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Point load strengths of Tertiary sedimentary rocks from the Batu Arang area, Peninsular Malaysia

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ABSTRACT Tertiary sedimentary rocks comprising silty to sandy shales interbedded with thin structureless clay layers, fine to coarse grained sandstones and a number of lignite seams are found in the Batu Arang area. Field point load tests on silty to sandy shales from three stratigraphic levels with moisture contents of 18.9, 14.3 and 10.3 % yield strength indices of 0.15, 0.30 and 0.52 MPa. These indices reflect variations in moisture contents as air dried samples with a moisture content of 0.8 % from the different levels yield a strength index of 1.40 MPa. A similar variation with moisture content is shown by the thin clay interbeds which yield strength indices of 0.07 and 0.88 MPa at moisture contents of 14.9 and 1.9 %. Field point load tests on blocks of the lignite seams yield strength indices ranging from 0.24 to 1.60 MPa, the range reflecting a decrease of strength owing to the influence of inherent fractures with increasing sample size. Point load strengths of the Tertiary silty to sandy shales and clay interbeds are thus dependent upon moisture content, whereas those of the lignite seams are dependent upon sample size.

ABSTRAK Di Batu Arang terdapat batuan sedimen berusia Tertiar terdiri daripada syal berlodak ke berpasir yang saling berlapis dengan lapisan-lapisan nipis lumpur tanpa struktur, batupasir berbutir halus ke kasar dan beberapa lipit lignit. Ujian-ujian beban titik di lapangan ke atas syal berlodak ke berpasir dari tiga aras stratigrafik dengan kandungan air 18.9, 14.3 dan 10.3 % memberi indeks-indeks kekuatan 0.15, 0.30 dan 0.52 MPa. Indeks-indeks ini mencerminkan perbezaan kandungan air kerana sampel-sampel kering dengan kandungan air 0.8 % dari tiga aras stratigrafik menunjukkan indeks kekuatan 1.40 MPa. Perbezaan dengan kandungan air yang sama ditunjukkan oleh lapisan-lapisan nipis lumpur yang memberi indeks kekuatan 0.07 dan 0.88 MPa pada kandungan air 14.9 dan 1.9 %. Ujian-ujian beban titik di lapangan ke atas bungkah-bungkah lipit lignit memberi indeks-indeks kekuatan yang berjulat dari 0.24 sehingga 1.60 MPa; julat ini menunjukkan kekurangan kekuatan dengan peningkatan saiz sampel akibat pengaruhan retakan-retakan yang sedia ada. Kekuatan beban titik syal berlodak ke berpasir dan lapisan-lapisan lumpur yang tersaling lapis adalah bergantung kepada kandungan air, semasa kekuatan beban titik lipit-lipit lignit bergantung kepada saiz sampel.

INTRODUCTION

The Point Load Strength [1] has gained widespread acceptance as an index test for the strength classification of rock material and as a means of estimating other strength parameters such as the uniaxial compressive strength [2, 3]. Little or no specimen preparation is needed for this test which involves the splitting of rock samples by application of a concentrated load through a pair of spherically truncated, conical platens. In this paper are presented the results of field and laboratory point load tests that have been carried out on Tertiary sedimentary rocks exposed in the Batu Arang area. Variations in the point load strength indices (IS_{50}) of the different strata are also discussed.

STUDY AREA - GENERAL GEOLOGY

The Tertiary sediments at Batu Arang (Fig. 1) form a roughly triangular basin encompassing an area of about 15 km^2 and lie unconformably on much older and steeply dipping metasediments which consist mainly of quartzites [4-6]. They are also unconformably overlain by a thick sequence of semi-consolidated, sandy to gravelly and bouldery sediments of a likely Pleistocene age. The Tertiary sediments proper, called the Batu Arang Beds [7] or the Coal Measures [8, 9], have a maximum recorded thickness of 265 m in the centre of the basin, but along the eastern and northern sides, are only some 183 to 244 m thick. The sediments consist mainly of silty to sandy shales that are commonly carbonaceous, structureless clay layers and fine grained sandstones as well as thin beds and lenses of coarser grained sandstone and some lignite seams.

The fine grained sediments range from stiff, structureless clays to well laminated and fissile shales with abundant carbonaceous matter, both in a finely disseminated form and as discrete plant fragments. The shales are often silty and even sandy and grade into clayey sandstone in places. The interbedded sandstones are mostly fine grained, though ranging up to coarse grained and even pebbly with colours of white to various shades of brown, depending upon the amount of carbonaceous matter.

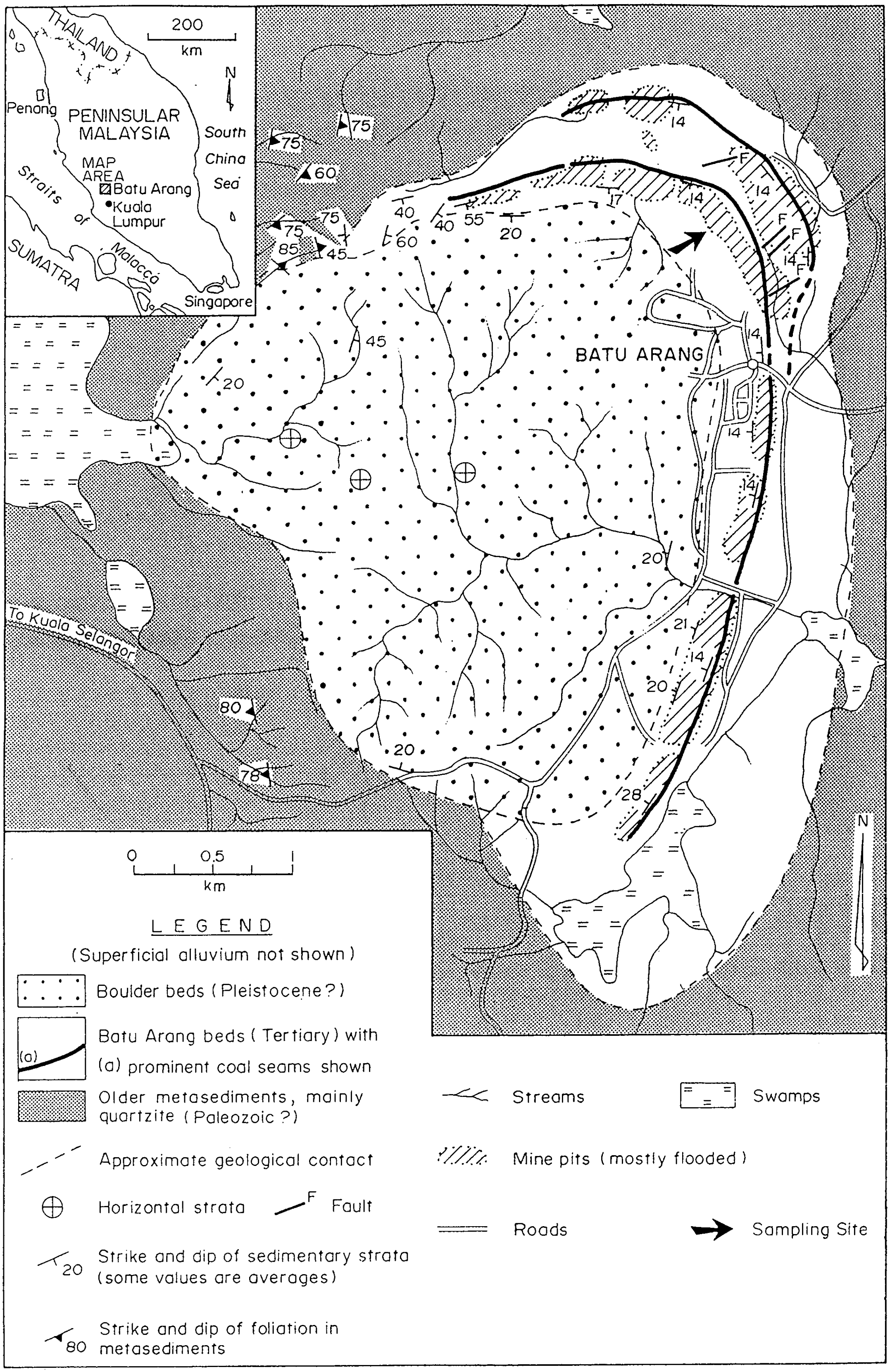

Figure 1. Geological sketch map of the batu arang area.

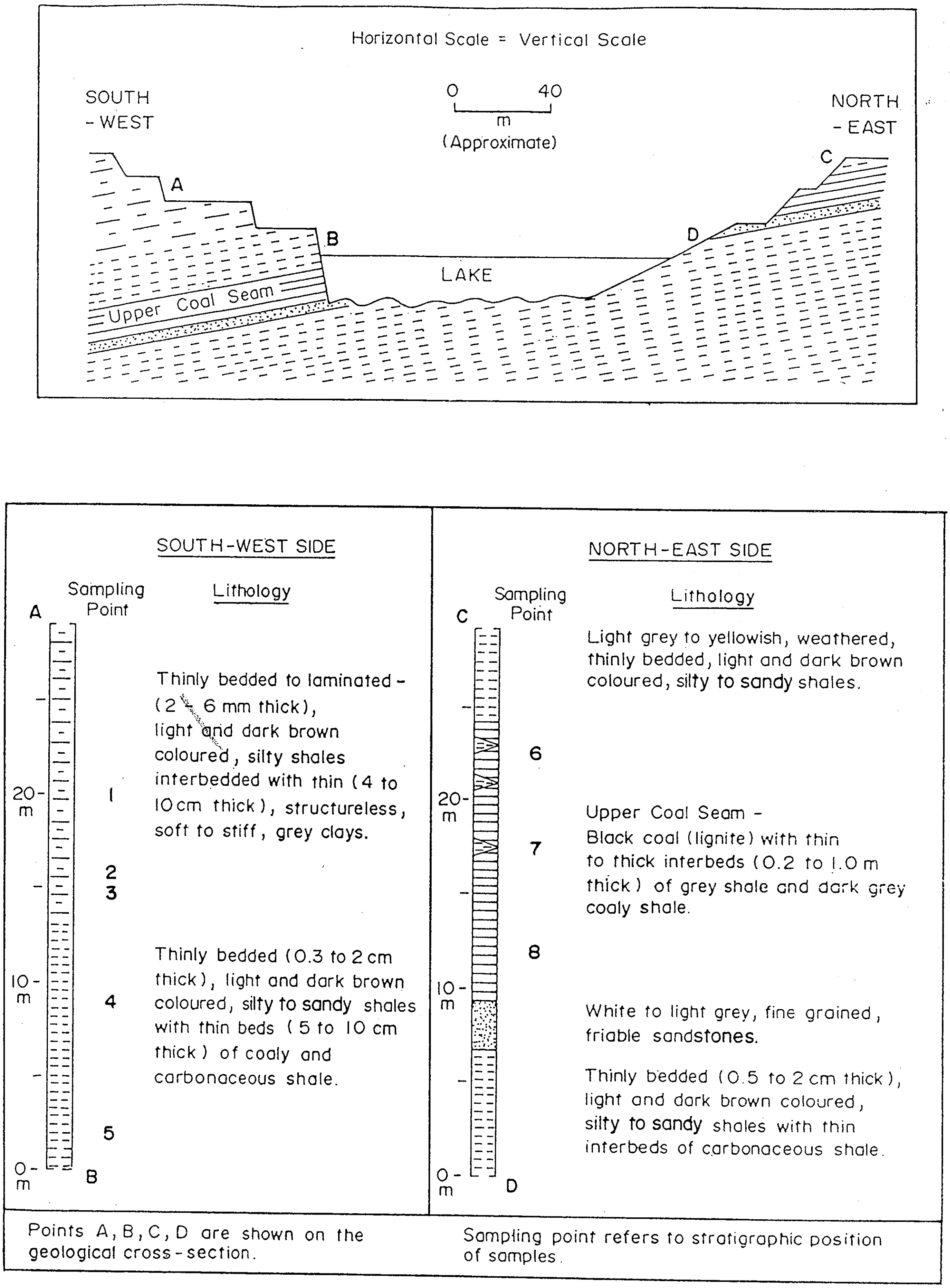

Figure 2. Geological cross – section and stratigraphic position of sampling points.

The coal occurs mostly as thin laminae or streaks in dark shales, but also builds thicker layers of more than 30 cm. In the eastern part of the basin, two thick coal seams are found as well as several thin beds of coal and coaly shale. The two thick seams are some 65 m stratigraphically apart, the upper seam being up to 15 m and the lower seam averaging 8 m. The coal, which is intermediate between high-grade lignite and sub-bituminous coal, is a hard, black rock with a reisinous lustre and a tendency towards conchoidal fracture.

Fossil leaves and other plant fragments within the coal-bearing sediments suggest the sediments to be Late Tertiary or younger in age [8], while palynomorph assemblages indicate that the coals are of a probable Oligocene to Eocene age, deposited in a lacustrine environment under seasonal climatic conditions [10].

The Tertiary sediments show a synclinal structure plunging southwestwards, though this is considered to reflect the basin of deposition, rather than tectonic activity. 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 (0.03 to 0.06 m).

METHOD OF STUDY

Field and laboratory point load tests were carried out in order to estimate the strengths of the different strata. Sampling points were, however, restricted to accessible sites within an open-cast pit where excavation was actively being carried out. Blocks of exposed bedrock materials were collected from a number of sampling sites, these sites varying in stratigraphic position within the exposed sequence of Tertiary rocks (Fig. 2).

The field tests were carried out by collecting and trimming small blocks from the open-cast slope faces before testing them at field moisture contents with an ELE Point Load Test Apparatus. Small samples were also collected from the different sampling points at the time of testing for determination of the field mositure contents. Densities and porosities [11, 12] of these samples are listed in Table 1. A few large blocks were also collected for point load tests in the laboratory, though they were air dried for three weeks before being trimmed and tested.

RESULTS AND DISCUSSION

Results of the field point load tests are shown in Tables 2 and 3 and the results of the laboratory tests in Table 4. As expected, the uncorrected point load strengths show a wide range of values varying not only with the size of the samples, but also with the stratigraphic position of sampling points. The corrected strength indices (Table 5) furthermore, show several interesting features, including the fact that different indices have been determined for similar materials.

Table 1. Physical properties of tertiary sedimentary rocks from Batu Arang.

Sample number	Dry density kg/cu.m.	Saturated density kg/cu.m	Porosity %	Rock type
A-1	1,503	1,868	34.6	Silty to sandy shales
A-2	1,459	1,802	36.6	
A-3	1,474	1,819	35.9	
A-4	1,581	1,918	31.3	
A-5	1,582	1,909	31.2	
A-6	1,550	1,876	32.6	
B-1	1,730	1,978	24.8	Structure-less clays
B-2	1,686	1,953	26.7	
B-3	1,679	1,949	27.0	
C-1	1,289			Upper coal seam lignite
C-2	1,289			
C-3	1,288			
C-4	1,281			

In the case of the silty to sandy shales, the corrected strength indices of field tests show a slight increase up the stratigraphic section (Fig. 3 and Table 5), though exactly similar rock materials have been tested. Variations in these indices reflect differences in moisture contents as the driest samples tested in the laboratory show the highest values and the most moist samples (close to the lake surface) tested in the field showing the lowest value. Variation of the strength index with moisture content is, however, not linear as there is a rapid decrease of strength with a small increase in moisture content (Fig. 5), as reported by other workers [13-15].

The structureless clay interbeds also show a variation of strength with moisture content, with the corrected strength indices of laboratory tests being much greater than those of the field tests (Fig. 4 and Table 5). This variation of the strength index

Table 2. Physical properties of tertiary sedimentary rocks from Batu Arang.

Sample Number	Length mm	Breadth mm	Height mm	Eqlt. core diameter squared sq. mm.	Eqlt. core diameter mm.	Load at failure kN	Load at failure lbf	Uncorrected point load strength MPa
			Sampling point No. 1 – damp, structureless, grey clay					
3a	120	50	45	2,864	53.5	0.20	50	0.070
3b	80	50	55	3,500	59.2	0.25	50	0.071
3c	90	80	52	5,295	72.8	0.30	60	0.057
3d	90	70	42	3,742	61.2	0.25	50	0.067
3e	90	70	50	4,455	66.7	0.30	60	0.067
			Sampling point No. 2 – slightly moist, silty to sandy shale					
4a	90	90	50	5,727	75.7	2.40	530	0.419
4b	80	60	40	3,055	55.3	1.50	340	0.491
4c	110	80	53	5,396	73.5	2.30	520	0.426
5a	120	90	55	6,300	79.4	2.60	590	0.413
5b	110	80	52	5,295	72.8	2.30	600	0.434
5c	80	70	49	4,366	66.1	2.00	450	0.458
5d	100	100	52	6,618	81.4	2.70	660	0.408
			Sampling point No. 3 – slightly moist, silty to sandy shale					
2a	100	75	33	3,150	56.1	1.50	340	0.476
2b	80	80	32	2,749	52.4	1.40	320	0.509
2c	110	80	32	3,258	57.1	1.60	360	0.491
2d	90	70	30	2,851	53.4	1.50	340	0.526
2e	90	60	30	2,291	47.9	1.20	270	0.524
2f	80	70	32	2,851	53.4	1.40	320	0.491
2g	80	60	33	2,520	50.2	1.30	300	0.516
2h	100	80	30	3,055	55.3	1.50	340	0.491
2i	100	80	31	3,156	56.2	1.60	360	0.507
			Sampling point No. 4 – moist, silty to sandy shale					
1bi	140	90	35	4,009	63.3	1.10	255	0.274
1bii	140	80	36	3,666	60.5	1.00	230	0.273
1f	90	90	60	6,873	82.9	1.70	380	0.247
1i	90	75	45	4,296	65.5	1.40	320	0.326
1m	80	48	45	2,749	52.4	0.80	190	0.291
			Sampling point No. 5 – damp, silty to sandy shale					
1a	105	90	50	5,727	75.7	0.80	180	0.140
1c	90	80	50	5,091	71.4	0.70	160	0.137
1d	80	70	31	2,762	52.6	0.40	100	0.145
1e	115	90	56	6,415	80.1	0.90	210	0.140
1f	90	60	55	4,200	64.8	0.60	140	0.143

Table 3. Uncorrected point load strengths of coal (lignite) samples from Batu Arang (field determinations – block smples tested perpendicular to bedding).

Sample Number	Length mm	Breadth mm	Height mm	Eqlt. core diameter squared sq. mm.	Eqlt. core diameter mm.	Load at failure kN	Load at failure lbf	Uncorrected point load strength MPa
				Sampling point No. 6 – upper part of upper coal seam				
7a	80	60	34	2,596	51.0	0.60	140	0.231
7b	100	60	47	3,589	59.9	0.80	180	0.632
7c	100	30	27	1,031	32.1	0.80	180	0.776
7d	100	60	29	2,215	47.1	1.40	320	0.632
7e	70	50	27	1,718	41.5	1.20	260	0.698
				Sampling point No. 7 – middle part of upper coal seam				
9c	50	33	35	1,470	38.3	0.60	140	0.408
9g	110	50	50	3,182	56.4	0.75	190	0.236
9h	60	25	25	795	28.2	1.30	300	1.634
9i	40	29	27	997	31.6	0.70	165	0.702
9j	80	48	48	2,932	54.2	0.70	165	0.239
9k	60	26	26	860	29.3	1.50	340	1.743
9l	85	43	43	2,353	48.5	0.55	125	0.234
9m	65	35	35	1,559	39.5	0.65	150	0.417
10b	75	46	46	2,693	51.9	1.00	220	0.371
10c	70	29	29	1,070	32.7	1.80	400	1.682
10e	70	46	43	2,518	50.2	0.95	210	0.377
10f	90	50	50	3,182	56.4	1.20	265	0.377
10g	100	50	50	3,182	56.4	1.90	420	0.597
10h	100	55	55	3,850	62.0	0.90	210	0.234
10i	65	28	28	998	31.6	1.70	380	1.704
				Sampling point No. 8 – lower part of upper coal seam				
6b	140	70	77	6,860	82.8	1.40	320	0.204
6c	100	60	63	4,811	69.4	1.60	360	0.333
6f	80	50	42	2,673	51.7	1.70	380	0.636
6h	100	85	78	8,438	91.9	1.70	380	0.201

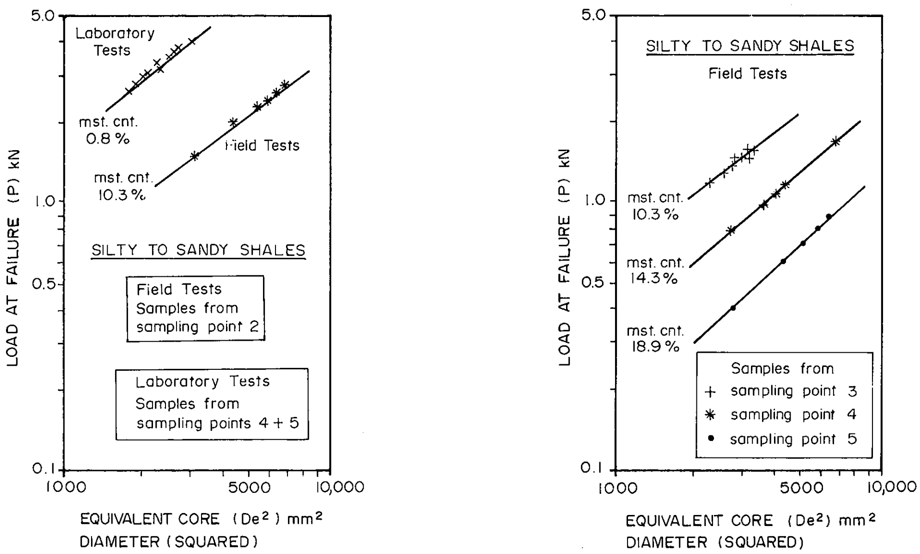

Figure 3. Log-log plots of loads at failure (P) versus squares of equivalent core diameters (De^2) of point load tests on block samples of thinly bedded, silty to sandy shales.

Table 4. Uncorrected point load strengths of tertiary sedimentary rocks from batu arang (laboratory determinations – smples tested perpendicular to bedding).

Sample Number	Length mm	Breadth mm	Height mm	Eqlt. core diameter squared sq. mm.	Eqlt. core diameter mm.	Load at failure kN	Load at failure lbf	Uncorrected point load strength MPa
		Samples from sampling point No. 1 – structureless, grey clay – air dried one month						
C1	93	60	38	2,902	53.9	2.50	570	0.862
C2	123	97	34	4,198	64.8	3.30	740	0.786
C3	75	50	30	1,909	43.7	1.80	400	0.943
C5	97	105	35	4,677	68.4	3.50	795	0.748
C6	118	80	38	3,869	62.2	3.00	680	0.775
C7	80	82	35	3,653	60.4	3.00	680	0.821
C8	53	50	30	1,909	43.7	1.90	420	0.995
C9	70	64	34	2,770	52.6	2.30	520	0.830
C10	70	55	33	2,310	48.1	2.25	510	0.974
C11	110	55	33	2,275	47.7	2.10	470	0.923
C12	80	50	40	2,546	50.5	2.30	520	0.904
		Samples from sampling point No. 4 – silty to sandy shale – air dried one month						
B1	105	90	23	2,635	51.3	3.80	850	1.442
B2	100	90	23	2,635	51.3	3.60	790	1.366
B3	73	60	23	1,756	41.9	2.65	640	1.509
B4	130	65	24	1,985	44.6	2.95	660	1.486
B5	90	80	25	2,546	50.5	3.70	840	1.454
		Samples from sampling point No. 5 – silty to sandy shale – air dried one month						
A1	75	70	24	2,094	45.8	3.10	700	1.481
A2	125	65	25	2,068	45.5	3.10	700	1.499
A3	105	80	22	2,240	47.3	3.35	750	1.496
A4	90	75	24	2,291	47.9	3.20	720	1.397
A5	110	90	26	2,978	54.6	4.00	900	1.343
A6	100	85	23	2,488	49.9	3.50	750	1.407
A7	90	60	24	1,833	42.8	2.80	625	1.528

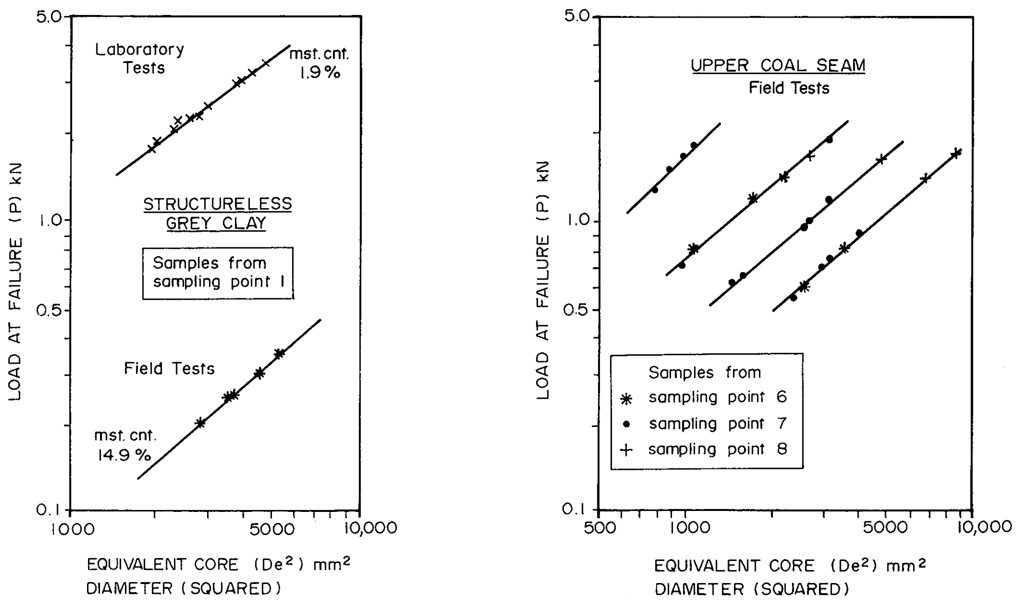

Figure 4. Log plots of loads at failure (P) versus squares of equivalent core diameters (De^2) of point load tests on block samples of structureless grey clay and upper coal seam.

Table 5. Point load strength indices of tertiary sedimentary rocks from Batu Arang (samples tested perpendicular bedding).

Sampling point	Description	Testing conditions	Moisture content %	Point load strength index MPa
1	Structureless, soft to stiff, grey clay	Laboratory	1.90	0.880
		Field	14.90	0.072
2	Thinly bedded, light & dark brow coloured, silty to sandy shale	Field	10.30	0.520
3		Field	10.30	0.520
4		Laboratory	0.80	1.400
4		Field	14.30	0.300
5		Laboratory	0.80	1.400
5		Field	18.90	0.152

Table 6. Variation of point load strength indices with block sizes of coal samples from Batu Arang.

Point load strength index MPa	Relevent range of equivalent core diameters (squared) sq. mm
1.600	600 to 1,100
0.640	900 to 3,000
0.380	1,400 to 5,000
0.236	2,000 to 9,000

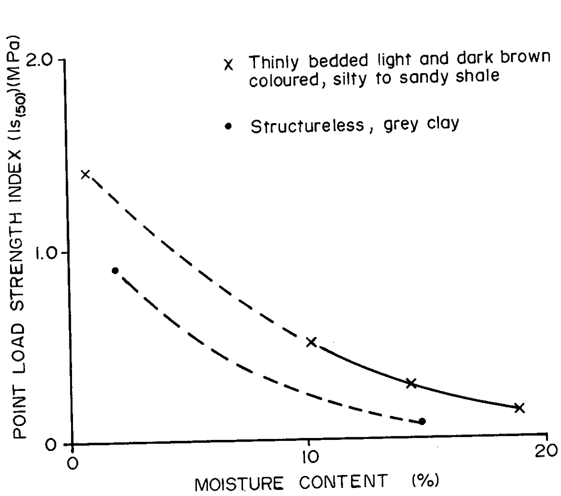

Figure 5. Point load strength index versus moisture content.

with differences in moisture content is, however, not distinct as only two sets of samples were tested, though a plot suggests a similar relationship to that shown by the silty to sandy shales (Fig. 5).

Plots of the loads at failure of the field tests on the coal samples against the squares of their equivalent core diameters show a wide scatter of points and a number of lines can be drawn to link the different points (Fig. 4). Extrapolation of the loads corresponding to an equivalent core diameter of 50 mm gives a number of corrected point load strength indices (Fig. 4 and Table 6) that reflect the influence of sample size, as the spacing of fractures in the coal seams influences their behaviour in compression. Plots of the uncorrected point load strengths versus the squares of equivalent core diameters (Fig. 6) also tend to an asymptotic value beyond a core diameter of about 50 mm, with samples of an equivalent core diameter of less than 25 mm showing the highest strengths. This feature coincides with the spacing of the joints in the coal seams of between 0.02 and 0.06 mm. This influence of sample size on the strength of coal has also been pointed

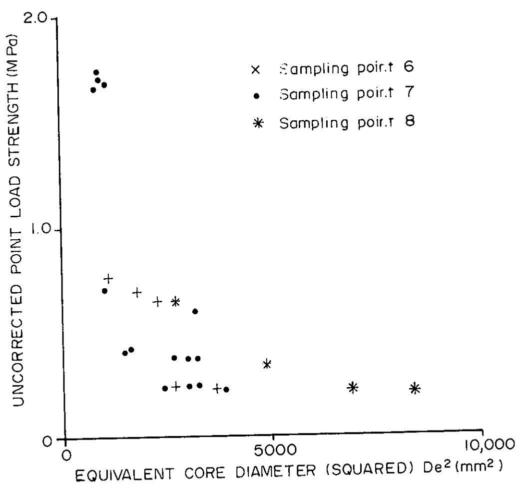

Figure 6. Uncorrected point load strength versus equivalent core diameter (squared) of coal (lignite) samples.

out by other workers who have shown that the strength of coal decreases with increasing size of cubic specimens and tends to an asymptotic value at a specimen size of about 1.5 m [16] or about 100 cm [17] partly because of discontinuities.

It is concluded that the point load strength indices of the Tertiary silty to sandy shales and clay interbeds at Batu Arang are dependent upon the moisture content of tested samples, while those of the lignite seams are dependent upon sample size.

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