# The Clay ShaleDurability Behavior of Jatiluhur Formation Based on Dynamic and Static Slaking Indices

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Abstract.

The mechanical properties of Clay Shale are very unique. When it is dry, it shrinks and hardens, but when it absorbs water, it swells and to some extent loses its shear strength so that the drop-in strength can occur suddenly even with its own weight. Due to the nature of the swell-shrink that are strongly influenced by climate and weather, clay shale durability may decrease over time when in direct contact with air and water. Research on clay shale was done in Sentul City, Bogor - West Java, Indonesia on Jatiluhur formation, using dynamic slaking (slake durability test) and slaking static test.

Dynamic slackingtest is done in three times i.e. after sampling, after 3 months andafter 9 months. Slake durability test results from 3 different drilling points, shows that within 9 months, has not seen the decreasing effect of durability. With a low Plasticity index, the durability research in Sentul City is in medium durability to medium-high durability classification.

To determine the effect of water and temperature on clay shale, static slaking index test were conducted. With a submerge variation it was found that the slaking index value ranged from 0,17 % to 11,15 % with the slaking classification from very low to medium. Size distribution that was produce from 1/4 and 1/2 sample submerge show bigger rock breakage than rock with 3/4 sample submerge and sample fully submerge. Observations of the sample in room temperature without contact of water and no additional mass were also done. The sample still intact untill the end of research work.

Keyword: Clay shale, durability, Slaking index

## 1. Introduction

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Sentul City is an area located east of the city of Bogor, West Java, Indonesia and currently undergoing development and carry out many developments such as the construction of business facilities, hospitals, tourist attractions and housing. This causes a lot of natural land that must be exposed. Sentul City's located in Jatilihur Formation, indicating that the rock location is dominated by clay shale.

Clay shale is generally in a water unsaturated zone because of the effects of capillarity play a greater role in the area and depend on the location of the groundwater surface, as well as the shale's behavior including as a transition material for soil and rock (Deen, 1981). Capillarity effect is very influential on the strength of clay shale. The style of capillarity arises from the negative force that arises and is able to crush the clay shale if the clay shale bond is inadequate.

Because of such degradation, clay shale may experience a decrease in altitude which is called slaking, if the material is in the open after contact with air and water.

The mechanical properties of Clay Shale are unique. When it is dry, it shrinks and hardens, but when it absorbs water it swells and, to some extent, loses its shear strength so that a drop-in strength can occur suddenly even with its own weight. Due to the nature of the swell-shring that are heavily influenced by climate and weather, it can change the shale from rocks to soil, especially in areas where the water level changes dramatically and rainfall is very high. Therefore, Shaledurability can easily decrease over time when there is direct contact with air and water.

Some of the major collapse cases in Indonesia that occurred in Clay shale rock include the Tulis water Power Plant Construction (1995), Hambalang Atlet Building (2013), the Penggaron highway (2015), the Cisomang highway (2017).

Because this area has a fairly high rainfall, it will certainly cause the layer of clay to react with water.

## 2. Geological Condition of Sentul City

The study was conducted in the Sentul City area located at coordinates 6º34 '4.68 "SL - 6º 34' 55.19" SL and 106º 51 '4.1 "EL - 106º 54' 34.2" EL, which is a tropical climatic region with large rainfall throughout the year. Average annual rainfall is quite high reaching 4000 mm. Average annual air humidity ranges between 76.86% - 87.91% with a temperature of 23.2 ° C - 27.5 ° C. The Jatiluhur Formation (Tmj) consists of napal, shale of clay with quartz sandstone insertions, gradually growing eastward from gray to black, easily crushed and swells, expansive if exposed to water.

Jatiluhur formation is in the middle of meosen end until the early final meosen. The top formation Jatiluhur fond with Subang formation. In some places Subang formation that covered the formation of Jatiluhur is not aligned. The surface precipitate of Qa Aluvium consists of clay, silt, gravel and pebble, especially in the river sediments which include sand and gravel from coastal deposits along the bay of Pelabuhanratu and Aluvial Fan (Qav) in the form of silt,

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sandstone, gravel and crust deposits of quartz volcanic rocks which are deposited back as Aluvial fan.

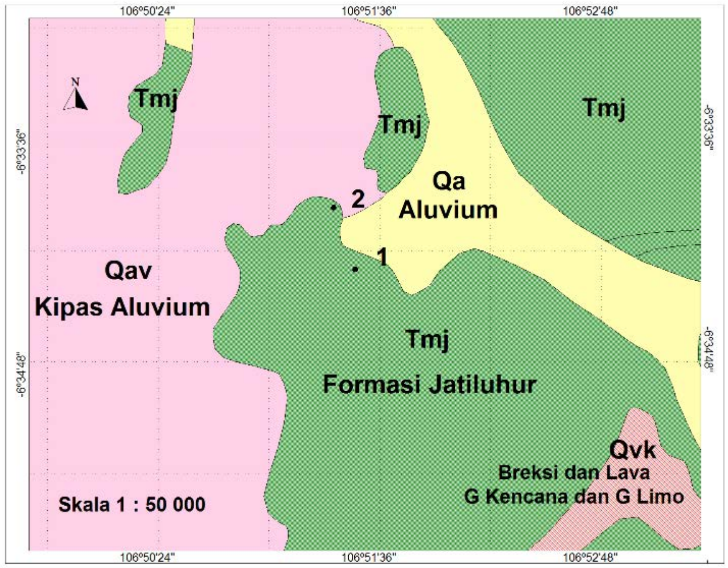



Fig. 1. Geological Map Sentul City, Bogor, West Java, Indonesia (Geological Map of The Bogor Quadrangle Java).

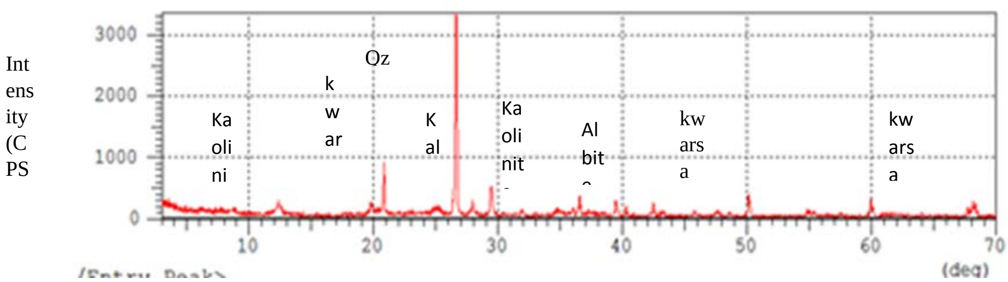


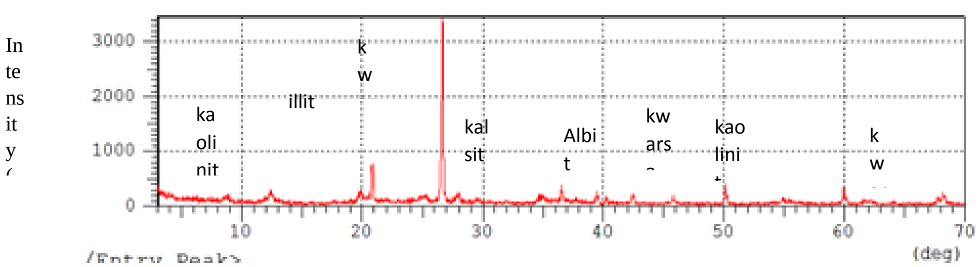
The rocks in this location are mostly composed by clay shale. The three-point sampling points are each marked with BD-1, BD-2 and BD-3. done by drilling and coring to a depth of 20 m - 30 m with a diameter of 2.5 inches. Hard material is at a drilling depth of more than 8 meters, with the formation of thin pieces that are easily destroyed, especially when squeezed by hand and was inserted with clay. The deeper we goes, the clay shale layer begins to intact. Field observations show that the exposed clay shale has laminate with a lot of fissility and the increasingly widespread cracks. Clay shale is susceptible to collapse or easily change from rocks that initially appear hard to weak rocks. This process of change takes place within a few months for the exposed clay shale.

Fig. 2. Condition of clay shale in Sentul City that has been exposed

Based on petrographic analysis using X-ray diffraction (XRD), Clay shale at the drilling point of BD-1 and BD-2 has mineral composition in the form of Quartz, Calcite, Albite, Illite and Kaolinite. Different mineral compositions are shown in the BD-3 sample. Where there is a mineral content of montmorillonite in addition to Quartz, Calcite, Albite, Illite and Kaolinite minerals. Montmorilonite is a mineral found in clay shale rocks in addition to Illite and Kaolinite minerals. Mineral Illite is a mineral that many found in advanced weathering. Illit has a stronger bond than kaolinite so it is more stable, and causes much greater illit activity





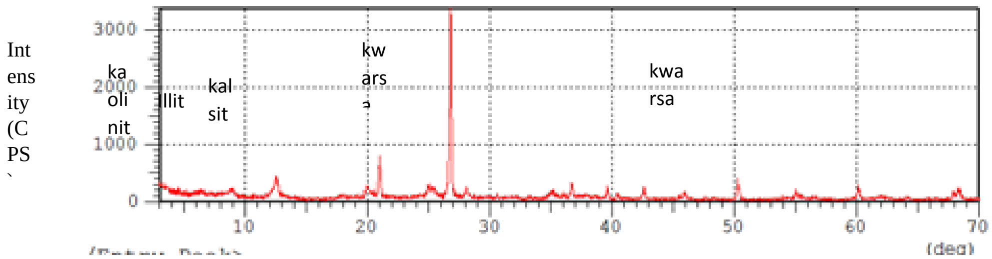



Fig. 3. X-ray Diffraction patterns of Sentul City Clay shale BD-1, BD-2, BD-3

3. Testing Methodology

Undisturbed sample taken in Sentul City area, Bogor, West Java, Indonesia at three points of drilling ie BD - 1 located at coordinates S06°34’18.2” E106°51’28.5” ; BD – 2 S06°34’16” E106°51’27.6” ; BD – 3 S06°34’14.9” E106°51’25.7”. The sample condition of BD -1 contained sand that was rough to medium and had only a small amount of clay. In the BD -2 sample the content of fine sand, flakes and clays. While the BD -3 content of material-sized silt and clays. The tests were conducted at Geotechnical Laboratory, Department of Civil Engineering, Parahyangan University, Bandung, Indonesia. The testing procedure is carried out in accordance with ASTM and SNI standards.

Slake dynamic test procedures (slake durability) is carried out in accordance with SNI 340.2011, ASTM D4644-87 standard (according to ISRM 1979), on Test Method for Slake Durability of Shales and Weak Rocks. Some examples are cut with representative size for each cycle, with a total sample weight ranging from 400-550 gr. The test is carried out with dry material that has been heated in the oven, so it does not reflect the natural condition. Especially for rock material that has low rock resistance in natural conditions.

Durability test equipment in the Geotechnical Laboratory of Parahyangan University, Indonesia consists of a set of drums with a diameter of 140 mm and a length of 100 mm with a sieve of 2 mm wire sieve. The drum is rotated with water in it as high as 150 mm at a temperature of 24°C – 27°C.

Fig. 4. Slake Durability Test Equipment

The sample is then placed in a drum and dried in an oven at 105 ° C for ± 14-16 hours until a constant weight. After the sample was removed from the oven and allowed to stand for 20 minutes. then weighed to calculate the water content. Insert the drum containing the sample into the durability test device and pour water as high as 15 Cm. Next, the drum rotation is driven by a motor capable of rotating the drum at 20 rpm, with a constant speed of 10 minutes. After slaking for the first 10-minute period, the rock samples are then dried in an oven at 105 ° C for 16 hours. Finally, dry samples are weighed. Testing is done for several cycles. With the rotation of the drum, there is a filtering of rocks, where a fraction larger than 2 mm will be suspended in the drum, while fractions of less than 2 mm will escape.

The qualitative result of this test is the slake durability index (Id) expressed in the formula:

$$I_d = \frac{WF-C}{B-C} \, x \, 100\% \qquad \text{..................} \quad (1)$$

Where: Id = slake durability index, B = drum weight plus dry sample before first cycle, gr, WF = drum weight plus dry sample after second cycle, gr, C = drum weight, gr.

Table 1. Class value and classification obtained from Slake Durability test (Gamble, 1971)

| Group Name | % retained after one 10 min cycle (dry weight basis) | % retained after two 10 min cycle (dry weight basis) |
|---|---|---|
| Very High Durability | > 99 | > 98 |
| High Durability | 98-99 | 95-98 |
| Medium High Durability | 95-98 | 85-95 |
| Medium Durability | 85-95 | 60-85 |
| Low Durability | 60-85 | 30-60 |
| Very Low Durability | < 60 | < 30 |

Slack dynamic test is done in three periods i.e. the test shortly after sampling, testing after 3 months and testing after 9 months. Samples are left open at room temperature 24°C – 26°C without water or loading. The goal is to determine whether there is a decrease in clay shale resistance naturally.

static test is a test on rocks in the form of observed rock behavior that can be used to investigate the process and the collapse mechanism of clay shale in more detail. This static slaking test is a development of the modification of slake index testing done by Deo (1972), Santi (1998) and further developed by Sadisun et al (2002).

The concept of the slaking index (Is) test is similar to the slaking test, which uses a wet-dry cycle. It's just that the sample was left submerged and was in free air with room temperature 24° C - 26°C.

The test procedure recommended by Sadisun (2002) is to dry the rock sample first in the oven for 24 hours at 105 ° C. The wet-dried cycles were then immersed in water for 48 hours and then filtered using a # 10 (2 mm) sieve size. Samples retained on sieve # 10 were dried in an oven at 105 ° C for 24 hours for subsequent cycles. While the samples that pass the filter # 10 after being dried and then weighed.

In testing of the slaking index (Is) this time, will be immersed in the sample with the variation of water level that soak the sample in the jar by soaking 1/4 part of the sample, 1/2 part of the sample, 3/4 part of the sample and sample soaked entirely.

In general, the preparation of specimens does not require a certain size dimension, either in the form of cylinders, cubes or irregular shapes.

The percent-loosen sample to initial oven dried mass is calculated and recorded as a slaking index value (Is) for that cycle, or it can be defined as an equation:

$$I_s = \frac{W_x - W_{x'}}{W_x - B}\ x\ 100\% \qquad .......................... \quad (2)$$

where Wx = total mass and oven dried material, Wx' = total mass and oven dried material retained on the 2.00 mm sieve, B = total mass container



Table 2. Class value and classification obtained from single cycle of slaking index test *(Imam A Sadisun, 2002)*

| Class | Slaking Index (%) | Classification |
|---|---|---|
| 1 | 0 - 5 | Very Low |
| 2 | 5 - 10 | Low |
| 3 | 10 - 25 | Medium |
| 4 | 25 - 50 | High |
| 5 | 50 - 75 | Very High |
| 6 | 75 - 100 | Extremely High |

In the last drying cycle, a filter sieve analysis was performed using a filter size of # 1 ½ (38.1 mm) - # 10 (2 mm). Each suspended weight is weighed. The stuck percentage is calculated by dividing the weight held with the total weight of the sample. This grain size distribution shows the degree of clay shale disintegration.

## 4. Testing results and discussion

Index properties of materials were tested prior to testing. Usually done before starting the slaking index test, first test the plasticity. Similarly, in this test atterberg limit test has been done to get the value of plastic index. The A curve in Fig. 5, shows the value of the liquid limit and the plastic index. With the value of Plastic Index (IP) 4 - 12, the clayshale sample tested is included in rock classification having CL character that is clay with liquid limit value below 50%.

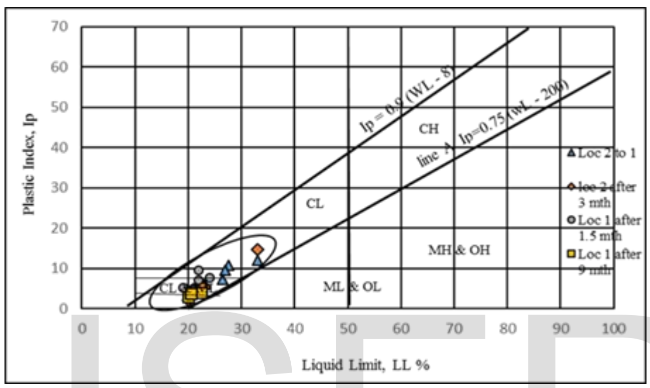



Fig. 5. index plasticity result grouping in chart A

### 4.a. Slaking Dynamic

Slake dynamic testing (slake durability) was carried out in three test periods namely first test BD.1- 1; BD.2 - 1; BD.3-1 was conducted shortly after sampling, the second test was conducted 3 months later BD.1-4; BD.2 - 4; BD.3 - 4 and the third test was carried out 9 months later BD.1-9; BD.2 - 9; BD.3 - 9.

Figure 6 shows the results of slake durability testing over time. Sample BD.1 with an indexability score of durability (Id2) above 85% is classified in medium high durability. Sample BD.2 at 51,4% - 73,33% durability index (Id2) value is classified as low durability to medium durability. Sample BD.3 on durability index value (Id2) 55,65% - 68% included in classification low durability to medium durability.

This curve shows that not all samples show decreased durability behavior with time. Sample BD.1 shows as though until the ninth month there is no change in the durability level. The clay shale conditions tested by extreme dry wet processes, however, still show some degree of medium-high durability. Crushed rock very little and shown on Figure 7.a. Sample BD.2, showing a decrease change in clay shale durability over time. In the first and third months, the level of durability is still in the medium durability classification. The decline was seen after testing in the 9th month which become low durability. Figure 6.b shows curve for sample BD.2.-9, after in dry condition and then wetted, sample's swell fast and then destroyed for all samples provided in testing from cycle to cycle. as shown in Figure 7.b. Further, different behaviors are

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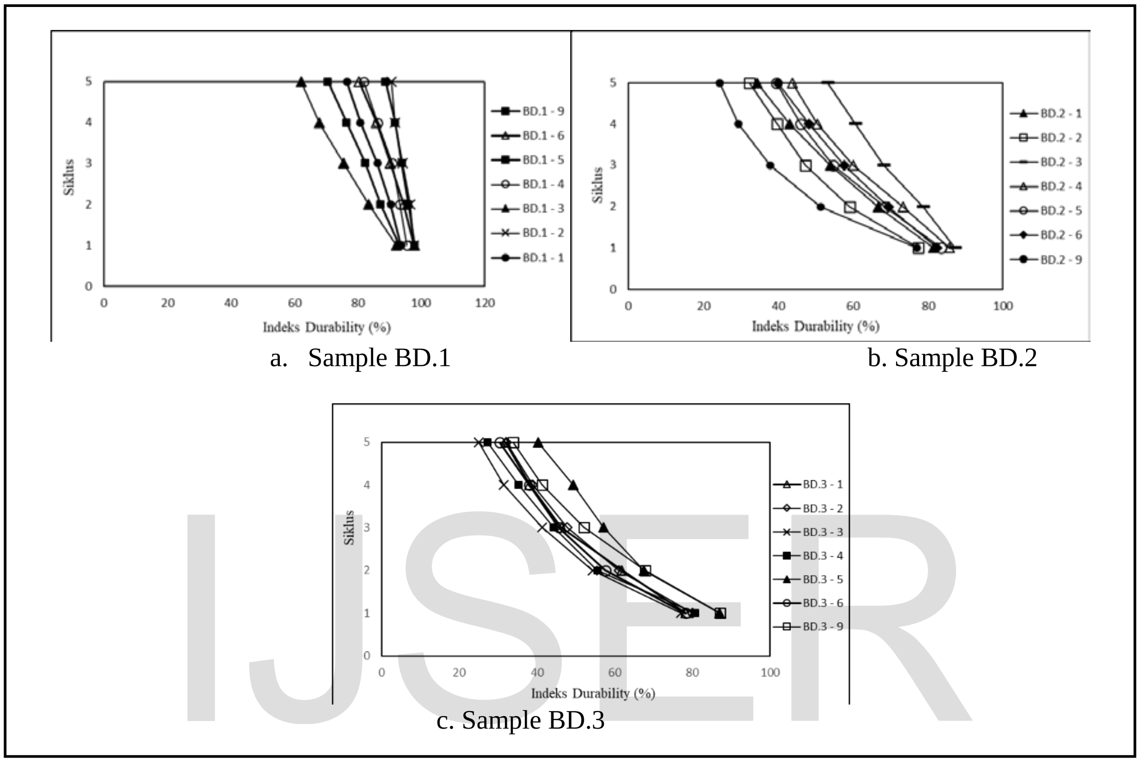
shown by the BD.3 sample of Figure 6.c. This curve shows that on the 3rd month test, clay shale showed a decrease in durability level from medium durability to low durability, but at the 9th month test there was no decrease in durability value and as if clay shale condition at month 9 is still the same as clay shale conditions in the early sampling.




a. Sample BD.1 b. Sample BD.2

c. Sample BD.3

Fig.6. Slake durability test result

Of the three drilling point tested, it was shown that the BD.3 sample had the lowest durability index ($Id_2$). This is consistent with the results of X-Ray Defraction testing, where clay shale in BD.3 samples contains mineral montmorillonite, which is a very active clays mineral that expands when there is water.

This curve show the occurrence of weakening acceleration of clay shale with a weak plasticity index.Furthermore, it shows relationship durability index with plastic index, where in that relationship can be made a curve that has upper limit value and lower limit value for clay shale behavior in Jatiluhur formation with equation average :

$$IP = 21{,}944e^{-0{,}008.Id}$$

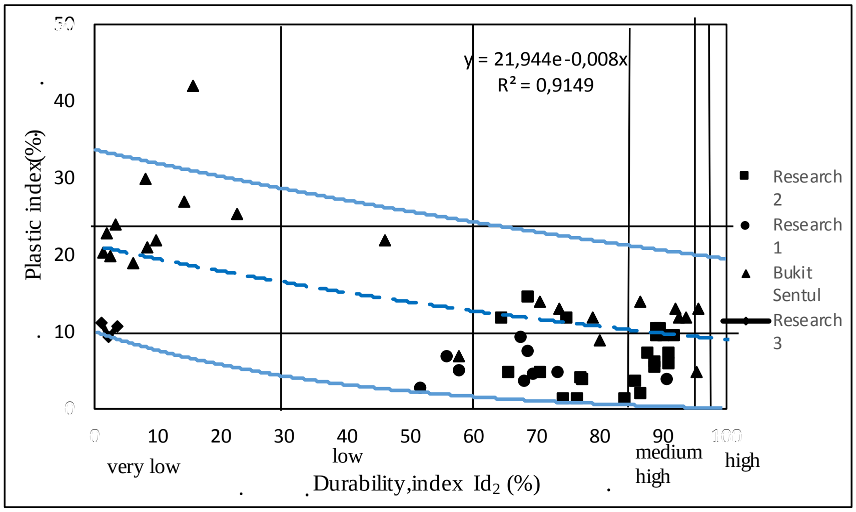



Fig. 7. Relationship curve durability index with plastic index

Figure 8 shows an example of a clay shale crushed form of each cycle. in the BD.1 sample, the shape of the destruction is not the same. From the first cycle until the fifth cycle, the process of degradation of rocks is slow. In the BD.2 sample, rock resistance is relatively lower than the BD.1 sample, so from the first cycle, clay shale directly degrades. In subsequent cycles the breakdown of clay shale is approximately uniform with a size smaller than 0.5 inch (12.7 mm). Sample BD.3 shows anequal rock destruction after repeating the dry-wet process. The crushed clay shale escapes from# 4 filter.

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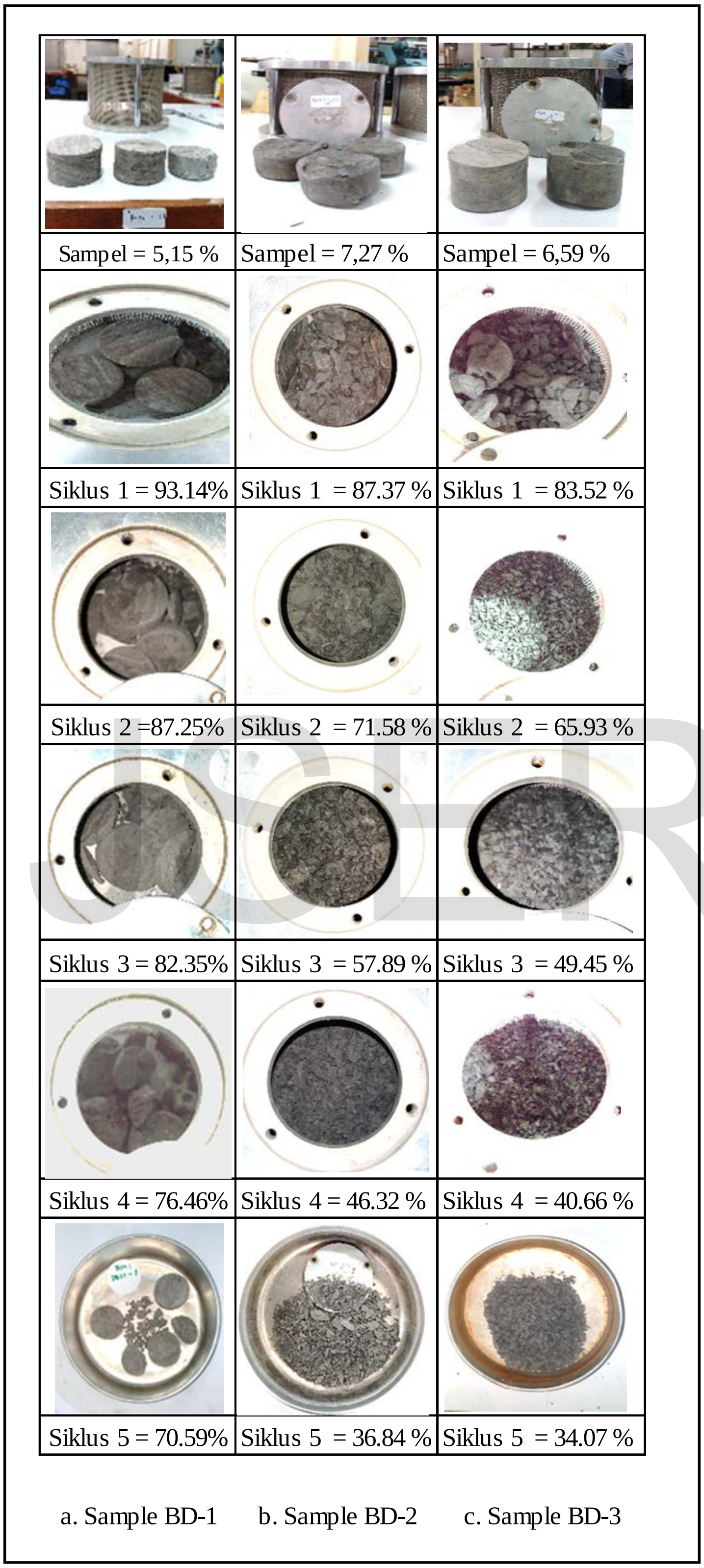


Fig. 8. Example of a clay shale crushed

## 4.b. Slaking Static

In this slaking index static, also conducted observations on rock samples are left in the open air with natural temperature 27 ° C - 31 ° C (tropical average temperature) without dry and wet condition, so that the sample is not disturbed or affected by water and loading pressure. Observation result after 10 months, shown that clay shale still intact, with no visible crack.A delicate and very thin crack appears in some parts only. Figure 9.a. During left in the open rock samples did not crack ,9. b. rock sample already have a crack from the beginning, because it does not get the influence of water and loading, this condition persists and not destroyed.

From the observations on the samples left in the open it can be seen that if one of the factors causing the weakening of clay shale in the form of temperature and water is eliminated, the process of weakening clay shale will run very slowly.


Fig.9. rock sample left in the open air

The result variation of the used amount of water for submerging the sample in static slaking test results with a static index value such as figure 8.Based on the grading and classification of slaking index by Imam A Sadisun, 2002, on the 1st cycle of the slaking Indexs ($Is_1$), variations for submerging 1/4 clay shale rock with the Is value of 0,78% - 11,15%, were classified in class 1 until class 3 ie from very low to medium classification, variations for submerging 1/2 clay shale rock with the Is value of 0,49 % - 10,06 %, were clasiffied in class 1- class 2 ie from very low to low classification, variations for submerging 3/4 clay shale rock with the Is value of 0,17 % - 7,93 %, are class 1 - class 2 ie from very low to low classification, and sample variations that

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submerge fully with the Is value of 0,56 % - 10,99 %, are clasified in class 1 until class 3 ie from very low to medium classification.

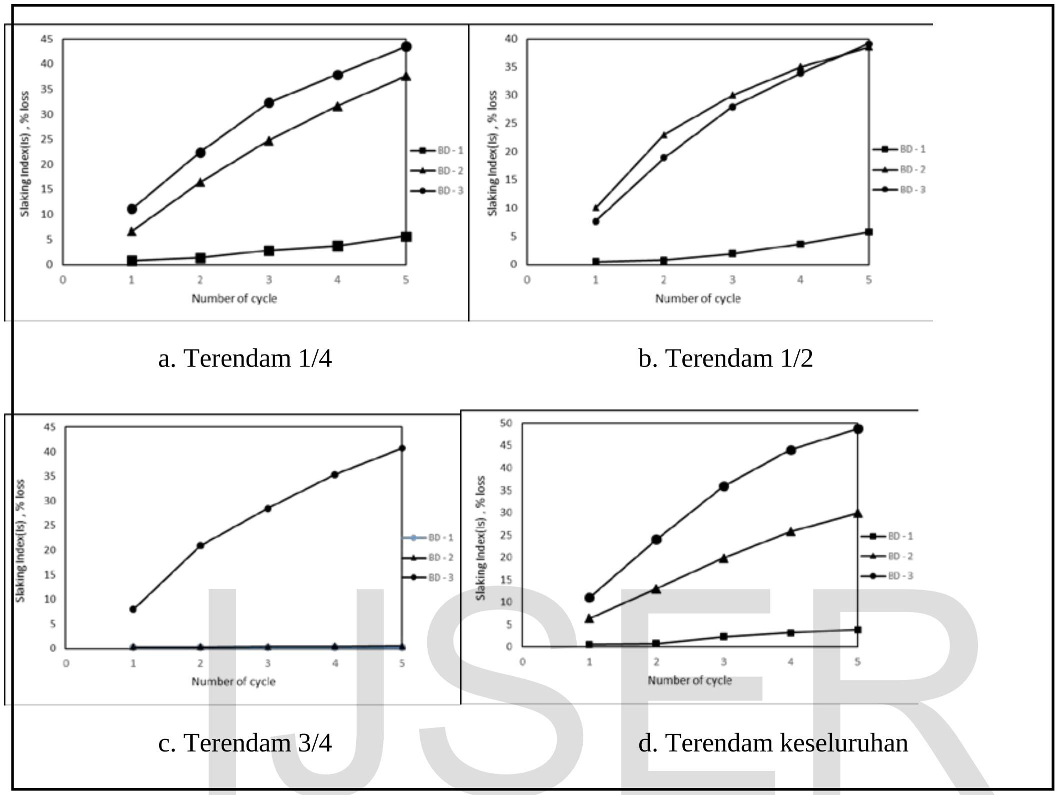


Fig. 10. Result of slaking index testing

Sample BD.1 shows very low slaking behavior. The sample remains intact because the slaking that occurs from cycle 1 to cycle 5 is just a subtle crack.

Sample BD.2 and BD.3 show that clay shale at location BD.2 and BD.3 has significant slaking at the beginning of the cycle, the sample has shown the effect of wet-dry change in the form of complete disintegration and, in the next cycle the slaking process continues even though itis experiencing a slight slowdown, so that the size of the destruction of the rock gets smaller.

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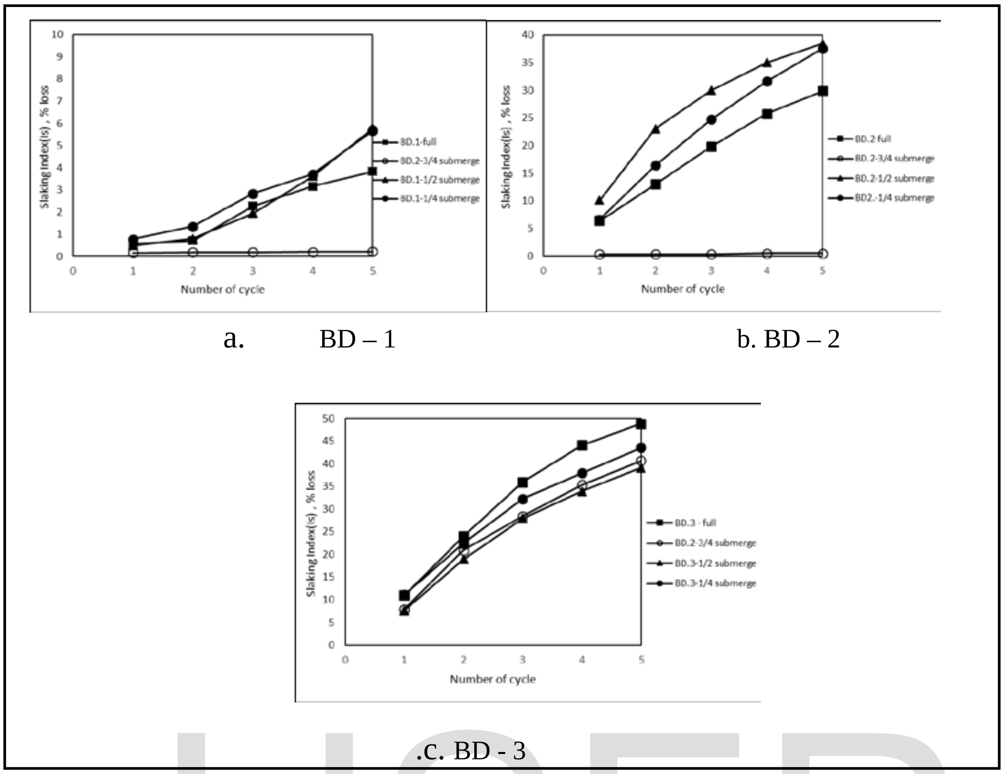


Fig. 11. Static Index (Is) on test variations submerged 1/4, 1/2, 3/4 and full

Figure 11, shows the curve of the immers variation in the sample. It is seen that by giving different amount of water in each sample, it does not have a great effect on the durability of a rock. it is evident that in the BD.1 and BD.2 samples that are immersed ¾ parts, gives a lower index slaking value when compared to immersed samples in ¼ or ½ parts. The influence of cemented clay shale formation, resulting in clay shale in this research location tends to be stronger than clay shale formed due to consolidation process. Sample BD.1 shows that clay shale is in very low slaking characterization,BD.2 shows that clay shale islow in slaking characterization and BD.3 shows that the clay shale is in the characterization of medium slaking

Capillary absorption process can happen in rocks that have cracks. Water quickly filled the gap, filling up the room and pushes the wall, until it finally destroyed. Like most substances, rock expands as it heats up and shrinks as it cools. By heating the rock in the oven, the rock thermally-expanded, and by dunking it into the water the surface layer of the rock cool down but the middle part still have some time to get cool down as the result of the surface of the rock shrink while the middle part expanding putting the rock in a lot of stress crack and by doing this test over and over again the crack become apparent

## 5.Conclusion

1. Clay shale located in Sentul city, Bogor, West Java, Indonesia has a different level of durability ranging from high durability to low durability. BD.1 shows durability index value above 87%, BD.2 gives durability index value 51.4% - 73,33% and sample BD.3 gives durability index 55,68% - 68,00%. The further north,the level of clay shale durability is lower. Testing in the first month, the third and ninth months shows that in this study site within 9 months has not experienced a decline in durability.
2. From the observations on the samples left in the open it can be seen that if one of the factors causing the weakening of clay shale in the form of temperature and water is eliminated, the process of weakening clay shale will run very slowly.
3. Slaking index test with submerge variation shows that clayshale were classified in very low to medium slaking properties with the value of index slaking (Is) of 0,17 % to 11,15 %. Changes in the weakness of the sample in the first and second cycles is bigger when compare to the next cycles that decrease in slaking.
4. Clay shale at location BD.1 is the most durable compared to BD.2 and BD.3. While clay shale at BD.3 location is in the classification of low durability and medium slaking. The more North it gets, the clay shale level of its durablity decreases.



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