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Slake durability indices of shales from the Batu Arang Beds, Selangor Darul Ehsan

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Abstract: The Eocene to Oligocene Batu Arang Beds outcrop within an approximately triangular basin covering some 15 km^2 and comprise stiff, structureless clays to well laminated and fissile shales inter-bedded with fine to coarse sandstones and several coal layers. The shales are often silty and even sandy and contain abundant carbonaceous material. The coal mostly occurs as thin laminae, though two thick seams, mined by open-cast and under-ground methods from 1915 to 1960, are found in the eastern part of the basin. To determine the weatherability characteristics of the shales, three samples (A, B and C) were collected at the western wall, and one sample (D) at the eastern wall, of an open-cast shale pit. Samples A and D are located some 10 m, and 5 m, below the ground surface, whilst samples B and C are 10 m, and 16 m, stratigraphically below sample A. Samples A, B and C, and D have average dry unit weights of 16.64, 14.49, and 15.40, kN/m^3 and average apparent porosities of 26.2%, 35.7% and 31.7%, respectively. Slake durability indices of all samples for one standard cycle of wetting and drying (Id_1) are between 98.3% and 99.3%, and for two standard cycles (Id_2), between 96.7% and 98.9%. Durability indices for three standard cycles (Id_3) are between 95.1% and 98.2%, and for four standard cycles (Id_4), between 93.3% and 97.6%. The indices lead to the conclusion that the shales are of high to extremely high durability and suitable for use as highway embankment or construction material. The high durability classification is supported by recent excavations at an overburden dump where relatively fresh shale blocks with little disaggregation or disintegration are exposed even after being buried for 78 to 85 years.

Keywords: Batu Arang Beds, Eocene to Oligocene strata, shales, slake durability indices

INTRODUCTION

Several earth materials, especially those with a high clay content, are prone to swelling, weakening or disintegration when exposed to short-term weathering processes of a wetting and drying nature. Such slaking characteristics or weatherability are of practical importance in engineering projects for they can influence the stability of excavations with time as well as the surface durability of canal and tunnel walls (Morgenstern & Eigenbrod, 1974).

The weatherability of clay-rick rock materials probably presents the most problems because their degree of induration may cause observers to be misled concerning their performance when exposed to the elements (Johnson & DeGraff, 1988). In view of this, the slake durability test was devised as a means of assessing the resistance offered by a rock material to weakening and disintegration when subjected to two standard cycles of drying and wetting (Franklin & Chandra, 1972). Standardized procedures for the slake durability test are provided in ISRM (1979) and AIT (1981).

The Colorado Department of Transport (CDOT, 2015) has recommended that shales used for highway embankments or as construction material be classified as being soil-like (non-durable) or rock-like (durable). Two methods of test were recommended to distinguish durable shales that can be used in rock fills from non-durable shales that must be placed and compacted as soil. The first method is the qualitative jar-slake test which involves six descriptive degrees of slaking determined from visual observation. The second method employs the slake durability apparatus where a number of oven-dried rock blocks are submerged in water and rotated in a wire drum cage. The jar-slake test is recommended as the basic screening test, whilst the slake durability test is considered to be the main index test. Identification of shales as being soil-like (non-durable) or rock-like (durable) is based on the slake durability index (Id)

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and the character of the retained wet rock materials (CDOT, 2015).

In Malaysia, there is limited published data on the durability of rock materials with (Azman Kassim & Edy Tonnizam Mohamad, 2007) stating that the slake durability index (Id_2) for two standard cycles of testing decreased with an increase in the weathering grade of sandstones and shales from the Mersing area. Zainab Mohamed *et al.* (2007) discussed the characterization and classification of weathered Kenny Hill Formation rocks and presented results of jar-slake tests as well as tests with the slake durability apparatus. Edy Tonnizam Mohamad *et al.* (2011) reported that jar slaking tests were more suitable for determining the durability of highly (Grade IV), and completely (Grade V), weathered sandstone from the Mersing area rather than tests with the standard slake durability apparatus.

Wong *et al.* (2018) concluded that the slake durability index (Id_2) for two cycles of wetting and drying is the ideal test to characterize the weathering grade of rocks from the Kati Formation of Carboniferous to Permian age in Perak State. The Formation comprises inter-bedded sandstones, siltstones and mudstones with Id_2 values <15% indicating completely weathered rocks, 22% to 67% highly weathered rocks, 68% to 83% moderately weathered rocks, and 87% to 98% slightly weathered to fresh rocks.

In a recent publication, Raj (2020) has discussed the slake durability indices of shales and fine grained sandstones from the Middle to Upper Triassic Gemas Formation. Durability indices (Id_2) for two standard cycles of wetting and drying were between 99.1% and 99.6% for the shales, and between 99.2% and 99.3% for the sandstones. Durability indices (Id_4) for four standard cycles of wetting and drying furthermore, were between 99.0% and 99.5% for the shales, and between 98.4% and 98.5% for the sandstones. It was thus concluded that fresh (unaltered) shales and sandstones from the Gemas Formation are of extremely high durability and suitable for use as highway embankment or construction material (rock fill).

As part of a study to determine the geotechnical properties of earth materials in Malaysia, were investigated outcrops of Tertiary sedimentary rocks in the Batu Arang area. Uniaxial compressive strengths of these rocks have been earlier discussed (Raj, 1994) as have been their point load strengths (Raj, 1995). In this short note are presented the results of laboratory tests carried out to determine the slake durability indices of shales from the Batu Arang Beds.

GENERAL SETTING OF STUDY AREA

Tertiary sediments at Batu Arang (Figure 1) form an approximately triangular basin, encompassing an area of about 15 km^2 and overlie with marked unconformity, much older and steeply dipping meta-sediments, mainly quartzites and phyllites, of the Kenny Hill Formation (Stauffer, 1973; Raj *et al.*, 2009). The Tertiary sediments, known as the Batu Arang Beds (Stauffer, 1973) or the Coal Measures (Roe, 1951) are also unconformably overlain by a thick sequence of semi-consolidated, sandy to gravelly and bouldery sediments of a probable Pleistocene age (Raj *et al.*, 2009). The Tertiary sediments proper have a maximum recorded thickness of 265 m in the center of the basin, but where the beds outcrop along the eastern and northern sides, the sequence is some 183 to 244 m thick (Raj *et al.*, 2009).

The Batu Arang Beds consist mainly of fine grained strata that range from stiff, structureless clays to well laminated and fissile shales inter-bedded with some sandstone and coal beds. The shales contain abundant carbonaceous material and are often silty and even sandy, with colors ranging from light grey through dark greyish brown to blackish brown and black. The interbedded sandstones are mostly fine grained, though ranging up to coarse grained, and even pebbly with colors of white to

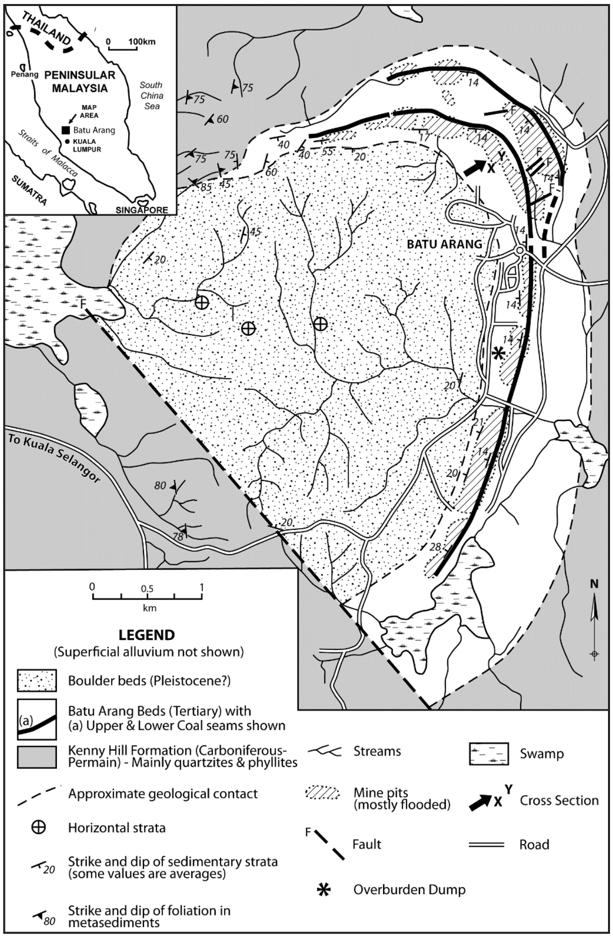

Figure 1: Geology map of the Batu Arang area, Selangor Darul Ehsan. (After Roe, 1951; Law, 1961; Stauffer, 1973; Raj, 1998; Raj *et al.*, 2009).

various shades of brown depending upon the amount of carbonaceous matter. Small-scale cross-bedding is very common, while pebbly beds sometimes contain rounded clay pebbles. The coal mostly occurs as thin laminae, though two thick seams are found in the eastern part of the basin; the Upper Seam with a thickness of up to 15 m, and the Lower Seam averaging 8 m in thickness. The two seams are some 65 m stratigraphically apart and have been mined by open-cast and under-ground methods from 1915 to 1960 (Renwick & Rishworth, 1966).

Fossil leaves and other plant fragments within the coal-bearing sediments indicate a young, possibly Late Tertiary or younger, age and also suggest a drier climate than at present, or a partly upland source for the transported plant material (Roe, 1951). More recent work utilizing palynomorph assemblages indicates that the coals are of a probable Eocene to Oligocene age and were deposited in a lacustrine environment under somewhat seasonal climatic conditions (Ahmad, 1993).

The Tertiary sediments show a synclinal structure that plunges southwestwards, though this is considered to reflect the basin of deposition, rather than tectonic activity (Stauffer, 1973). Two to three sets of joints are found in the silty to sandy shales; the two more prominent sets showing steep dip angles and striking perpendicular to bedding with variable spacings of 0.1 to 0.5 m. Joints (cleats) are also present in the coal seams, though their orientations are more variable and their spacings closer, ranging from 0.03 to 0.06 m.

METHODOLOGY OF STUDY

In view of the need for fresh (unaltered) samples, sampling points were limited to accessible sites at an open-cast shale pit where excavation was being actively carried out (Figure 2). Three sampling points were located on the west wall of the pit; sample A at a depth of 10 m below the ground surface, and samples B and C some 10 m, and 16 m, stratigraphically below sample A (Figure 3). The fourth sampling point (sample D) was located on the east wall of the pit at a depth of 5 m below the ground surface (Figure 4). Several large blocks (each about 0.03 m^3 in volume) of fresh shale were collected at each of the sampling points and taken to the laboratory where they were diamond-sawn into smaller tetrahedral blocks. The visible textural and structural features of each of the blocks was then described before the densities, unit weights and apparent porosities of representative, wax coated specimens determined following the saturation and bouyancy technique described in ISRM (1979) and AIT (1981).

The corners of the tetrahedral blocks were rounded off, and about ten of them (each weighing about 40 to 60 g) selected to give a total weight of some 400 to 600 g

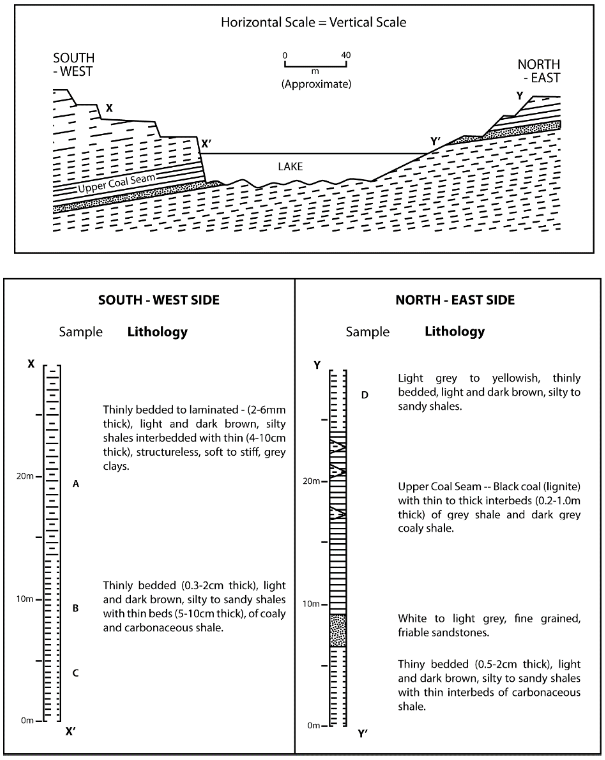

Figure 2: Geological cross-sections and locations of samples. (Points X and Y are shown in Figure 1).

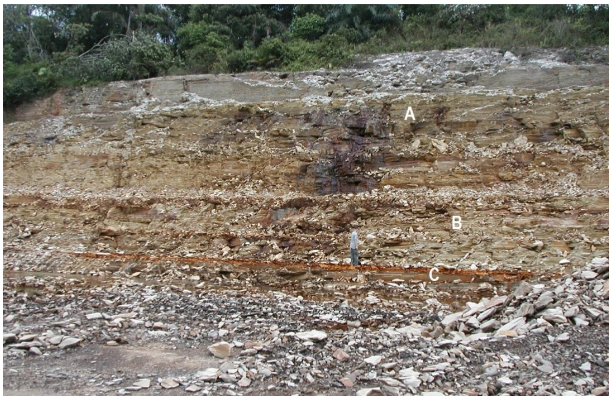

Figure 3: View of sampling points A, B and C.

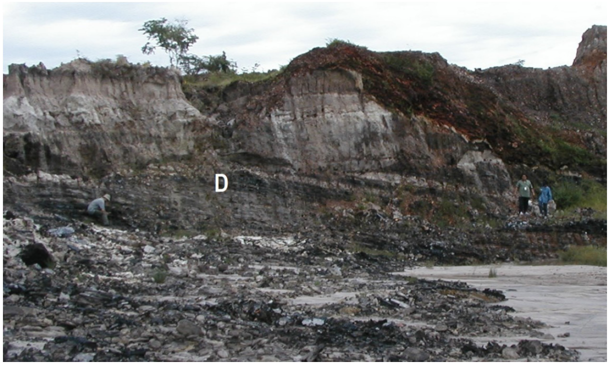

Figure 4: View of sampling point D.

for each test sample. Each sample (comprising some ten individual blocks) was oven-dried at 105°C overnight, and then placed in the drum of the slake durability apparatus. The weight of the drum and test specimen was then determined (Weight A) before the drum was covered with a lid and placed in the trough attached to the motor-drive unit. The trough was filled with tap water to a level some 20 mm below the drum axis, and the drum rotated at 20 rev/min for a period of 10 minutes. The drum (with the retained specimen) was then removed from the trough and oven-dried (over-night) at 105°C before the weight was measured (Weight B). The same process was repeated and the oven-dried weight of the drum and retained specimen determined (Weight C). The drum was then oven-dried (over-night) at 105°C and its weight determined (Weight D). The slake durability index (Id_2) for the two cycles of wetting and drying was then calculated as a percentage ratio of the final to initial dry specimen weight as follows:

$$\text{Slake durability index } (Id_2)\ \% = ((C-D)/(A-D)) \times 100$$

Repetition of the wetting and drying cycles with determination of oven-dry weights then gave slake durability indices for increasing numbers of cycles.

The apparatus used for the slake durability tests was manufactured by ELE (Engineering Laboratory Equipment) and consisted of a base-mounted, motor-drive unit that allowed rotation of drums at 20 revolutions per minute. Four mesh drums and four water tanks could be attached to the motor-drive unit with quick-release assemblies to allow for the simultaneous testing of four samples.

RESULTS

Physical properties of shales

Densities, unit weights and apparent porosities of representative specimens of the tested samples A, B, C and D are shown in Table 1. The laminated, dark brown shale (sample A) is the densest shale with an average dry unit weight of 16.64 kN/m^3, dry density of 1698 kg/m^3 and apparent porosity of 26.2 %. The thinly bedded, light brown, sandy shale (sample D) is the next most dense one with an average dry unit weight of 15.40 kN/m^3, dry density of 1574 kg/m^3, and apparent porosity of 31.7%. The thinly bedded, brown, silty shale (samples C and D) is the least dense shale with an average dry unit weight of 14.49 kN/m^3, dry density of 1479 kg/m^3, and apparent porosity of 35.7%.

Slake durability indices

Slake durability indices show some variability; the single cycle index (Id_1) of the laminated, dark brown shale (sample A) being 99.3%, and that of the other shales (samples B, C and D) between 98.3% and 98.6% (Table 2). The durability index (Id_2) for two standard cycles of wetting and drying of the laminated, dark brown shale (sample A) is 98.9%, and that of the other shales (samples B, C and D) between 96.7% and 97.4% (Table 2).

The slake durability index (Id_3) for three standard cycles of wetting and drying is more variable; the laminated, dark brown shale (sample A) with an index of 98.2%, the brown, silty shale (samples B and C) with an average index of 95.3%, and the light brown, sandy shale (sample D) with an index of 96.2% (Table 2). The durability index (Id_4) for four standard cycles of wetting

Table 1: Physical properties of selected shales from the Batu Arang Beds.

Sample	Lithology	Dry Unit Weight (kN/m^3)	Apparent Porosity (%)	Dry Density (kg/m^3)
A (1)	Laminated, dark brown, shale	16.95	24.8	1730
A (2)		16.52	26.7	1686
A (3)		16.45	27.0	1679
Average		16.64	26.2	1698
B (1)	Thinly bedded, brown, silty shale	14.73	34.6	1503
B (2)		14.30	36.6	1459
C (1)		14.45	35.9	1474
Average		14.49	35.7	1479
D (1)	Thinly bedded, light brown, sandy shale	15.49	31.3	1581
D (2)		15.50	31.2	1582
D (3)		15.19	32.6	1550
Average		15.40	31.7	1574

Table 2: Slake durability indices of selected shales from the Batu Arang Beds.

Sample	Lithology	Slake Durability Index			
		Cycle 1 (Id_1)	Cycle 2 (Id_2)	Cycle 3 (Id_3)	Cycle 4 (Id_4)
A	Dark brown, shale	99.3	98.9	98.2	97.6
B	Brown, silty shale	98.3	97.1	95.5	93.3
C	Brown, silty shale	98.6	96.7	95.1	93.8
D	Light brown, sandy shale	98.6	97.4	96.2	95.0

and drying is most variable; the laminated, dark brown shale (sample A) with an index of 97.6%, whilst the brown, silty shale (samples B and C) has an average index of 93.6%, and the light brown, sandy shale (sample D) an index of 95.0% (Table 2).

DISCUSSION

Variations in slake durability indices

As the samples were collected at different stratigraphic positions and depths below the ground surface, there can be expected some differences in slake durability indices. The indices for different cycles of wetting and drying, however, are quite close with some correlation between the physical properties and durability indices (Tables 1 and 2). The laminated, dark brown shale (sample A) with the largest values of dry unit weight and dry density but lowest apparent porosity has the highest durability indices for different cycles, whilst the thinly bedded, brown, silty shale (samples B and C) with the lowest values of dry unit weight and dry density, but highest apparent porosity, has the lowest indices. The thinly bedded, light brown, sandy shale (sample D) with intermediate values of dry unit weight and density as well as apparent porosity furthermore, has intermediate values of durability indices. Increasing density and unit weight but decreasing apparent porosity thus results in increasing durability of the shales.

Comparison with published data

The durability indices for two cycles of wetting and drying (Id_2) of the Batu Arang shales are between 96.7% and 98.9%; a range that is comparable with the durability indices (Id_2) of 91.6%, and between 82.5% and 87.1%, reported for slightly weathered (grade II), and moderately weathered (grade III) shale. Details on the age of the investigated shale are, however, not provided (Azman Kassim & Edy Tonnizam Mohammad, 2007).

The single cycle durability indices (Id_1) of between 98.3% and 99.3% for the Batu Arang shales are furthermore, compatible with the indices (Id_1) of 98%, and 92%, reported for a slightly weathered sandstone, and a highly weathered shale, from the Kenny Hill Formation (Zainab Mohamed *et al.*, 2007).

The durability indices for two standard cycles of wetting and drying (Id_2) of the Batu Arang shales between 96.7% and 98.9% can also be considered comparable with the indices (Id_2) of 87% to 98%, and 68%, reported for slightly weathered to fresh sandstones, and moderately weathered mudstone, from the Carboniferous to Permian Kati Formation in Perak State (Wong *et al.*, 2018).

The single cycle durability indices (Id_1) of between 98.3% and 99.3% of the Batu Arang shales are directly comparable with the indices (Id_1) of between 99.8% and 99.9% of shales from the Middle to Upper Triassic Gemas Formation (Raj, 2020). The slake durability indices for two standard cycles of wetting and drying (Id_2) of between 96.7% and 98.9% are also comparable with the indices (Id_2) of 99.1% to 99.7% of shales from the Gemas Formation (Raj, 2020).

Durability classification of shales

The shales from the Batu Arang Beds have slake durability indices for two cycles of wetting and drying (Id_2) of between 97.1% and 98.9%. These indices thus allow the shales to be classified as being of extremely high durability in terms of the classification proposed by Franklin & Chandra (1972).

In terms of the Colorado Department of Transportation classification (CDOT, 2015) furthermore, the laminated. dark brown shale (sample A) would be classified as being of very high durability, whilst the other shales (samples B, C and D) would be classified as being of high durability. This high to very high durability classification thus indicates that shales of the Batu Arang Beds are suitable for use as highway embankment or construction material (CDOT, 2015). Problems with ground settlement at overburden dumps associated with coal mining in the Batu Arang area can therefore, not be attributed to disaggregation or disintegration of shale blocks.

Validity of durability classification of shales

The large durability indices for two cycles of wetting and drying (Id_2) of the shales and their classification as being of high to extremely high durability is somewhat surprising in view of their relatively young geological age (Eocene to Oligocene). Over-burden loads on the Batu

Figure 5: Recent excavation in overburden dump (25.03.2023) - Dumping 1937-1945 with coal extraction at Open-Cast No. 8 in Upper Coal Seam. (30 cm ruler for scale)

Figure 6: Relatively fresh shale blocks at overburden dump (25.03.2023) - Overburden dumping from 1937 to 1945. (30 cm ruler for scale)

Arang Beds are also not expected to be large in view of their present exposure at the ground surface.

Recent excavations at an overburden dump from the early days of coal mining expose relatively fresh shale blocks that have experienced little disaggregation or disintegration over the years (Figures 5 and 6). This overburden dump, with a minimum thickness of 4 m, is located some 20 m from the west edge of former Open Cast Coal Mine No. 8, and some 100 m south of the adit to the old underground Centre Mine No. 3 (Figure 1). Open Cast Mine No. 8 in the Upper Coal Seam was started with over-burden stripping in 1936 and followed by coal extraction in 1937 and subsequent years till about the start of the Second World War (Roe, 1951; Renwick & Rishworth, 1966). The over-burden earth materials at the dump are thus some 78 to 85 years of age.

CONCLUSION

It is concluded that slake durability tests allow shales from the Eocene to Oligocene Batu Arang Beds to be classified as being of high to extremely high durability and thus suitable for use as highway embankment or construction material. Four shale samples were tested; three of them (A, B and C) from the western wall of an open-cast shale pit, and one sample (D) from the eastern wall. Samples A and D are located some 10 m, and 5 m, below the ground surface whilst samples B and C are 10 m, and 16 m, stratigraphically below sample A. Samples A, B and C, and D have average dry unit weights of 16.64, 14.49, and 15.40, kN/m^3 and average apparent porosities of 26.2 %, 35.7% and 31/7%, respectively.

Slake durability indices for one standard cycle of wetting and drying (Id_1) of all samples are between 98.3% and 99.3%, whilst indices for two standard cycles (Id_2) are between 96.7% and 98.9%. Durability indices for three standard cycles (Id_3) are between 95.1% and 98.2%, and indices for four standard cycles (Id_4) between 93.3% and 97.6%. The high to extremely high durability classification of the shales is validated by recent excavations at an overburden dump where relatively fresh shale blocks with little disaggregation nor disintegration are exposed even though they have been buried for some 78 to 85 years.

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CONFLICT OF INTEREST

The author has no conflicts of interest to declare that are relevant to the content of this article.

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