ISSN 1533-9211
DOI 10.5281/zenodo.8241262

STUDY OF THE SHEAR STRENGTH OF CLAYSTONES AGAINST CONSTANT TRANSFER RATE RATINGS

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Abstract

Rock shear strength is an important parameter of rock mass characteristics which among other things can be determined by direct shear tests. Direct shear tests with a certain rate rating are almost never performed on claystone. The International Society for Rock Mechanics provides standards for horizontal displacement rates from 0.1 – 0.5 mm/min. Because the shear parameters in planning the activities of an open pit mine are very important, it is necessary to carry out a direct shear test. The test was carried out on an original sample of claystone with a cylindrical shape of 54 mm in diameter and 70 mm in height. The results obtained show that for the rate range of 0.1 mm/min to 0.5 mm/min the relationship between speed and shear strength is very significant ($R^2 > 0.5$) so that it can be said that a certain rate rating affects the shear strength and shear parameters. While for the rate range of 0.5 mm/min to 1.5 mm/min there is no effect of displacement rate on shear strength and shear parameters. Evidenced by the statistical test $F_{count} < F_{table}$ and the coefficient of determination ($R^2 < 0.5$) is relatively low. Ideally the rate given for direct shear tests on claystone is 0.25 – 0.5 mm/min.

Keywords: Shear parameter, Constant Rate, Direct Slide

I. INTRODUCTION

Rock shear strength is the most important parameter of rock mass characteristics. From the direct shear strength test results obtained two parameters of mechanical properties, namely: Cohesion (*C*) and internal shear angle (ϕ), which greatly affect the planning of an open pit mining activity, such as slope stability. Direct shear tests can be carried out in the field or in the laboratory.

Testing in the field (in situ) will be more representative and more representative of the actual state of the rock mass compared to laboratory test results, because it involves a larger shear area of the rock and appropriate environmental conditions.

One of the procedures that must be followed in the uniaxial compressive strength test (UCS) is the loading rate, if the loading rate is high, the compressive strength will be greater than when the loading rate is low. According to the International Society for Rock Mechanics [1] the loading rate is 0.5 – 1.0 MPa/sec, whereas in the shear strength test based on [1] and the American Standard of Testing and Material [2, 3] that the shear strength test horizontal is between 0.1 mm/min to 0.5 mm/min for peak fiber value 0.02 – 0.2 mm/min for residual value.

Displacement rate is one of the important parameters in the shear test in addition to normal loads. So it is considered necessary to carry out research by providing variations in normal stress levels and constant displacement rates and assuming other factors have no effect.

The Seybold REPORT

ISSN 1533-9211

DOI 10.5281/zenodo.8241262

The important results of this study will measure the effect of the displacement rate on the Cohesion value (***C***) and the inner shear angle (ϕ), besides that the results of this study can be taken into consideration both when laboratory tests are to be carried out and when using values (***C***) and value (ϕ) as input in analyzing slope stability, landslide probability and safety factor.

In this study, it can be identified by analyzing the factors that influence the direct shear test, such as the relationship between shear stress and normal stress, shear stress and shear displacement, maximum shear stress on shear displacement rate and time on shear displacement and the effect of speed on parameters shift.

The hypothesis of the study is expected to provide answers in the range of what is the ideal rate to be given for direct rock shear tests.

II. LITERATURE REVIEW

In a rock mass in nature, it is generally in a balanced state, where the stress distribution in the rock and soil is in a steady state. If there is activity on the rock and soil, so that the balance is disturbed, then the rock/soil tries to reach equilibrium by reducing the load in the form of an avalanche [4].

When a landslide occurs, this means that the shear strength of the rock has been exceeded. Then the slope will be stable if the materials on the slope hold each other against the downward pulling force. The forces that resist each other are "shear forces".

2.1 Factors Affecting Shear Strength

Rock shear strength is the rock's internal resistance per unit area to the shear force/stress acting on the rock (shear) along the shear plane in the rock. In addition, it can also be interpreted that the shear strength of rock/soil is the resistance to the movement of grain particles between one another, which is influenced by the intrinsic characteristics of the rock itself such as shear parameters and roughness of the shear plane as well as by external factors such as applied stresses, fill material, presence of water and sample dimensions [5].

2.1.1 Intrinsic factor of rock shear strength

2.1.1.1 Shear strength parameters

The shear test on rock is a testing process that must be carried out to determine the shear strength of the rock (τ) where the shear strength is affected by cohesion (***C***), internal shear angle (ϕ) and normal stress (σ_n).

This test uses the direct shear test method using several samples (minimum 3 samples), in order to obtain more accurate shear parameters. For each example a certain normal force (Fn) is applied (see Figure 1), which is applied perpendicular to the surface tension of the discontinuous plane. From a given constant shear transfer rate will produce a shear force (Fs). The magnitude of the shear displacement (δ_s) is measured at intervals of 15 seconds to obtain the working shear force.

ISSN 1533-9211
DOI 10.5281/zenodo.8241262

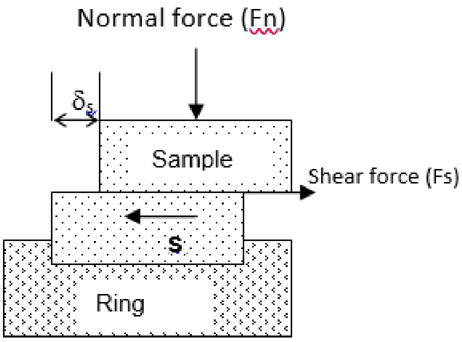

Figure 1: Scematic of Shear Force and Normal on the Shear Plane [6]

The shear force required for the rock to begin to form fractured shear and displacement planes will increase in accordance with the increase in the normal force (Fn). In the direct shear test, the shear stress (τ) and the normal stress (σn) are representative of the shear force and the normal force divided by the contact area.

If the peak shear strength (τp) and residual shear strength (τr) are obtained from different normal stress levels (σn) with the same type of rock sample and then plotted against each normal stress, a linear relationship will be obtained as (Figure 2).

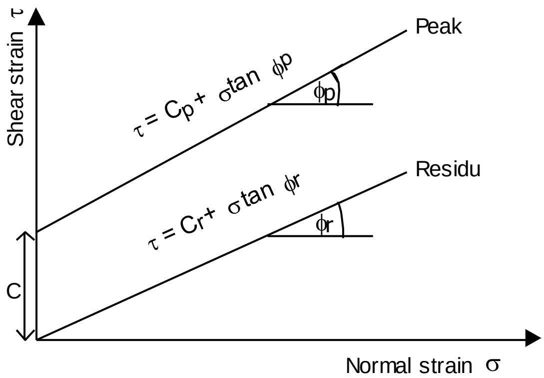

Figure 2: Diagram of Peak and Residual Shear Strength

The slope of the line is defined as the shear angle in the peak (ϕp) and the shear angle in the remainder (ϕr). The intersection of these lines with the shear stress axis is called cohesion (*C*p). The relationship between (ϕp) and (σn) is defined by equation (1).

$$(\tau p) = (Cp) + (\sigma n).\ \tan(\phi p) \quad (1)$$

While the relationship between residual stress and normal stress is:

$$(\tau r) = (\sigma n).\ \tan(\phi r) \quad (2)$$

The Seybold Report
ISSN 1533-9211
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2.1.1.2 Surface Roughness of the Shear Plane

The surface of natural discontinuous planes in hard rock is not always smooth (almost 100% rough), the roughness and unevenness of this surface have a significant influence on the shear behavior of the rock itself [6]. In general, the surface roughness increases the shear strength of the rock.

2.1.2 External Factors of Rock Shear Strength

a. Normal Stress

In general, rock masses have fractures caused by loading that has occurred since their formation. Fractures have a major influence on the behavior of the rock mass. This is because the displacements are generally concentrated in these fractures, which can affect the mechanical properties of a rock mass. The magnitude of the dilatance that exists during the displacement provides restraint on the section between the shear planes, thereby increasing the shear resistance.

The condition of constant normal stress is only realistic for shear on a planar surface, without undulation, where the normal stress acts on the main shear plane which is relatively constant, this affects the shear strength of the rock. Shifting on a very rough shear surface with a certain loading system, will cause an increase in normal stresses and also a very significant dilatancy [8].

b. Fill Material on Discontinuous Planes

The shear strength will be drastically reduced when part or all of the surface is not completely in contact, but is covered by a soft filling material such as clay gouge. On flat surfaces such as bedding planes in sedimentary rocks, the presence of thin clay will result in a significant reduction in shear strength.

Barton & Choubey and Tolodo & Die Freitas [8] state that shear failure of filled joints undergoes two stages, the first is shear stress and shear displacement is influenced only by the strength of the filling material. Second, after displacement, the rock surface experiences contact and the strength of the discontinuous plane is determined by the roughness and strength.

c. Effect of Water Presence and Water Pressure

When water pressure (U) is present in the rock mass, the surface discontinuity is partially compressed and the normal stress (σn) is reduced. Under steady state conditions, where there is sufficient time for the water pressure on the rock mass to reach equilibrium, the normal stress reduction ($\sigma n'$) is defined as (Equation 3):

$$(\sigma_n') = (\sigma_n - U) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

d. Dimensions of the Test Sample

The heterogeneity of the rock mass is affected by the dimensions of the test sample, the wider the shear area, the greater the possibility of discontinuity in the rock mass and greatly influences

The Seybold Report
ISSN 1533-9211
DOI 10.5281/zenodo.8241262

the results obtained. The results of research by [9] indicate an increase or decrease in a certain property (decrease in shear stress, an apparent transition zone from brittle to plastic occurs, a decrease in the shear angle in the crest as a result of a decrease in the peak dilatance angle and aspiriti failure) of rocks with increasing sample size.

III. RESEARCH METHODOLOGY

3.1 Location of Sampling of Claystone

All samples of claystone (surface layer A1) taken from the coal open pit mine at Pit-I Muara Tiga Besar Utara PT. Bukit Asam Coal Mine (PT. BA) Tanjung Enim. The sampling method is carried out by taking blocks on the north side of the slope. Then immediately do the core drilling (coring). The claystone drill core (diameter 54 mm and height 70 mm) which was obtained was wrapped in aluminum foil and then put into a plastic pipe and covered with paraffin. The physical properties of the material are shown in Table 1.

Table 1: Indexs Properties Claystone

Condition	Unit	Sample			
		I	II	III	Average
Natural density (gn)	gr/cm^3	1.68	1.72	1.71	1.70
Dry density (gd)	gr/cm^3	1.43	1.46	1.46	1.45
Saturated density (gs)	gr/cm^3	1.86	1.89	1.91	1.89
Moisure (w)	(%)	17.31	17.93	16.87	17.37
Saturated moisure (ws)	(%)	19.02	19.59	19.28	19.30
Degree saturated (S)	(%)	91.02	91.48	87.50	90.00
Porositas (n)	(%)	30.59	31.95	31.96	31.50
Void ratio (e)		0.44	0.47	0.47	0.46

3.2 Equipment Preparation

The shear test equipment used is only in the Geomechanics Laboratory of ITB, which is a tool that can provide a constant normal stress and a constant rate during the test time. The equipment is made with a pendulum system (dead weight) for normal loads and a mechanical drive motor for a constant displacement rate, so that the application of force and speed can be constant even though the sample has been deformed (Figure 3) [15].

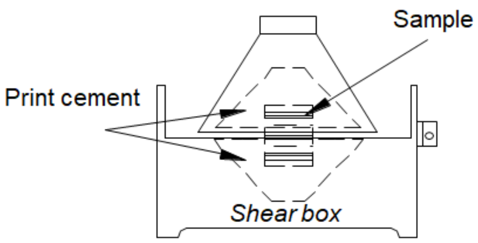

Figure 3: Placement of Samples in the Shear Test Box [7]

The Seybold Report
ISSN 1533-9211
DOI 10.5281/zenodo.8241262

IV. RESULTS AND DISCUSSION

The data needed to analyze the effect of speed on shear strength and shear parameters include: displacement rate, normal stress, shear stress, cohesion and internal shear angle, as shown in Table 2.

The results obtained from the direct shear test with varying rates showed that the average cohesion value of the claystone peaks was 0.15 MPa. For the value of the shear angle in the crest the average claystone is 480 (see Table 2). Seeing the results above, the cohesion value of claystone is relatively within the range of previous researchers (Table 3).

Table 2: Parameters of Shear Strength at a Constant Rate at Normal Stress Levels

σ_n (MPa)	V_{sr} (mm/min)	Displacement (mm)		Shear strain (MPa)		Cohesion (MPa)	Internal shear angle (ϕ^o)		Sample
		(δ_p)	(δ_R)	(τ_p)	(τ_R)	(C)	(ϕ_p)	(ϕ_R)	
0.22	0.1	1.10	0.78	0.40	0.32				
0.33	0.1	0.88	0.42	0.57	0.41	0.22	42^0	41^0	
0.43	0.1	0.94	0.60	0.59	0.50				
0.22	0.25	1.02	0.61	0.33	0.28				C
0.33	0.25	0.43	0.46	0.45	0.32	0.17	38^0	28^0	L
0.43	0.25	0.42	0.55	0.49	0.39				A
0.22	0.5	0.64	0.89	0.38	0.29				Y
0.33	0.5	0.60	1.22	0.49	0.32	0.23	36^0	35^0	S
0.43	0.5	1.48	1.92	0.53	0.50				T
0.22	0.75	1.08	0.40	0.34	0.24				O
0.33	0.75	0.81	0.84	0.56	0.44	0.09	51^0	49^0	N
0.43	0.75	0.53	1.03	0.60	0.48				E
0.22	1	0.62	1.30	0.52	0.27				
0.33	1	0.87	2.05	0.89	0.49	0.06	66^0	64^0	
0.43	1	1.80	0.88	0.99	0.71				
0.22	1.25	0.65	2.04	0.39	0.30				
0.33	1.25	1.04	1.70	0.64	0.34	0.08	60^0	55^0	
0.43	1.25	1.18	2.28	0.71	0.60				
0.22	1.5	0.22	0.95	0.33	0.27				
0.33	1.5	0.88	0.43	0.49	0.33	0.16	41^0	28^0	
0.43	1.5	0.44	1.10	0.51	0.38				
Average				0.53	0.39	0.15	48^0	43^0	
	0,1 - 0,5			0.47	0.37	0.21	39^0	35^0	
	0,5 - 1,5			0.56	0.40	0.12	51^0	46^0	

4.1 Analysis of Shear Strength

The peak shear strength test results with a displacement rate rating (0.1 – 1.5 mm/min) of 0.53 MPa (Table 4.1), while the shear strength value at a rate of (0.1 – 1.5 mm/min) is smaller (0.47 MPa) compared to the rate (0.1 – 1.5 mm/min). On the other hand, at a rate of (0.5 – 1.5 mm/min) the shear strength of the claystone is 0.56 MPa.

The direct shear test system with variable rate is to provide a constant (mechanical) displacement rate on the sample and the shear force is measured as a function of time. While

The Seybold Report
ISSN 1533-9211
DOI 10.5281/zenodo.8241262

the standard shear test [3], the displacement rate is given and the shear force is measured based on the distance function.

Thus the direct shear test using a measured (constant) shear force generator is relatively better than using a standard shear tester using a hydraulic pump (manual and the resulting rate is not constant).

Table 3: Parameters of Shear Strength at a Constant Rate at Normal Stress Levels

Stone type	Cohesion (C) (MPa)	Internal shear angle (ϕ)	σn (MPa)	τ=C+σn.tanϕ (MPa)	Locaton	Researcher
Sandstone Clay	1 – 70 0 – 1	6^0 - 54^0 17^0 - 35^0	0.43	1,05 - 70,59 0,13 - 1,30	-	Franklin dan Desault (1989)
Sandstone Claystone	0.123 0.113	30^0 30^0		0.37 0.36	(Slope) Air Laya-PT.BA	Aljon Albertus (1995)
Sandstone Claystone	2 7.5 2 2.59 5.5 5.5	50^0 42^0 59^0 49^0 35^0 58^0		2.51 7.89 2.72 3.08 5.80 5.84	(Depth Mining) Ombilin	S. Koesnaryo (1999)
Sand siltstone Clay siltstone Rough sandstone Fine sandstone	0.154 0.165 0.142 0.128	33^0 28^0 12^0 23^0		0.43 0.39 0.23 0.31	(Slope) MTBU-Pit 1 PT.BA	Syafriadi dan M. Daroji (2000)
Sandstone Claystone	0.655 0.096	$46{,}2^0$ 39^0		1.1 0.44	(Slope) Air Laya-PT.BA	A. Rivai (2001)
Claystone	0.360	52^0		0.91	(Slope) MTBU-Pit 1 PT.BA	Catur dan Kramadibrata (2002)
Claystone Sandstone	0,082 0.031 0.033	19^0 14^0 23^0		0.23 0.14 0.22	(Slope) Pit MTS – Ext MTBU-Pit 1	Geotechnic lab. PT. BA (2002)
Claystone Sandstone	0.150 0.310	48^0 51^0		0.63 0.84	(Slope) MTBU-Pit 1 PT.BA	Writer

Simulation from Equation 1 on shear parameters with a normal stress of 0.43 MPa (maximum applied stress) obtained a shear strength ratio as shown in Table 3, from the research of [5], obtained a shear strength of claystone 0.91 MPa, while that obtained by [10] the shear strength of claystone is 0.44 MPa and sandstone is 1.1 MPa. Other researchers conducted by [13] obtained the shear strength of claystone 3.08 – 5.84 MPa and sandstone 2.51 – 7.89 MPa.

ISSN 1533-9211
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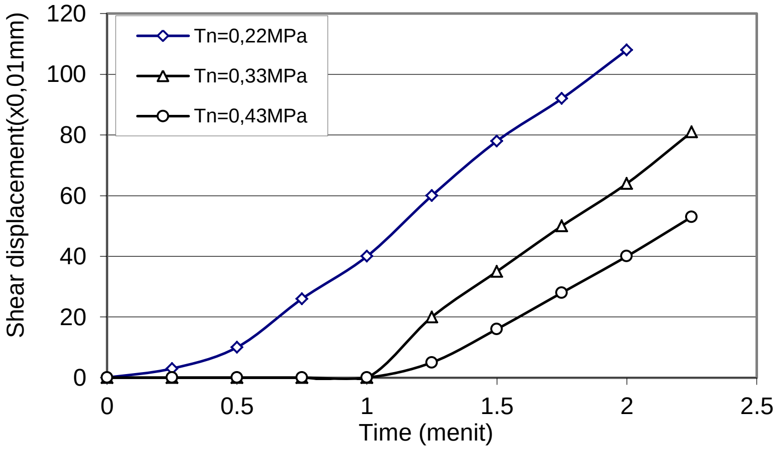

Figure 4: Relationship of Shear Displacement against Time at a Rate of 0.75 mm/min

4.1.1 Effect of Displacement Rate on Peak Shear Strength

Tests [11] under constant normal load (CNL) and constant normal stiffness (CNS) conditions that an increase in normal stress will also increase the shear stress. [13] conducted an experiment on a physical model of shear tests on concrete samples, with conditions of CNL 0.05 – 2.43 MPa, CNS 8.5 kN/mm and aspiriti angle of 9.50 and displacement rates between 0.35 mm/ min to 1.67mm/min. The results show that the shear stress will increase as the displacement rate increases. This may be due to the homogeneity of the samples and discontinuous areas that have been modeled and the tools used.

The loading rate in the uniaxial test, if the loading rate is large, the compressive strength will be greater. Whereas Figure 4 shows the relationship between the displacement rate and the peak shear strength (with a normal stress of 0.22 – 0.43 MPa) does not show an increase in shear stress as the displacement rate increases. If the point of observation is made in the rate range of 0.1 – 0.5 mm/min [1], that increasing the rate will decrease the shear strength and the value of the internal shear angle (increasing cohesion value). The description of the trend with power law shows that the relationship between the two variables is very close ($R^2 > 0.5$).

ISSN 1533-9211
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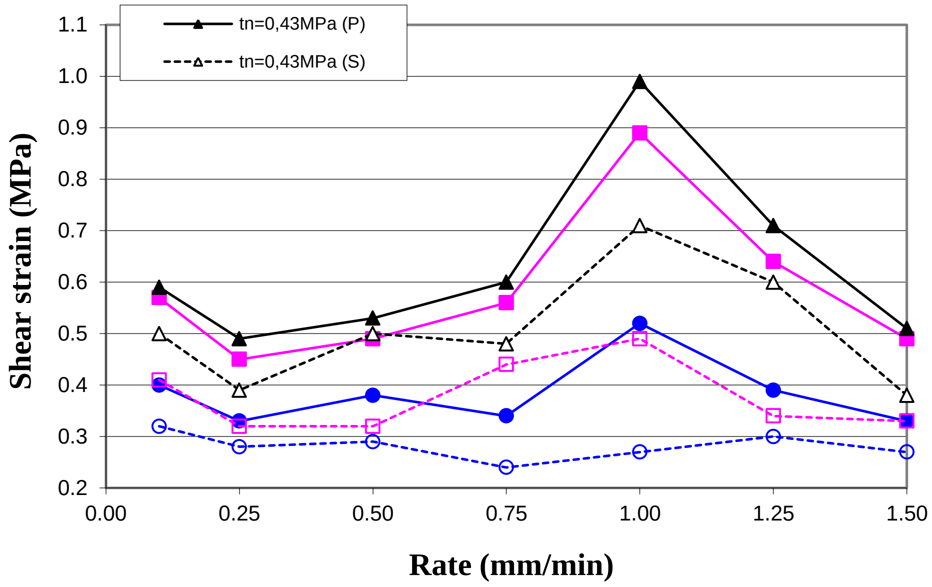

Figure 5: Relationship of Rate & Shear Stress on Variations of Normal Stress

Figure 5 the relationship between speeds and shear strength in the range of 0.5 – 1.5 mm/min shows that the increase in speed is not accompanied by an increase in shear strength. This means that the relationship between speed and shear strength is very weak (R^2 <0.5). This meets the requirements of [1] so that the horizontal displacement rate should be within the range of 0.1 – 0.5 mm/min.

Ideally, when seen in Figure 5, the rate given for the horizontal displacement rate in the direct shear test in the range of 0.25 – 0.5 mm/min yields results that have the same relative trend, compared to the rate range of 0.1 – 0.5 mm /min (descending trend).

There is a very significant difference in Figure 5, especially at a rate of 1.0 mm/min, which tends to be caused by the fact that the given constant rate fluctuates. This means that the design speed of the shear force generating motor experiences a momentary resistance when the sample is about to collapse and releases energy when the sample collapses, so that the speed that causes the difference is the influence of the nature of the sample and the limited number of samples tested.

4.1.2 Effect of Displacement Rate on Shear Parameters

Judging from the approach through the power law curve of Figure 6, the peak conditions in the example have a tendency to increase in cohesion values as the speed increases (ignoring 1 (one) point that is biased, it is considered that the bias point is the most remote than the other points). And the resulting negative equation relationship **C** = 0, 106.Vsr$^{-0,\,34}$ (Table 4).

The Seybold Report
ISSN 1533-9211
DOI 10.5281/zenodo.8241262

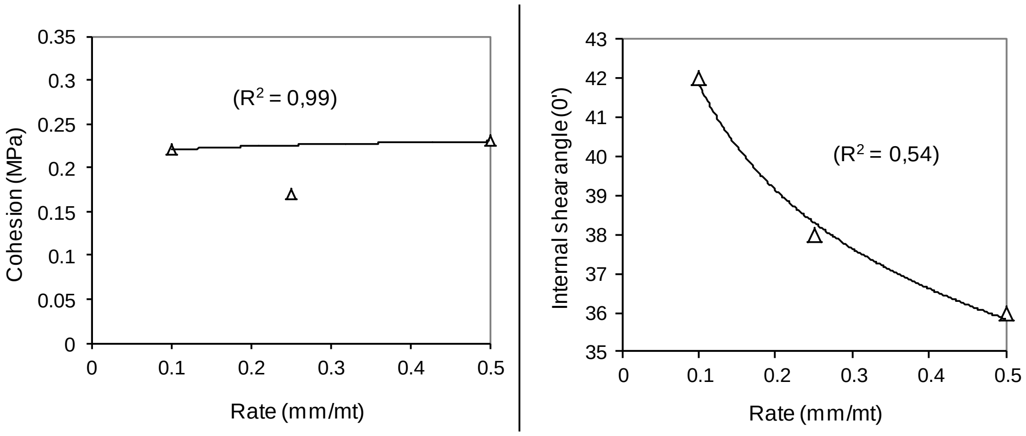

Figure 6: Relationship Of Shear Parameters to Speed (range 0.1 – 0.5 mm/min)

On the other hand, in the rate range of 0.5 – 1.5 mm/min, the cohesion value decreased as the displacement rate increased (Figure 7) with a relatively low coefficient of determination ($R^2 < 0.5$). It can be said that Figure 6 is the opposite of Figure 7, whereas the displacement rate increases, the internal shear angle increases (rate range 0.5 – 1.5 mm/min).

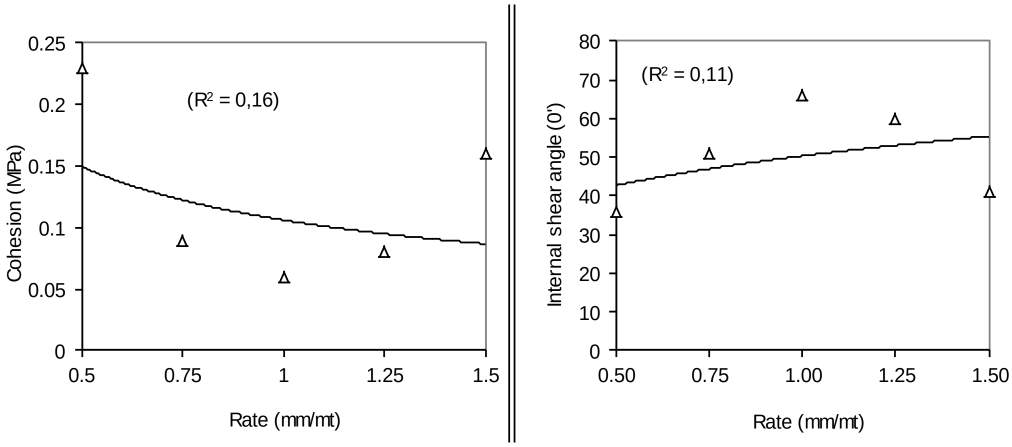

Figure 7: Relationship Of Shear Parameters to Speed (range 0.5 – 1.5 mm/min)

This is shown in the power law equation in Table 4. The value of the coefficient of determination (R^2) shows a very low relationship, for the apparent condition ($R^2 = 0.1$) and the peak condition ($R^2 = 0.2$). So it can be said that the relationship between the displacement rate and the internal shear angle is low.

Table 4: Relation power low in rate versus (*C*) & (ϕ) (Range rate 0, 1 - 1,5 mm/min)

Condition	Equality power law	R^2	F_{hitung}	F_{table}	H_0
Peak	$C = 0{,}106 \,.\, V_{sr}^{-0{,}3402}$	0,4	3,35	5,99	Accepted
Peak	$\phi_p = 49{,}909.\, V_{sr}^{0{,}1196}$	0,2	1,64		Accepted
Residu	$\phi_R = 43{,}102.\, V_{sr}^{0{,}068}$	0,1	0,37		Accepted
Note: V_{sr} = Rate displacement R^2 = Determination coefisien					

The Seybold REPORT

ISSN 1533-9211

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From geotechnical research on rock characteristics conducted by [4, 15] by evaluating based on statistics, the range for the value of the coefficient of determination (R^2) is low (0.13 - 0.25), moderate (0.25 - 0.5) and high (0.5 – 1.0).

So it can be said that the relationship between displacement rate and cohesion is very low for sandstones (R^2 = 0.1) and moderate for claystones (R^2 = 0.4). Based on statistical tests, the Fcount value is obtained as in Table 4, while the Ftable value with a 95% confidence level is 5.99. Because the value of $F_{count} < F_{table}$, the null hypothesis (Ho) which states that "The decrease in cohesion values is not caused by variations in rate is accepted". This means that the cohesion value is not affected by variations in displacement rates. Likewise, what happens in the speed range of 0.5 – 1.5 mm/min shows the opposite relationship where increasing speed causes an increase in the value of the inside shear angle, with a relatively low coefficient of determination (R^2 <0.5), meaning that there is no relationship between speed and internal shear angle.

V. CONCLUSION

1. The representation of the average shear parameter values obtained in the range of 0.1 – 1.5 mm/min is a cohesion value of 0.14 MPa. As for the shear angle in the peak of 480 and 420 in apparent conditions.
2. The effect of the horizontal displacement rate on the shear strength parameter at a rate of 0.1 – 0.5 mm/min (according to ISRM standards, 1981) shows a significant relationship. Evidenced by the power law equation with a relatively high coefficient of determination (R2 > 0.5).
3. Ideally, from the results of the research conducted, the direct shear test is given at a rate of 0.25 – 0.5 mm/min, where the trend is relatively the same (increases). As for the smaller rate of 0.25 mm/min, the results obtained tend to be invalid because the testing process is too long and if the rate is greater than 0.5 mm/min the results obtained tend to fluctuate.

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