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Point load strength of clastic sedimentary rocks from the Semanggol Formation, Beris Dam, Kedah Darul Aman

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Abstract: The Beris Dam is founded on a sequence of thick bedded conglomerates and pebbly to fine grained sandstones with minor mudstone mapped as the Semanggol Formation of Triassic age. The conglomerates have an average dry unit weight of 23.85 kN/m^3, and apparent porosity of 9.8%, whilst the pebbly sandstones have corresponding values of 25.35 kN/m^3, and 3.9%, respectively. Coarse, and medium, grained sandstones have similar apparent porosities of 3.8%, but dry unit weights of 25.33, and 25.36, kN/m^3. Fine grained sandstones, which are laminated, have an average dry unit weight of 25.81 kN/m^3, and apparent porosity of 2.2%.

Diametral tests on air dried core specimens (of 51.6 mm diameter) show them to fail in typical tensile splitting mode, except where inherent fracture or bedding planes are present. The fine grained sandstones split along laminae and yield a point load strength index [$Is_{(50)}$] of 2.44 MPa, whilst the relatively porous conglomerates yield an index of 5.16 MPa. Diametral tests on pebbly sandstones yield a strength index [$Is_{(50)}$] of 6.89 MPa, while those on coarse and medium grained sandstones yield indices of 8.64, and 8.83, MPa, respectively. Decreasing strength indices with increasing particle size are considered to result from the greater surface area of the coarser grains that allows preferential extension of failure crack traces along grain boundaries.

It is concluded that the point load strength of clastic rocks from the Semanggol Formation is influenced by their texture as well as inherent discontinuity planes present.

Keywords: Point load strength, Semanggol Formation, clastic rocks

INTRODUCTION

The point load strength, as described by Broch & Franklin (1972), has gained widespread acceptance as an index test for the strength classification of rock material and as a means of estimating other strength parameters as the uniaxial compressive strength (Bieniawski, 1974; ISRM, 1985; Brook, 1985). Little or no specimen preparation is needed for the test which involves the splitting of rock specimens by application of a concentrated load through a pair of spherically truncated, conical platens. The samples can be in the form of cores (diametral and axial tests), cut blocks (block test) or irregular lumps (irregular lump test).

Experience over the years has shown that there are some short-comings with the accepted practice, including the variability and scatter of test results on anisotropic rock material, the influence of core sample geometry on axial tests, and the correlation of the point load strength index with the uniaxial compressive strength (Forster, 1983). Notwithstanding these short-comings, in view of the absence of meticulous specimen preparation, and the possibility of carrying out the test both in the field and in the laboratory, the point load test is acknowledged to be generally the most convenient test for the strength classification of rock material (Brook, 1985).

The most widely known version of the test involves the diametral testing of rock cores and determination of the point load strength index [$Is_{(50)}$] which is referenced to a core diameter of 50 mm. Where cores with other diameters are tested, a size correction factor needs to be introduced, whilst both shape and size correction factors need to be introduced where specimens with shapes other than cores are tested (ISRM, 1985; Brook, 1985).

In Malaysia, point load strength indices [$Is_{(50)}$] have been reported for several rock types, including marble (Raj, 1992; 2006), Tertiary sedimentary rocks (Raj, 1995); igneous rocks (Raj, 1993; Raj & Nadzmi, 1994; Raj, 1998) and metamorphic rocks (Raj, 2004; Raj & Nadzmi, 2007). Field point load tests on irregular blocks of the Semanggol Formation have been reported by Tajul & Ismail (2003), whilst laboratory point load tests on meta-siltstone and meta-sandstone cores from the Jurong Formation in Singapore are discussed by Li & Wong (2015).

In this short note are presented the results of laboratory point load tests on borehole specimens of clastic sedimentary rocks from the Triassic Semanggol Formation at the Beris Dam in Kedah state. Variations in strength indices [$Is_{(50)}$] are discussed and conclusions reached on the factors influencing the point load strength of rocks from the Semanggol Formation.

GEOLOGICAL SETTING OF SAMPLES

The concrete-faced rockfill Beris Dam is located in the narrow valley of Sungai Beris, some 1.6 km upstream of its confluence with Sungai Muda in Sik District in Kedah state (Figure 1). The dam, which is 40 m high and about 155 m long at its crest, was completed in 2004 and used to regulate flows in the Sungai Muda drainage basin to augment water available for irrigation as well as domestic and industrial water supply and other uses (DID, 2018). The dam has a catchment area of 166 km^2; the reservoir at normal pool level covering an area of 13.7 km^2 and at maximum pool level inundating an area of 16.1 km^2 (Tajul & Ismail, 2003).

The Beris Dam and Reservoir overlie a sequence of thick conglomerates interbedded with fine to coarse and pebbly sandstones with minor mudstones that have been mapped as the Semanggol Formation of Triassic age by the Geological Survey of Malaysia (Teoh, 1992).

Conglomerates predominate at the right abutment and under the main dam, whilst at the left abutment and spillway, the conglomerates are inter-bedded with gritstone and coarse sandstone. The conglomerate, gritstone and sandstone then exposed at the foundation, abutments and spillway, were reported to be slightly to moderately weathered (Grades II - III) (Tajul & Ismail, 2003).

The matrix-supported, polymict conglomerates contain gravel to pebble-sized clasts of dark slate and mudstone, cert, quartz and other rock fragments (possibly volcano-clastics, sandstone and quartzite), whilst the matrix comprises coarse sandy to gritty materials of quartz, feldspar and rock fragments (Tajul & Ismail, 2003). The rocks were reported to be generally hard, compact and well indurated; requiring several blows of the geological hammer for the collection of samples (Tajul & Ismail, 2003).

The gritstones are transitional between the conglomerate and sandstone, and composed of fine gravel to coarse sand grains of quartz, quartzite, sandstone, chert and mudstone as well as other rock fragments. They are grey, hard, compact, and occur as inter-beds in the conglomerate and sandstone. The sandstone is generally a light grey, fine to coarse-grained, hard, compact and well indurated rock. In places, the thick sandstone beds contain shale/mudstone partings (Tajul & Ismail, 2003).

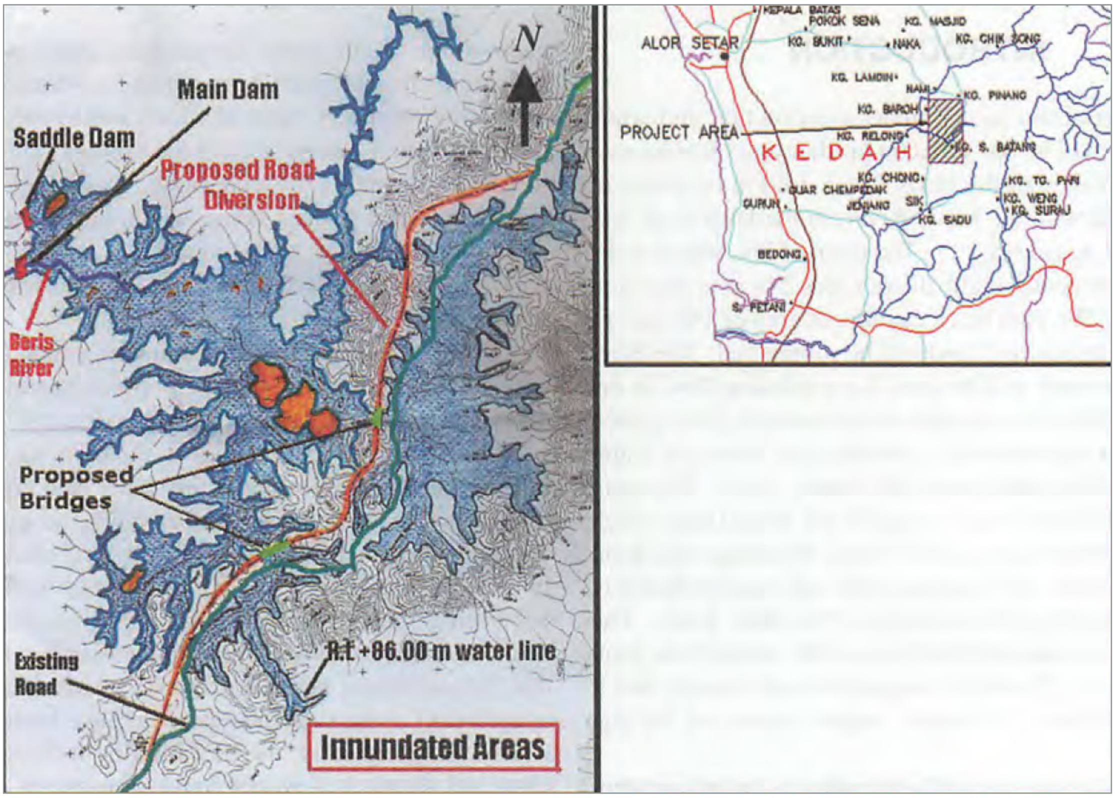

Figure 1: Location of the Beris Dam in Kedah Darul Aman. From Figure 1 in Tajul Anuar Jamaluddin & Ismail Yusoff (2003).

The bedding planes are often not clearly defined due to the thick to massive bedding. At the right abutment, however, bedding planes strike about west to west-southwest with dips of 15° to 30° towards north. At the left abutment, the bedding strikes about east-west with dips of 45° to 52° towards south. The rocks are intensely faulted and jointed with a total of 5 to 6 major joint sets having been identified (Tajul & Ismail, 2003).

Several boreholes were drilled during site investigation works for the Beris Dam and associated structures and some cores were provided to the author for study and determination of their physical properties.

METHODOLOGY

The given cores were first sawn with a diamond blade into smaller specimens and these then air-dried before unit weights, densities and apparent porosities of representative specimens determined according to the saturation and bouyancy procedure of ISRM (1979). The specific gravity of the constituent mineral grains of some specimens was also determined with a pycnometer (RRL, 1952).

The visible textural and structural features of each of the individual specimens were then described and indicated that graded bedding was present in the core samples. Thin-sections were also prepared from representative specimens of different grain sizes to identify their composition and other textural features.

The specimens were then air-dried for a week before being tested with a point load apparatus manufactured by Engineering Laboratory Equipment Limited. Diametral tests were carried out with the core specimens having a diameter of 51.6 mm which is close to the standard reference core diameter of 50 mm. Size corrections were therefore, not carried out in this study.

RESULTS

Petrography of investigated rock materials

The conglomerates and pebbly sandstones are seen in thin-section to be poorly to moderately sorted with clasts of chert, quartz and rock fragments in a finer grained matrix of similar composition. Clasts in the conglomerates are 1 to 6 mm, and the matrix some 0.1 to 0.5 mm, in size, whilst those in the pebbly sandstones are 1 to 4 mm, and the matrix some 0.13 to 0.25 mm, in size. The clasts are sub-angular to angular in shape with the rock fragments including quartz-mica schist, siltstone and sandstone. Both mono-crystalline and poly-crystalline quartz clasts are present with some grains being well rounded.

The medium and coarse grained sandstones are seen in thin-section to be well sorted with angular to sub-angular, and more rarely, rounded, grains of quartz, chert and rock fragments. In the coarse grained sandstone, the grains are some 0.15 to 1.5 mm in size with a mean value of about 0.35 mm, whist in the medium grained sandstone, the grains are 0.1 to 1.5 mm in size with a mean value of 0.25 mm. Opaque mineral grains and heavy minerals including tourmaline and zircon are sometimes seen in the thin-sections.

The fine grained sandstones are seen in thin-section to be distinctly laminated and well sorted with sub-angular to rounded grains of quartz, chert and rock fragments as well as mica flakes. The grains are some 0.06 to 0.5 mm in size with a mean value of 0.15 mm. A few heavy minerals including tourmaline and zircon are sometimes seen in the thin-sections.

Physical properties of investigated rock materials

Laboratory determined dry unit weights show variations with grain size; the conglomerates having the minimum value of 23.85 kN/m^3, and the fine gained sandstones, the maximum value of 25.81 kN/m^3 (Table 1). The pebbly sandstones have an average dry unit weight of 25.35 kN/m^3, whilst the coarse and medium grained sandstones have values of 25.33, and 25.36, kN/m^3, respectively (Table 1). There is a distinct increase in dry unit weight with decreasing grain size; a feature which may be attributed to better compaction in the finer grained sandstones. Values of dry density also show a similar variation with grain size; the conglomerates having the minimum dry density of 2,432 kg/m^3, and the fine gained sandstones, the maximum density of 2,632 kg/m^3 (Table 1).

Laboratory determined apparent porosities also reflect the variations in dry unit weights and densities; the conglomerates having the maximum value of 9.8%, and the fine grained sandstones, the minimum value of 2.2% (Table 1). The pebbly sandstones have an apparent porosity of 3.9%, whilst the coarse and medium grained sandstones have a similar value of 3.8% (Table 1). There is thus a distinct decrease in apparent porosity with decreasing grain size; a feature that again may be attributed to better compaction in the finer grained sandstones.

The specific gravity values of mineral grains in the different specimens show little variation and range between 2.62 and 2.64 (Table 1). This limited variation in values is not unexpected given the closely similar composition of the mineral grains present in the different specimens.

Loads at failure

The tested specimens all display typical tensile failure mode, splitting into two approximately equal halves (Table 2). Most of the breakage surfaces were grey and rough to the touch, though a few were marked by smooth, orange stained surfaces indicating failure along inherent fracture planes. The laminated, fine grained sandstones furthermore, split along inherent bedding planes (laminae), marked by smooth, grey breakage surfaces.

Table 1: Physical properties of core specimens from the Semanggol Formation.

Sample Number	Bulk Unit Weight (kN/m³)	Dry Unit Weight (kN/m³)	Apparent Porosity (%)	Bulk Density (kg/m³)	Dry Density (kg/m³)	Specific Gravity Grains
Conglomerate						
Cgl 1	24.76	23.77	10.1	2,525	2,423	2.64
Cgl 2	24.82	23.87	9.7	2,531	2,434	2.65
Cgl 3	24.85	23.90	9.7	2,534	2,437	2.64
Average	**24.81**	**23.85**	**9.8**	**2,530**	**2,432**	**2.64**
Pebbly Sandstone						
PSst 1	26.02	25.73	3.0	2,653	2,624	2.63
PSst 2	25.44	24.97	4.8	2,594	2,546	2.62
Average	**25.73**	**25.35**	**3.9**	**2,624**	**2,585**	**2.62**
Coarse grained Sandstone						
CSst 1	25.69	25.32	3.7	2,619	2,582	2.62
CSst 2	25.71	25.34	3.8	2,622	2,584	2.62
Average	**25.70**	**25.33**	**3.8**	**2,621**	**2,583**	**2.62**
Medium grained Sandstone						
MSst 1	25.83	25.46	3.7	2,634	2,597	2.63
MSst 2	25.64	25.26	3.9	2,615	2,576	2.62
Average	**25.74**	**25.36**	**3.8**	**2,624**	**2,586**	**2.62**
Fine grained Sandstone						
FSst 1	25.96	25.72	2.4	2,647	2,622	2.64
FSst 2	26.10	25.91	2.0	2,662	2,642	2.63
Average	**26.03**	**25.81**	**2.2**	**2,654**	**2,632**	**2.63**

The influence of inherent discontinuity planes on the loads at failure is unexpected given that the planes represent existing planes of weakness in the rock material. Results of tests where the specimens split along inherent fracture planes were thus discarded as the values are not indicative of failure through the rock material. In the case of the fine grained sandstones, however, the laminae are the over-riding control on failure through the rock material and the loads at failure are the lowest amongst the different clastic rock types (Table 2).

Apart from the influence of inherent discontinuity planes, the loads at failure are also influenced by the texture of the core specimens (Table 2). The relatively porous conglomerate thus shows loads at failure ranging from 11.0 to 16.5 kN, whilst the more dense pebbly sandstone has values between 14.0 and 21.0 kN. The coarse grained sandstone furthermore, shows loads at failure between 20.0 and 24.0 kN, and the medium grained sandstone loads at failure between 20.0 and 27.0 kN (Table 2).

DISCUSSION

Point load strength indices [$Is_{(50)}$]

The point load strength indices [$Is_{(50)}$] that have been determined are dependent upon two main factors, i.e. presence of inherent bedding planes and texture of the specimens. The influence of inherent bedding planes is seen in the fine grained sandstones where failure occurs along laminae (very fine beds <1 cm thick). The fine grained sandstone thus yields a point load index of 2.44 MPa.

The influence of bedding planes is not seen in the other tested specimens which are sampled from thick to massive beds. Li & Wong (2015) in Singapore have also pointed out that failure crack traces in point load tests on meta-siltstones and meta-sandstones of the Triassic Jurong Formation were mostly independent of bedding orientation. This independence, however, was considered to result from low-grade metamorphism which tended to "fuse" the bedding and thus offer a higher strength. The existing bedding planes therefore, no longer served as the preferential planes of weakness as experienced in many sedimentary rocks (Li & Wong, 2015).

Texture refers to the size, shape and arrangement of the constituent discrete grains or particles in a sedimentary rock and is a factor that can be expected to influence the development of the failure crack trace during point load tests. In the present tests, there can be seen an increase in the point load strength index [$Is_{(50)}$] with decreasing grain size. The conglomerates yield an index of 5.16 MPa, whilst the pebbly sandstones have a value of 6.89 MPa.

Table 2: Results of diametral point load tests on core specimens from the Semanggol Formation.

Sample Number	Load at Failure (kN)	Strength Index ($Is_{(50)}$) (MPa)	Comments on Test
Conglomerate			
Cgl C	11.0	4.12	Split in 2 along irregular surface - Good
Cgl 2	14.0	5.26	Split in 2 along irregular surface - Good
Cgl B	13.5	5.07	Split in 2 along irregular surface - Good
Cgl E	16.5	6.20	Split in 2 along irregular surface - Good
Average	-	**5.16**	
Cgl 1	10.0	3.76	Split in 2 along fracture plane - Not good
Cgl A	6.00	2.25	Split in 2 along fracture plane - Not good
Cgl D	5.05	1.90	Split in 2 along fracture plane - Not good
Pebbly Sandstone			
PSst 1	14.0	5.26	Split in 2 along irregular surface - Good
PSst 2	20.0	7.51	Split in 2 along irregular surface - Good
PSst 3	21.0	7.89	Split in 2 along irregular surface - Good
Average	-	**6.89**	
PSst 4	8.0	3.00	Split in 2 along fracture plane - Not good
Coarse grained Sandstone			
CSst 1	24.0	9.01	Split in 3 along irregular surfaces - Good
CSst 2	22.0	8.26	Split in 3 along irregular surfaces - Good
CSst 3	20.0	7.51	Split in 2 along irregular surface - Good
Average	-	**8.64**	
CSst 4	15.0	5.63	Split in 2 along fracture plane - Not good
Medium grained Sandstone			
MSst 1	20.0	7.51	Split in 2 along irregular surface - Good
MSst 2	27.0	10.14	Split in 2 along irregular surface - Good
MSst 3	25.0	9.39	Split in 2 along irregular surface - Good
Average	-	**8.83**	
MSst 4	16.0	6.01	Split in 2 along fracture plane - Not good
MSst 5	11.0	4.13	Chipped - Not good
Fine grained Sandstone			
FSst 1	7.00	2.63	Split in 2 along bedding plane - Good
FSst 2	6.50	2.44	Split in 2 along bedding plane - Good
FSst 3	6.00	2.25	Split in 2 along bedding plane - Good
Average	-	**2.44**	
FSst 4	4.70	1.77	Chipped - Not good

The coarse, and medium, grained sandstones furthermore, yield strength indices of 8.64, and 8.83, MPa, respectively.

The increase in strength index with decreasing grain size is considered to result from differences in the surface areas of the constituent grains. The larger grains present in the conglomerate and pebbly sandstone have relatively greater surface areas in comparison with those of the coarse and medium grained sandstones. As the composition of the constituent grains is closely similar, the extension of failure crack traces during application of loads is thus likely to follow grain boundaries. The greater surface areas of the coarser grains will therefore, allow for preferential extension of failure crack traces along grain boundaries.

The point load strength indices [$Is_{(50)}$] of between 4.12 and 7.91 MPa (Table 2) for conglomerate and pebbly sandstone in the present tests are comparable with the corrected indices [$Is_{(50)}$] of between 2.32 and 6.43 MPa, with an average value of 3.63 MPa determined in the field on mainly conglomerates then exposed at the

Table 3: Strength classification of core specimens from the Semanggol Formation based on point load strength indices ($Is_{(50)}$).

Sample Number	Strength Index ($Is_{(50)}$) (MPa)	Strength Classification (After Bieniawski, 1974)
Conglomerate		
Cgl C	4.12	High Strength
Cgl 2	5.25	High Strength
Cgl B	5.07	High Strength
Cgl E	6.20	High Strength
Pebbly Sandstone		
PSst 1	5.26	High Strength
PSst 2	7.51	High Strength
PSst 3	7.89	High Strength
Coarse grained Sandstone		
CSst 1	9.01	Very High Strength
CSst 2	8.26	Very High Strength
CSst 3	7.51	High Strength
Medium grained Sandstone		
MSst 1	7.51	High Strength
MSst 2	10.14	Very High Strength
MSst 3	9.39	Very High Strength
Fine grained Sandstone		
FSst 1	2.63	Medium Strength
FSst 2	2.44	Medium Strength
FSst 3	2.25	Medium Strength

abutments during construction of the Beris Dam (Tajul & Yusoff, 2003). Similar tests on irregular blocks of conglomerate and sandstone then exposed at the Spillway walls furthermore, yielded corrected point load strength indices [$Is_{(50)}$] of between 1.57 and 8.71 MPa, with an average value of 4.28 MPa (Tajul & Ismail, 2003).

In Singapore, point load tests on meta-siltstones, and meta-sandstones, of the time equivalent Jurong Formation have yielded average point load strength indices [$Is_{(50)}$] of 9.38, and 12.84 MPa, respectively (Li & Wong, 2015). The strength indices [$Is_{(50)}$)] furthermore, ranged from 6.70 to 10.24 MPa in the case of the meta-siltstones and from 10.60 to 15.02 MPa in the case of the meta-sandstones. These strength indices are higher than those determined in the present study, though this is to be expected as the rocks have experienced low grade regional metamorphism.

Rock strength classification

Bieniawski (1974) considered the point load strength index [$Is_{(50)}$] to be a quick and reliable means for the strength classification of rock materials and proposed a classification based on their unconfined compressive strength (UCS) and point load strength index [$Is_{(50)}$]. In terms of this classification, the clastic rocks from the Semanggol Formation show variations with texture, the fine grained sandstones being of 'medium strength' whilst the conglomerates and pebbly sandstones are of 'high strength'. The medium and coarse grained sandstones are of 'high' to 'very high' strengths.

Rock samples from the left and right abutments of the Muda Dam during construction were reported to be slightly and moderately weathered (Grade II-III) with point load tests showing them to be "strong to very strong" rocks (Tajul & Ismail, 2003). Rock samples collected randomly from the spillway walls were also reported to be slightly and moderately weathered (Grades II - III) with point load tests indicating them to be "medium strong to very strong" rocks (Tajul & Ismail, 2003).

CONCLUSIONS

It is concluded that determination of the point load strength of clastic rocks from the Semanggol Formation is influenced by their texture as well as inherent discontinuity planes. Conglomerates with an average dry unit weight of 23.85 kN/m^3, and apparent porosity of 9.9%, are characterized by a point load strength index [$Is_{(50)}$] of 5.13 MPa. Pebbly sandstones with an average dry density of 25.35 kN/m^3, and apparent porosity of 3.9%, are characterized by a point load strength index [$Is_{(50)}$] of 6.89 MPa. Coarse, and medium, grained sandstones have similar average apparent porosities of 3.8%, but dry unit weights of 25.33, and 25.36, kN/m, and are characterized by point load strength indices [$Is_{(50)}$] of 8.64, and 8.83, MPa, respectively. Fine grained sandstones, which are laminated, with an average dry unit weight of 25.81 kN/m^3, and apparent porosity of 2.2%, split along inherent bedding planes and yield a point load strength index $Is_{(50)}$] of 2.44 MPa.

Decreasing strength indices with increasing particle size are considered to reflect the greater surface areas of the coarser grains that allow preferential extension of failure crack traces along grain boundaries.

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