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The interface shear strength reduction between argillaceous rock and soil overburden in slope stability due to the increasing of the rain fall intensity

Réduction de la résistance au cisaillement à l'interface entre la roche argileuse et le sol des morts-terrains en raison de l'intensité des précipitations pour la stabilité des pentes

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ABSTRACT: Many failure of slopes in Indonesia, generally occur during high rainfall intensity. The increasing of water content generally decreases the shear strength of the soil which in certain circumstances trigger failure of slopes. In some cases the slip plane exists on the plane between two types of soil with different characteristics such as argillaceus rock with overburden layer (OBL) above it (interface) which can be from compacted weathered argillaceous rock or clay shale. The shear strength of interface is usually low, and decreases during water intrusion from the overburden layer to the surface of fresh argillaceous rock, and also depends to OBL density. The interface is usually a compacted weathered argillaceous rock or clay shale (WCS). The shear strength of interface is strongly influenced by the density of WCS and its moisture content due to rainfall intensity. At the maximum density of 100%, the interface shear strength ratio ($\tau/\sigma n$) is 1.89 (maximum) at the optimum moisture content of OBL. This interface shear strength ratio will decrease to 0.56 or remain up to 29% due to increased water content until fully saturated conditions. The effect of OBL density on optimum water content, interface shear strength ratio decreases until remaining 34% from 100% dry density maximum to 85% OBL density, and remaining 10% if fully saturated condition or Sr = 100%.

RÉSUMÉ : De nombreux échecs de pentes en Indonésie se produisent généralement lors de fortes précipitations. L'augmentation de la teneur en eau diminue généralement la résistance au cisaillement du sol qui, dans certaines circonstances, déclenche la rupture des pentes. Dans certains cas, le plan de glissement existe sur le plan entre deux types de sol avec des caractéristiques différentes telles que la roche argillaceus avec une couche de mort-terrain (OBL) au-dessus (interface) qui peut être de la roche argileuse altérée compactée ou du schiste argileux. La résistance au cisaillement de l'interface est généralement faible et diminue pendant l'intrusion d'eau de la couche de mort-terrain à la surface de la roche argileuse fraîche, et dépend également de la densité OBL. L'interface est généralement une roche argileuse ou argileuse (WCS) altérée et compactée. La résistance au cisaillement de l'interface est fortement influencée par la densité du WCS et sa teneur en humidité en raison de l'intensité des précipitations. À la densité maximale de 100%, le rapport de résistance au cisaillement de l'interface ($\tau/\sigma n$) est de 1,89 (maximum) à la teneur en humidité optimale de l'OBL. Ce rapport de résistance au cisaillement d'interface diminuera à 0,56 ou restera jusqu'à 29% en raison de l'augmentation de la teneur en eau jusqu'à ce que les conditions soient complètement saturées. L'effet de la densité OBL sur la teneur en eau optimale, le rapport de résistance au cisaillement d'interface diminue jusqu'à ce qu'il reste 34% de 100% de densité sèche maximum à 85% de densité OBL, et 10% restant si condition complètement saturée ou Sr = 100%.

KEYWORDS: Interface, shear strength, interface shear strength ratio, argillaceous rock, clay shale, OBL, WCS.

1 INTRODUCTION

Argillaceous rock is called clay shale and sometimes also claystone has a very high shear strength before experiencing the weathering process. Argillaceous rock slopes that are protected by an overburden layer are generally very stable. It is because argillaceous rock has a very high shear strength if it does not react with the hydrosphere and the atmosphere (Sadisun 2003). The interface is a plane between the argillaceuous rock mass at the bottom and the overburden layer at the top. This over burden layer can be a layer of tuff breccias, or a layer of weathered clay shale (Weathered Clay Shale / WCS), or other types of soil in the form of past deposits. In general, the failure surface of slope does not. only occur in the weathered argillaceous rock, but it may occurs also in the plane where the overburden layer meets the argillaceous rock (interface plane). One of the causes of failures in the interface area is an increasing of water content due to rainwater that seeps into the permeable overburden layer, and finally the water is retained on the surface of the argillaceous rock interface with a layer of overburden. This paper discusses the interface shear strength between the overburden layer in the form of compacted weathered clay shale with fresh argillaceous rock with several variations of properties of the overburden layer. Discussion will be extended to effect of increasing the intensity of rainfall in the form of increasing water content in the interface zone. This effect on reducing the interface shear strength is conducted in the laboratory. The case of slope failure at STA 19 + 250 Semarang - Bawen Toll Road, Central Java, Indonesia (Alatas 2015; Irsyam 2011) was caused by cut slope activity of argillaceous rock for building highway toll road, as shown in Figure 1 (Himawan 2013). The failure of fill slopes where fill material used was argillaceous rock excavated material for infrastructure work in Cariu, West Java as shown in Figure 2 and Figure 3. Fill material as result of excavation activities was used follow the standard procedure of compaction work for roadbed construction. Fresh excavated material is usually suitable material to use for embankment. However, after weathering in some times, the material becomes unsuitable.

Figure 1. Slope failure on clay shale at STA 19+250 Semarang-Bawen tol road during construction (Himawan 2013)

Figure 2. Slope are backfilled with weathered argillaceous rock at Cariu, West Java, Indonesia, before failure on Januari 21th, 2020 (Alatas 2020)

Figure 3. Slope failured at Cariu, West Java Indonesiao on March 5th 2020 (Alatas 2020)

2 SHEAR STRENGTH REDUCTION OF ARGILLACEOUS ROCK IN JAVA ISLAND

Several studies have been conducted to investigate decreasing shear strength of argillaceous rock (clay shale) in Semarang-Bawen, Central Java, and Hambalang, West Java Indonesia from 2015 to 2017 (Alatas 2017). In Table 1, it can be seen that decreasing peak shear strength and the residual argillaceous Semarang-Bawen due to the weathering process of drying for 80 days, without being contaminated with water. Figure 4 shows a drying wetting cycles for 40 days, with 5 minutes of soaked carried out for every 4 days. It can be seen that weathering process with a drying wetting cycle decreases shear strength of the peak stress and the residual, it will occur faster than the weathering by drying proces only.

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Table 1. Shear strength degradation due to drying process effect of Semarang - Bawen Argillaceous rock (Alatas 2017)

Condition	Unit	Weathering by Drying Process (days)											
		0	4	8	16	24	32	40	48	56	64	72	80
Peak Stress	C (kN/m^2)	700	350	320	260	250	270	290	280	260	240	230	220
	ϕ (°)	60	60	72	73	70,8	70,4	68,1	61,3	54,2	47,1	42,75	38,4
Residual Stress With Stress Realese	Crp (kN/m^2)	285	270,3	240,9	211,5	225,7	207	137,5	145	102	59	44	29
	ϕrp (°)	46	29,4	28,99	28,57	28,15	28	32,6	37,2	30,1	23	15,9	8,9
Residual Stress Without Stress Realese	Crf (kN/m^2)	26,7	19,2	11,8	7,5	41	9	16,5	3	7,4	11,7	8,4	5
	ϕrf (°)	23,5	22,5	20,73	18,96	17,2	16,1	15	12,33	9,66	7	6	3,1

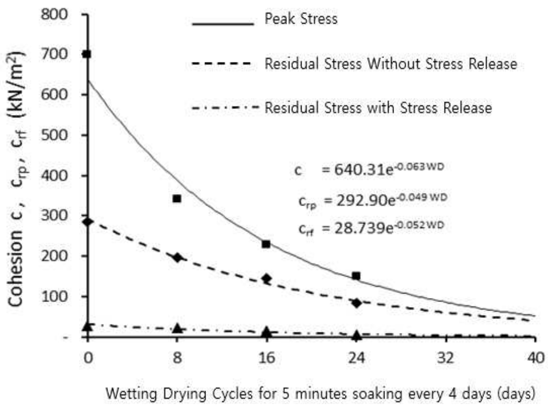

Figure 4. Shear strength degradation due to drying-wetting effect of Semarang - Bawen argillaceous rock (Alatas 2017)

Weathering studies of reducing the shear strength of argillaceous rock have long been proven (Gartung 1986; Pineda 2008). Meanwhile, shear strength testing with the multistage method on the triaxial has also been frequently carried out (Anderson 1974; Ho 1982; Sharma 2011). Shear strength is also carried out by means of multistage with direct shear (Gan 1988). A study of the interface shear strength between compacted clay and hemp fibers was carried out in 2019. In the same year, Wang (2019) studied the shear strength interface between clay and cement paste (Ammar 2019; Wang 2019).

The study on the interface shear strength is started in 1961, where the investigation is focused mainly to determine the values of skin friction between different types of soils (sand, clay, and granular soil mixed from both sand and clay) and construction materials such as steel, concrete, and wood (Potyondy 1961). Lupini (1981) introduced although not focusing on the soil-solid interfaces, the topic of cohesive soils in residual strength and its shearing behavior with a ring shear apparatus. In 2000, following the research in Lupini (1981), the study of the clay-interface shear resistance with the ring shear apparatus on both the peak and residual strength was conducted (Lemos and Vaughan 2000). The study concluded that different clay content would react differently with the interface roughness. In 2018, a research was conducted to investigate the effect of interface roughness and unloading effect on the interface shear mechanical properties through the large direct shear test and a series of normal unloading stresses with three different structural interface roughness and unloading on the interface shear strength, interface shear modulus, and the interface shear dilatancy (Zhao 2018). Also in 2019, a unique interface test was done between a compacted natural clay and hemp fibers which were focused on three main parameters: compaction water content, type of interface test, and drainage conditions rate of loading (Ammar 2019).

3 METHODOLOGY

The Multistage Reversal Progressive Shear Test (MRPST) is modeled to determine the interface shear strength between fresh argillaceous rock and the soil layer above the overburden layer (OBL). The initial stage of determining the interface shear strength was carried out by means of one-way multistage with 3 different normal stresses and at the initial OBL water content Wn-1. The next step is to determine the interface shear strength due to the addition of water content after the first stage is completed define as Wn-2, where Wn-2 > Wn-1. The additional moisture content of the sample is carried out in the OBL section by removing the normal stress from the previous test and spraying additional water (Water Spray) to the surface of the OBL sample. The next test is carried out in the opposite direction from the initial (reversal) loading direction with the same normal stress addition stages in each stage. Testing with the MRPST method, obtained several interfaces of the shear strength of the two materials (argillaceous rock and OBL), a number of variations in the addition of water content provided until the OBL sample becomes saturated (full soaked) and variations of the OBL density. OBL density starts from 85% to 100% maximum dry density in the standard proctor. The schematic of the MRPST testing methodology is shown in Figure 5 below.

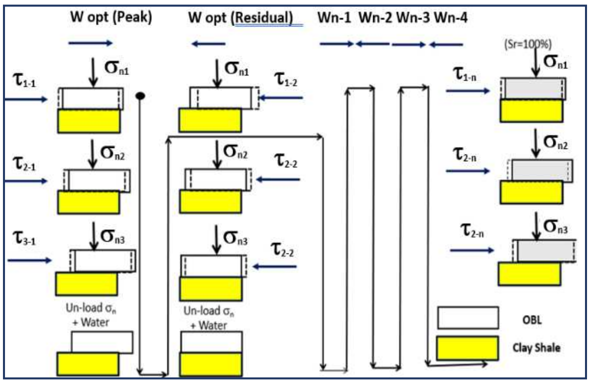

Figure 5. Testing procedure for interface shear strength test by MRPST

Testing of MRPST method is carried out in five directions of shear forces by a reversal manner for each OBL density variation, starting from 100%, 95%, 92.5%, 90%, 87.5% and 85 % of the dry density maximum standard laboratory proctor. And in each direction of shear force is carried out by means of multistage with 3 times the normal stress increasingly. The given normal stress is the same every time there is a change in the direction of the shear force. For each change in the shear force direction, water is added to the OBL layer, so that the direction of the last shear force on OBL sample has a moisture content so that the saturation degree becomes fully saturated (Sr = 100%), as shown in Figure 5.

4 THE INTERFACE SHEAR STRENGTH REDUCTION BETWEEN ARGILLACEOUS ROCK AND SOIL OVERBURDEN

4.1 *Stress strain on MRPST methods*

Figure 6 shows stress-strain of interface between fresh argillaceous rock and OBL for 100% max dry density. During the test there was a progressive increasing in OBL moisture content, so that the OBL saturation rate becomes 100% (fully saturated). It can be seen that with the addition of water content in OBL, there is a decreasing of interface shear strength.

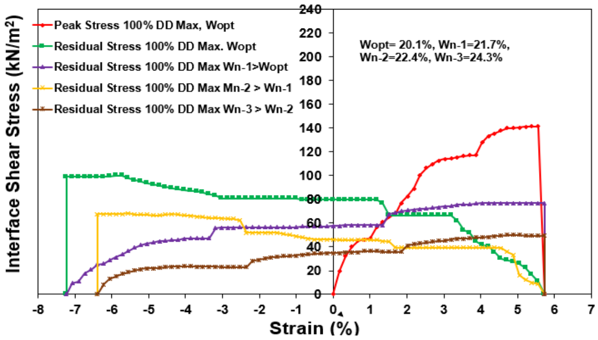

Figure 6. Interface shear strength between fresh argillaceous rock and OBL as compacted WCS with 100% dry density max in various increasing water content

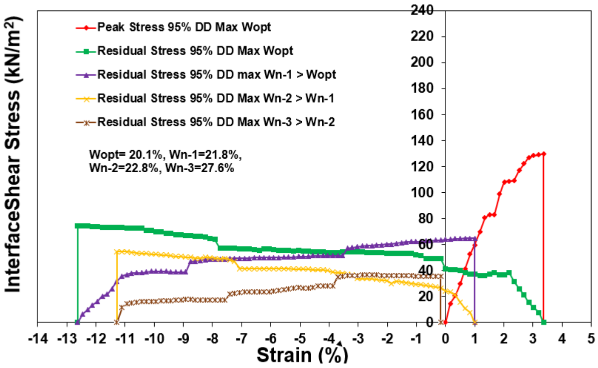

Figure 7. Interface shear strength between fresh argillaceous rock and OBL as compacted WCS with 95% dry density max in various increasing water content

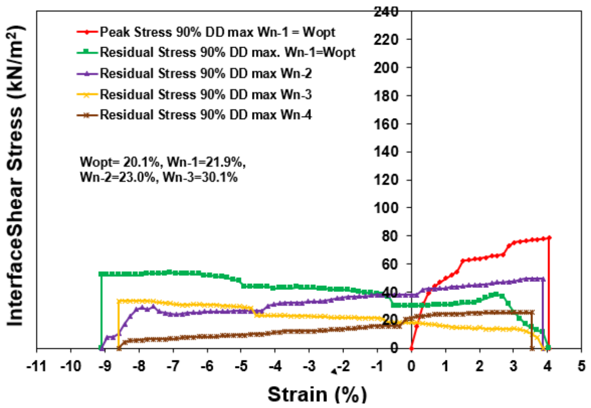

Figure 8. Interface shear strength between fresh argillaceous rock and OBL as compacted WCS with 90% dry density max in various increasing water content

Figure 7 shows a stress strain curve for OBL density 95 % of the dry density maximum. Figure 8 shows the OBL density as 90 % of the maximum dry density. It can be seen that the interface shear stress decreases by decreasing density of OBL and increasing water content of OBL. The same thing, if the OBL density is even smaller, that is, the OBL density is 85% of the maximum dry density, the interface shear stress will decrease again as shown in Figure 9. Each of all test stages is carried out using the same normal stress. The gradually addition of water to the OBL is an approximation to model rainwater soaking the OBL layer. The increase in the water content stage which results in an increasing in the degree of saturation from this test can be seen in Table 1 and Table 2. From the curves in Figure 6, Figure 7, Figure 8 and Figure 9, the cohesion and internal friction angle of interface can be obtained, as shown in Table 3 and Table 4.

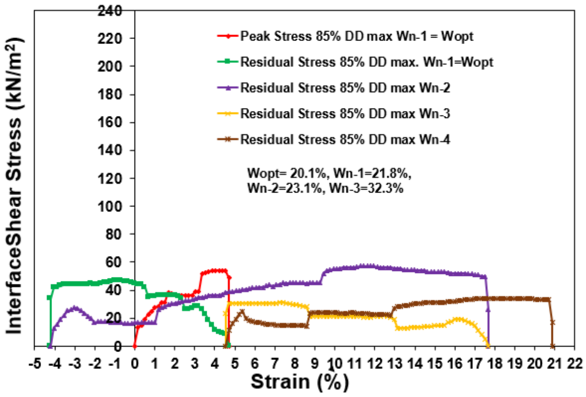

Figure 9. Interface shear strength between fresh Argillaceous rock and OBL as compacted WCS with 85% dry density max in various increasing water content

Table 1. Increasing water content on overburden layer (OBL) due to falling rainwater

OBL Density	Water content OBL (%)			
	W opt	Wn-1	Wn-2	Wn-3
100 % γd Max	20.1	20.1	21.7	22.4
95 % γd Max	20.1	20.1	21.9	22.9
92.5 % γd Max	20.1	20.1	21.9	22.8
90 % γd Max	20.1	20.1	22.0	23.0
87.5 % γd Max	20.1	20.1	22.1	23.0
85 % γd Max	20.1	20.1	21.9	23.1

Table 2. Degree of saturation of overburden layer (OBL) due to increasing water

OBL Density	Degree of Saturation of overburden layer (OBL) due to increasing water (%)			
	W opt	Wn-1	Wn-2	Wn-3
100 % γd Max	81	88	92	101
95 % γd Max	71	77	82	100
92.5 % γd Max	72	78	82	100
90 % γd Max	64	70	75	101
87.5 % γd Max	60	66	71	101
85 % γd Max	61	66	71	100

The increasing water content on OBL of WCS from each stage of the test can be seen in Table 1. At the same density level, changing of interface shear strength are determined due to the addition of water content OBL of WCS to reach Wn-3. Where the water content of Wn-3, OBL of WCS has reached fully saturation, or Sr = 100%, as shown in Table 2.

Table 3. Interface cohesion between Argillaceous rock and variation density of compacted WCS as Over Burden Layer, due to increasing OBL water content

OBL Density	Interface cohession (kN/m²)				
	Peak	Residual with increasing Wn			
100 % γd Max	63.64	50.01	31.46	25.19	9.73
95 % γd Max	60.99	35.59	26.03	22.72	8.44
92.5 % γd Max	44.59	25.12	20.99	13.12	5.15
90 % γd Max	42.82	18.87	15.25	9.68	1.52
87.5 % γd Max	29.96	18.48	13.50	8.08	5.28
85 % γd Max	22.16	8.77	7.02	5.30	3.36

Table 4. Interface internal angle friction between Argillaceous rock and Variation density of compacted WCS as Over Burden Layer, due to increasing OBL water content

OBL Density	Interface Internal Angle Friction (Degree)				
	Peak	Residual with increasing Wn			
100 % γd Max	37.06	24.85	23.05	21.97	20.86
95 % γd Max	33.94	19.70	20.49	16.62	15.07
92.5 % γdMax	24.17	18.99	20.49	14.27	14.27
90 % γd Max	18.98	17.44	18.20	12.62	12.62
87.5 % γdMax	17.05	15.89	15.45	10.99	8.50
85 % γd Max	14.25	15.89	10.59	9.75	7.67

A shear strength decreasing of the interface between fresh argillaceous rock with variations OBL of WCS and water content increasing in OBL of WCS, is shown in Figure 10 and Figure 11. The higher density OBL of WCS, more greater interface shear strength reducing due to increase water.

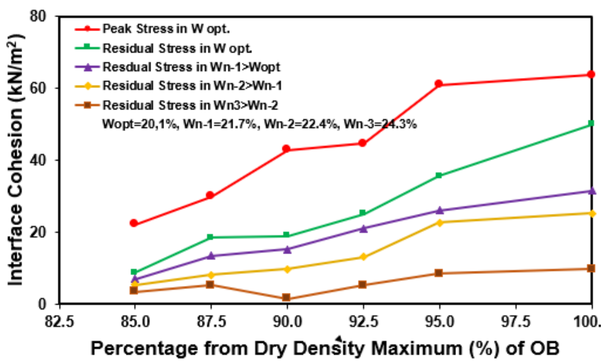

Figure 10. Interface cohesion between argillaceous rock and variation density of compacted WCS as overburden layer, due to increasing water content.

Normalized interface shear strength to normal stress represents the two main parameters of shear strength; cohesion and internal angle friction. The normalized is formed by ratio between shear stress to normal stress, as shown in Figure 12. It is clearly seen that the interface shear strength reduces by decreasing OBL density and increasing water content. Normalized interface shear strength reach 1.89 at 100% dry density maximum of the OBL density. The interface shear strength fall to 0.65 for density of OBL at 85% dry density maximum.

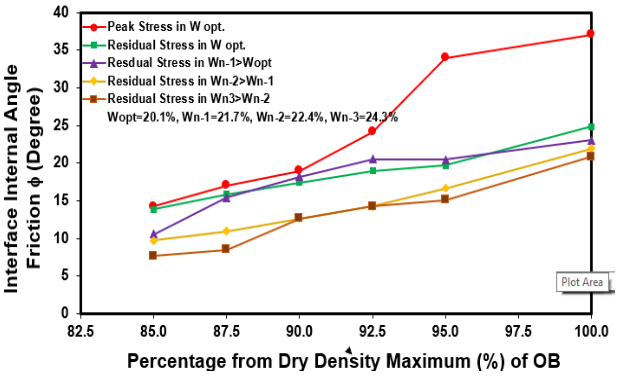

Figure 11. Interface internal angle friction between argillaceous rock and variation density of compacted WCS as overburden layer, due to increasing water content.

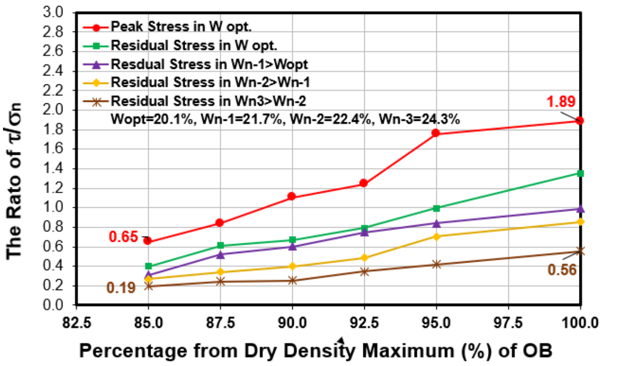

Figure 12. Degradation of shear strength ratio (τ/σ_n) due to OBL density and increasing water content

Table 5 shows percentage degradation of normalized interface shear strength from optimum condition. Degradation of interface shear strength shake to 34% at 85% dry density maximum. This is quite significant degradation, it is reasonable if the clay shale layer becomes susceptible to fail.

Table 5. Degradation of percentage shear strength ratio (τ/σ_n) due to decreasing density and increasing water content

OBL Density	The Average Precentage Degradation of Ratio of τ/σn				
	Peak. Wopt	Res. Wn-3 Wopt	Wn-1		Wn-2
100 % γd Max	100	72	52	45	29
95 % γd Max	93	53	44	37	22
92.5 % γd Max	66	42	40	26	18
90 % γd Max	59	36	32	21	13
87.5 % γd Max	44	32	27	18	13
85 % γd Max	34	21	16	14	10

5 CONCLUSIONS

From this study, it can be drawn the following conclusions

1. The interface shear strength between argillaceous rock and OBL in the form of compacted weathered argillaceous rock (WSC), is strongly influenced by the density of the WCS and its moisture content..
2. The OBL of WCS density with 100% dry density maximum, the interface shear strength ratio (τ / σn) is 1.89 (maximum) at the optimum OBL moisture content. This shear strength ratio will drop to 0.56 or the remaining up to 29% due to the increase in water content until it is fully saturated.
3. The effect of density OBL of WCS on the optimum water content, the interface shear strength ratio decreases until it remains 34% at 85% density OBL of WCS, and it remains 10% if fully saturated (Sr = 100%)

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