Durability characterisation of weathered sedimentary rocks using slake durability index and jar slake test

Wong Jia Mang* & Abdul Ghani Md Rafek

Department of Geoscience, Faculty of Science & Information Technology, Universiti Teknologi PETRONAS, 32610, Seri Iskandar, Perak
*Corresponding author email address: jia_16001961@utp.edu.my

Abstract: Weathering causes the rocks to loose their original strength and the increment in slakability can trigger slope instability. Furthermore, weathering of heterogeneous sedimentary rock mass produces a non-systematic weathering profile that is dependent on the characteristics of the unweathered, interbedded sedimentary sequence. However, the increase in slakability limits sampling of rocks for physical and mechanical rock tests. Thus, slake durability test and jar slake test have been applied to characterise a sedimentary rock mass weathering profile. The advantages of these methods are in the simple test procedures which only requires small size of rock block samples and relatively low cost testing equipments. The study was conducted at a roadcut that consists of Kati Formation which had undergone slight to complete weathering. Results show that the durability decreases with increases of weathering grades. However, presence of iron staining and iron recementation improve the rock durability. Completely weathered sandstone has the mean second cycle slake durability index, I_{d2} of 0.3 % to 15.0 %, highly weathered sandstone is from 22.0 % to 67.0 %, slightly weathered sandstone is 87.0 % to 98.0 % depending on the presence of iron recementation and fresh sandstone is 91.0 %. For mudstone, mean I_{d2} for completely weathered is 2.0 % while highly weathered mudstone is 12.0 %. Moderately weathered mudstone has an average value of 68.0 %. Mean I_{d2} for slightly weathered shale, is 83.0 % and slightly weathered chert has the average I_{d2} of 98.0 %. Jar slake test has the advantage to differentiate between highly weathered and completely weathered sandstone and mudstone. Completely weathered rocks have higher slaking properties where the rock samples breakdown completely. For highly weathered rocks, the breakdown is into chips and fractures. Jar slake test is suitable only for weathered rocks with slake durability value, I_{d2} below 25 %.

Keywords: Durability, weathered rocks, sedimentary rocks, slake durability index, jar slake test

Abstrak: Luluhawa menyebabkan batuan kehilangan kekuatan asalnya dan peningkatan keperoian boleh mengakibatkan ketidakstabilan cerun. Tambahan pula, luluhawa jasad batuan sedimen heterogen menghasilkan profil luluhawa yang tidak sistematik yang dipengaruhi ciri-ciri asal jujukan batuan berlapisan sebelum terluluhawa. Tambahan pula, peningkatan sifat pemeroian batuan membatasi kerja pensampelan batuan untuk menjalankan ujian fizikal dan mekanikal batuan. Justeru, ujian kebolehtahanan pemeroian dan ujian pemeroian dalam balang telah diaplikasikan untuk mencirikan profil luluhawa batuan sedimen. Kelebihan kaedah-kaedah ini ialah prosidur ujian yang ringkas dengan hanya memerlukan sampel batuan kecil dan kos peralatan ujian rendah. Kajian ini telah dilakukan di cerun jalan yang terdiri daripada Formasi Kati yang telah mengalami luluhawa sedikit hingga lengkap. Hasilnya, kebolehtahanan batuan menurun dengan peningkatan gred luluhawa. Walau bagaimanapun, kehadiran perwarnaan besi oksida dan penyimenan semula besi oksida meningkatkan kebolehtahanan batuan. Batu pasir terluluhawa lengkap mempunyai purata index ujian kebolehtahanan pemeroian kitaran kedua, I_{d2} dari 0.3 % hingga 15.0 %, batu pasir terluluhawa tinggi dari 22.0 % hingga 67.0 %, batu pasir terluluhawa sedikit ialah 87.0 % hingga 98.0 % bergantung kepada kehadiran penyimenan semula besi oksida dan batu pasir segar ialah 91.0 %. Untuk batu lumpur, purata I_{d2} untuk terluluhawa lengkap ialah 2.0 % manakala batu lumpur terluluhawa tinggi ialah 12.0 %. Batu lumpur terluluhawa sederhana mempunyai purata nilai 68.0 %. Untuk syal terluluhawa sedikit ialah 83.0 % dan rijang terluluhawa sedikit mempunyai nilai purata I_{d2} 98.0 %. Ujian pemeroian dalam balang mempunyai kelebihan untuk membezakan batu pasir dan batu lumpur yang terluluhawa tinggi dan terluluhawa lengkap. Batuan terluluhawa lengkap mempunyai sifat pemeroian yang lebih tinggi di mana sampel batuan terurai sepenuhnya. Untuk batuan terluluhawa tinggi, penguraiannya adalah kepada serpihan dan rekahan. Ujian pemeroian dalam balang hanya sesuai untuk batuan terluluhawa dengan nilai ujian keboletahanan pemeroian, I_{d2} di bawah 25 %.

INTRODUCTION

Weathered rocks depending on the degree of weathering and rock types, can easily disintegrate, have lower strength and high slakability. This can result in slope instability (Abramson *et al*., 2002). Miščević & Vlastelica (2014) stated that slope instability by weathering of soft rocks can occur through surface exfoliation of weathered materials and sliding along joints in which the weathering process has developed. The intensity of slope instabilities depend upon the intensity of slaking process (Sadisun *et al*., 2003). Progressive slake deterioration of exposed surface can cause the slope to undergo increased soil erosion which is a precursor to shallow landslide. This can decrease engineering lifetime of a slope, leading to high maintenance costs and can constitute a safety hazard (Sadisun *et al.*, 2005). Although erosions due to degradation process only occur on the exposed surface without affecting the global rock mass stability, Cano *et al*. (2017) suggested that it should also be considered as a type of failure mode, rather than just a triggering factor.

The study area of this research is the roadcut of Kati Formation sedimentary rocks that consists of sandstone, siltstone, mudstone and chert. The heterogeneity of sedimentary rock mass with addition of tectonic deformation causes differential weathering. This produces a non-systematic erosion on the slope with some detached fragments accumulating at the bottom of the slope (Figure 1). However, long term overhanging blocks that finally detach from the slope depend on the weathering rate when the tensile strength of the material is exceeded (Miščević & Vlastelica, 2014). This damage can threaten human lives and also cause the roadway to be blocked. Thus, investigations of rock durability and degradation behaviour are important to quantify the lifetime of the roadcut. Furthermore, weathering effects on the rocks should always be highlighted as our country experiences both wet season and dry season throughout the year.

The properties of weak weathered rocks makes sampling of rock materials for mechanical and physical strength tests such as uniaxial compressive strength (UCS) extremely difficult. Therefore, slake durability test and jar slake test offer an alternative to determine the rock strength as the testing materials required are only small and irregular bulk samples. According to Sadisun *et al*. (2005), the basis of these tests are to analyse the rock's resistance to short term weakening and disintegration or breakdown when subjected to a simulated rapid weathering process.

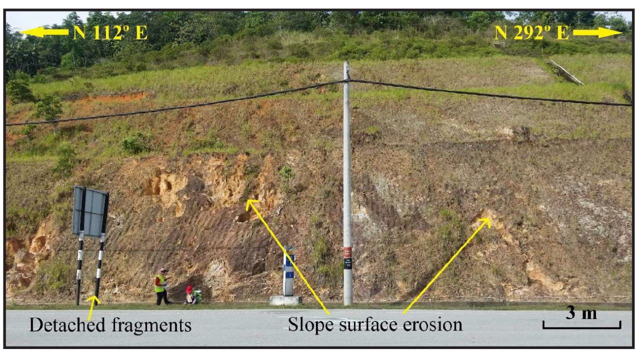


Figure 1: Non-systematic surface erosion and accumulation of detached materials observed at the cut slope, 8 km of the road from Parit to Kuala Kangsar, A164, near the junction to Kampung Perah.

STUDY AREA

The study was conducted at the outcrop located at 8 km along the road A164, from the Parit junction to Kuala Kangsar (N04º32', E100º56') that is mainly composed of Kati Formation, as shown in Figure 2. This area is selected because it consists various clastic sedimentary rocks that have undergone slight to complete weathering.

Kati Formation is a turbidite formation of marine slope of Carboniferous to Permian age (Rosle & Teh, 1998). According to the sedimentology study of Kati Formation at four outcrops at Seri Iskandar by Alkhali & Chow (2015), the rocks are generally consisting of sandstone, mudstone and siltstone with strikes of 325º and having steep to almost vertical dips.

METHODOLOGY

Field observation method was used to identify the rock types and also the weathering grades of the rock. Rock weathering grade can be classified into two systems that are descriptive or qualitative based on visual inspection of discolouration and quantitative based on rock strength. In this research, field techniques of weathering classification system that have been established by earlier studies (BS, 5930, 1981; IAEG, 1981; ISRM, 2007 & GCO, 2017) were applied. This weathering grade classification system classify rocks into six weathering grades - grade I (fresh rock), grade II (slightly weathered), grade III (moderately weathered), grade IV (highly weathered), grade V (completely weathered) and grade VI (residual soil). Density and porosity of rock samples are determined using standard method proposed by International Society of Rock Mechanics, ISRM (2007) and ASTM (2004) to quantify the weathering grades.

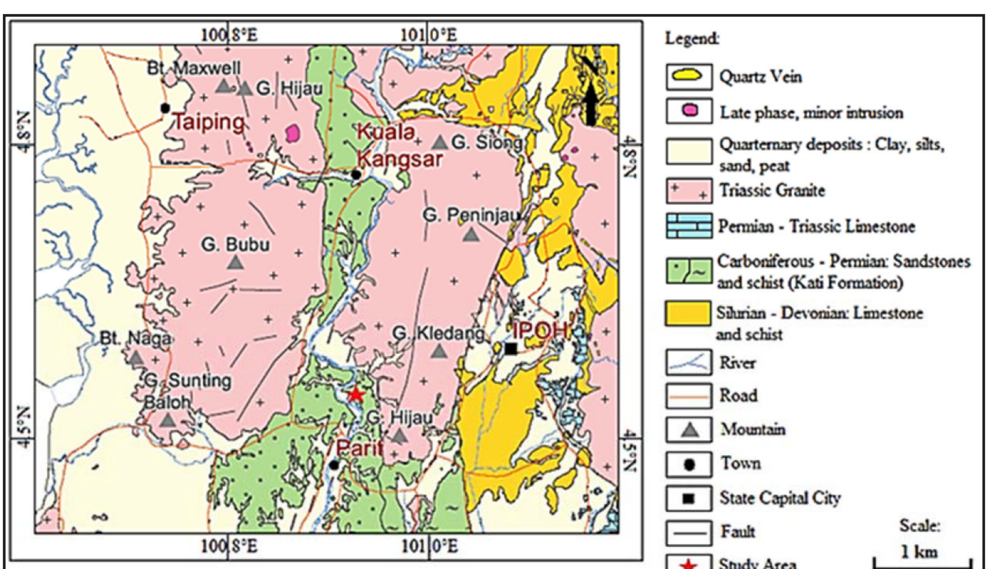


Figure 2: Location of study area shown on the geological map of Central Perak. Source: Modified from Geological Map of Peninsular Malaysia 9th Edition (2014).

The weathered rock characterisation was conducted using two approaches which are the slake durability index test and jar slake test. Due to the interbedding nature of the sedimentary rocks, different strata have undergone different degree of weathering. In order to characterise the weathering of each strata, different weathering grades within each strata were sampled for laboratory testing. Residual soil is excluded as disaggregated matter is not suitable for laboratory rock testing.

Slake durability index test

Slake durability index test was conducted according to the standard method proposed by ISRM (2007) and ASTM (2004). Ten irregular rock samples with the mass of 40 g to 60 g are put in the drum with 2 mm sieve for 10 minutes rotation in water. The mass of dried samples before and after the test are measured and the slake durability index, I_d values are calculated based on the formula as below:

$$I_{dx} (\%) = [(WF – C)/(B-C)] \times 100 \quad (1)$$

Where,
I_{dx} = slake durability index of the cycle (%)
B = mass of drum plus oven-dried sample before the cycle (g)
C = mass of drum (g)
WF = mass of drum and oven dried sample retained after the cycle (g)

Both standards suggested the test to be applied up to two standard cycles while many researchers such as Martinez-Bofill *et al*. (2004) recommended that the slake durability test of up to five cycles is more appropriate. The final laboratory results were classified using slake durability classification based on Franklin & Chandra (1972).

Jar slake test

Mohamad *et al.* (2011) suggested that jar slaking test is more suitable to measure durability of weak rock especially highly weathered (grade IV) and completely weathered (grade V) rocks compared to slake durability index values using I_{d1} or I_{d2}. Furthermore, Czerewko & Cripps (2001) stated that the slake durability index is too aggressive to characterize low durability mudrocks and small size slaking samples that are greater than 2 mm are not considered. For the jar test, Santi (1998) suggested to observe the behaviour of samples at the interval of 30 minutes and 24 hours. However, Mohamad *et al*. (2011) observed the changes for 10 minutes, 15 minutes, 30 minutes and 60 minutes and found it to be more precise.

Thus, the test procedures are conducted by modification of standard method from Washington State Department of Transportation (2017), Czerewko & Cripps (2001), Santi (1998), and Mohamad *et al.* (2011). Rock samples with dimension approximately 7 cm X 5 cm were dried in an oven at 100 °C for more than 16 hours to obtain zero moisture content samples. Smooth surface samples are preferable so that the minor changes and fractures on the surface can be observed easily. The changes of rock samples after immersion in tap water at 5 minutes, 10 minutes, 15 minutes, 30 minutes, 60 minutes, 120 minutes and 1440 minutes (24 hours) were observed and then categorised using index classification by Santi (1998) as shown in Figure 3.

RESULTS AND DISCUSSION

The sedimentary rocks found at the outcrop consist of sandstone, mudstone, shale and chert. Based on the field observations of hand specimens by discolouration and rock strength, the sandstone was classified into fresh grey sandstone to completely weathered and residual soil while mudstone was classified as moderately weathered to completely weathered. Shale found at the slope is slightly weathered while only slightly weathered chert is present at the outcrop. The field descriptions and physical properties of the rock types for each weathering grade are shown in Table 1 and Table 2. Despite the discolouration, it is found that the sedimentary rocks contain uneven iron oxide distribution that increases the rock strength. This causes the rocks weathering classification to be more complicated.

The average values of slake durability index from 38 samples of different weathering grades and lithology were calculated and plotted in the graph as shown in Figure 4 and Figure 5. Although the durability tests were conducted for up to five cycles, results show that two cycles are more suitable in this study as there is constant changes in the slake durability graph. The completely weathered rocks with high slaking cannot be determined up to five cycles as the total samples disintegrated during the third cycle. Although the second cycle value for completely weathered sandstone is negligible which is nearly 0.3 %, the first cycle value cannot

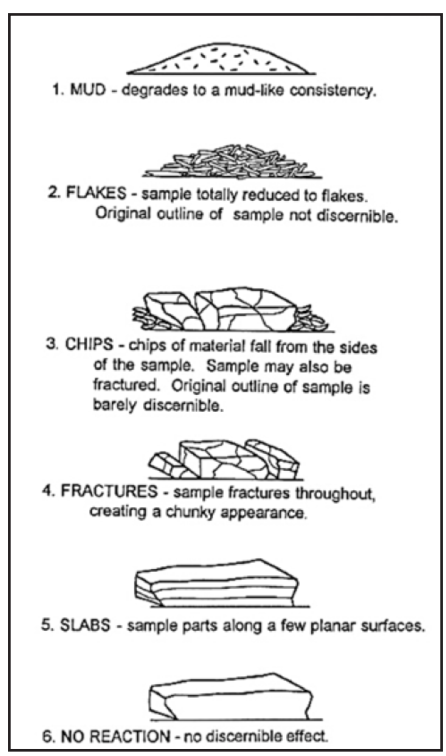
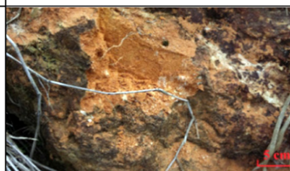


Figure 3: Jar slake classification proposed by Santi (1998) by using categories of 1, 2, 3, 4, 5 and 6.

Table 1: Weathering classification of sandstone according to ISRM (1981), GCO (2017) and IAEG (1981) with the field descriptions and physical properties.

Weathering Grades and Rock Types	Rock Samples	Field Description	Physical Properties
Residual Soil		• All rock material is converted to soil • Can be crumbled by hand and finger pressure into constituent grains	• The shear strength is more than 0.45 MPa when tested with pocket penetrometer
Completely weathered sandstone		• Light orange in colour • All rock material is decomposed and/or disintegrated to soil • Original rock texture preserved; can be crumbled by hand and finger pressure into constituent grains	• Mean density: 2.22 g/cm³ • Mean porosity : 18.86 %
Completely weathered sandstone with iron staining		• Light orange in colour with some iron staining on surface • All rock material is decomposed and/or disintegrated to soil • Original rock texture preserved; can be crumbled by hand and finger pressure into constituent grains; easily indented by point of geological pick	• Mean density: 2.22 g/cm³ • Mean porosity: 18.86 %
Highly weathered orange sandstone		• Light orange in colour • Can be broken by hand into smaller pieces; makes a dull sound when struck by hammer; not easily indented by point of pick	• Mean density: 2.39 g/cm³ • Mean porosity: 13.10 %
Highly weathered iron banded fractured sandstone		• Iron oxide filled fractured sandstone • Can be broken by hand into smaller pieces; makes a dull sound when struck by hammer; not easily indented by point of pick	• Mean density: 2.32 g/cm³ • Mean porosity: 20.00 % (value is high due to fractures)
Highly weathered iron recemented sandstone		• Uneven distribution of iron recementation • Not broken easily by hammer; makes a ringing sound when struck by hammer	• Mean density: 2.35 g/cm³ • Mean porosity : 10.70 %
Slightly weathered sandstone		• Light orange in colour, a little discolouration • Not broken easily by hammer; makes a ringing sound when struck by hammer	• Mean density: 2.55 g/cm³ • Mean porosity: 7.23 %
Slightly weathered iron recemented sandstone		• Light orange in colour with uneven distribution of iron recementation • Not broken easily by hammer; makes a ringing sound when struck by hammer	• Mean density: 2.65 g/cm³ • Mean porosity : 5.5 %
Fresh grey sandstone		• Grey in colour, no discolouration • Not broken easily by hammer; makes a ringing sound when struck by hammer	• Density: 2.67 g/cm³ • Porosity: • 5.63 %

be used to determine the durability of rocks as the first cycle values of some rocks have high standard deviation which range value of I_{d1} for same types of rock samples are very large that cannot represent the rock durability. Thus, slake durability index for second cycle, I_{d2} is more stable and suitable to use as the index of durability.

For completely weathered sandstone, the range of second cycle slake durability test, I_{d2} is 0.0 % to 1.0 % with

Table 2: Weathering classification of mudstone, shale and chert according to ISRM (1981), GCO (2017) and IAEG (1981) with the field descriptions and physical properties.

Weathering Grades and Rock Types	Rock Samples	Field Description	Physical Properties
Completely weathered mudstone		• Greyish/white in colour • All rock material is decomposed and/or disintegrated to soil • Original rock texture preserved; can be crumbled by hand and finger pressure into constituent grains; easily indented by point of geological pick	• Mean density: 1.36 g/cm³ • Mean porosity : 37.85 %
Highly weathered mudstone		• White in colour • Can be broken by hand into smaller pieces; makes a dull sound when struck by hammer; not easily indented by point of pick	• Mean density: 1.86 g/cm³ • Mean porosity: 17.25 %
Moderately weathered mudstone		• Greyish in colour • Cannot usually be broken by hand; easily broken by hammer; makes a dull or slight ringing sound when struck by hammer	• Mean density: 2.20 g/cm³ • Mean porosity: 15.50 %
Slightly weathered shale		• White in colour with a little discolouration • Not broken easily by hammer	• Mean density: 2.39 g/cm³ • Mean porosity: 23.16 % (value is high due to fractures and
Slightly weathered chert		• Grey in colour, no discolouration • Not broken easily by hammer; makes a ringing sound when struck by hammer	• Mean density: 2.69 g/cm³ • Mean porosity: 2.68 %

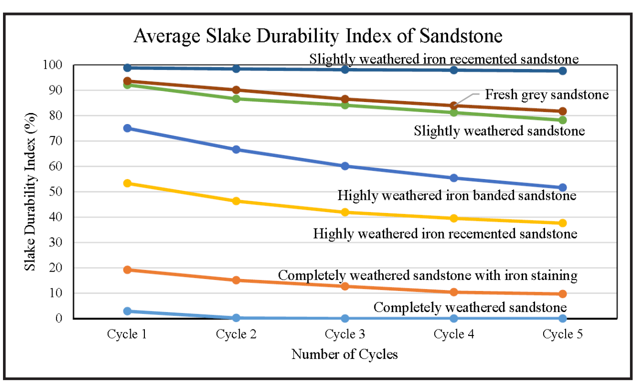


Figure 4: Slake durability index value of sandstone based on the weathering grades.

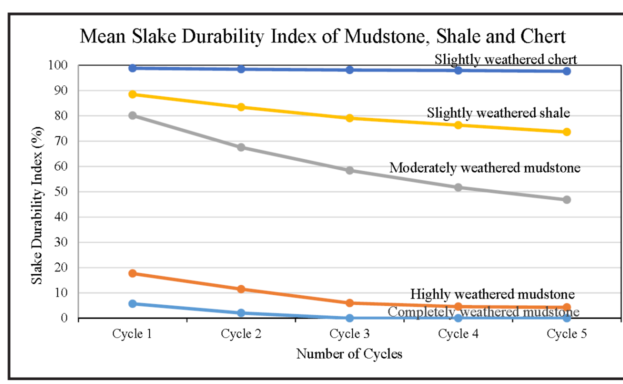


Figure 5: Slake durability index of mudstone, shale and chert based on the weathering grades.

mean value of 0.3 % and standard deviation of 0.4 while completely weathered sandstone with iron has a range of 14.0 % to 22.0 %, with a mean value of 15 % and standard deviation of 1.57. Highly weathered grey sandstone has the mean value of 22.0 %. Highly weathered sandstone with iron recementation and iron banded has a range from 42.0 % to 67.0 % and the mean 54.0 %, depending on the quantity of iron oxide present. It has the highest standard deviation which is 11.6. Slightly weathered sandstone, slightly weathered iron recemented sandstone and fresh grey sandstone have consistent values of second cycle slake durability index. Their mean values are 97.0 %, 98.0 % and 91.0 % respectively.

Theoretically, durability of rocks decreases with increasing weathering grades. However, the results show that the second cycle slake durability index of slightly weathered iron recemented sandstone is higher than fresh grey sandstone and slightly weathered sandstone by 8.0 % and 12.0 % respectively. With the same weathering grades, completely weathered sandstone has slake durability index, I_{d2} approximately 15 % lower that completely weathered sandstone with the presence of iron oxide. This can conclude that the presence of iron oxide recementation increases the durability of rocks.

For completely weathered mudstone, the value of I_{d2} is in the range of 0.4 % to 3.2 % and the mean is 2.0 % with standard deviation of 1.29. Highly weathered mudstone has a range value of 9.0 % to 15.0 % with the mean and standard deviation of 12.0 % and 2.57 respectively. Next, moderately mudstone has a range of values from 66.0 % to 69.0 %, mean of 68.0 % and standard deviation of 1.54. The second cycle slake durability value for slightly weathered shale has a range of 83.0 % to 84.0 %, mean 83.0 % and standard deviation of 0.14. Slightly weathered chert has a mean I_{d2} value of 98.0 %.

Jar slake test is a qualitative test to observe the changes of rock samples when immerse in the water without any movement or external forces applied on it. In this test, completely weathered sandstone shows a quick slaking process in which the samples break into chips and fractures immediately after being immersed in the water and finally totally disintegrate into grains after 15 minutes in water. However, the presence of iron oxide in the completely weathered sandstone improve the rock durability. This can be shown by the completely weathered sandstone with iron staining during the jar slake test. The chip materials continuously fall from the sides of the sample after immersion of 5 minutes. At the end of the test, only 27 % of the mass of sample retained. For highly weathered grey sandstone, the samples breaks into fractures after 5 minutes and remains in that state until the end of the test. Next, highly weathered sandstone with iron recementation, slightly weathered sandstone, slightly weathered sandstone with iron recemented and fresh sandstone do not show any changes throughout the test when immersed in the tap water. The mass retained of the extremely durable rocks after the test is more than 98 %.

Completely weathered mudstone immediately breaks into few fractures after immersed in water. At the 15th minute, it completely breaks into flakes until the end of the test. Highly weathered grey mudstone started to fractures after 5 minutes and remains as fractures until the end of the test. Moderately weathered mudstone, slightly weathered shale and slightly weathered chert have high durability as they do not show any changes throughout the 24 hours in the water. The mass of rocks retained after the laboratory test is more than 95 %. The summary of the rocks behaviour for jar slake test results is illustrated in Figure 6 and Figure 7. For all the jar slake tests conducted, there was no further changes in the rock's behaviour after 30 minutes.

The laboratory results are shown in Table 3 and Table 4 according to the weathering grades and using slake durability classification based on Franklin & Chandra (1972) and also weathering grades of the rocks. For both sandstone and mudstone, jar slake test is only applicable to samples of very low durability with the I_{d2} of below 25 %. The samples will either break into fractures, form many chips or completely breakdown to grains, depending on the weathering grades. Mudstone will not break down into mud but flakes at the end of the jar slake test.

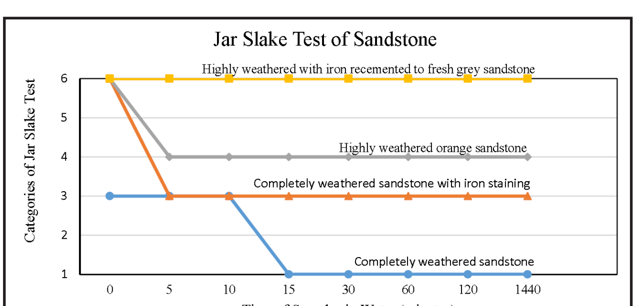


Figure 6: Jar slake test results based on category proposed by Santi (1998) for sandstone of different weathering grades.

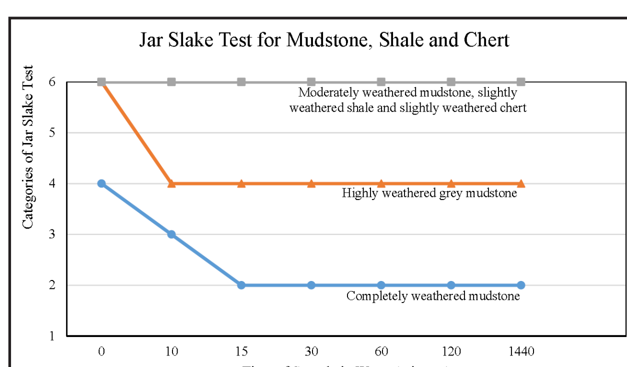


Figure 7: Jar slake test results based on category proposed by Santi (1998) for mudstone, shale and chert with different weathering grades.

CONCLUSION

Completely weathered sandstone has the mean second cycle slake durability index, I_{d2} of 0.3 % to 15.0 %, highly weathered is from 22.0 % to 67.0 %, slightly weathered is 87.0 % to 98.0 % depending on the presence of iron recementation and fresh sandstone is 91.0 %. For mudstone, mean I_{d2} for completely weathered is 2.0 % while highly weathered mudstone is 12.0 %. Moderately weathered mudstone has an average value of 68.0 %, slightly weathered shale 84.0 % and slightly weathered chert has the average I_{d2} of 98.0%. Jar slake test has the advantage to differentiate between highly weathered and completely weathered sandstone and mudstone. Completely weathered rocks have higher slaking properties where the rock samples breakdown completely. For highly weathered rocks, the breakdown is into chips and fractures. Jar slake test is suitable only for weathered rocks with slake durability value, I_{d2} below 25 %.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the partners for their support and guidance in conducting

Table 3: Slake durability index, Id2 and jar slake test results for sandstone.

Weathering Grades and Rock Types	Average Id2 (%)	Durability Classification based on Franklin & Chandra (1972)	Jar Slake Test
Completely weathered sandstone	0.3	Very low	Completely breakdown to grains
Completely weathered sandstone with iron staining	15.0	Very low	Breaks rapidly and form many chips/ develop new fractures
Highly weathered orange sandstone	22.0	Very low	Sample fractures create chunky material
Highly weathered iron recemented sandstone	46.0	Low	No change
Highly weathered iron banded fractured sandstone	67.0	Medium	No change
Slightly weathered sandstone	87.0	High	No change
Slightly weathered iron recemented sandstone	98.0	Extremely high	No change
Fresh grey sandstone	91.0	Very high	No change

Table 4: Slake durability index, Id2 and jar slake test results for mudstone, shale and chert.

Weathering Grades and Rock Types	Average Id2 (%)	Durability Classification based on Franklin & Chandra (1972)	Jar Slake Test
Completely weathered mudstone	2.0	Very low	Completely breakdown to flakes
Highly weathered mudstone	12.0	Very low	Breaks slowly and develops few fractures
Moderately weathered mudstone	68.0	Medium	No change
Slightly weathered shale	83.0	High	No change
Slightly weathered chert	98.0	Extremely high	No change

this study. Besides that, the authors would also like to acknowledge the laboratory assistants and Geoscience Department, Universiti Teknologi PETRONAS that provided laboratory testing equipment for the study. This research is supported by the research grant FRGS/1/2016/STG08/UTP/01/1 of the Malaysia Government and is acknowledged.

REFERENCES

Abramson, L.W., Lee, T.S., Sharma, S. & Boyce, G.M., 2002. Slope Stability and Stabilization Methods (2 Ed.). John Wiley & Sons, New York. 736 p.

Alkhali, H.A. & Chow, W.S., 2015. The Kati Formation: a review. In ICIPEG 2014. Springer, Singapore, 303-312.

ASTM D4644, 2004. Standard Test Method for Slake Durability of Shales and Similar Weak Rocks. ASTM International, West Conshohocken, 816-818.

British Standard (BS), 1981. Code of Practice for Site Investigations (5930). British Standards Institution, London. 204 p.

Cano, M., Tomás, R. & Riquelme, A., 2017. Relationship between monitored natural slaking behaviour, field degradation behaviour and slake durability test of marly flysch rocks: oreliminary results. Procedia Engineering, 191, 609-617.

Czerewko, M. & Cripps, J., 2001. Assessing the durability of mudrocks using the modified jar slake index test. Quarterly Journal of Engineering Geology and Hydrogeology, 34(2), 153-163.

Franklin, J. & Chandra, R., 1972. The slake-durability test. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, 9(3), 325-328.

Geotechnical Control Office (GCO), 2017. Guide to Rock and Soil Descriptions (Geoguide 3): Geotechnical Control Office, Hong Kong.

International Association of Engineering Geology (IAEG), 1981. Soil description and classification for engineering geological mapping. Report by the IAEG Commission on Eng. Geol. Mapping. Bull. of the IAEG, 24(1), 235-274.

International Society for Rock Mechanics (ISRM), 2007. The complete ISRM suggested methods for rock characterization, testing and monitoring: 1974-2006. International Soc. for Rock Mechanics, Commission on Testing Methods.

Martinez-Bofill, J., Corominas, J. & Soler, A., 2004. Behaviour of the weak rock cut slopes and their characterization using the results of the slake durability test. Engineering Geology for Infrastructure Planning in Europe, Springer, Berlin, Heidelberg, 405-413.

Mohamad, E.T., Saad, R. & Abad, S., 2011. Durability assessment of weak rock by using jar slaking test. Electron. J. Geotech. Eng., 16, 1319-1335.

Miščević, P. & Vlastelica, G., 2014. Impact of weathering on slope stability in soft rock mass. Journal of Rock Mechanics and Geotechnical Engineering, 6(3), 240-250.

Rosle, Q.A. & Teh, G., 1998. The stratigraphy, structure and significance of the Nenering Tertiary beds, Pengkalan Hulu (Keroh), Hulu Perak. Bulletin of the Geol. Soc. of Malaysia, 42, 161-177.

Sadisun, I. A., Bandono, Shimada, H., Ichinose, M. & Matsui, K., 2003. Slope instability of road cuts due to rocks slaking. 12th Asian Regional Conf. on Soil Mechanics & Geotechnical Engineering, 747-750.

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 & Geological Engineering, 23(3), 199-218.

Santi, P. M., 1998. Improving the jar slake, slake index, and slake durability tests for shales. Environmental & Engineering Geoscience, 4(3), 385-396.

The Director General of Mineral and Geoscience Malaysia, 2014. Geological Map of Peninsular Malaysia (9th ed.). Scale 1:750000.

Washington State Department of Transportation, 2017. WSDOT Test Method T 501 Test Method to Determine Durability of Very Weak Rock. WSDOT Materials Manual.

Manuscript received 30 July 2018
Revised manuscript received 9 August 2018
Manuscript accepted 13 August 2018