Properties of Clay Shale On Geotechnical Engineering Design of Infrastuctures

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Abstract

The decrease in the shear strength of clay shale occurs due to several weathering processes, including the drying process. Or due to the wetting and drying cycle process which will cause an even faster decrease in shear strength. This decrease in the shear strength of clay shale occurs at all peak stress and residual stress conditions. While residual stress can occur due to without stress release or in conditions with stress release, there is an even greater decrease in shear strength. The occurrence of slope failure on clay shale is not only caused by degradation due to weathering, or in some cases the trigger for weakness is due to the interface shear strength between the clay shale and the overburden layer which is a layer of pervious material, which can absorb water well, thus causing a decrease in interface shear strength. faster, causing a decrease in the safety factor which results in landslides on the slopes. The re-use of completely weathered clay shale material as fill material on random slopes often causes failure. Efforts to improve by using excessive compaction energy also did not obtain satisfactory results, even adding cement did not result in an increase in slake durability that qualifies as embankment material.

Keywords

Clay shale, weathering, degradation

Introduction

Clay shale is a type of sedimentary rock that is formed from deposits of fine particles such as mud or dust which then a process of physical and chemical change in the earth's crust. The geological process that causes clay shale to form involves several steps as follows (Tucker 1982)

Weathering: The process begins with the weathering of pre-existing rocks, which breaks them down into smaller particles such as clay, silt, and sand. This weathering can occur due to various factors like water, wind, temperature changes, and biological activity.

Erosion and Transportation: The weathered particles are then transported by natural agents like water (rivers, streams, oceans), wind, or ice. They are carried away from their original location to a new site where sedimentation can occur.

Deposition: Once transported, the particles settle out of the transporting medium (water, wind, or ice) and accumulate in layers on the Earth's surface. This deposition typically occurs in low-energy environments such as lake bottoms, river deltas, or shallow marine environments.

Compaction: Over time, the weight of overlying sediment layers compresses the deposited particles, squeezing out water and air. This compaction reduces the volume of the sediment and increases its density.

Cementation: As sediment compacts, pore spaces between particles decrease, allowing minerals dissolved in groundwater to precipitate and fill in the gaps. These cementing minerals, such as calcite or silica, bind the sediment grains together, transforming loose sediment into solid rock.

Diagenesis: This refers to the physical and chemical changes that occur as sediments are buried deeper within the Earth's crust. During diagenesis, clay minerals may undergo alteration, and additional cementation may occur, further hardening the sediment into rock.

Lithification: The final stage involves the transformation of compacted sediment into solid rock. Under the continued pressure and temperature conditions of burial, the sediment undergoes lithification, becoming shale, a fine-grained sedimentary rock composed primarily of clay minerals.

These processes operate over vast timescales, typically millions of years, and are influenced by factors such as climate, tectonics, and sediment source material (Tucker 1982)

The scope of this article is to discuss the degradation of clay shale properties due to the weathering process, to be used as a consideration for geotechnical engineers in the use of clay shale properties in the engineering design process. All the contents of this paper are our research experience on clay shale in Central Java and West Java which began in the last ten years.

The first thing is how the shear strength of clay shale degrades due to the weathering process. What is the shear strength of clay shale due to degradation due to the drying process or wetting drying process? The shear strength referred to is in peak stress or residual stress conditions.

The second thing is how the interface shear strength of clay shale is degraded due to water penetrating from the surface to the overburden layer so that the water content at the interface area increases. This is a very serious problem in analyzing the stability of slopes in clay shale with the potential interface area. on a slope.

The third thing is how weathered clay shale behaves when used as embankment material, especially on slopes, and how does its durability increase when compacted by increasing compaction energy or by adding portland cement before compacting.

The most important parameters in clay shale

In geotechnical design on clay shale soil, information about clay shale parameters is very important, especially regarding the special parameter characteristics that must be known, so that the geotechnic design results are in accordance with the special parameter characteristics of the clay shale compared to the parameter requirements of other clay soils.

For a geotechnical engineer, understanding the physical and mechanical properties of clay shale is very important to evaluate the geotechnical potential and rock behavior in civil engineering projects. Several important parameters of clay shale that geotechnical engineers must know include:

1. Mineral Composition: Knowing the composition of the major minerals in clay shale, such as the dominant types of clay minerals, can provide insight into the physical and chemical characteristics of the rock and its geotechnical behavior.
2. Slake Durability Index (SDI) value: SDI measures the ability of rocks to resist decay when exposed to water. This information is important for evaluating the weathering and disintegration potential of rocks under different environmental conditions.
3. Mechanical Properties (Shear Strength Properties): Including compressive strength, shear strength, and elasticity module of clay shale. These mechanical properties influence the ability of clay shale to withstand loads and pressure from civil engineering structures. Knowledge about the potential for reducing shear strength is important, because the nature of clay shale is that it easily rots when it reacts with atmosfere (air) or hydrosphere (water).

Understanding these parameters helps geotechnical engineers develop accurate geotechnical models, plan safe and efficient construction, and manage risks associated with the use of clay shale in civil engineering project

Disintegration Ratio (DR) And Shear Strength Degradation Of Clay Shale Due To Weathering Process.

Fig. 1 Changes in the physical properties of Semarang-Bawen and Hambalang clay shale due to the drying process and the drying wetting cycle (Alatas I M 2015 d)

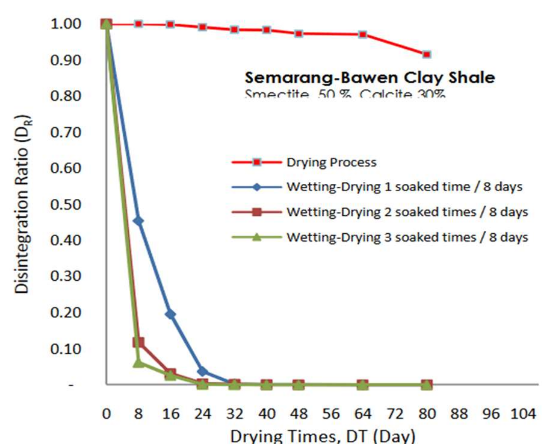

Fig. 2 Decrease in disintegration ratio, DR due to variations of weathering processes up to 80 days for Semarang Bawen clay shale(Alatas I M 2015 d)

Decrease of disintegration ratio due to the weathering process variation for Semarang-Bawen and Hambalang clay shale are shown in Figures 2 and 3. In comparison, the disintegration ratio of Semarang-Bawen clay shale has decreased faster than the Hambalang clay shale. This has reveals that Semarang-Bawen clay shale is less durable compared to Hambalang clay shale. In 80 days of testing, the Hambalang clay shale has not completely non-durable (refer to Fig. 1)

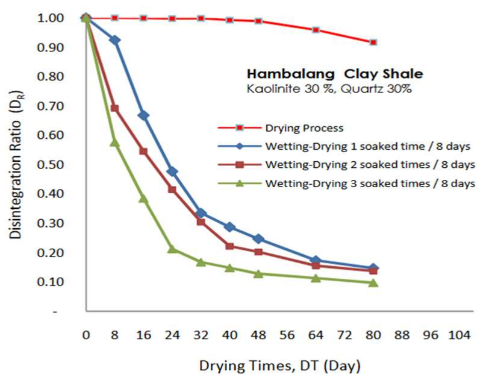

Fig. 3 Decrease in disintegration ratio, DR due to variations of weathering processes up to 80 days for Hambalang clay shale(Alatas I M 2015 d)

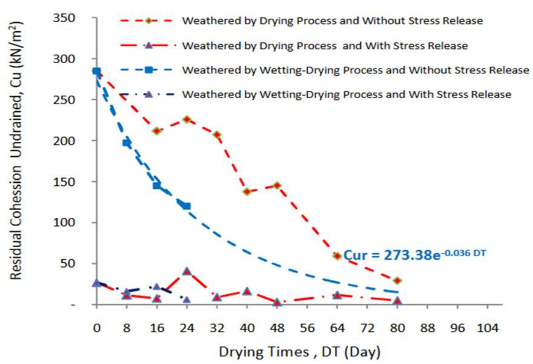

Fig. 4 The residual cohesion reduction on unsaturated Semarang-Bawen clay shale due to natural drting process and wetting-drying cycle process (soaked 2 times in every 8 days(Alatas I M 2015 d)

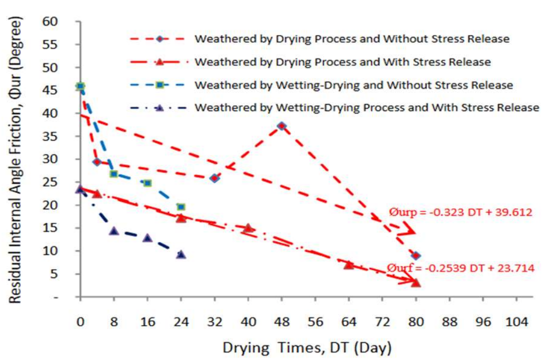

Fig. 5 The residual internal angle friction reduction on unsaturated Semarang-Bawen clay shale due to natural drying process and wetting drying cycle process (soaked twice in every 8 days)(Alatas I M 2015 d)

Table 1 Summary of shear strength reduction at the peakstress, Residual Without and With Stress Release condition (Alatas I M 2015 c)

Drying Time (day)	PEAK STRESS CONDITION					
	Cohesion Undrained			Internal Angle Friction		
	UnSat	Saturated		UnSat	Saturated	
	Cu	Cu_{tot}	Cu_{eff}'	Øu	$Øu_{tot}$	$Øu_{eff}$'
	kN/m²	kN/m²	kN/m²	kN/m²	kN/m²	kN/m²
0	700	300	300	59.4	53.2	53.2
40	270	105	107	68.1	24.2	23.7
80	220	70	79	38.1	19.3	19.3
Reduction (%)	31 %	10 %	11 %	64 %	32 %	32 %

Drying Time (day)	RESIDUAL STRESS WITHOUT STRESS RELEASE					
	Cohesion Undrained			Internal Angle Friction		
	UnSat	Saturated		UnSat	Saturated	
	Cur	Curp	Curp'	Øu	Øurp	Øurp'
	kN/m²	kN/m²	kN/m²	kN/m²	kN/m²	kN/m²
0	285	172	177	46	27.4	28.1
40	207	95	93	31.5	17.8	18.3
80	29	35	36.5	8.9	10.8	10.2
Reduction (%)	4 %	5 %	5 %	15 %	18 %	17 %

Drying Time (day)	RESIDUAL STRESS WITH STRESS RELEASE					
	Cohesion Undrained			Internal Angle Friction		
	UnSat	Saturated		UnSat	Saturated	
	Cur	Curp	Curp'	Øu	Øurp	Øurp'
	kN/m²	kN/m²	kN/m²	kN/m²	kN/m²	kN/m²
0	26.7	28	21.7	23.5	25.3	21.6
40	16.5	10.7	9	15	13.2	14.4
80	5	4.7	8.3	3.1	4.6	4.6
Reduction (%)	1 %	1 %	1 %	5 %	8 %	8 %

Fig. 1 is an example of the disintegration behavior of a claystone sample after varying periods of exposure to natural climatic conditions. Grain size distributions were used to quantify the amount of disintegration of each sample,in terms of DR, after varying periods of exposure to natural conditions (Erguler Z A 2009, Shakoor A 2015, Alatas I M 2015 d)

The summary of shear strength reduction due to drying clay shale in the sun in 80 days of drying can be seen in Table 1 to 3. In Table 1 percentage of cohesion and internal angle friction at the peak stress decreased to 31% and 64% for unsaturated clay shale, and 10% and 32% for saturated clay shale, respectively. Table 1 shows percentage of cohesion and internal angle friction at the residual stress without stress release decreased to 4% and 15% for unsaturated clay shale, and 5% and 18% for saturated clay shale, respectively. And also in Table 1 similar reduction can be seen in percentage of cohesion and internal angle friction at the residual stress with stress release, 1% and 5% for unsaturated clay shale, and 1% and 8% for saturated clay shale, respectively. The percentage is calculated based on the parameters of shear strength prior to beginning of weathering.

Interface shear strength of clay shale

The interface shear strength of clay shale can occur between layers of clay shale, between fresh clay shale, between fresh and weathered clay shale or between clay shale and other types of soil as an overburden layer.(Alatas I.M. 2023, F. H. Sagitaningrum 2024).
The innterface shear strength of clay shale can occur between layers of clay shale, between fresh clay shale, between fresh weathered or between clay shale and other types of soil as overburden layers. Interface stress strain relationship is obtained from testing by means of reversal multistage direct shear progressive test, a test which is a development of the ASTM standard (ASTM D6528-17 2017).

The Metodology of The Multistage Reversal Progressive Shear Test (MRPST)

The Multistage Reversal Progressive Shear Test (MRPST) is modeled to determine the interface shear strength between fresh clay shale and the soil layer above the overburden layer (OBL). Testing with the MRPST method, obtained several interfaces of the shear strength of the two materials (fresh clay shale 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 (Alatas I. M 2022, Alatas I.M. 2023, F. H. Sagitaningrum 2024). The schematic of the MRPST testing methodology is shown in Fig. 6 below.

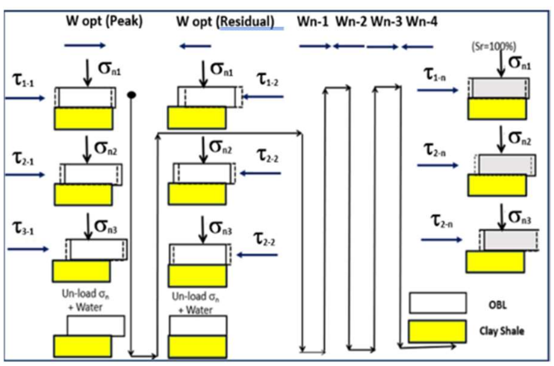

Fig. 6 Testing procedure for interface shear strength test by MRPST (Alatas I. M 2022, Alatas I.M. 2023, F. H. Sagitaningrum 2024)

Stress strain on MRPST methods

In Fig.7 that shows stress-strain of interface between fresh clay shale and OBL for 100% max dry density. Duringthe 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.

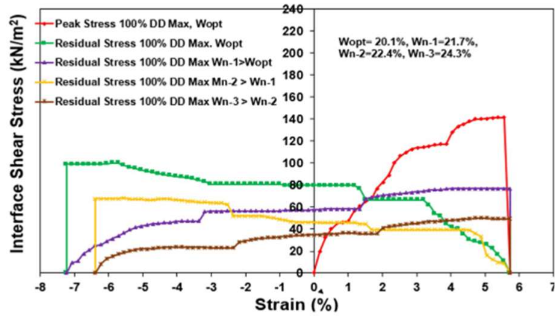

Fig. 7 Interface shear strength between fresh argillaceous rock and OBL as compacted WCS with 100% dry density max in various increasing water content (Alatas I. M 2022, Alatas I.M. 2023, F. H. Sagitaningrum 2024)
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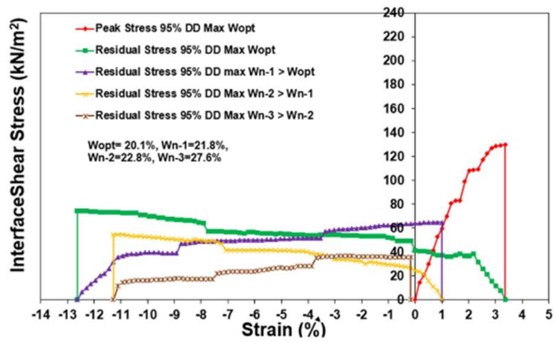

Fig. 8 Interface shear strength between fresh argillaceous rock and OBL as compacted WCS with 95% dry density max in various increasing water content (Alatas I. M 2022, Alatas I.M. 2023, F. H. Sagitaningrum 2024).

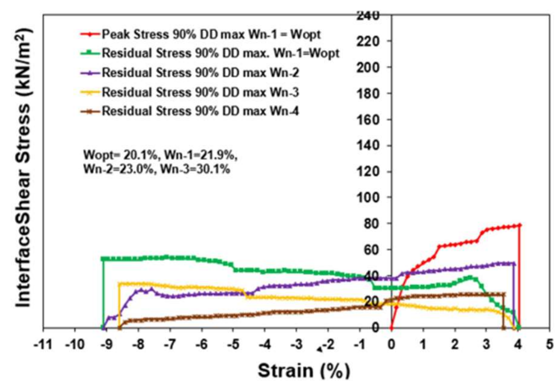

Fig. 9 Interface shear strength between fresh argillaceous rock and OBL as compacted WCS with 90% dry density max in various increasing water content

(Alatas I. M 2022, Alatas I.M. 2023, F. H. Sagitaningrum 2024).

Fig. 8 shows a stress strain curve for OBL density 95 % of the dry density maximum. Fi. 9 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 Fig 10. 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 Fig. 7, Fig. 8, Fig. 9 and Fig. 10, the cohesion and internal friction angle of interface can be obtained, as shown in Table 3 and Table 4.

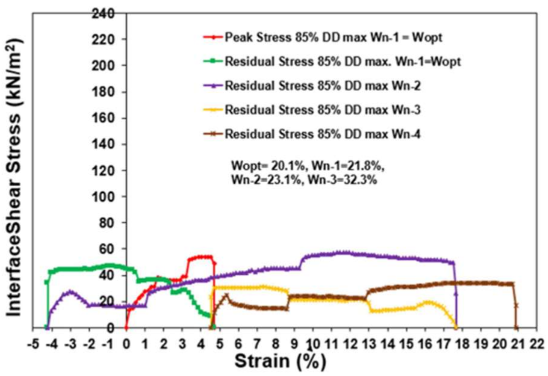

Fig. 10. Interface shear strength between fresh Argillaceous rock and OBL as compacted WCS with 85% dry density max in various increasing water content (Alatas I. M 2022, Alatas I.M. 2023, F. H. Sagitaningrum 2024).

Table 1. Increasing water content on overburden layer (OBL) due to falling rainwater (Alatas I. M 2022).

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

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 2. Degree of saturation of overburden layer (OBL) due to increasing water (Alatas I. M 2022).

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

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/m^2)				
	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(Alatas I. M 2022).

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 clay shale with variations OBL of WCS and water content increasing in OBL of WCS, is shown in Figure 11 and Figure 12. The higher density OBL of

WCS, more greater interface shear strength reducing due to increase water.

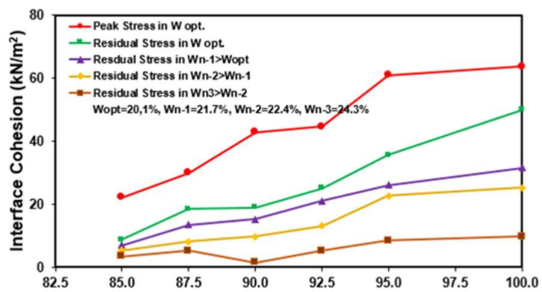

Fig. 11. Interface cohesion between clay shale and variation density of compacted WCS as overburden layer, due to increasing water content(Alatas I. M 2022).

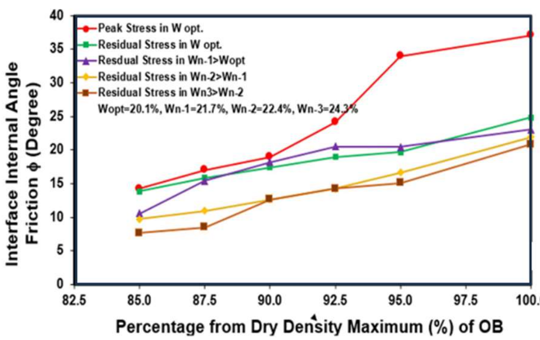

Fig. 12. Interface internal angle friction between clay shale and variation density of compacted WCS as overburden layer, due to increasing water content(Alatas I. M 2022)

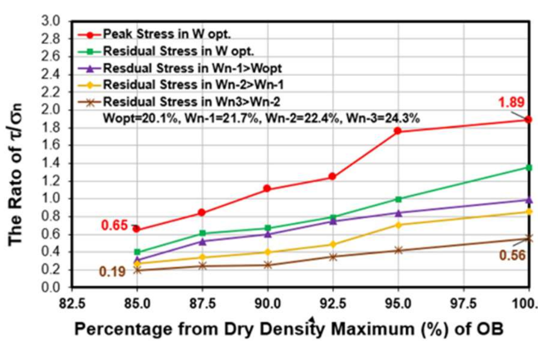

Fig. 13 Degradation of shear strength ratio (τ/σn) due to OBL density and increasing water content

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 13. 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.

Characteristic of Compacted Weathered Clay Shale With Added Port land Cement

The maximum dry density of Hambalang Weathered Clay Shale (WCS) from the laboratory compaction test with modified proctor is 2.018 t/m³. This value is much smaller than the dry density value of fresh clay shale, which is 2.30 t/m³ to 2.40 t/m³ (Alatas I M 2017).

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The use of WCS as embankment material has caused many geotechnical problems in several cases of infrastructure work in Indonesia (Himawan A 2011, Irsyam M 2011, Alatas I M 2015 b). So the use of WCS as embankment material is not recommended.

Efforts to utilize WCS because of the difficulty of obtaining embankment material at the work location that meets technical requirements, soil stabilization research was carried out by adding portlant cement (stabilization). The results of the research are explained in this paper.

The drying of the sample was undertaken for 41 days in open air protected from rainwater by placing a sample in a room protected by transparent plastic, allowing sunlight to penetrate and illuminate the sample and water, but protected from rainwater, as seen in Fig.14, for the first-day condition.

Fig. 15 shows the weathering occurred for Hambalang clay shale until the end of the 9th cycle (Day 41). The figure shows that the concentration of Portland Cement has a significant influence on the re-weathering process. Increasing percentage of PC to stabilized clay shale shows a better resilience to re-weathering. However, 6% PC indicates a good agreement to resist weathering.

Fig. 16 present the result of change disintegration ratio (DR) to clay shalefor various percentage of stabilization material when compacted at optimum moisture content. Disintegration ratio (DR) change was observed up to the 9th cycle or on the 41st day. Sample without stabilization material on the 9 th cycle gives D R=0.007 (completely non-durable). With 3% stabilization material, it obtained DR = 0.119, while for 6% stabilization material, DR = 0.549 (moderate durable), 9% stabilization material DR = 0.700 (well-durable), and 12% stabilization material DR = 0.958 (completely durable)(Alatas I M 2019 a, Alatas I M 2019 b)

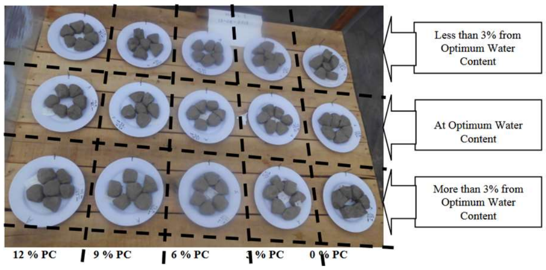

Fig. 14. Initial condition for all clay shale samples, with % PC variation and initial water content (Alatas I M 2019 a, Alatas I M 2019 b).

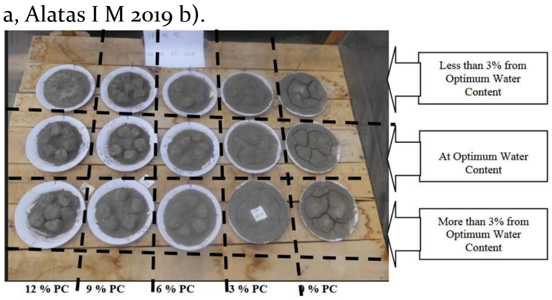

Fig. 15 Final condition after 41 days of wetting-drying cycles for all clay shale samples, with %PC variation and initial water content (Alatas I M 2019 a, Alatas I M 2019 b).

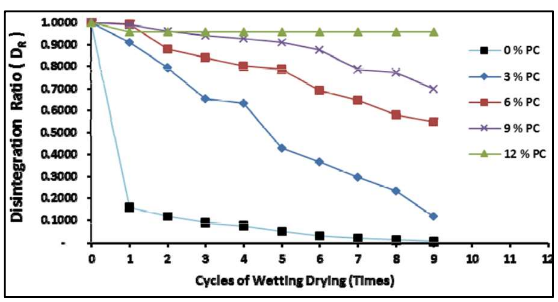

Fig. 16 Correlation between disintegration ratio (DR) of Hambalang clay shale and variety of stabilization material up to 9th cycle of the wetting-drying processes (Alatas I M 2019 a, Alatas I M 2019 b).

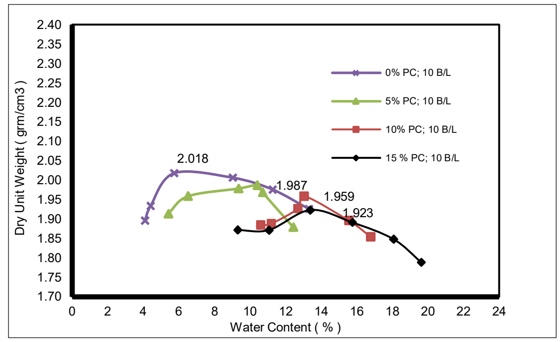

Fig. 17. Compaction curve Modified Proctor ASTM D 1557 by added with PC(P. T. Simatupang 2022)

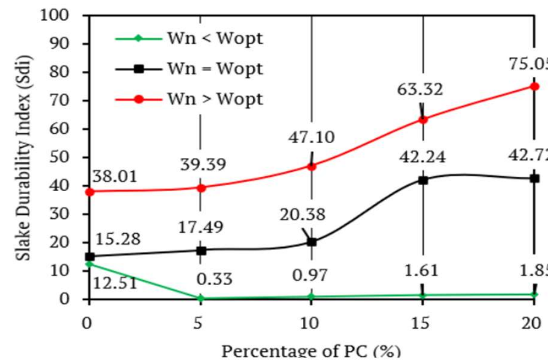

Fig. 18 Slake durability index behavior of the compacted weathered clay shale with varying PC and moisture content (P. T. Simatupang 2022).

In the Fig. 17 the laboratory results of the modified proctor test of compacted WCS and with the addition of a percentage of Portland cement up to 15%. In Fig. 19, The addition of the PC percentage causes a slight decrease in maximum dry density. However, in Fig. 18 it shows that compaction of the soil above a little (3 to 5%) of the optimum water content will affect the increase in slake durability at each percentage of cement usage. If compacted at a water content lower than its optimum water content (3 to 5%), the Slake durability Index will be smaller. The addition of compaction energy to the sample has an impact on increasing the maximum dry density. However, it is still smaller than the natural dry density of fresh clay shale

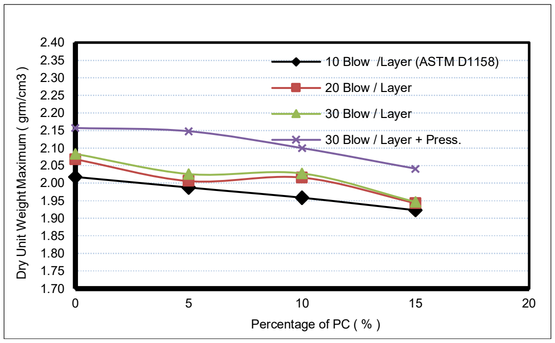

Fig. 19 Dry Density Maximum due to PC Percentage and No of Blow/Layer (Alatas I.M. 2022, P. T. Simatupang 2022)

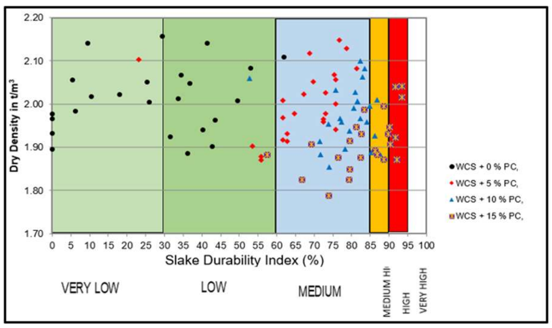

Fig.20 Slake Durability Index WCS due to percentage of PC & dry density incCycle-1 (Alatas I.M. 2022, P. T. Simatupang 2022)

From Fig. 20, it is obtained that the slake durability index in cycle-1 of all modified proctor samples in the laboratory, shows that with the addition of 15% cement, the sample has a Slake durability Index between medium to high (60% to 95%). If the cement usage is between 0% to 10%, the sample has a slake durability index between very low to low (0% to 60%). This can be interpreted that if you want to use weathered clay shale material as a fill material, in order to get good performance against the potential for re-weathered after being compacted, then a minimum of 15% cement is required.

To obtain a medium high to high SDI value, further testing is carried out using extra energy, namely with 30 Blow/layer plus static pressure of 50 kN/m2. The results can be seen in Table 5 below. By adding 15% cement with the loading energy as above, an SDI value of between 85% and 95% (Medium high to high) is obtained with maximum water content at optimum water content conditions, as in Table 5 below.

Table 5. Compaction with 30 B/L (ASTM D 1557 ++) Plus Static Pressure (50 kN/m²) and Slake Durability Index(Alatas I.M. 2022)

Compacted Weathered CS with energy : 30 B/L (ASTM D 1557 ++) Plus Pressure With Variation of Percentage PC									
Slake Durability Index	% PC	Blow/Layer	Cycle	Wn-1	Wn-2	Wn-3	Wn-4	Wn-5	Wn-6
				4,8	7,0	8,6	10,7	12,3	13,7
			γd t/m³	2,142	2,157	2,141	2,109	2,049	2,013
1	0	30+Press	1	9,42	29,36	41,37	61,85	36,61	33,66
2	0	30+Press	2	0,000	0,000	0,072	0,117	0,119	0,070
Slake Durability Index	% PC	Blow/Layer	Cycle	Wn-1	Wn-2	Wn-3	Wn-4	Wn-5	Wn-6
				3,4	6,3	8,1	9,8	11,6	13,1
			γd t/m³	2,102	2,118	2,148	2,129	2,083	2,023
1	5	30+Press	1	23,15	68,75	76,78	78,62	81,40	67,22
2	5	30+Press	2	0,147	0,542	0,560	0,567	0,629	0,457
Slake Durability Index	% PC	Blow/Layer	Cycle	Wn-1	Wn-2	Wn-3	Wn-4	Wn-5	Wn-6
				7,9	9,2	10,8	13,5	14,6	16,1
			γd t/m³	2,060	2,082	2,100	2,062	2,032	1,967
1	10	30+Press	1	52,68	83,51	82,37	82,83	75,78	82,29
2	10	30+Press	2	0,443	0,709	0,699	0,723	0,596	0,638
Slake Durability Index	% PC	Blow/Layer	Cycle	Wn-1	Wn-2	Wn-3	Wn-4	Wn-5	Wn-6
				8,6	10,6	12,4	13,7	15,2	17,6
			γd t/m³	1,995	2,015	2,041	2,040	1,987	1,914
1	15	30+Press	1	88,56	93,38	93,52	91,68	83,30	79,48
2	15	30+Press	2	0,731	0,806	0,801	0,766	0,657	0,637

Conclusion

From the discussion of clay shale properties in the design of infrastructure buildings, several conclusions can be obtained, including the following:

1. Adequate knowledge and experience are needed to be able to specifically understand the potential for changes in clay shale properties in the clay shale formations encountered, as well as all potentials that cause changes in the characteristics of clay shale properties for long-term conditions.
2. Understand the causes of clay shale property degradation, determine the parameters used in the design process that produce safe and efficient design results in geotechnical infrastructure design
3. Disintegration ratio (DR) degradation occurs due to the weathering process. Weathering that occurs due to the wetting and drying cycle process occurs faster than the drying process. This conclusion will be similar if the parameters observed are others, such as the shear strength of clay shale.
4. Peak Shear Strength parameters of clay shale remaining due to the weathering process range from 10% to 45% of the initial peak shear strength parameter. In the residual shear strength condition without stress realease it ranges from 4% to 18%, while in the residual shear strength with stress release it ranges from 1% to 8%.
5. The interface shear strength between clay shale and OBL in the form of compacted weathered clay

shale (WSC), is strongly influenced by the density of the WCS and its moisture content.

6. The OBL of WCS density with 100% dry density maximum, the interface shear strength ratio (τ / σ_n) 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. 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%)
7. By providing extra compaction energy of 30 Blow/layer plus static load of 50kN/m2, the slake durability index value in cycle -1 is between 88% to 93%. (medium high to high)

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