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Preliminary studies on the correlation of index properties and engineering properties of Malaysian rocks.

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Abstract: Ten different rocks obtained as drill cores from various localities in Malaysia were tested in the laboratory for their index and engineering properties. The rock properties investigated include the dry density, the Shore scleroscope hardness, the point load strength index and the unconfined compressive strength. An attempt is then made to correlate these properties so as to enable one to predict the unconfined compressive strengths of rocks based on the results of the more easily carried out index tests (such as the Shore hardness and/or point load tests).

The various test methods are also discussed briefly, including the effect of the variation of sample length/diameter ratio in the point load test.

INTRODUCTION

In spite of the numerous construction projects that have been carried out in the past decade and those that are presently in progress throughout the country, little data or information on the engineering properties of Malaysian rocks have been published or made available to the general public. The purpose of the present studies is to gather systematically data on the engineering properties of Malaysian rocks by carrying out a series of laboratory tests on the various rocks in Malaysia. The ultimate, long-term objective is to initiate or stimulate the preparation of engineering geologic maps which are currently non-existent in Malaysia. Such engineering-geologic maps, when available, will be of great usefulness to the construction and civil industries.

Since most engineering property tests such as the unconfined compression test, the triaxial test, etc, are rather elaborate and time consuming and involve tedious specimen preparations, an attempt is also made to correlate index properties of rocks to their engineering properties. An index property is defined here as a physical or mechanical property of the rock whose determination can be carried out relatively easily, and yet bears a significant relationship to the engineering properties of the rock. Index properties are thus indicators of engineering properties, and the correlation between the two, when properly established (Deere, 1966), can be used to predict engineering properties of the rock.

ROCK PROPERTIES INVESTIGATED

Ten different rocks (including granite, limestone, marble, sandstone and a volcanic rock) obtained as drill cores from various localities in Malaysia were tested in the laboratory for their index and engineering properties. The rock properties investigated include the dry density, the Shore scleroscope hardness, the point load strength index and the unconfined compressive strength. The testing programme will be extended to include other rock properties such as the modulus of elasticity, Poisson's ratio, dynamic properties (sonic velocity test) and studies on the anisotropy of the rock.

Dry Density, γd

The dry density was determined by directly measuring the volume and weight of the cylindrical specimens. Specimens were air-dried, and average values for two or three specimens taken.

Shore Scleroscope Hardness, Hd

The hardness test follows that recommended by the International Society of Rock Mechanics (ISRM) (Atkinson, 1977). The scleroscope hardness was determined by using the Model C-2 Scleroscope manufactured by the Shore Instrument Mfg. Co., Jamaica, New York, U.S.A. (Plate 1). The instrument measures the height of elastic rebound of a small diamond-pointed hammer (diameter 5.94 mm, weight = 2.30 gms) dropped vertically onto the polished test surface. The hammer falls from a height of 25 cm and rebounds within a close-bore glass tube. The height of rebound is read from a scale of 0–140 divisions. The rebound of the hammer varies in proportion to the hardness of the material tested, the harder the material, the higher the rebound.

Readings were taken for each of the two polished ends of the core along four separate diameters (four readings per diameter and one reading at centre) making a total of 34 end readings per specimen. The hardness value was taken as the average of these 34 readings. Readings were also taken along the sides of the core but since the sides of drill cores tend to be rough and pitted, they consistently gave lower hardness values and were thus discarded.

The scleroscope was checked periodically with two steel standards (Hardness values of 89–91 and 24–26) supplied by the manufacturer.

Point Load Strength Index, Is

The point load strength index was determined using a Model RM-730 Rock Point Load Tester manufactured by Soiltest Inc., Evanston, Illinois, U.S.A. The apparatus comprises a 10,000 kg hydraulic ram with 5.4 cm stroke and hand pump mounted in a rigid and compact load frame of 5000 kg capacity (Plate 2). The core specimens are compressed diametrally at midlength between two pointed conical platens of standard dimensions till failure. Specimen diameter is read directly on a scale attached to the upper platen assembly, while failure load is measured by an attached pressure gauge. The point load strength index (Is) is given by:

$$Is = P/D^2 \text{ kg/cm}^2$$

where P = pressure gauge reading in kg at failure,
D = diameter of sample in cm.

If P is expressed in Newtons and D in mm, then Is is expressed in Mega Pascals (MPa). Average readings of 3-5 specimens were taken. The advantage of this method is that specimens are merely cut to proper length and do not require machining or polishing before testing. Also, the failure load is about 1/10 of that for compression tests.

The effect of the variation of length/diameter ratio was studied for two rocks by testing cores of different lengths.

In accordance with the recommendations made by the International Society for Rock Mechanics (Bieniawski & Franklin, 1972), the point load strength index was also corrected for a standard reference core diameter of 50 mm using the correction chart

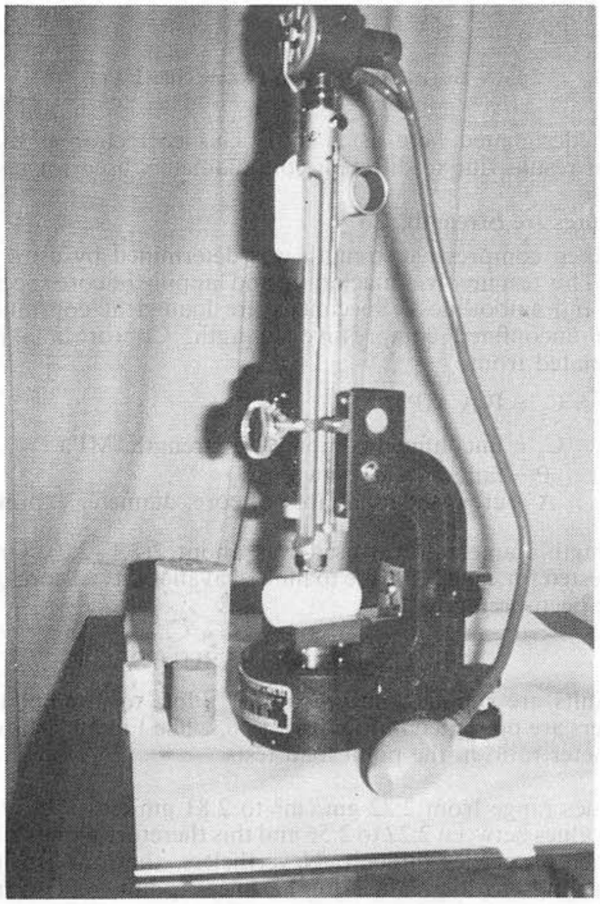

Plate 1. The Shore Scleroscope. (Diameter of core in test position = 28 mm)

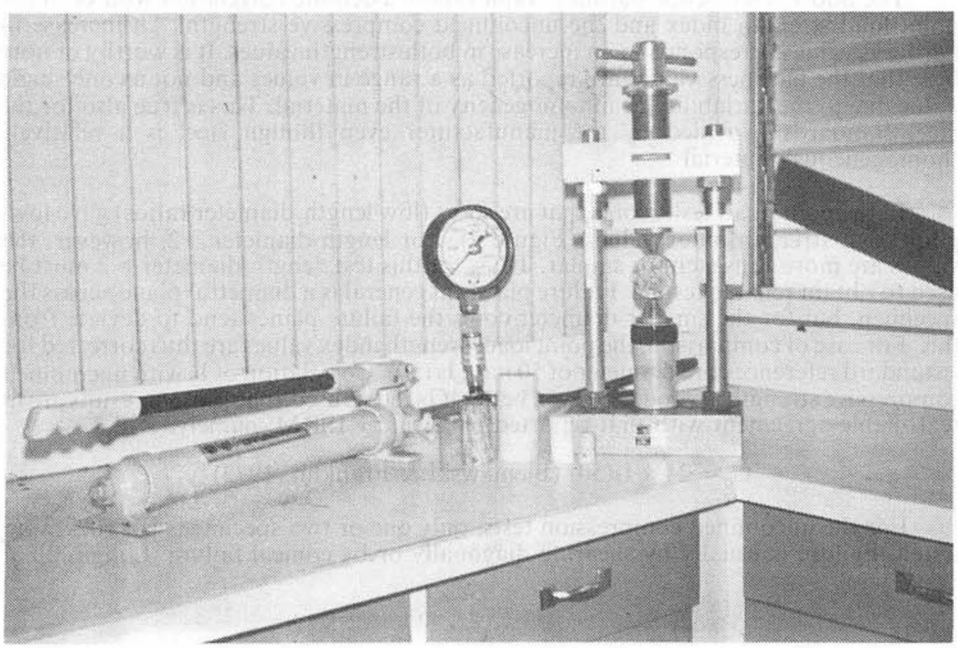

Plate 2. The Point-load Strength Tester (Diameter of core in test position = 54 mm)

given by ISRM, designated here as Is (50). This correction is made to remove differences in test results due to different core diameters used for testing.

Unconfined Compressive Strength, Co

The unconfined compressive strength was determined by using a compression testing machine. This test involves machining and lapping of core specimens to obtain end parallelism and smoothness. Specimens are loaded at constant stress rate to failure, and the unconfined compressive strength. Co (or uniaxial compressive strength) is calculated from

$$C_0 = P/A \text{ MPa}$$

where C_0 = unconfined compressive strength, MPa
P = failure load, Newtons
A = cross-sectional area of core; diameter expressed in mm.

The core length/diameter ratio used was about 2(2.1–2.2). Only one or two specimens were tested for each rock due to limited availability of cores, although more tests would have been preferable.

DISCUSSION OF RESULTS

The test results are summarised in Table 1. Plots to attempt to correlate the various parameters are presented in Figures 1 to 6, while Figure 7 shows the effects of core length/diameter ratio in the point load tests.

Density values range from 2.22 gm/cm^3 to 2.81 gm/cm^3. Unfortunately, a gap exists in density values between 2.22 to 2.56 and this therefore makes correlation of dry density with other properties difficult. Nevertheless, the low density value of the sandstone corresponds to low values for hardness, point load strength index and unconfined compressive strength.

The Shore scleroscope hardness values show a definite correlation with both the point load strength index and the unconfined compressive strength. An increase in hardness value corresponds to an increase in both strength values. It is worthy of note here that the hardness values are reported as a range in values and not as one single value due to the variability or inhomogeneity of the material. This is true also for the steel standards provided by the manufacturer even though steel is a relatively 'homogeneous' material.

In the point load tests, cores that are short (low length/diameter ratios) gave low-point load strength index values (Figure 7). For length/diameter $\geqslant 2$, however, the values are more consistent or similar. Thus, for this test, length/diameter $\geqslant 2$ must be used to obtain reliable results. Failure planes in general is a diametral plane across the specimen, but for the smaller diameter cores the failure planes tend to deviate from this. For ease of comparison, the point load strength index values are thus corrected for a standard reference core diameter of 50 mm, Is (50). Correlation of Is with unconfined compressive strength is good, and even better if Is (50) is used. The present results are in reasonable agreement with that reported or given by ISRM, namely:

$$C_0 = 24 \times \text{Is}(50) \text{ (Bieniawski \& Franklin, 1972)}$$

For the unconfined compression tests, only one or two specimens per rock were tested. Failure is usually by shearing diagonally or by conical failure. Longitudinal

TABLE 1.

SUMMARY OF RESULTS

Rock No.	Lithology	γd (g/cm³)	Hd	Is (MPa)	Is (50) (MPa)	Co (MPa)
1	Sandstone, red, fine grained, homogeneous	2.22	12–16	1.42	1.1	21.41
2	Limestone, grey, fine grained with calcite veinlets	2.69	42–43	5.62	4.9	197.71 109.23
3	Limestone, dark grey, fine grained & banded	2.72	42–43	6.06	5.4	98.39
4	Marble, white, fine grained, homogeneous	2.68	46–52	7.33	5.2	118.52
5	Marble, white, fine grained, homogeneous	2.70	36–37	6.71	4.9	65.61
6	Marble, white, fine grained homogeneous	2.81	35–37	6.17	4.6	164.39
7	Granite, medium grained, homogeneous	2.57	63–64	10.23	5.5	132.98
8	Granite, medium grained, homogeneous	2.56	63–64	17.93	9.0	100.67
9	Granite, coarse grained, with calcite vein	2.61	87–92	9.79	10.1	62.13
10	Volcanic rock (metadasite), grey, fine grained with 2 mm pyroclasts.	2.67	50–52	13.46	7.1	171.15

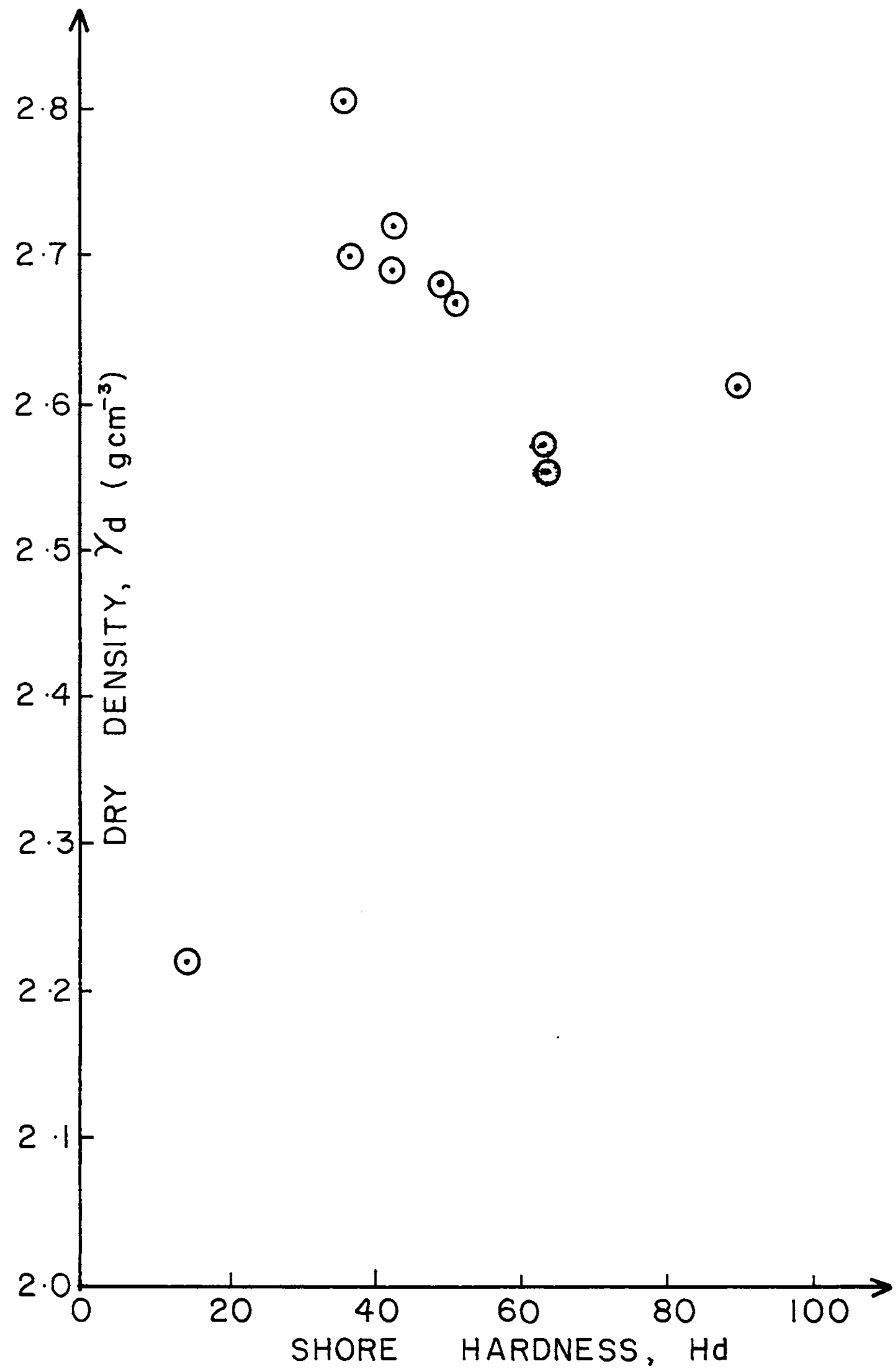

Fig. 1. Correlation of dry density, γd, with Shore scleroscope hardness, Hd.

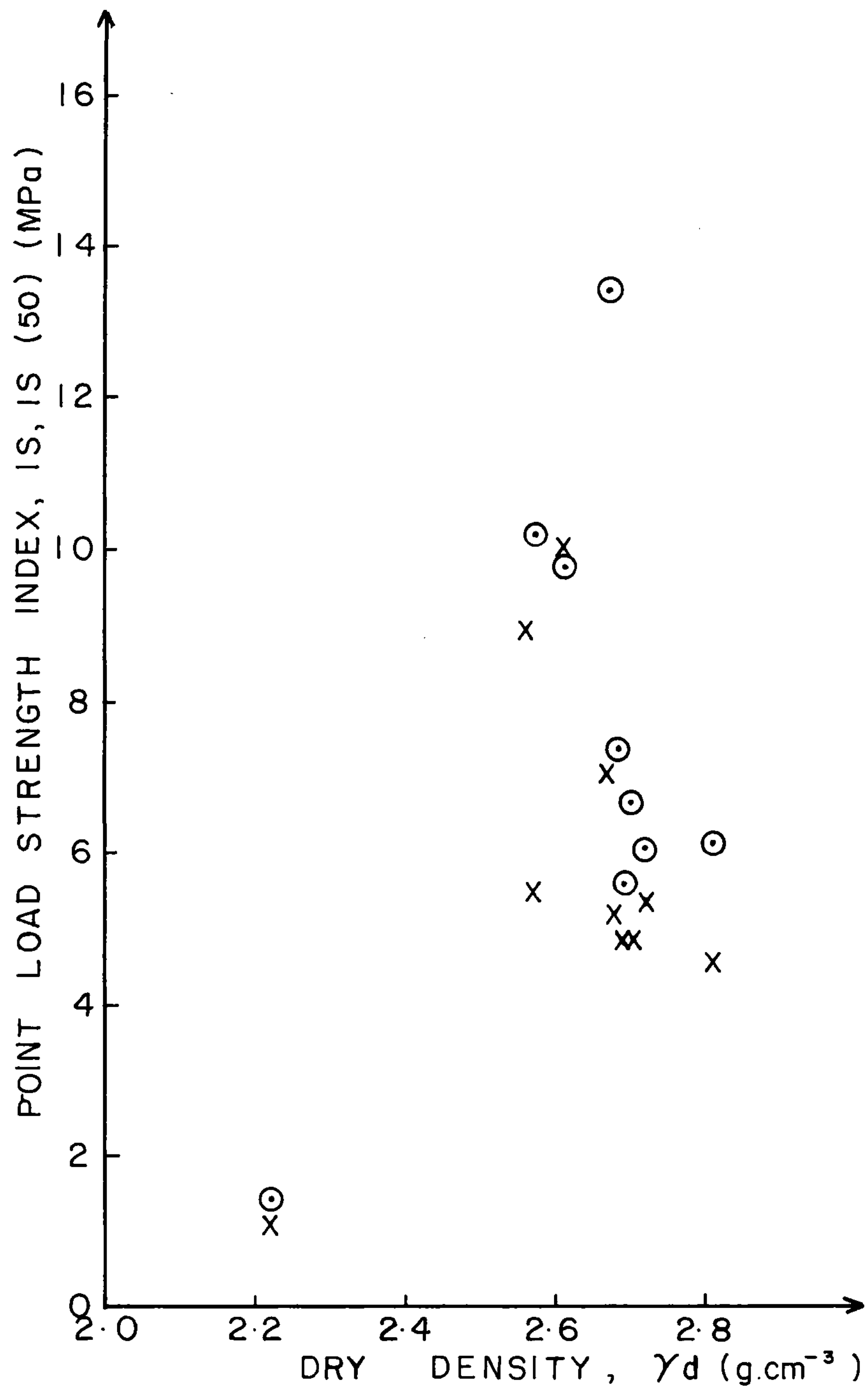

Fig. 2. Correlation of point load strength index, Is & Is (50), with dry density, γd.

⊙ = Is
X = Is (50)

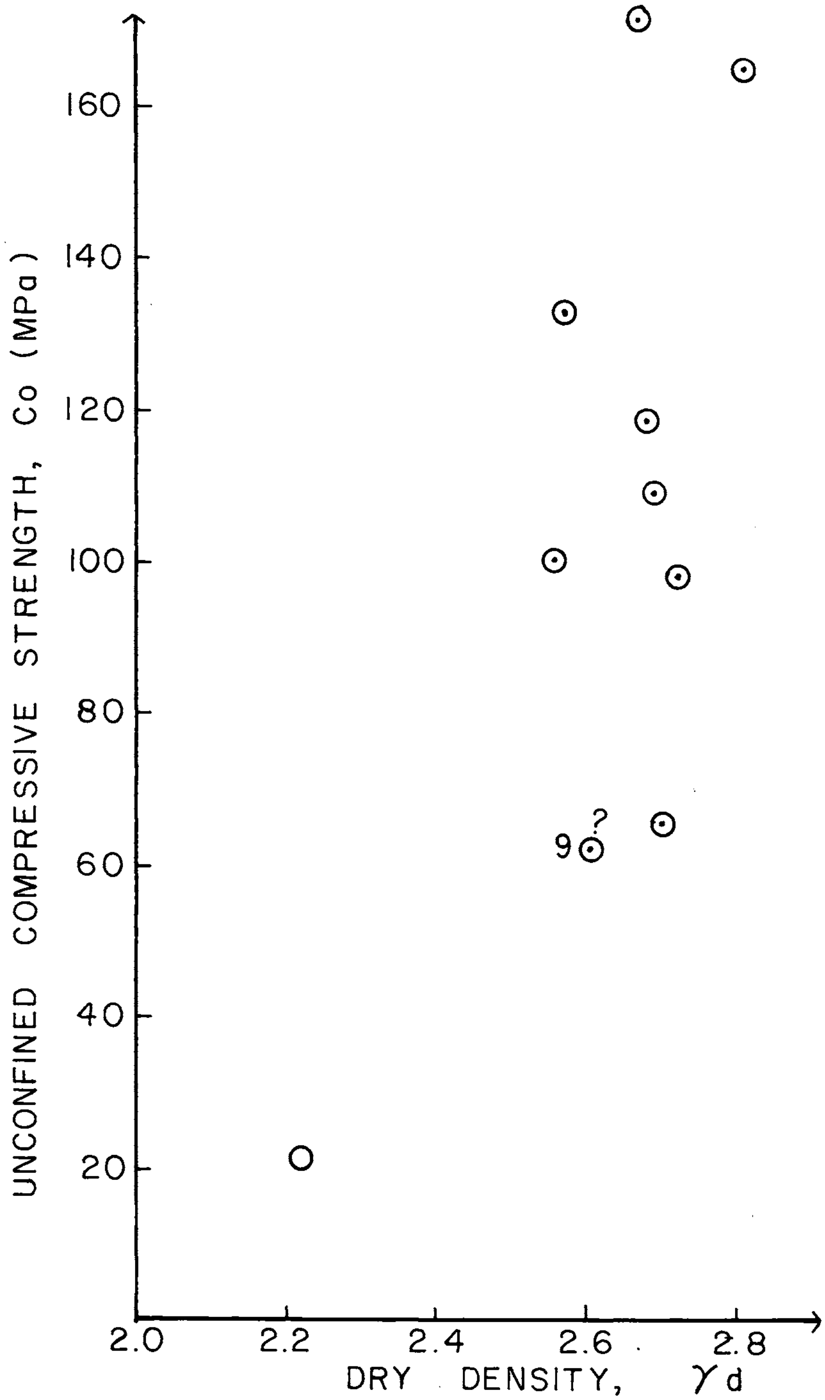

Fig. 3. Correlation of unconfined compressive strength, Co, with dry density, γd. (Rock No. 9, coarse-grained granite, failure along pre-existing vein)

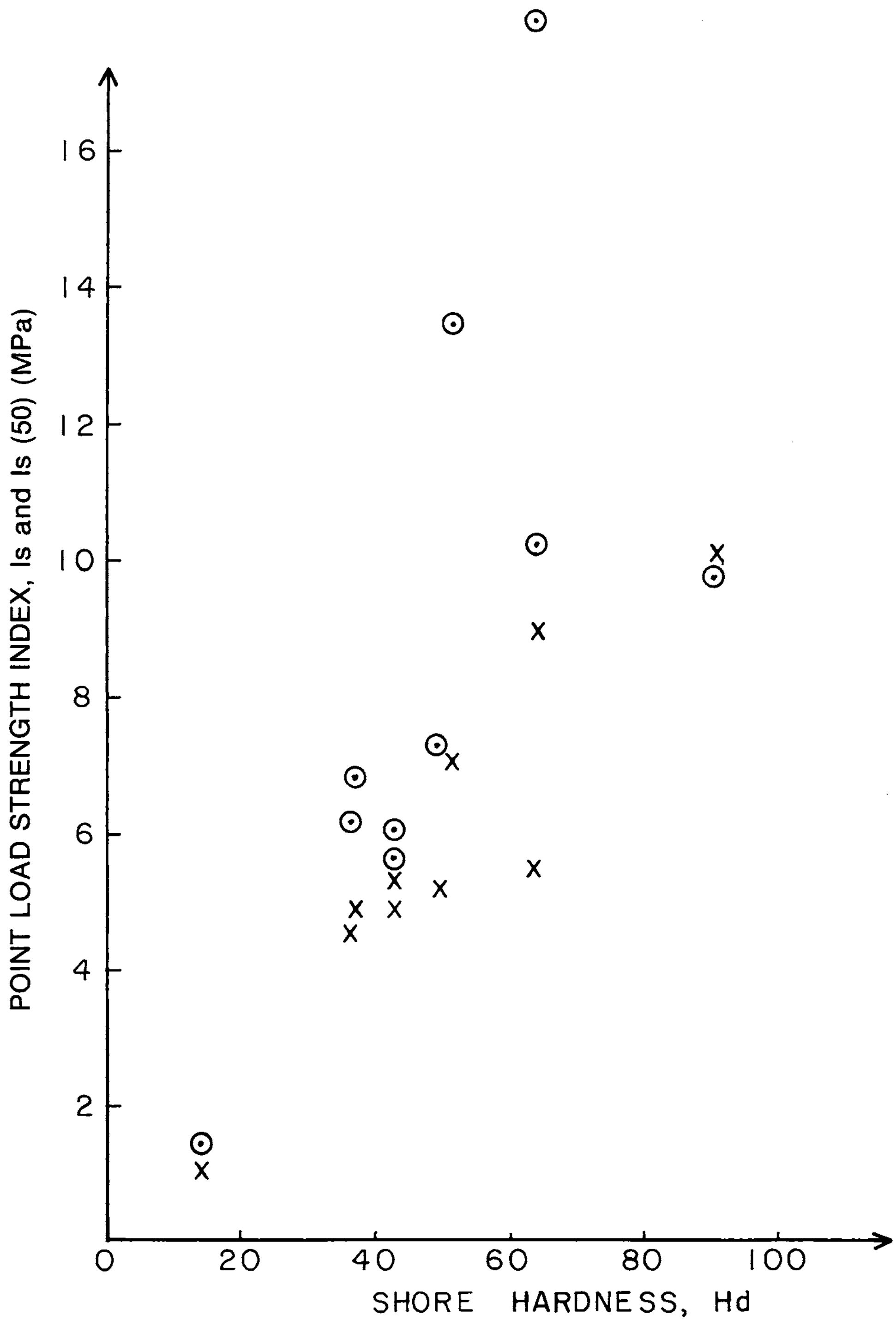

Fig. 4. Correlation of point load strength index, Is & Is (50), with Shore scleroscope hardness, Hd.

⊙ = Is
X = Is (50)

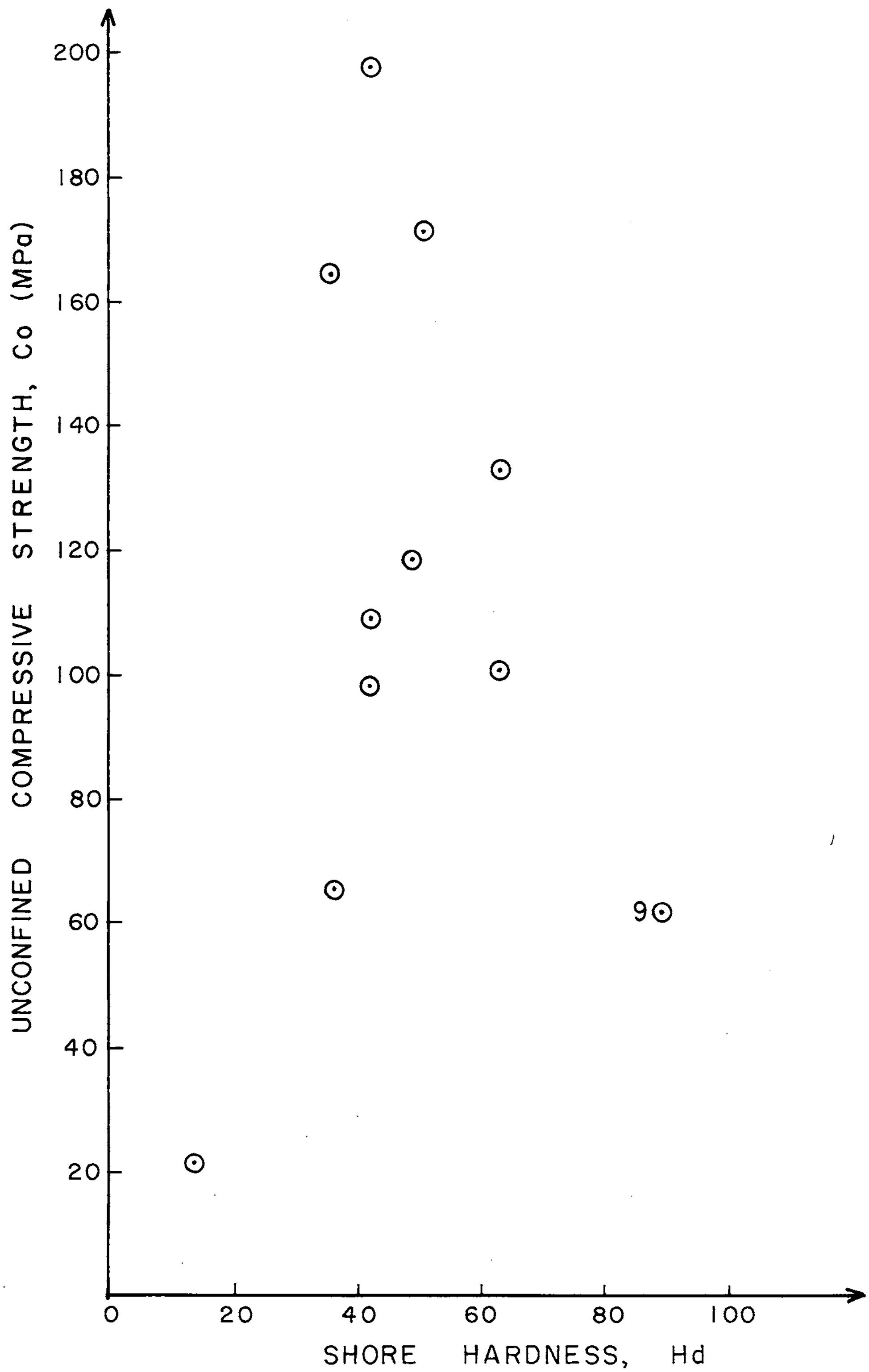

Fig. 5. Correlation of unconfined compressive strength, Co, with Shore scleroscope hardness, Hd. (Rock No. 9, coarse-grained granite, failure along pre-existing vein)

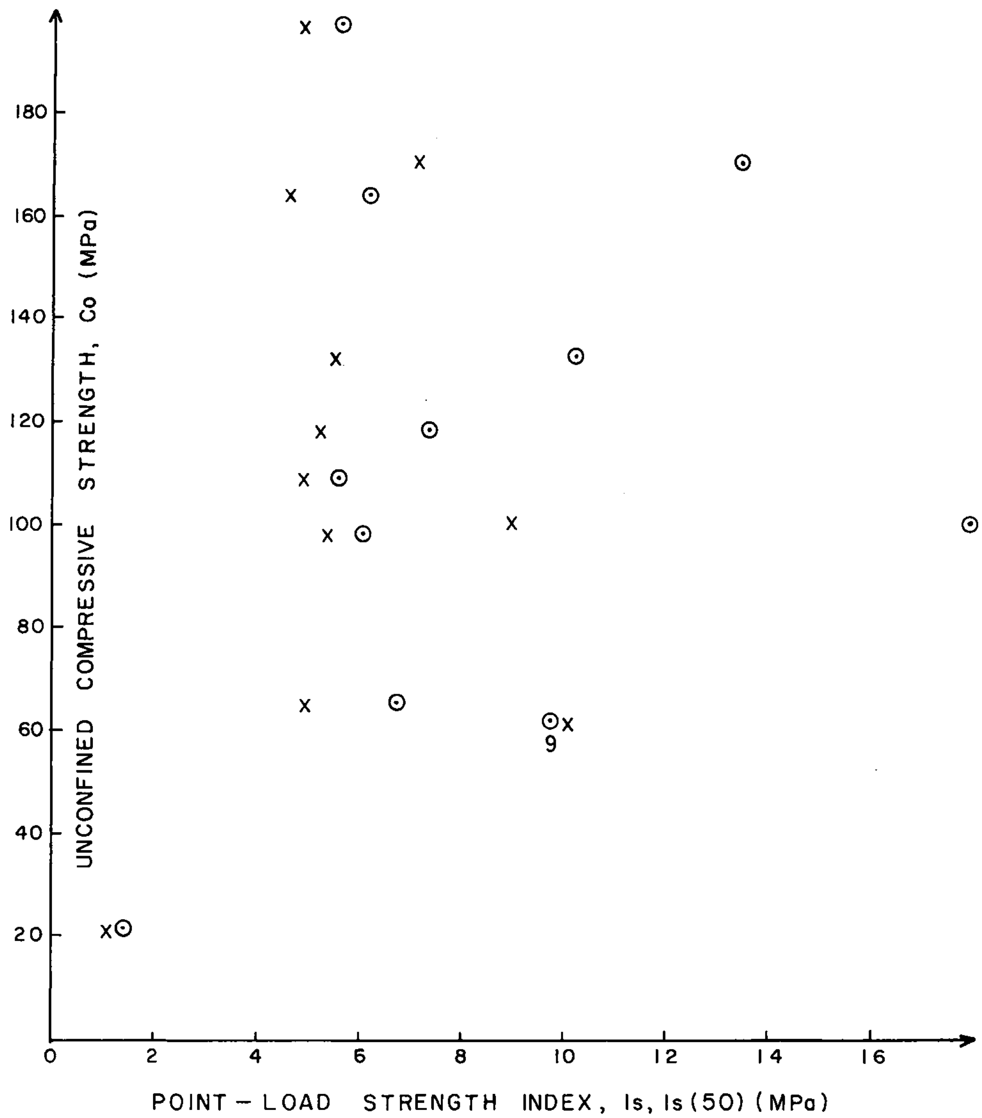

Fig. 6. Correlation of unconfined compressive strength, Co, with point load strength index, Is & Is (50).

⊙ = Is
X = Is (50)

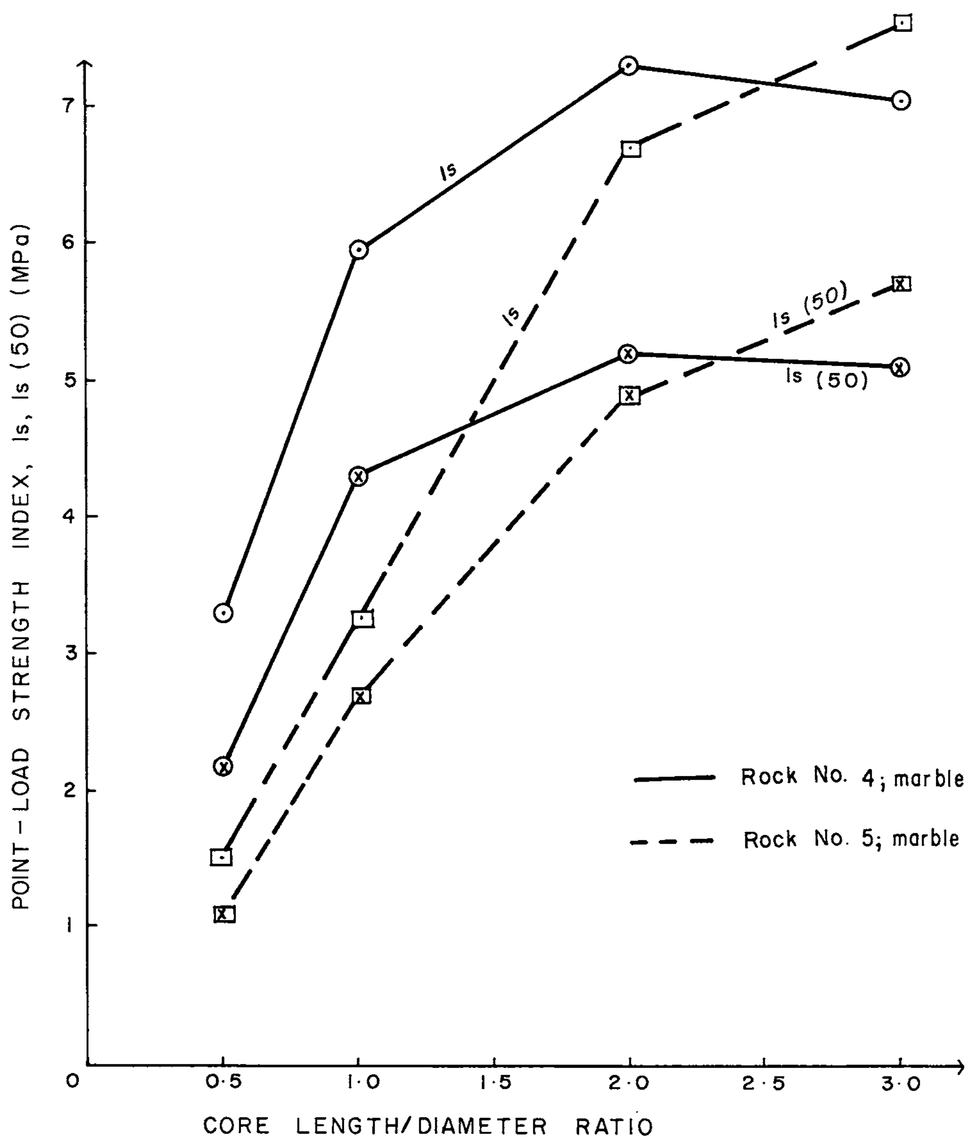

Fig. 7. Effect of core length/diameter ratio on the point load strength tests.

failure occurs also following pre-existing planes of weakness as in Rock Number 3 (banded limestone). In one case (Rock Number 9, coarse grained granite), failure occured along a calcite vein thus giving lower strength values than expected.

CONCLUSIONS

Of the four rock properties investigated, definite correlations can be made among the Shore scleroscope hardness, point load strength index and unconfined compressive strength. However, more tests are needed to develop a better correlation through statistical or regression analysis.

The results for point-load and unconfined compressive tests are affected by the core length/diameter ratio. Length/diameter ratios of $\geqslant 2$ are thus required for more consistent results, and preferably core diameters of about 50 mm should be used for these tests. Inhomogeneity or anisotropy of specimens should be considered as they tend to affect the strength values obtained, as shown by compression test results of the banded limestone (Rock No. 3) and the coarse-grained granite (Rock No. 9). These factors will be considered further in future studies.

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