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INTERFACE SHEAR STRENGTH DEGRADATION IN PROGRESSIVE LANDSLIDE OF WEATHERED CLAY SHALE OVERBURDEN ON UNDISTURBED CLAY SHALE

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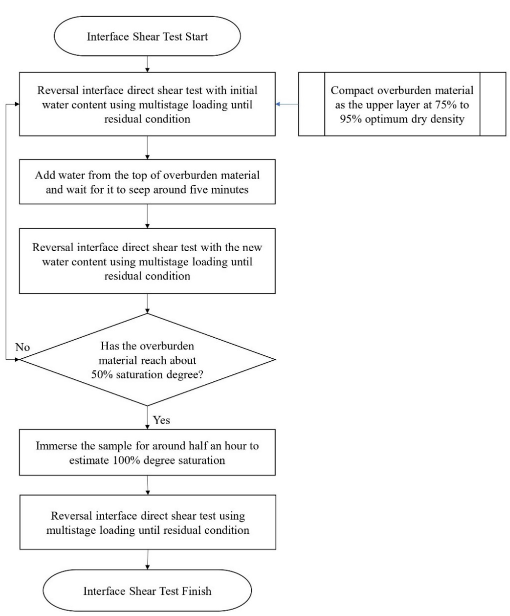
Graphical abstract



Abstract

In accomplishing Sustainable Development Goals (SDGs), the construction of roads played a substantial role in achieving economic equity. However, landslides due to problematic soil would hinder its construction process. Thus, it is essential to understand the mechanism of slope movement to reduce landslide problems. A landslide that happened during the construction of the Semarang-Bawen toll road was analyzed in this research. The landslide was known to fail between the interface of the tuff breccia overburden and the problematic clay shale soil. This research proposed the direct shear test to determine the interface shearing behavior. Before the test, the overburden was differentiated as various sand and weathered clay shale ratios. After the overburden soils were compacted, a multistage interface direct shear test was conducted with three different loadings. Water was added to the overburden layer to model the infiltration at the interface by increasing the water content. From the test, results such as the interface cohesion, friction angle, and average stress ratio were obtained. Overall, the interface shear strength decreased as the water content increased. The decreasing value was due to the wetting at the interface. Thus, it would moisten the interface and disrupt the structure of both the top and bottom layers of the sample. In conclusion, the interface direct shear test was able to describe the shear behavior at the clay shale interface. It also indicated that water had a considerable role in triggering interface landslides for two different soil layers.

Keywords: Clay Shale, Direct Shear Test, Interface Shear Strength, Landslide, Water Infiltration

1.0 INTRODUCTION

Every country has a responsibility to promote the Sustainable Development Goals (SDGs), which would develop prosperity while also protecting the planet. One of the means is connecting rural areas. Several SDGs which could be fulfilled by this method are SDG 1 to SDG 6, SDG 8, SDG 9, SDG 11, and SDG 13, which focused on alleviating the quality of life in rural areas. One of many methods to achieve this is by providing both a sufficient transportation system and its facilities. Thus, constructing roads is critical since it would give access to many areas [1].

One of the projects in connecting these areas is the Semarang-Bawen toll road in Central Java, Indonesia. The consideration of building the tollway was not only to complete the Trans Java tollway but also to connect Ungaran as an industrial city in Central Java. However, due to its geological terrain, many landslides happened during its construction until its operation in recent times. The main reason for its vulnerability is its geographical terrain which varied from gentle hills and steep cliffs [2, 3]. In 2015, during its construction period, a landslide happened when the cut and fill process was conducted in KM 483 + 200. Additional testing was needed to understand the source of failure and several improvements were needed to resolve the slope failure. The failure resulted in additional repair costs and loss of construction time [4]. In 2020, during the operation of the tollway, a landslide happened after a long period of heavy rainfall in KM 426 + 600. Due to the landslide, a lane was covered in soil and generated traffic in the tollway [2]. Lastly, soil improvements were also discovered in STA 19 + 525; during the period of construction [3], and STA 5 + 500 to STA 6 + 300 [5]. Specifically for the location of STA 5 + 500 to STA 6 + 300, the landslide happened in 1974 which resulted in 80 houses collapsing and the relocation of the entire Susukan village [5]. Thus, it is clear that the entire section of the tollway has a long history of landslides.

Another factor for the Semarang-Bawen landslide was its geological formation that spanned several formations. One of the formations was the Kaligetas formation which consisted of rocks from volcanic breccia and claystone. However, a landslide at KM 483 + 200 indicated that the clay stone in the area had similar characteristics to clay shale [4, 6].

Clay shale is known as a problematic soil, especially in Indonesia, due to its unique property of weathering [7, 8, 9]. The weathering in clay shale is defined as a disintegration process of the soil which would break it into smaller pieces [10]. Initially, clay shale existed in nature in its form as a rock. However, weathering disintegrated clay shale from its rock to soil condition. From previous research on clay shale in Indonesia, the main reason for its disintegration process was due to the continuous wetting-drying cycle by rainfall [11].

For the Semarang-Bawen landslide case at KM 483 + 200, the landslide was seen to have a translational slip surface at the interface between the tuff breccia layer and clay shale rock bed. The landslide report stated that a cut and fill process was conducted during a long period of the simultaneous cycle of heavy rainfall and hot weather. Other than the weathering process at the surface, the translational slip surface indicated that the interface degraded after the simultaneous wetting-drying cycle from the weather. Thus, it was predicted that interface shear strength degradation happened during the cut and fill process due to water infiltration [4, 11].

Interface shear strength research was dominant in soil-solid interface experiments [12, 13]. However, current trends demonstrated that the soil-soil interface behavior started to emerge and several conclusions about the behavior of the interface between two different strengths of soils were obtained [14]. In general, an interface of different strengths of soil would have higher shear strength than the initial shear strength of clay soil. It would have a lower friction angle and higher cohesion when one side of the interface has higher initial shear strength [15, 16, 17].

As the water also affected the Semarang-Bawen toll road landslide, it was important to understand the effect of water on interface shear strength. From previous studies, water significantly affected the determination of interface shear strength like soil type [18, 19]. When water was added to the interface, cohesion would be formed in a formerly zero value from its dry condition. However, it had little effect in increasing the interface shear strength as the overall strength would decrease due to the existence of water.

As previous research had separately discussed clay shale properties and interface shear strength, this paper aims to fill the gap between the two topics. Thus, a method is proposed to determine the interface shear strength behavior between clay shale and its overburden. Furthermore, water is also added to the proposed test since it is known to be the most common cause of landslides in Indonesia.

2.0 METHODOLOGY

The research was modeled based on the slope failure at the Semarang-Bawen toll-way in 2015. The precise location of the landslide was 483+200 km from the Semarang-Bawen toll-road section. According to the geological map, the slope was located at the Kaligetas and Kerek formations [6]. The Kaligetas and Kerek formations were surrounded by shale, clay stone, and tuff breccia. In some cases, the upper part of the undisturbed clay shale might also be a mix of weathered clay shale with sand. Thus, undisturbed clay shale samples and modified overburden samples are needed.

2.1 Sample Preparation

The clay shale samples were taken during the rainy season of 2019 at the location where the landslide occurred. During the sampling period, the clay shale slope was covered in shotcrete. Thus, it was necessary to scrape the shotcrete to take the clay shale soil underneath. Due to the condition of the slope, only a limited area was able to be scrapped. A limited amount of samples was inevitable in the process of collecting both the disturbed and undisturbed clay shale samples. Thus, the samples could not represent the rock formation of the location and only represented a fraction of the slope. However, it was still sufficient since the focus of the study was to predict the interface shear strength and not the cause of the landslide or the characteristic of the whole formation.

After scraping the surface, a one-meter-deep test pit was constructed to obtain sufficient sampling depth. The clay shale removed during the digging of the test pit was collected as the disturbed samples. At the same time, the undisturbed clay shale was collected using a core-drilling method from the test pit specified by previous research [4].

A combination of weathered clay shale and sand were modified by weight to model the tuff breccia overburden. Before mixing the overburden material, the disturbed clay shale taken from the site needed to be weathered from its rock-like form to soil. Thus, several wetting-drying cycles were conducted until the sample was changed into its soil form [20]. Afterward, the weathered clay shale and sand were divided into five mixture ratios according to their weight. These ratios are 100% Sand, 75% Sand: 25% Weathered clay shale, 50% sand: 50% weathered clay shale, 25% sand: 75% weathered clay shale, and 100% weathered clay shale.

2.2 Proposed Interface Direct Shear Test with Water Infiltration

An interface direct shear test was proposed to understand the interface shear strength behavior due to water infiltration.

The first step was to prepare the samples. The obtained undisturbed clay shale samples were cut to fit the bottom part of the shear box. At the same time, the overburden sample was compacted at the top of the shear box until its estimated optimum dry density.

The top and bottom boxes were connected when the compaction was conducted. Each overburden variation would result in one sample of shear box.

Due to the limitation of the direct shear test apparatus for this study, several assumptions needed to be pointed out. First, the test was conducted using the Unconsolidated-Undrained (UU) condition. Second, the test was done in a multi-stage condition with a strain-controlled environment to achieve the residual shear strength. Third, the test used a set of three loads: 1 kg, 2 kg, and 3 kg. The variation was selected to shorten the testing time as lower pressure would give lower peak and residual stress. The loads would result in 0.34 kg/cm^2, 0.70 kg/cm^2, and 1.05 kg/cm^2 pressure on the sample. Fourth, as the shear rate could also affect the interface shear strength, it would not be considered in this test [15]. Fifth, fissures were not considered since the test was done in element size. Lastly, the effect of water infiltration was modeled as the change of water content of the overburden layer [21]. Overall, the process of the interface direct shear test can be seen in Figure 1.

The process of the interface direct shear test is as follows. First, the sample was placed in the direct shear test apparatus. Second, shearing of the sample was conducted with the three loads using the multi-stage condition. The shearing stopped when the reading of both peak and residual shear strengths were recorded. After the test was stopped, the loads were removed from the direct shear apparatus. At the same time, the shear box was reversed for the next shearing. In the third step, water was added to the upper part of the overburden layer. The sample was then left for five minutes to let the water seep through the overburden layer to the interface. Fourth, shearing started with the first load until its residual condition was achieved. The shearing continued with the other two loads until the sample's residual condition, similar to the first shearing at its initial water content condition. Then, the loads were removed again from the device. Likewise, the shear box was reversed again to its initial direction. The same steps were conducted until the degree of saturation of the overburden material reached around 50%. Subsequently, the sample was fully-soaked in water for half an hour, estimated as a fully saturated state. Lastly, the interface direct shear test was conducted to determine the interface shear strength in fully saturated conditions.

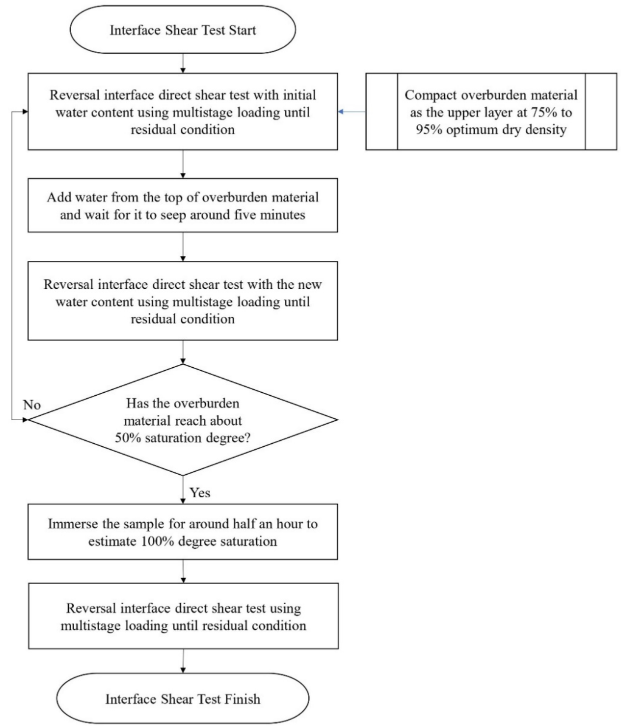


Figure 1 Interface Shear Test Flowchart

3.0 RESULT AND DISCUSSION

From the methodology, the interface shear test was conducted for both the peak and residual conditions. The results from the tests were a shear-strain graph, interface cohesion, and interface friction angle. The average stress ratio was also formulated to understand the moving trend of the stress for various overburden conditions. The average stress ratio is the average of shear stress divided by normal stress for each test conducted. In simplifying the overburden variation terms, the sand is further annotated as S and the weathered clay shale as WCS.

3.1 Shear Strain Graphs

The first result was the peak shear-strain graph from the multi-stage interface direct shear test. The graphs compared the shear stress and strain of the soil from the three applied normal stresses. From the peak shear-strain graph, the highest interface peak stress was achieved by the 100% sand variation. On the contrary, the lowest shear stress was achieved by the 100% weathered clay shale variation. From the strain values, the 100% sand variation had the lowest value, whereas the 50% sand: 50% weathered clay shale had the highest value. The results can be seen in Figure 2.

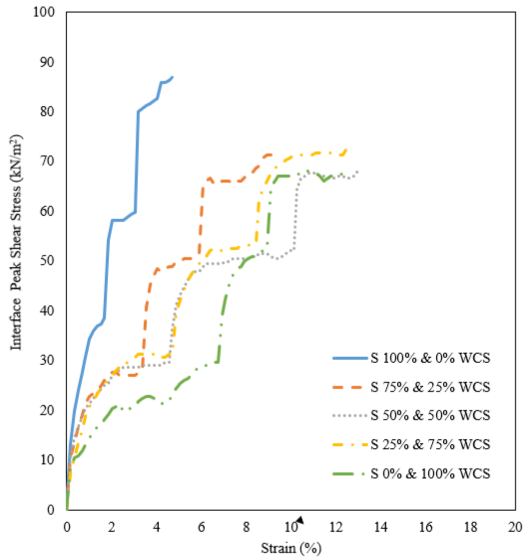


Figure 2 Peak Shear-Strain Graph for All Overburden Variations

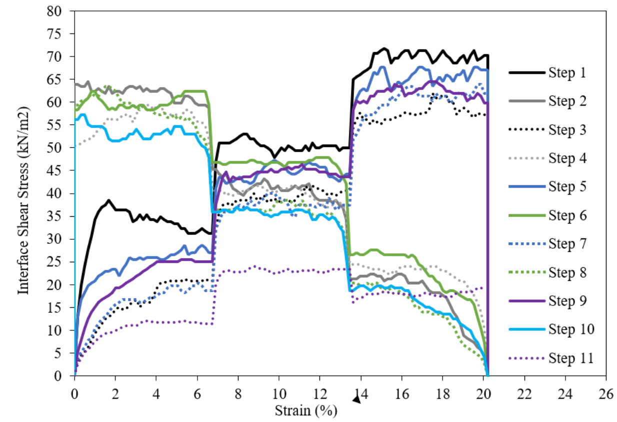
The increase of shear and strain values were calculated as a percentage of its initial condition. The percent form was selected to understand the change of both the shear and strain behavior from the test. The numbers can be seen in Table 1.

Table 1 Increase Percentage of Strain and Shear Stress for Various Overburden Composition at Peak Stress

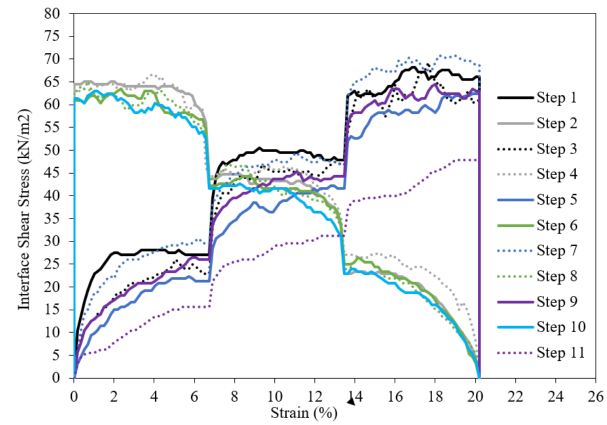
Sand – weathered clay shale variations	Strain (%)			Shear Stress (%)		
	1	2	3	1	2	3
100% S	35.71	25.00	32.14	44.31	6.59	7.78
75% S: 25 % WCS	35.71	25.00	35.71	39.13	15.22	8.70
50% S: 50% WCS	34.62	41.03	21.79	43.51	22.90	5.34
25% S: 75% WCS	36.84	27.63	32.89	42.86	19.29	14.29
100% WCS	54.05	16.22	27.03	43.85	20.00	3.85

From Table 1, the largest stress and strain increase was seen at the first stage of loading. The increase of stress was seen to have discrete values, whereas the strain indicated a similarity from each variation. The different behavior was due to the nature of the strain-controlled test. Thus, although the values varied according to Figure 2, the change was similar.

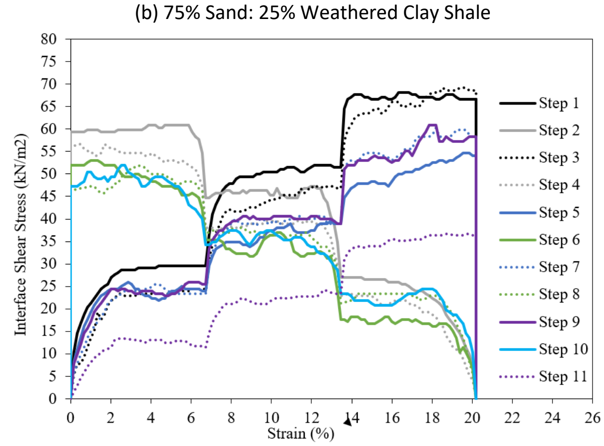
Another strength condition is the residual shear strength, which is essential in clay shale soil since it was categorized as an over-consolidated clay. Furthermore, over-consolidated clay tended to be mobilized for failure in its residual condition [22, 23]. Thus, it is crucial to understand the behavior of the residual shear strength at the interface for the clay shale sample. Throughout the test, a total of eleven steps of shearing were recorded. The first step of shearing indicated the initial water content of the overburden material. On the other hand, the final step represented the fully-soaked condition of the sample. The results for the multi-stage interface residual shear-strain graphs can be seen in Figure 3. The results included all of the overburden variations in this study.



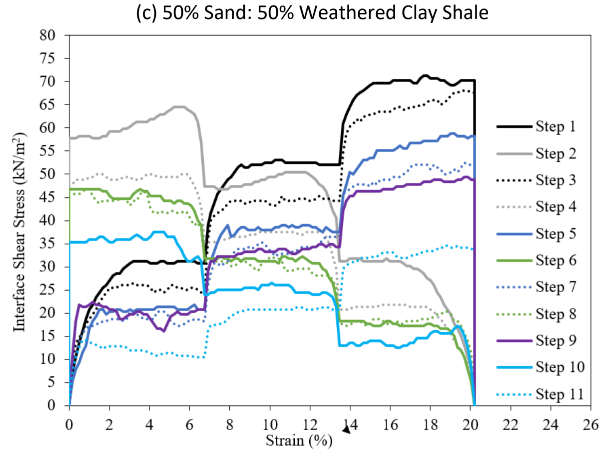
(a) 100% Sand



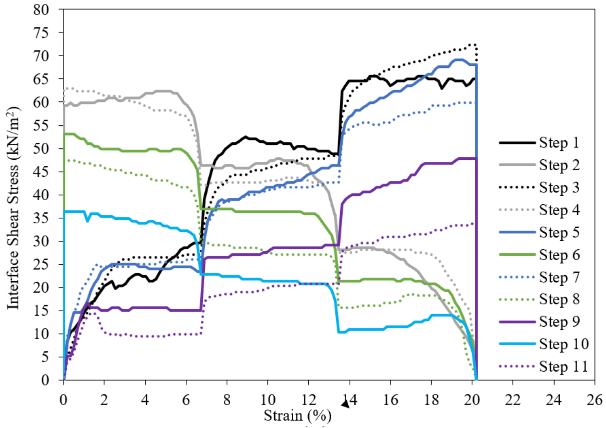
(b) 75% Sand: 25% Weathered Clay Shale



(c) 50% Sand: 50% Weathered Clay Shale



(d) 25% Sand: 75% Weathered Clay Shale



(e) 100% Weathered Clay Shale

Figure 3 Shear-strain graph for residual stress

Several behaviors of the residual shear strength at the interface of the overburden and undisturbed clay shale could be seen in Figure 3. First, the highest shear stress was seen at the first step of shearing for all of the overburden variations. The high shear stress was due to the low water content of the overburdens. As mentioned in previous research, clay with lower water content would give higher shear strength [17, 18].

Second is the movement of the shear-strain graph of the residual interface shear strengths. The direction of the first step depicted one direction of shearing. After the shearing was completed, the loads were removed, which resulted in a shear stress value of zero. The next shearing was conducted after the addition of water to the overburden layer. However, the direction was reversed from the first shearing. Thus, the direction of the shear-strain line for Step 2 was reversed. The same treatment was used repeatedly until the last step.

The third is the shear stress value. From Figure 3(a) to Figure 3(e), the shear stress decreased as the water content increased. Thus, the interface shear strength would decrease with the increase of water content at the interface of all the overburden variations and the undisturbed clay shale.

Last is the effect of the weathered clay shale ratio in the overburden variations. The ratio of weathered clay shale contributed to the effect of water. The gaps from the shear stress value from the increasing steps were seen to expand with the increase of the weathered clay shale ratio in the overburden variations. The expanding gaps with the increasing weathered clay shale ratio were due to the nature of clay as a cohesive soil. Thus, the surface at the interface between the overburden and the rock-like undisturbed clay shale was dominantly affected by the adhesion of the weathered clay shale [19].

3.2 Shear Strength Parameters

The other result from the interface direct shear test was the shear strength parameters. The parameters were determined from the correlation between normal stress and shear stress for each sample. Three points were plotted from the results of the direct shear test. Afterward, the linear trendline was used to determine the interface cohesion and friction angle for each water content and overburden variations. The degree of saturation was used instead of the water content for the varying water condition of each overburden variation. It was selected due to its definition, which had a cap of 0 to 100 percent regardless of the soil condition. Thus, it is easier to compare the water condition for all variations.

The first shear strength parameter discussed is the interface residual cohesion. It was typical to find negative cohesion interpretation using a direct shear test. However, no shear strength parameters are supposed to be negative. Thus, in this paper, the negative cohesion values were interpreted as zero. In Figure 4, the interface residual cohesion was compared to the degree of saturation from the overburden. From the graph, all the overburden variations had a negative trend when compared to the degree of saturation. The trend line described that the increase in the degree of saturation would decrease the cohesion. It means that water would negatively affect the value of cohesion or adhesion. However, the value seems to be scattered. Thus, the relationship was only predicted purely by the linear trendline.

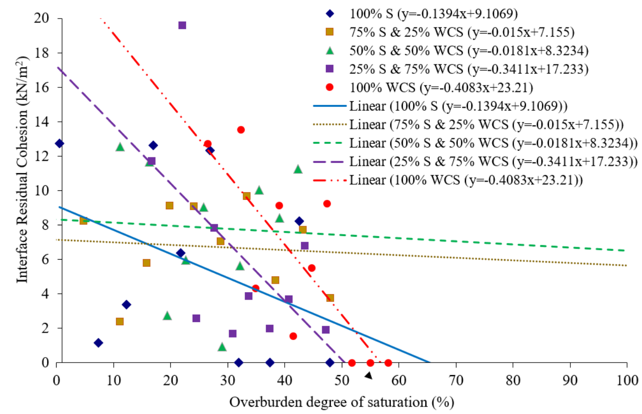


Figure 4 Interface cohesion for all overburden layers

The second shear strength parameter discussed is the interface friction angle seen in Figure 5. In general, the results from the test indicated that the friction angle would decrease with the increase of the degree of saturation. However, an anomaly was seen from the 100% sand variation. The trendline for the 100% sand variation showed a slightly increasing trend. Previous research stated that increasing water content would decrease the shear strength parameters, including the friction angle [11, 17, 18, 24]. Similar to the interface cohesion, the values for the interface friction angle were also scattered.

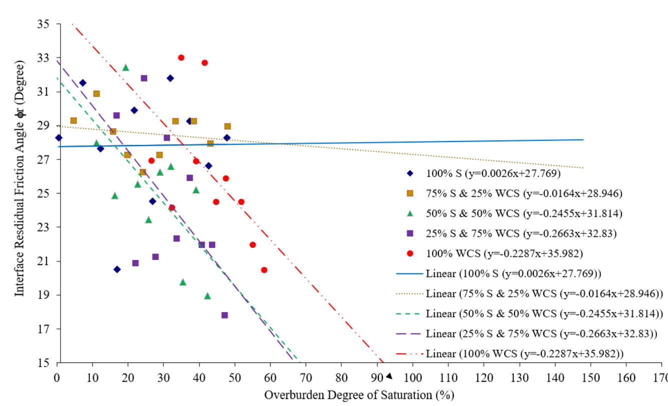


Figure 5 Interface friction angle for all variations

Lastly, the average stress ratio was calculated from the test. The average stress ratio was determined by dividing the average shear stress by the average normal stress in each testing condition. The average stress ratio was used to understand the overall change of stress for each variation due to water at the interface. From Figure 6, all variations led to a decreasing average stress ratio for the increase in the degree of saturation. The values of the interface friction angle were quite scattered but were seen to be close to the linear trend line.

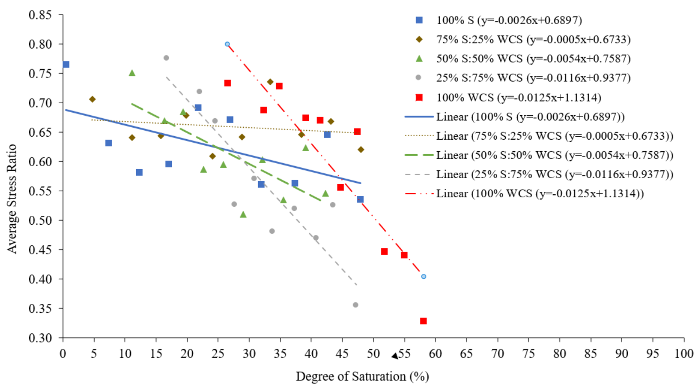


Figure 6 Average stress ratio for overburden degree of saturation of all variations

3.3 Discussion

From the results, the shear-strain graphs and the shear strength parameters of the interface shear strength between the overburden variations and the undisturbed clay shale could be analyzed.

The first result was the shear-strain graph for the peak and residual interface shear strength. The peak shear-strain graph showed that the highest interface peak stress was seen in the 100% sand variation. The behavior indicated that granular materials would give higher shear stress with lower strain. The addition of weathered clay shale would lower the shear stress value. The shear stress decrease was due to the low innate strength of weathered clay shale. However, it was considered common that the higher the weathering degree of clay shale, the lower the shear strength [11]. In determining the residual shear strength, water was added as a variable throughout the reversal multi-stage testing. The strain was seen to be limited to 20% due to the strain-controlled type of the direct shear test. Also, a reverse direction of the shear-strain graph was determined, following the direction of the test. It was clear that water had a significant role in decreasing the shear stress at the interface. Furthermore, the content of weathered clay shale would also widen the gap between each water addition due to the susceptibility of clay shale to water. Thus, water affected the interface residual strength [11, 17, 18, 19]. From the shear strength parameters seen in Figure 4 to Figure 6, the values were all scattered. Moreover, the moving trendline could only visually show the decrease of shear strength with the increase in the degree of saturation. Thus, the R^2 value was calculated to see the precision of the values for each test. The decreasing percentage was also calculated from the highest and lowest value of each parameter. Similar to the R2 values, the decreasing percentage was calculated for each overburden variation. Both the R^2 values and the percentage of the decrease could be seen in Table 2.

From the calculations, the greatest decrease for all of the shear strength parameters was seen in the 25% Sand and 75% Weathered Clay Shale variation. The value of 100% was seen on the 100% Sand and 100% Weathered Clay Shale interface cohesion. However, the values were due to the lowest cohesion value of 0 kPa. As previously mentioned, the negative cohesion value in the test was considered zero. Thus, the reduction was seen as 100%. For the R^2 values, the precision of the data can be examined. In Table 2, most of the shear strength parameters data have R^2 values of under 0.50. It means that the data were quite scattered. When compared, most of the R^2 values that surpass 0.50 was seen in the average stress ratio. Thus, the average stress ratio could describe the trendline of the interface shear behavior for this study than the cohesion and friction angle.

Table 2 Decrease of Shear Strength Parameters and R2 Values of Overburden Material Variations

Sand and Weathered Clay Shale Variations	100% S	75% S: 25% WCS	50% S: 50% WCS	25% S: 75% WCS	100% WCS
Decrease (%)					
Cohesion	100	54.49	10.06	83.79	100
Friction Angle	0.03	1.15	32.22	25.79	23.98
Average Stress Ratio	29.99	12.23	27.33	54.13	55.2
R^2 Value					
Cohesion	0.156	0.007	0.002	0.348	0.622
Friction Angle	0.0001	0.031	0.414	0.346	0.327
Average Stress Ratio	0.337	0.36	0.545	0.826	0.823

It was clear that water affected the decrease of interface shear strength. Water moistened the interface and disrupted the undisturbed clay shale structure at the interface [17, 18]. Lastly, the presence of clay also affected the decrease of the interface shear strength. The shear strength decrease showed a higher percentage for higher weathered clay shale. It is quite the opposite of previous research, whereas clay had higher shear strength than sandy soil [8, 9]. The lower shear strength was due to the low innate shear strength of weathered clay shale itself [11]. Thus, the higher the weathered clay shale ratio in the overburden, the higher the shear strength decreases.

4.0 CONCLUSION

The study evaluated the shearing behavior from the proposed interface reversal multi-stage direct shear test. For this study, the interface shear strength was conducted on an undisturbed clay shale with an overburden material consisting of weathered clay shale and sand. Several conclusions are presented.

First, this study presented the peak and residual interface shear-strain graphs from the interface reversal multi-stage direct shear test. Factors considered in the graphs were the shearing direction and effect of water. The higher the degree of saturation at the interface, the lower the interface shear stress. Other than water, the weathered clay shale has also affected the shear-strain graph of the interface reversal multi-stage direct shear test. The higher the weathered clay shale ratio in the overburden material, the higher the shear stress decrease with increasing water content.

Second, the shear strength parameters were assessed from the test. The parameters included interface cohesion, friction angle, and average stress ratio. The three shear strength parameters are seen to have similar behavior, but different precision. The trendline showed a negative value meaning that water at the interface would decrease the interface shear strength parameters. However, due to the low data precision, it is recommended to use the average stress ratio to understand the shear strength behavior instead.

Lastly, the weathered clay shale is known to have a significant role in determining the interface shear strength. The high decrease of shear strength parameters with the increase of the degree of saturation was available in higher weathered clay shale ratios. The behavior is due to the low innate strength of weathered clay shale and the structure of clay itself. Clay has adhesion, which means that it would stick to another surface, especially with high water content. Thus, the shear strength would decrease with the increase of water content.

Overall, the interface shearing method proposed has a satisfying result. The interface shear behavior was also captured accurately. Further studies on different overburdens and investigations on the interface during shearing would enhance the research.

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References

[1] Cook, J. R., Huizenga, C., Petts, R., Sampson, L. R., Visser, C., & Yiu, A. 2017. Rural Transport Research in Support of Sustainable Development Goals. Transport and Communications Bulletin for Asia and the Pacific. 87.

[2] Gunawan, Ade & Pratama, Yoga. 2020. Studi Analisis Penanganan Longsor pada Slope Timbunan yang Tegak (Studi Kasus Longsoran di Jalan Tol Ruas Semarang-BAwen KM 426+600) (in Indonesian). *Jurnal Engineering Indonesia*. 1(2): 16-22

[3] Khrisna, R. H., Atmanto, I. D. & Wibowo, H. Evaluasi Stabilitas Lereng yang Telah Diperkuat pada Jalan Tol Semarang- Solo Seksi V Ungaran – Bawen (in Indonesian). *Jurnal Karya Teknik Sipil*. 2(4): 343-352.

[4] Alatas, I. M. 2017. Kesan Luluhawa terhadap Kekuatan Ricih Syal Lempung dalam Penentuan Parameter Kestabilan Cerun (in Malaysian). PhD Thesis. Universiti Teknologi Malaysia.

[5] Retno, S. P., Wardani & Muhrozi. 2011. Problem of High Embankment on Clay Shale at Semarang-Ungaran Toll Road STA 5 + 500 to 6 + 300. Proceedings of *3rd International Conference on Geotechnical Engineering for Disaster Mitigation and Rehabilitation* 2011. 159 – 171.

[6] Thades, R. E, Sumadirja, H., & Richards, P. W. 1975. *Geologic Map of the Magelang and Semarang Quadangels, Java.* 1:100,000. Geological Survey of Indonesia, Ministry of Mines. Indonesia.

[7] Seedsman, R. W. 1993. *Characterizing Clay Shales.* Pergamon, Oxford, United Kingdom. https://doi.org/10.1016/B978-0-08-042066-0.50014-8

[8] Oktaviani, R., Rahardjo, P. P., & Sa*disun, I. A. 2018. Landslides Induced by Slaking of Geomaterial. Proceedings of International Conference on Disaster Management (ICDM) 2*018. 229. https://doi.org/10.1051/matecconf/201822903011

[9] Sadisun, I. A., Bandono, Shimada, H., Ichinose, M., & Matsui, K. 2003. Slope Instability of Road Cuts Due to Rock Slaking. *Proceedings of 12th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering.* 747-750. https://doi.org/10.13140/2.1.2418.4963

[10] Sadisun, I. A., Shimada, H., Ichinose, M., & Matsui, K. 2005. Study on the Physical Disintegration Characteristics of Subang Claystone Subjected to a Modified Slaking Index Test. *Geotechnical and Geological Engineering.* 23:199-218. https://doi.org/10.1007/s10706-003-6112-6

[11] Alatas, I. M., Kamaruddin, S. A., Nazir, R., & Irsyam, M. 2016. Effect of Weathering on Disintegration and Shear Strength Reduction of Clay Shale. Jurnal Teknologi. 7-73(78): 93-99. https://doi.org/10.11113/jt.v78.9491

[12] Li, Y.-K., Han, X.-L., Ji, J., Fu, D.-L., Qiu, Y.-K., Dai, B.-C., & Lin, C. 2015. Behavior of Interfaces between Granular Soil and Structure: A State-of-the-art Review. *The Open Civil Engineering Journal*. 9: 213-223. https://doi.org/10.2174/1874149501509010213

[13] Zhang, G., Jianmin, Z. 2009. State of the art: Mechanical Behavior of Soil-Structure Interface. *Progress in Natural Science.* 19: 1187-1196. https://doi.org/10.1016/j.pnsc.2008.09.012

[14] Sagitaningrum, F. H., Kamaruddin, S. A., Nazir, R., Soepandji, B. S., & Alatas, I. M. 2020. Soil-solid interface shear strength review and its possibility on interlayer slope stability analysis. *Proceedings of the 3rd International Conference on Eco-Engineering Development*. 426. https://doi.org/10.1088/1755-1315/426/1/012062

[15] Suzuki, M., Hai, N. V., & Yamamoto, T. 2017. Ring Shear Characteristics of Discontinuous Plane. *Soils and Foundations*. 57: 11-22. https://doi.org/10.1016/j.sandf.2017.01.001

[16] Frikha, W. & Jellali, B. 2018. Numerical and Experimental Studies of Sand-Clay Interface. *Proceedings of The Ground Improvement and Earth Structure.* 108-190. https://doi.org/10.1007/978-3-319-63889-8_9

[17] Shakir, R. R. & Zhu, J. 2009. Behavior of Compacted Clay-Concrete Interface. *Front Architecture Civil Engineering China.* 3(1): 85-92. https://doi.org/10.1007/s11709-009-0013-6

[18] Shakir, R. R. & Zhu, J. 2009. Mechanical Behavior of Soil and Concrete Interfaces. Proceedings of ICEM 2008: *International Conference on Experimental Mechanics* 2008. 73756R1-73756R8. https://doi.org/ 10.1117/12.839390

[19] Pellet, F. L. & Keshavarz, M. 2014. Shear Behavior of the Interface Between Drilling Equipments and Shale Rocks*. Journal of Petroleum Exploration and Production Technology*. 4: 245-255. https://doi.org/10.1007/s13202-014-0108-z

[20] Sadisun, I. A., Shimada, H., & Matsui, K. 2000. Characterization of Weathered Claystone and Their Engineering Significance. *Proceedings of Indonesian Scientific Meeting 2000.* 1-8. https:/doi.org/10.13140/2.1.2447.1685

[21] Chung, S. H. 2019. Study of the Rainfall Infiltration Effect and Soil Strength Variation on Unsaturated Laterite Terraces*. Proceedings of the 4th World Congress on Civil, Structural, and Environmental Engineering. ICGRE 1841-1848*. https://doi.org/10.11159/icgre19.184

[22] Skempton, A. W. 1985. Residual Strength of Clays in Landslides, *Folded Strata, and the Laboratory. Geotechnique.* 38(1): 3-19.https://doi.org/10.1680/geot.1985.35.1.3

[23] Stark, T. D. & Hussain, M. 2010. Drained Residual Strength for Landslides. *Proceedings of Geoflorida 2010: Advances in Analysis, Modeling, and Design.* https://doi.org/10.1061/41095(365)328

[24] Alatas, I.M. 2020. Perilaku Kekuatan Geser Interface antara Batuan Andesit dengan Variasi Material Timbunan Akibat Interusi Air (in Indonesian). *Proceedings of Pertemuan Ilmiah Tahunan Himpunan Ahli Teknik Tanah Indonesia* XXIV.