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Classification of excavated material based on simple laboratory testings

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Abstract: During the past decade the norm of contract specification on earthwork is to classify the method of excavation based on two category of materials, either soil or rock. The problem arises from an unclassified intermediate material which does not fit the description as documented in the contract specification. Failure to address this problem in the contract document may result in delays and an increased in project cost is unavoidable.

Four types of tests were proposed to assess the engineering properties of the material which are related to mode of excavation. The tests comprise of physical property test, Schmidt rebound hammer test, sonic velocity test and point-load test. The engineering properties derived from these tests may be used as a basis for argument that the material being excavated exhibits similar engineering behaviour as rock.

Data obtained from these tests were plotted against standard charts used by construction machinery supplier and the plotted values may serve as guidelines in selecting the suitable method of excavation.

INTRODUCTION

There is no dispute between contractor and client if the material excavated consists of rock, e.g. granite, limestone and sandstone. Depending on the method of excavation used, the contractor can claim for the rate of ripping or blasting, as long as the volume and nature of the rock material agree with the specification on excavation as stated in the tender document.

However, disagreement is inevitable if the materials encountered during excavation comprise of hard-pan and cap-rock (duricrust), because these materials cannot be classified as rock based on their mode of origin. Experiences show that excavation of hard pan may involve ripping. Normally, geological names and descriptions provide little information (to the client/engineer) on the engineering behaviours of the materials. The client prefers numerical values or parameters which represent the engineering properties of the excavated material and give some indication on the degree of difficulty for excavation. Under such circumstances the contractor has to convince the client that the excavated materials exhibit engineering behaviours similar to rock.

As far as excavation work is concerned, these parameters include compressive strength, hardness, seismic property and some other related physical properties such as density and unit weight (Caterpillar, 1991). Simple laboratory testings are available to determine these parameters and the results can be used as guideline in assessing the rippability of the excavated material.

In the following paragraphs, recommendations are made on the types of test that can be employed and methods of assessment of test results. The findings enclosed herewith are based on series of tests conducted on hard-pan.

The objective of this study is also to recommend additional conditions to be added to the existing specification for excavation and also as an initial step towards a more detailed and elaborate investigation.

GENERAL CLASSIFICATION OF EARTHWORK MATERIALS

Generally, specification in the document of contract classifies excavated materials as 'Rock' or 'Soft Materials'. Usually, 'Rock' is defined as those geological strata indicated in the contract to be regarded as such and individual boulders exceeding certain size (in the range of 0.4–0.5 m^3) or other masses of hard material outside those strata which necessitate the use of blasting or approved pneumatic tools for their removal or by other rock quarrying methods. Most specification does not qualify hard material in term of its strength or other engineering parameters related to excavation.

Materials other than stated above is classified as soft materials which shall be excavated by using any excavation equipments, e.g. backhoe, bulldozer, hydraulic excavator etc.

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Intermediate materials which do not fit the description and require different technique of excavation, as compared to soft soil, should be considered as an additional classification of excavated materials.

The importance of classifying these intermediate materials is to reduce problems faced by the parties involved in the construction industry (Farmer, 1983).

COLLECTION AND PREPARATION OF SAMPLES

Samples for laboratory investigation consist of hardpan were collected from Pasir Gudang, Johor. Figure 1 exhibits the general view of hard pan formation found at the site. As far as excavation is concerned, the sampling procedures must include geological information of the site, location, relative quantity in the site and other pertinent information.

Block of samples collected were classified into six groups S1, S2, S3, S4, S5 and S6.

Samples were trimmed to suitable size using water-cooled, diamond-tipped masonry disk cutter. Prepared specimens were cubical in shape with the dimensions of 50 x 50 x 100 mm (Fig. 2).

Observation made during samples preparation did indicate the degree of hardness and cementation possess by hard pan as exhibited by minimal over-breakage and smooth cutting planes.

It is also highly recommended to include petrographic analysis in the laboratory investigation as this may assist us in classifying the samples. For instance, if the cement matrix consists of ferruginous material then, hard pan is classified as iron pan.

LABORATORY TESTINGS

For 'Rippability Investigation and Prediction Services (RIP)', CATERPILLAR Inc. U.S.A. recommends two phases of investigation namely; laboratory testing and site investigation (Caterpillar, 1988). Assessment made during laboratory testing will provide some guides in

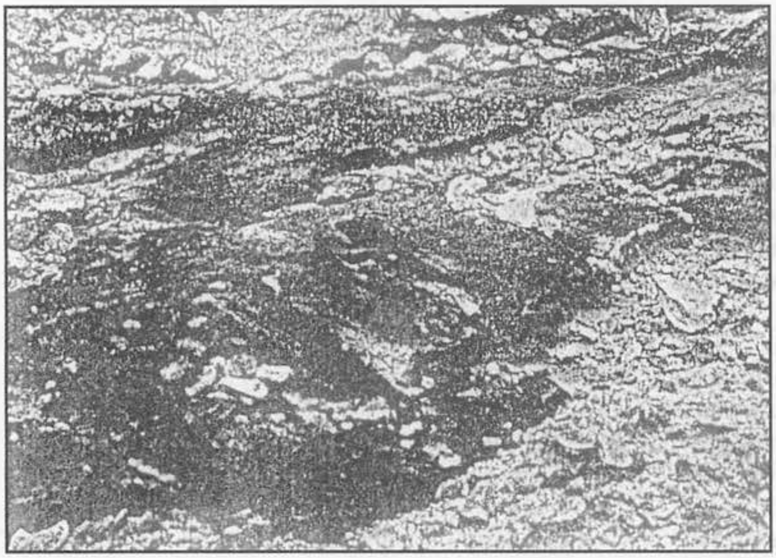


Figure 1. General view of hard pan formation found at the site, Pasir Gudang, Johor.

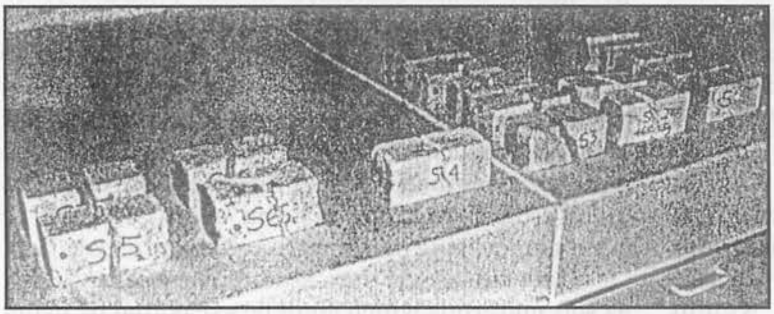


Figure 2. Specimens trimmed to cubical shape with the dimensions of 50 x 50 x 100 mm.

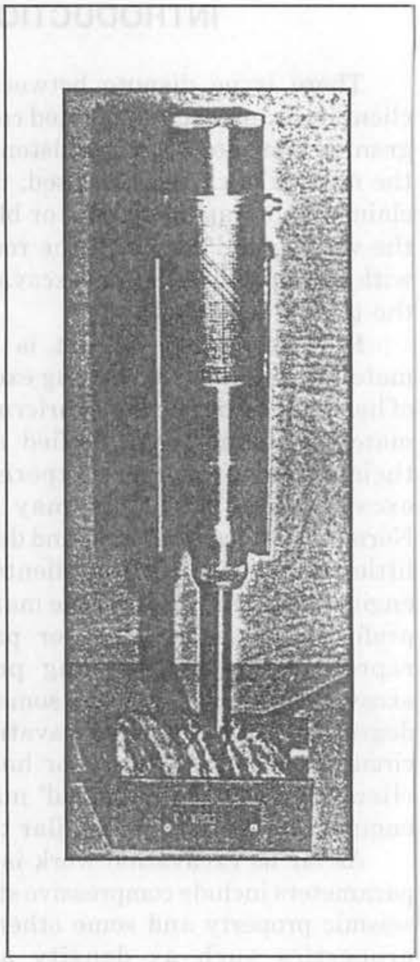


Figure 3. The Schmidt (rebound) hammer.

Table 1. Summary of physical properties.

Sample No.	Volume (ml)	Natural Weight (gm)	Dry Wt. (gm)	Bulk Density (kg/m³)	Dry Density (kg/m³)
S1(a)	245	532.5	492.5	2173	2010
S1(b)	250	513.2	538.5	2170	2054
S1(c)	250	494.5	431.4	1978	1726
S2(a)	250	494.5	431.4	1978	1726
S2(b)	249	465.1	423.3	1868	1700
S3(a)	238	533.8	529.0	2243	2223
S3(b)	260	571.1	564.1	2284	2256
S3(c)	255	572.1	564.4	2244	2213
S3(d)	260	578.1	572.8	2223	2203
S3(e)	263	582.8	577.2	2216	2195
S4(a)	295	577.0	514.5	1956	1742
S4(b)	265	497.1	449.9	1876	1698
S5(a)	260	542.0	527.0	2085	2027
S5(b)	260	542.6	528.3	2087	2032

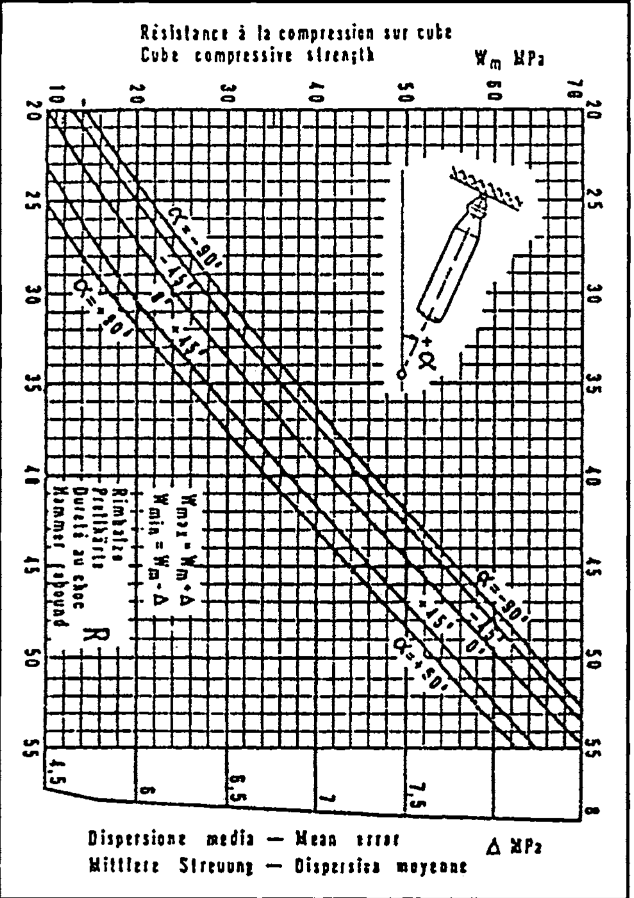


Figure 4. Correlation chart to convert into cubic compressive strength.

making decision as to whether the second phase is required. The second phase normally involved more detailed *in situ* investigation which includes rock type, degree of weathering, bedding fractures, joint characteristics and other pertinent geological features thus, a time consuming and a costly operation.

This paper is intended to discuss only on the first phase of the investigation, i.e. laboratory testings. Among these tests include laboratory sonic velocity test, compressive and tensile strength test, Schmidt hammer hardness test (Caterpillar, 1991).

Determination of Physical Properties

Before trimming, samples were tested for physical properties which include S.G., bulk and dry density. Table 1 depicted the summary of the physical properties of the samples tested under laboratory condition.

Schmidt (Rebound) Hammer Test

The Schmidt Hammer has been widely used to assess the surface hardness and resistance of concrete material (Figure 3). In the field of Rock Engineering, the hammer provides an indication of surface hardness and strength of rock samples.

Generally, the test relates the sound, rebound and impact marks of hammer blow to the general strength of the rock sample (Hudson, 1989). Thus, the harder and the more compact is the sample the higher is the rebound number. Depending on the angle of orientation of the hammer relative to the surface being tested, the rebound number can be converted into cubic compressive strength using a correlation chart (Fig. 4).

The applicability of this equipment, as a quick means of assessing the strength and hardness of rock material, has been proven by many researchers (Hudson, 1989; Brown, 1981; Franklin, 1974; Rankilor, 1974; Komoo, 1974).

Due to its simplicity and portability, rebound hammer test can be conducted at site. The number of tests can be as many as required consequently, giving a better mean value of data collected.

Limitations exist in using Schmidt hammer for assessing the strength of rock samples as it is sensitive to variation influenced by rock anisotropy (Komoo, 1982; Ghosh and Srivastave, 1991). For a quick, practical and fairly reliable test, Schmidt hammer superseded other types of test.

Schmidt hammer tests were conducted on untrimmed block samples. It is important to note that the size of samples tested must be massive enough to eliminate movement and vibration during testing.

Table 2. Approximate cube ompressive strength (MPa) based on Schmidt Hammer Test.

Sample No.	Avg. Rebound No based on 10 rdgs.	Approximate Cube Compressive Strength MPa
S1	35	32.5
S2	21.5	12.9
S3	36.5	34.7
S4	20.5	11.3
S5	26.0	18.1
S6	25.5	17.4

Table 3. Relative propagation wave (P-wave) velocity.

Sample No.	Length (mm)	P-wave Propagation time (micro-sec.)	P-Wave Velocity	
			m/s	ft/s
S1(a)	100	51.2	1953	6406
S1(b)	99	40.4	2450	8036
S1(c)	99	45.8	2162	7090
S2(a)	99	58.0	1707	5600
S2(b)	96	56.2	1708	5600
S3(a)	100	49.1	2037	6700
S3(b)	99	34.0	2912	9551
S3(c)	101	44.2	2285	7459
S3(d)	100	32.2	3106	10,186
S3(e)	99	32.2	3065	10,053
S4(a)	113	105.3	1073	3500
S4(b)	112	103.3	1084	3557
S5(a)	101	56.3	1794	5884
S5(b)	99	60.8	1629	5341
S6(a)	99	46.0	2152	7059
S6(b)	100	42.2	2370	7773

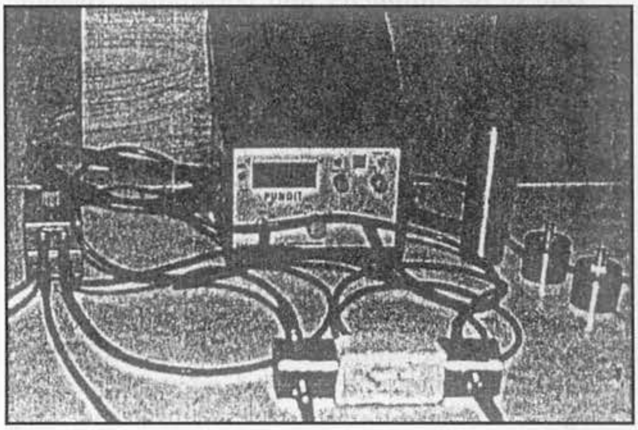


Figure 5. Portable Ultrasonic Non-destructive Digital Indicator Tester (PUNDIT) used for seismic velocity test.

Table 2 shows the results of Schmidt hammer tests conducted. Average rebound number (based on 10 readings) was used to estimate the cubic compressive strength of block samples.

Sonic Velocity Test

There are three methods available for laboratory seismic velocity test in rock testing and the most common is 'high frequency ultrasonic pulse technique' (Brown, 1981).

The test can be performed using PUNDIT (Portable Ultrasonic Non-destructive Digital Indicator Tester). This particular instrument measures the propagation velocity of P-wave (Primary or Compressional wave) through rock specimens. It consists of two transducers (transmitter and receiver) and a digital display unit (see Figure 5). Given the specimen length and propagation time, the propagation velocity can be obtained (i.e. length/time m/s).

The basic principle is that P-wave travels faster in a denser material and at much slower speed in material with higher porosity and lower density. It has been widely used for detecting microcracks and honeycomb in finished masonry work.

Similar to other tests, it does suffer from several limitations, particularly due to grain size, sample length and poor contact between transducers and sample (Mohd Amin, 1989).

A slightly modified version of PUNDIT instrument, which measures both P- and S-wave

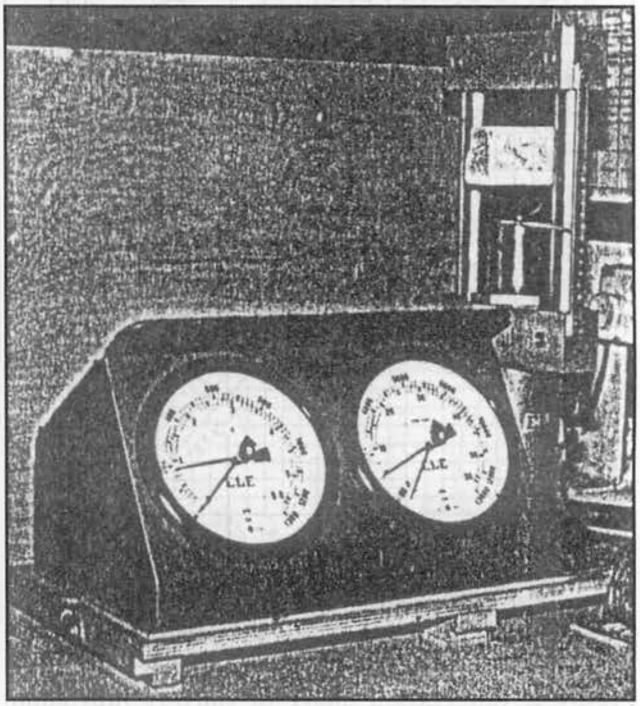


Figure 6. Point-load test equipment.

has been used for estimating the dynamic Young's modulus and Poisson's ratio of rock (Mohd Amin, 1989).

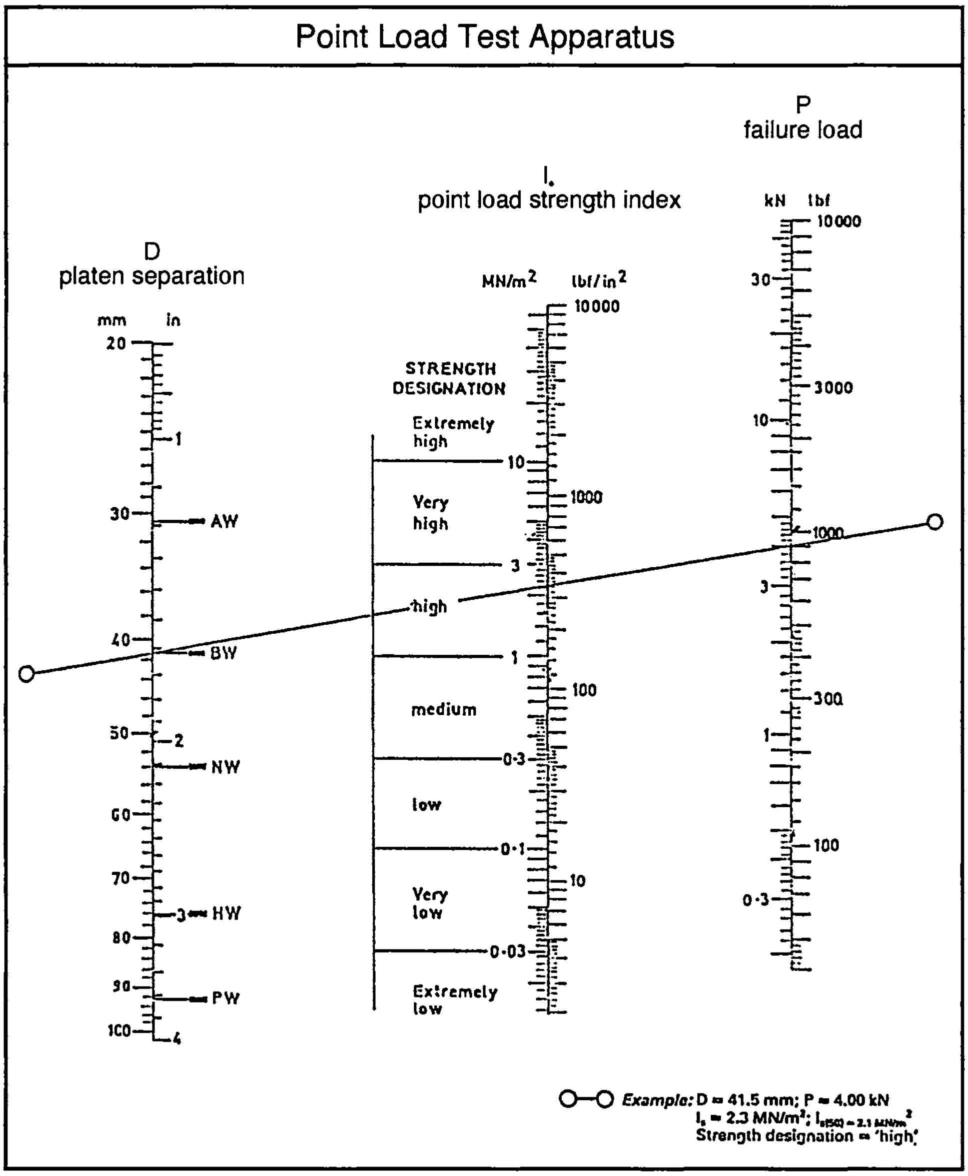
Sonic velocity test was conducted on trimmed samples. Aluminium foil and grease were used for effective coupling between transducers and specimen. The test results are shown in Table 3 where, the propagation velocity of P-wave through specimen s tested are given in m/s and ft/s.

Point-load Test

Point-load test is another portable equipment that has been widely used to estimate strength of rock (Figure 6). The test result is comparatively more accurate and gives fair assessment of rock strength though sensitivity to rock anisotropy remains in the result (Ghosh and Srivastave, 1991). May it be in the field or laboratory, the test is easy to perform and specimen can be irregular lump, cubic or core sample obtained from coring.

However, the test is limited to rocks with uniaxial compressive strengths above 25 MPa or equivalent point load Index above 1 MPa (Bell, 1983).

It has long been known that the point-load index strength, I_s, can be converted to unconfined compressive strength (UCS) using the relation UCS = 24 I_s (Broch and Franklin, 1972). Numerous work have been conducted to determine the value of the conversion factor for different type of rocks. These include Lee (1992), Rankilor (1974) and Ghosh and Srivastave (1991) and the range of values vary between 16–24. Variation in the values has not been justified perhaps it requires further


Point Load Test Apparatus

Example: D = 41.5 mm; P = 4.00 kN
I_s = 2.3 MN/m²; $I_{s(50)}$ = 2.1 MN/m²
Strength designation = 'high'

Figure 7. Nomogram for computing point load strength index $I_s = P/D_e^2$.

Table 4. Unconfined compressive strength based on Point-Load Test.

Sample No.	Width W-mm	Depth D-mm	Load P-kN	Equiv. Dia De - mm = 4WD	Point Load Strength value Is - MPa Is = P x 1000 (D)	Strength Designation - MPa (Nomogram)	Compression Strength - MPa	
							c = 24 (Is) after Franklin, 1972	c = (14 + 0.175D) Bieniawski, 1975
S1(a)	50	50	4.5	3183	1.4	high	33.6	31.9
S1(b)	52	50	4.3	3374	1.3	high	31.2	31.9
S1(c)	50	52	5.1	3183	1.5	high	36.0	34.7
S2(a)	50	51	2.2	3247	0.6	medium	14.4	13.8
S2(b)	49	50	1.8	3119	0.6	medium	14.4	13.7
S3(a)	50	51	3.9	3246	1.2	high	28.8	27.5
S3(b)	52	50	5.0	3310	1.5	high	36.0	34.1
S3(c)	52	50	5.2	3310	1.6	high	38.4	36.4
S3(d)	50	52	6.0	3310	1.8	high	43.2	41.6
S3(e)	52	51	5.2	3377	1.5	high	36.0	34.4
S4(a)	50	50	0.5	3183	0.2	low	4.8	4.6
S4(b)	50	51	0.6	3246	0.2	low	4.8	4.6
S5(a)	50	51	2.8	3247	0.9	medium	21.6	20.6
S5(b)	52	51	2.2	3377	0.7	medium	16.8	16.1
S6(a)	52	50	2.3	3310	0.7	medium	16.8	15.9
S6(b)	52	49	2.9	3244	0.9	medium	21.6	20.3

investigation for verification. For present study the conversion factor of 24 will be used to estimate the unconfined compressive strength of the tested material.

The load required to break the sample (P) and platen separation/specimen height (D) is read directly from the equipment and these values can be converted to point load index strength, I_s, in two ways; using nomogram (Fig. 7) or by calculation. However, by calculation, sample with thickness D not equal to 50 mm needs to be corrected for equivalent diameter (D_{50}). The following shows the typical calculation:

Samples S1 (a)

D = 50 mm, W = 50 mm, P = 4.5 kN

Equivalent dia. D_e^2 = (4A)/p

(where A = W x D)

= 3183 mm^2

I_s = P/D_e^2

= 1.4 MPa

Using correlation UCS = 24 I_s, the UCS of sample S1(a) is 33.6 MPa. Table 4 shows UCS values obtained using equations proposed by Franklin (1972) and Bieniawski (1975).

ANALYSIS AND DISCUSSION OF RESULTS

The analysis of data collected from laboratory tests was mainly consists of comparison with typical properties of rock and other earth materials. The relevant data were plotted against standard charts used for ripping assessment.

Dry Density

Dry density of hard pan (1,700–2,300 kg/m^3; Table 1) was compared with the typical density of overburden materials, which ranges between 1,360–1,680 kg/m^3 (Table 5; Hoek and Bray, 1974). The comparison clearly indicate the difference between hard pan and soil materials.

Rebound Hammer and Point Load Test Results

Both tests revealed the approximate unconfined compressive strength (UCS) of the tested materials. The general classification of earth materials based on UCS is readily available, as an example is Table 6 (Brown, 1981). As shown, the UCS values for cohesive soils lie in the range of 0.025–0.5 MPa

[Note: As a rule of thumb, 1 MPa can be considered as the interface between soils and rock strength (Hudson, 1989)].

Rebound hammer test results indicate UCS values of hard pan between 11.3–34.7 MPa and point-load test gives UCS values between 4.8–43.2 MPa. Comparing these values with the typical UCS of soils clearly indicate a distinctive difference between hard pan and soil materials.

Sonic Velocity Test

Practically speaking, seismic property of a material is not a unique value. These can be clearly explained by looking at Table 7, which shows an over-lap of range of seismic velocities for different type of materials. As shown in Table 7, the seismic velocity for materials like topsoils to soft sandstone lie in the range of 188–1,870 m/s (600–6,000 ft/s). However, hard pan exhibits relatively higher seismic

Table 5. Typical rock and soil properties (Hoek and Bray, 1974).

			Density		Friction angle			Cohesion c	
Type		Material	kg/m^3	lb/ft^3	Material	Degs.	Material	kg/m^2	lb/ft^2
Cohesionless	Sand	Dry coarse sand	1440	90	Compacted, well graded, uniform	40-45			
		Dry fine sand	1600	100					
		Wet sand	1840	115	Uniform, coarse, medium fine or silty sand	35-40			
		Very wet sand	1920	120					
					Loose, well graded sand	35-40			
					Fine dry sand	30-35			
	Gravel	Common mixed	1760	110	Common mixed	35-45			
		River gravel	2240	140	Shingle	40			
		Loose Shingle	1840	115	Sandy compact	40-45			
		Sandy gravel	1920	120	Sandy loose	35-40			
	Waste Rock	Granite	1600-2000	100-125	Crushed or broken rock	35-45			
		Basalt and dolerite	1760-2240	110-140	Broken chalk	30-45			
		Limestone and sandstone	1280-1920	80-120	Broken shale	30-35			
		Chalk	1000-1280	62-80					
		Shale	1600-2000	100-125					
Cohesive	Clay	Dry clay	1760	110	Dry boulder clay	30	Very stiff boulder clay	17600	3600
		Damp, drained clay	1840	115	Damp, drained boulder clay	40	Hard shaley clay	14600	3000
		Sandy loam	1600	100	Stiff clay	10-20	Stiff clay	9800	2000
		Marl	1760	110	Soft clay	5-7	Firm clay	4900	1000
		Gravelly clay	2000	125	Clay gouge	10-20	Soft clay	2400	500
					Calcite shear zone material	20-27			
					Shale fault material	14-22			
	Overburden	Top soil	1360	85					
		Dry soil	1440	90	Overburden soil	30-35	Overburden soil	490-4900	100-1000
		Moist soil	1600	100					
		Wet soil	1680	105					
	Rock Mass	Granite	2614	164	Granite	30-50	Hard rock mass (granite, porphyry etc.)	9800-30000	2000-6400
		Quartzite	2614	164	Quartzite	30-45			
		Sandstone	1950	122	Sandstone	30-45	Sandstone mass	4900-14600	1000-3000
		Limestone	3169	180	Limestone	30-50	Limestone mass		
		Porphyry	2580	160	Porphyry	30-40			
		Shale	2400	150	Shale	27-45	Shale or soft rock mass	2400-9800	500-2000
		Chalk	1760	110	Chalk	30-40			

velocity, ranges between 1,100–3,100 m/s (3,500–10,200 ft/s). Therefore, hard pan cannot be classified as loose or unconsolidated earth materials like topsoils, soft clays or gravelly clay.

RIPPABILITY ASSESSMENT

Obviously, the ideal test for determining rippability is to put a ripping tractor on the job and see if it can rip the material — test by trial! But this may not be practical due to the time and expense involved. Therefore, in order to determine if ripping is feasible, a basic knowledge of geology and material characteristics affecting ripping is necessary (Caterpillar, 1988).

Generally, the physical characteristics of a formation which favour ripping may be summarised as follows (Caterpillar, 1988):

1) Frequent planes of weakness (e.g. faults and laminations)
2) Weathering
3) Moisture permeated formations
4) High degree of stratification
5) Brittleness
6) Low strengths
7) Low field seismic velocity

As far as the laboratory test results are concerned, they can be correlated with method of excavation. Charts and tables are available and may be used as a guide in predicting the rippability

Table 6. Uniazial compressive strength of rocks and soil materials (Brown, 1981).

Grade	Description	Field identification	Approx. range of uniaxial compressive strength (MPa)
S1	Very soft clay	Easily penetrated several inches by fist	< 0.025
S2	Soft clay	Easily penetrated several inches by thumb	0.025-0.05
S3	Firm clay	Can be penetrated several inches by thumb with moderate effort	0.05-0.10
S4	Stiff clay	Readily indented by thumb but penetrated only with great effort	0.10-0.25
S5	Very stiff clay	Readily indented by thumbnail	0.25-050
S6	Hard clay	Indented with difficulty by thumbnail	> 0.50
R0	Extremely weak rock	Indented by thumbnail	0.25-1.0
R1	Very weak rock	Crumbles under firm blows with point of geological hammer, can be peeled by a pocket knife	1.0-5.0
R2	Weak rock	Can be peeled by a pocket knife with difficulty, shallow indentations made by firm blow with point of geological hammer	5.0-2.5
R3	Medium strong rock	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow of geological hammer	25-50
R4	Strong rock	Specimen requires more than one blow of geological hammer to fracture it	50-100
R5	Very strong rock	Specimen requires many blows of geological hammer to fracture it	100-250
R6	Extremely strong rock	Specimen can only be chipped with geological hammer	> 250

Note: Grades S1 to S6 apply to cohesive soils, for example clays, silty clays and combinations of silts and clays with sand, generally slow draining.

Discontinuity wall strength will generally be characterized by grades R0-R6 (rock) while S1-S6 (clay) will generally apply to filled discontinuities (see Filling).

Some rounding of strength values has been made when converting to S.1 units.

of a formation. These include Figs. 8 and 9 (McLean and Gribble, 1979) and Figures 10 and 11 (Caterpillar, 1991).

Figure 8 relates rebound number, R, and uniaxial compressive strength, q_u, with method of excavation. As for Figure 9, it relates rebound number and seismic velocity, V, with rippability of a material.

However, Figures 10 and 11 relate seismic velocity with rippability of various materials (e.g. soil and rock materials) for a given ripping tractor horsepower (D9N and D10N indicate 370 fwhp and 520 fwhp, respectively).

Results obtained from laboratory testings; **rebound number** (Schmidt hammer), **P-wave/seismic velocity** (Sonic velocity test) and **uniaxial compressive strength** (Point-load test), were plotted against these charts. Assessment made on the plotted values indicate that, in terms of rippability, hard pan falls in the zone of rippable and marginal/intermediate zone (i.e. transition from ripping to blasting).

Table 7. Relative seismic velocities (P-waves), ft/sec (J.O. Bickel and T.R. Kuesel, 1982).

Rock and Soil Material	Velocity (ft/sec)
Dry, loose topsoils and silts.	600-1,200
Dry sands, loams; slightly sandy or gravelly soft clays.	1,000-1,600
Dry gravels, moist sandy and gravelly soils; dry heavy silts and clays; moist silty and clayey soils.	1,500-3,000
Dry, heavy, gravelly clay; moist, heavy clays; cobbly materials with considerable sands and fines; soft shales; soft or weak sandstones.	3,000-4,800
Water, saturated silts or clays, wet gravels.	4,800-5,000
Compacted, moist clays; saturated sands and gravels; soils below water table; dry medium shales, moderately soft sandstones, weathered, moist shales and schists.	4,800-6,000
Hardpan; cemented gravels; hard clay; boulder till; compact, cobbly and bouldery materials; medium to moderately hard shales and sandstones; partially decomposed granites; jointed and fractured hard rocks.	5,500-8,000
Hard shales and sandstones, interbedded shales and sandstones, slightly fractured hard rocks.	8,000-12,000
Unweathered limestones, granites, gneiss, other dense rocks.	12,000-20,000

* Note that the velocity of sound in air at sea level and 32°F is 1,087 feet/second.

CONCLUSION AND DISCUSSION

Laboratory test data together with geological background of the site provide a great deal of information pertaining to rippability assessment. The related information of the site include material types, degree of weathering and geological features such as bedding and joint.

The findings derived from laboratory investigation (1st-phase investigation) discussed in this study may also be used as justification for the requirement of detailed site investigation (2nd-phase) on hard materials encountered during excavation.

A joint study between construction machinery suppliers and construction engineers is highly recommended in producing a more comprehensive specification for excavation that are acceptable to local conditions.

Based on the case study conducted, the following conclusions can be withdrawn:

- Simple laboratory tests can be used to obtain the engineering properties of hard materials which are related to mode of excavation.
- The need for a more comprehensive specification on excavation work in document of contract particularly, pertaining to the engineering properties of materials which are related to method of excavation. These engineering properties include seismic properties, strength and density.
- Some modifications of the rippability assessment charts may be required to suit local condition and the requirement of local construction industry, e.g. ripping tractor HP and typical field seismic velocity of hard materials.
- The need for additional tests on the laboratory investigation such as petrographic analysis and slake durability test as to suffice the data for rippability assessment.
- There is yet limited experience in using the proposed tests with various limitations in interpreting the test results particularly, the use of conversion factor 24 in estimating the uniaxial compressive strength of hard pan.

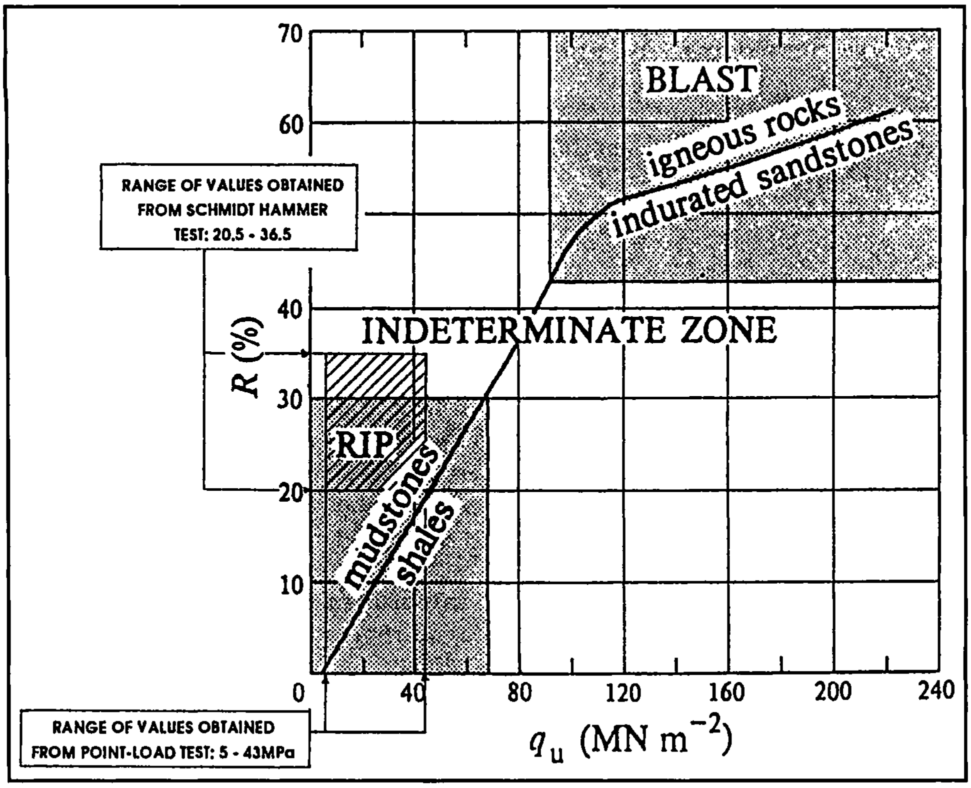


Figure 8. Rebound number (R) plotted against unconfined compressive strength (q_u) for various rock types (McLean and Gribble, 1979).

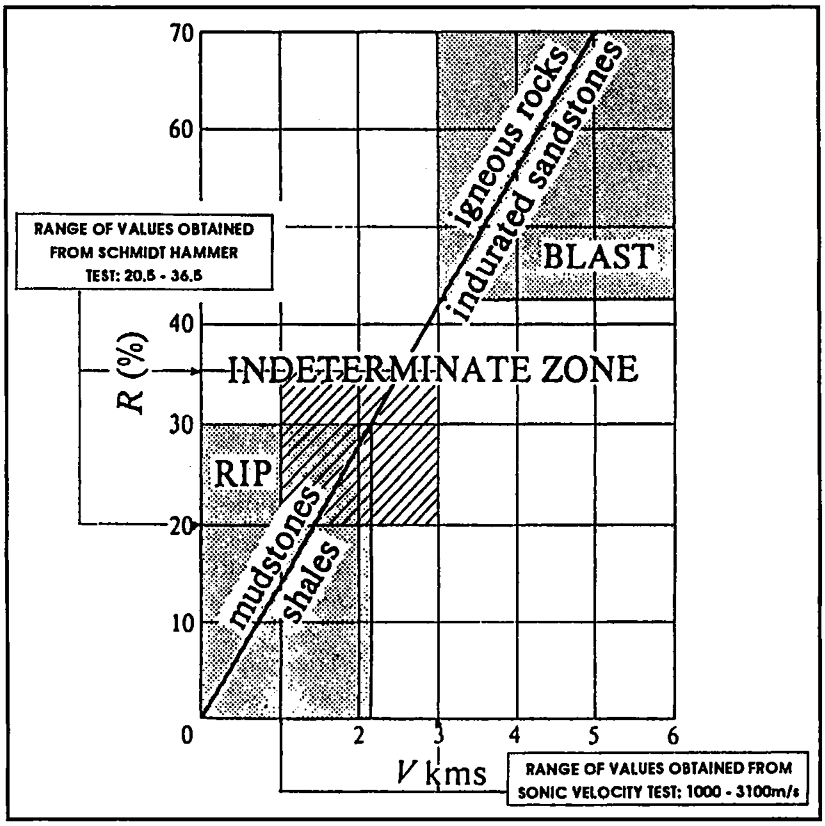


Figure 9. Laboratory-determined seismic velocity (V_p) plotted against rebound number (R) for various rock types (McLean and Gribble, 1979).

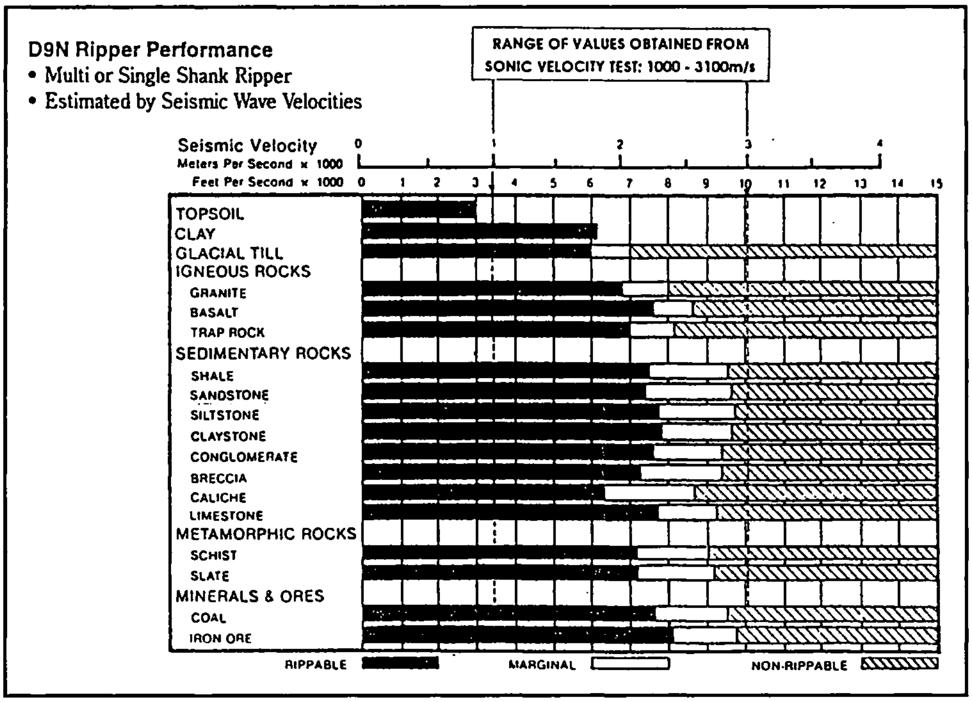


Figure 10. Seismic velocity plotted against rippability of various materials at D9N ripper performance.

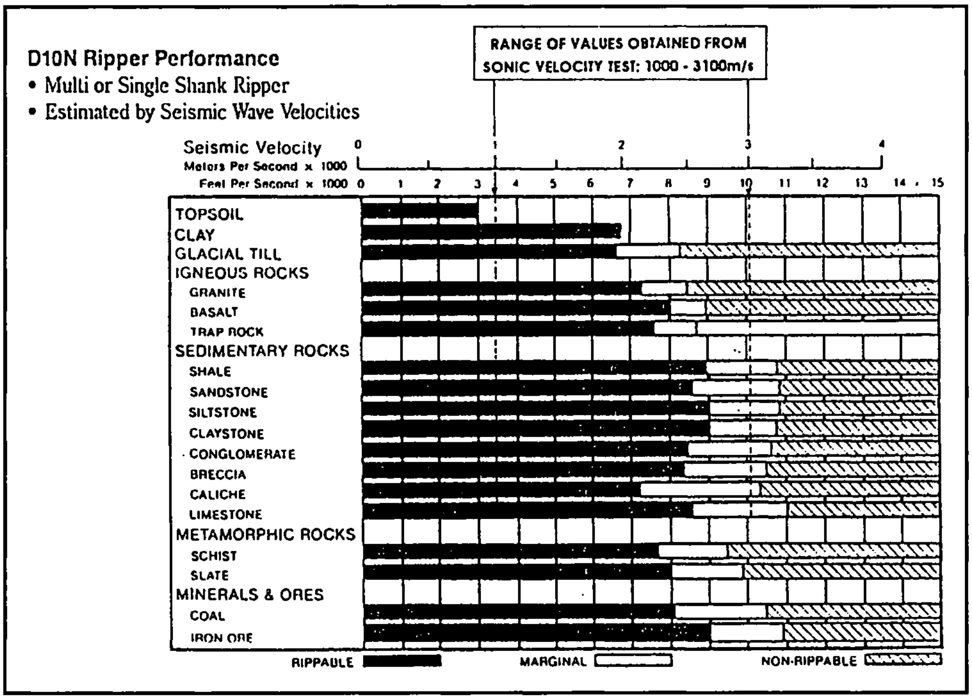


Figure 11. Seismic velocity plotted against rippability of various materials at D10N ripper performance.

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