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Slake durability indices of fresh shales and sandstone from the Gemas Formation, Ayer Hitam, Johor Darul Takzim

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Abstract: At the slope cut between km 81.30 and 81.05 (southbound) of the North-South Highway near Ayer Hitam are exposed dark grey to black, fresh (unaltered) shales and fine grained sandstones of the Middle to Upper Triassic Gemas Formation. The strata with bed thicknesses of between 0.2 and 1.5 m, strike about 165° and dip eastward at 35° to 43°. The shales have an average dry unit weight of 24.85 kN/m^3 and an average apparent porosity of 5.9%, whilst the sandstone has an average dry unit weight of 24.83 kN/m^3 and an average apparent porosity of 4.8%. Slake durability indices (Id_2) of the shales for two standard cycles of wetting and drying are between 99.1% and 99.6%, whilst indices (Id_4) for four cycles are between 99.0% and 99.5%. Slake durability indices (Id_2) of the sandstone for two standard cycles of wetting and drying are between 99.2% and 99.3%, and for four cycles (Id_4) between 98.4% and 98.5%. It is concluded that the fresh (unaltered) shales and sandstone are of "extremely high durability" and suitable for use as highway embankment or construction material (rock fill).

Keywords: slake durability indices, Gemas Formation

INTRODUCTION

Several earth materials, particularly 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 of earth materials are of practical importance in engineering projects and can influence the stability of excavations with time as well as the design of fills and the surface durability of canal and tunnel walls (Morgenstern & Eigenbrod, 1974).

The weatherability of clay-rich 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. Standardized procedures for the slake durability test are provided in manuals published by the International Society for Rock Mechanics (ISRM, 1979) and the Asian Institute of Technology (AIT, 1981).

The Colorado Department of Transport (CDOT, 2015) furthermore, notes that shales as highway embankments (or construction material) should 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) 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 Mohammad (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 shales and sandstones from the Mersing area rather than tests with the standard slake durability apparatus.

In this geological note are presented the results of tests carried out with the slake durability apparatus on fresh (unaltered), dark grey shales and fine grained sandstone from the Gemas Formation that outcrop along the North-South Highway close to the town of Ayer Hitam in Johor State.

GEMAS FORMATION

The name 'Gemas Formation' was adopted by Lum (1982) to replace the term 'Gemas Beds' which had earlier been applied by Foo (1972) to denote the Middle to Upper Triassic sedimentary-pyroclastic sediments outcropping in northwest Johor. In the Gemas area, the Gemas Formation is mainly composed of rapidly alternating inter-beds of shale, sandstone, tuff, and tuffaceous sandstone and shale, with minor lenticular bodies of conglomerate and limestone. There are several fossil locations in the area, with 3 locations yielding faunal assemblages of shell imprints of pelecypods and ammonites which give a reliable Middle to Upper Triassic age (Lum, 1982).

The Gemas Formation has a general north-northwest strike (340^{o}) with moderate to steep dips (>35^{o}) towards both east-northeast and west-southwest. Joints are well developed in all the rock units with bedding data indicating a single phase of folding (Lum, 1982). The joints show variable strikes with steep to vertical dips, though the major set strikes east-northeast. Minor normal and reverse faults with displacements of up to several tens of centimeters are seen in places, while major faults are marked by slickensides, quartz-filled fissures and sheared outcrops (Lum, 1982).

Earthworks for the North-South Highway between Yong Peng and Ayer Hitam in northwest Johor have resulted in several slope cut exposures of the Gemas Formation (Figure 1). At the 27 m high cut between km 81.30 and 81.05 (south-bound) was exposed in the lower two benches, fresh (unaltered), dark grey to black, shales and fine grained sandstones. Overlying the fresh bedrock is some 14 to 18 m of *in situ* moderately to completely weathered shales and sandstones characterized by light grey to white colours (Plate 1). The shales are the predominant lithology with bed thicknesses of 0.5 to

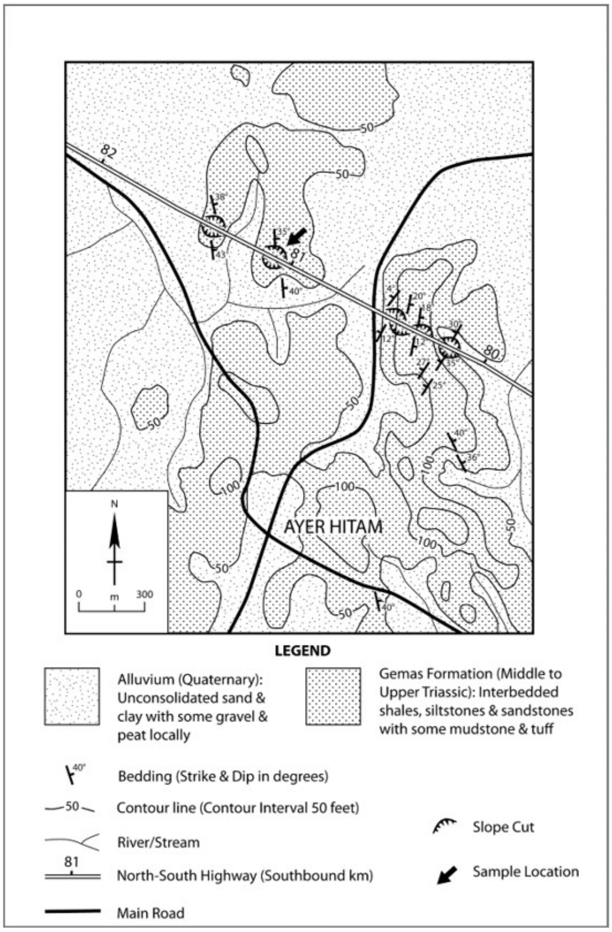

Figure 1: Geology map of the Ayer Hitam area, Johor Darul Takzim. (After Sanisah Binti Ahmad, 1992).

Plate 1: View of shales and sandstones during excavation works.

1.5 m, whilst the fine grained sandstone beds are 0.2 to 1.0 m thick. Joints of variable orientations and lengths are present within the beds which strike about 165°, and dip eastwards at 35° to 43°.

METHODOLOGY

Several large blocks (each about 0.09 m^3 in volume) of fresh (unaltered), dark grey shales and fine sandstone were first collected in the field and taken to the laboratory where they were diamond-sawn into smaller tetrahedral blocks. The visible textural and structural features of each of these blocks was then described before the densities, unit weights and apparent porosities of representative specimens were determined according to the saturation and bouyancy technique described in ISRM (1979) and AIT (1981).

The corners of the tetrahedral blocks were then rounded off, and about ten of them (each weighing about 40 to 60 g) selected to give a total weight of about 400 to 600 g for each test specimen. A total of seven specimens were tested with the slake durability apparatus; five for the dark grey shales (Samples GA and GC) and two for the dark grey, fine grained sandstone (Sample GB).

Each of the specimens (comprising some ten rock 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 will give 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

Densities, unit weights and apparent porosities of representative specimens of the two dark grey shales (Samples GA and GC), and single fine grained sandstone (Sample GB) tested, are shown in Table 1. The dark grey shales have average dry densities of 2,525 kg/m^3, and 2,544 kg/m^3, and average dry unit weights of 24.76 kN/m^3, and 25.42 kN/m^3. The dark grey shales (Samples GA and GC) also have average apparent porosities of 6.8%, and 4.9%, respectively. The dark grey fine grained sandstone has an average dry density 2,533 kg/m^3, an average dry unit weight of 24.83 kN/m^3, and an apparent porosity of 4.8%. The relatively large values of dry density and dry unit weight, as well as low values of apparent porosity, indicate that the fresh (unaltered) shales and sandstone are indurated and dense.

Slake durability indices (Id_2) of the dark grey shales for two standard cycles of wetting and drying are between 99.1% and 99.7%, whilst similar indices (Id_4) for four standard cycles are between 99.0% and 99.5% (Table 2). The slake durability index (Id_5) of one dark grey shale sample for five standard cycles of wetting and drying furthermore, is 99.4% (Table 2). Slake durability indices (Id_2) of the sandstone for two standard cycles of wetting and drying are between 99.2% and 99.3%, while those (Id_4) for four standard cycles are between 98.4% and 98.5% (Table 2).

In view of the slake durability indices for two cycles of wetting and drying (Id_2) exceeding 99.0%, the fresh (unaltered), dark grey shales and fine grained sandstone can be classified as being of "extremely high durability" according to the classification proposed by Franklin & Chandra (1972).

DISCUSSION

It is not surprising that the fresh (unaltered), dark grey shales and fine grained sandstone of the Gemas Formation are of "extremely high durability" in view of their indurated nature as shown by their high densities and unit weights as well as low apparent porosities. The fresh, dark grey shales furthermore, would be classified as being rock-like shales (durable) in terms of the Colorado Department of Transport classification of shales (CDOT, 2015).

Locally published data with which the present results can be compared is that of Azman Kassim & Edy Tonnizam Mohammad (2007) who reported a slake durability index (Id_2) after two cycles of testing of 91.6% for a slightly weathered (Grade II) shale, and between 82.5% and 87.1% for a moderately weathered (Grade III) shale. Though the age of the shales is not known, the reported values compare favorably with the presently determined slake durability index (Id_2) of between 99.1% and 99.7% for fresh (unaltered) shales (Samples GA and GC) from the Gemas Formation. The durability indices (Id_2) of

Table 1: Physical properties of fresh (unaltered) dark grey shales and fine grained sandstone from the Gemas Formation.

Sample Number	Lithology	Dry Density (kg/m^3)	Saturated Density (kg/m^3)	Apparent Porosity (%)	Dry Unit Weight (kN/m^3)	Saturated Unit Weight (kN/m^3)
GA 1a1	Dark grey Shale	2,577	2,642	6.5	25.27	25.91
GA 1a2		2,444	2,519	7.5	23.97	24.70
GA 1d1		2,547	2,611	6.4	24.98	25.61
GA 1e3		2,530	2,599	6.9	24.81	25.49
Mean		2,525	2,593	6.8	24.76	25.43
GC 2a	Dark grey Shale	2,598	2,620	2.3	25.48	25.69
GC 2c		2,533	2,550	1.7	24.84	25.01
GC 2d		2,581	2,653	7.2	25.31	26.02
GC 3b		2,519	2,542	2.3	24.70	24.93
GC 4a		2,529	2,594	6.5	24.80	25.44
GC 4d		2,560	2,624	7.3	25.10	25.73
GC 4h		2,490	2,563	7.3	24.42	25.13
Mean		2,544	2,592	4.9	24.95	25.42
GB 1a	Dark grey, fine grained Sand-stone	2,466	2,539	7.3	24.18	24.90
GB 1d		2,560	2,566	0.6	25.10	25.16
GB 2a		2,545	2,600	5.5	24.96	25.50
GB 2b		2,515	2,554	4.0	24.66	25.05
GB 2c		2,518	2,572	5.4	24.69	25.22
GB 2f		2,536	2,596	6.0	24.87	25.46
GB 3e		2,588	2,634	4.7	25.38	25.83
Mean		2,533	2,580	4.8	24.83	25.30

Table 2: Results of slake durability tests on fresh (unaltered), dark grey shales and fine grained, sandstone from the Gemas Formation.

Sample Number	Lithology	Cycle 1 Slake Durability Index (Id_1)	Cycle 2 Slake Durability Index (Id_2)	Cycle 3 Slake Durability Index (Id_3)	Cycle 4 Slake Durability Index (Id_4)	Cycle 5 Slake Durability Index (Id_5)
GA 1	Dark grey Shale	99.8	99.6	99.6	99.5	-
GA 2		99.9	99.7	99.6	99.5	99.4
GC 1	Dark grey Shale	99.5	99.1	99.1	99.0	-
GC 2		99.8	99.6	99.4	99.2	-
GC 3		99.8	99.6	99.6	99.5	-
GB 1	Dark grey, fine grained Sandstone	99.5	99.2	98.8	98.5	-
GB 2		99.7	99.3	98.7	98.4	-

the fresh (unaltered), shales from the Gemas Formation also compare favorably with the durability index (Id_1) of 92% for a single cycle of wetting and drying reported by Zainab Mohamed *et al.* (2007) for a highly weathered shale from the Kenny Hill Formation.

The slake durability indices (Id_2) of fresh (unaltered), fine grained sandstone from the Gemas Formation of between 99.2% and 99.3% for two standard cycles of wetting and drying, compare favorably with the single cycle durability index (Id_1) of 98% reported by Zainab Mohamed *et al.* (2007) for a slightly weathered sandstone from the Kenny Hill Formation. The slake durability indices (Id_2) of fresh (unaltered), fine grained sandstone from the Gemas Formation also compare favorably with the slake durability index (Id_2) after two cycles of testing of 94.3% for a slightly weathered (Grade II) sandstone, and 79.0% for a moderately weathered (Grade III) sandstone reported by Azman Kassim & Edy Tonnizam (2007).

CONCLUSION

It is concluded that fresh (unaltered), dark grey shales and fine grained sandstones from the Gemas Formation are of "extremely high durability" and suitable for use as highway embankment or construction material (rock fill).

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