024LL^{2} + 0,02062LL + 17,514 \qquad (2)$$

Table 5 Void ratio for each Liquid Limit (LL) and consistency

Plasticity	Consistency	Void ratio (e)
LL 30%	Medium	0,76
	Stiff	0,64
	Very Stiff	0,54
LL 60%	Medium	1,42
	Stiff	1,37
	Very Stiff	1,18
LL 90%	Medium	1,49
	Stiff	1,34
	Very Stiff	1,08

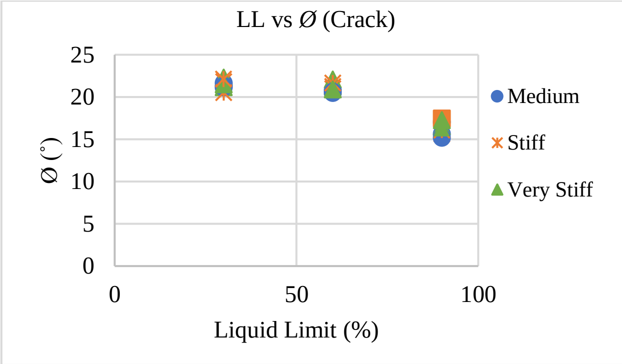

Figure 9 Relationship of liquid limit (LL) and friction angle (Ø)

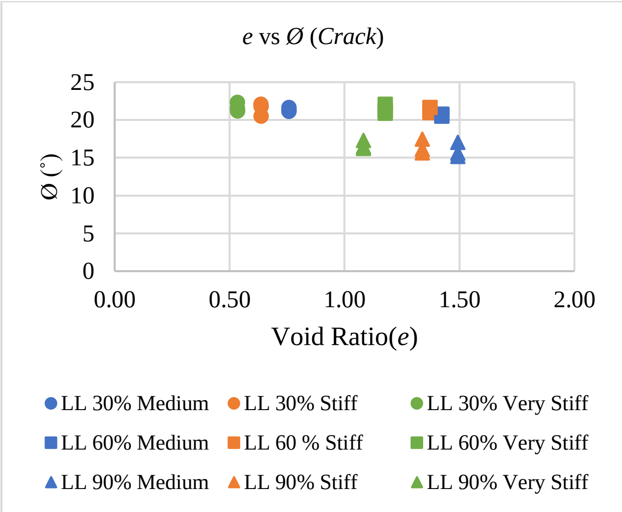

Figure 10 Relationship of void ratio (e) and friction angle (Ø)

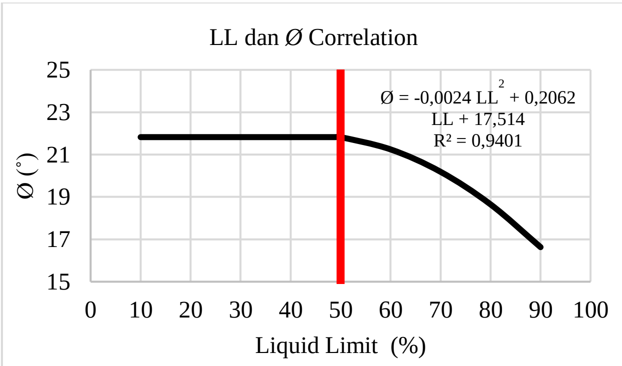

Figure 11 Empirical formulation of LL and Ø correlation

Table 6 Cracked Soil Physical and Shear Parameters

LL (%)	Consistency	Void Ratio (e)	Cracked Soil 1 C (kg/cm^2)	Cracked Soil 1 Ø (˚)	Cracked Soil 2 C (kg/cm^2)	Cracked Soil 2 Ø (˚)	Cracked Soil 3 C (kg/cm^2)	Cracked Soil 3 Ø (˚)
30	Medium	0,76	0,01	21,66	0,02	21,34	0,05	21,14
30	Stiff	0,64	0,05	21,81	0,06	22,08	0,04	20,54
30	Very Stiff	0,54	0,08	22,32	0,08	21,17	0,08	21,51
60	Medium	1,42	0,01	20,79	0,02	20,51	0,00	20,64
60	Stiff	1,37	0,01	20,97	0,02	21,24	0,01	21,65
60	Very Stiff	1,18	0,02	22,07	0,03	21,29	0,03	20,89
90	Medium	1,49	0,03	15,63	0,03	15,17	0,03	17,06
90	Stiff	1,34	0,04	15,64	0,04	16,10	0,03	17,47
90	Very Stiff	1,08	0,06	16,48	0,04	16,22	0,04	17,29

CONCLUSIONS

Based on the results of this research, it can be concluded that:

1. Water pressure does not affect the shear strength of the cracked soil that was showed by the cracked soil test result using the same total pressure and various water pressure having no significant difference in shear stress for each water pressure.

2. The friction angle of the cracked soil is not affected by its density (void ratio value). It is showed by cracked soil specimens with different consistency having the same friction angle value (no significant difference). Besides that, the void ratio is the main variable of cohesion derivatives; so, if the soil specimens cracked the cohesion is lost and the void ratio does not affect the soil shear strength (friction angle).

3. The correlation between the parameters LL and friction angle (*Ø*) on the cracked soil (*C* = 0) is as follows:

$LL < 50\%$:

$$\Phi = 22^o \tag{3}$$

$LL \geq 50\%$:

$$\Phi = -0,0024LL^2 + 0,02062LL + 17,514 \tag{4}$$

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