



**GEOTECHNICAL SOCIETY
OF SINGAPORE (GeoSS)**



GUIDELINES ON IDENTIFICATION OF ROCK DURING BORED PILING WORKS



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and

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This “Guidelines on Identification of Rock During Bored Piling Works” is a joint publication of GeoSS and BCA, produced under the collaborative efforts of an Industry Working Group, which comprises major government agencies involving in piling works, IES, ACES and practitioners. The composition of the industry working group is as follows:

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Disclaimer

Although efforts have been made to check the accuracy of the information and validity of the guidelines, neither the members nor the agencies accept any responsibility for mis-statements contained or misunderstanding arising here forth.



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Guidelines on Identification of Rock During Bored Piling Works

1. Introduction

Project parties involved in the bored piling works include, amongst others,

- (1) **Builder** (Piling Contractor, Site Engineer) – who is responsible for constructing the bored piles in accordance with acceptable standards or execution codes (e.g. BS EN 1536) based on the approved design provided by the Qualified Person.
- (2) **Qualified Person** (QP) – who is responsible for designing the bored piles as foundation elements to carry the intended design actions in accordance with codes and regulations, including SS EN 1997-1, SS EN 1997-2, BCA Regulations and BCA Advisory Notes.
- (3) **Supervision Team** (Qualified Person (Supervision), Resident Engineer, Resident Technical Officer) – who is responsible for supervising the construction of the bored piles in accordance with the approved design.
- (4) **Quantity Surveyor** – who is responsible for evaluating and quantifying the work done by the Builder in accordance with the contract specifications and provisions and recommendation of payment to the Builder.

For bored piles involving rock socketing, determination of the beginning depth of rock stratum is important in design and construction. For the guidelines, rock stratum is defined as the stratum of bedrock with weathering classification Grade III (moderately weathered) or better.

In practice, rock identification by various project parties can be subjective. Complication arises as the rock samples retrieved from the pile bores are normally fragmented and often mixed with soils due to the rock coring process.

At one extreme, the Qualified Person and Supervision Team may adopt a very conservative approach in determining the beginning depth of rock stratum, which may result in excessive rock drilling, causing undue high cost, delay and unproductive pile construction. At the other extreme, imprudence or incompetence in rock identification may result in unsafe building foundation due to piles not embedded adequately in the intended competent rock layer. Both extremes are undesirable.

The objective of the guidelines is to establish a consistent, practical and more objective system for the project parties to identify the beginning depth of bedrock stratum during the construction of bored piles. The aim is to remove ambiguity among the project parties

so that the piles are constructed with adequate rock socket in accordance to the Qualified Person's design intent while the Builder can deploy suitable types of machineries and equipment to carry out the rock drilling works to fulfil the design requirements and contractual obligations.

2. Weathering Classification of Rocks in Singapore

The two common types of rocks encountered in Singapore are igneous rocks (e.g. granite) and sedimentary rocks (e.g. sandstone, siltstone, mudstone and limestone).

Based on Annex B of BS EN ISO 14689, Approach 2 shall be followed for the weathering classification of rocks in Singapore. **Table 1** presents the approach 2 rock weathering classification extracted from BS EN ISO 14689.

Table 1: Approach 2 - Classification for Uniform Materials

Grade	Classifier	Typical Characteristics
I	Fresh	Unchanged from original state.
II	Slightly weathered	Slight discolouration. Slight weakening.
III	Moderately weathered	Considerably weakened, penetrative discolouration. Large pieces cannot be broken by hand.
IV	Highly weathered	Large pieces can be broken by hand. Does not readily disaggregate (slake) when dry sample immersed in water.
V	Completely weathered	Considerably weakening. Slakes. Original texture apparent.
VI	Residual Soil	Soil derived in situ weathering but retaining none of the original texture or fabric.

This has no conflict with the definition in NA to SS EN 1997-2:2010 (2015). The weathering classification shall follow the local practices defined in TR 26 : 2010, which further makes reference to BS 5930 : 1999. Similar rock classification tables have been published locally in CP 4 : 2003, and LTA Civil Design Criteria E/GD/09/106/A1 Feb 2010. Simple indicators for the assessment of weathering grades of igneous rocks and sedimentary rocks in Singapore, as shown in **Table 2** and **Table 3**, are also published in the three local references cited below.

Table 2: Simple indicators for assessment of weathering grades of igneous rocks

Grade	Basis for assessment
I	Intact strength, unaffected by weathering. Not broken easily by hammer – rings when struck. No visible discolouration.
II	Not broken easily by hammer – rings when struck. Fresh rock colours generally retained but stained near joint surfaces.
III	Cannot be broken by hand. Easily broken by hammer. Makes a dull or slight ringing sound when struck with hammer. Stained throughout.
IV	Core can be broken by hand. Does not slake in water. Completely discoloured.
V	Original rock texture preserved, can be crumbled by hand. Slakes in water. Completely discoloured.
VI	Original rock structure completely destroyed. Can be crumbled by hand.

Table 3: Simple indicators for assessment of weathering grades of sedimentary rocks

Grade	Basis for assessment
I	Intact strength, unaffected by weathering
II	Slightly weakened, slight discolouration, particularly along joints.
III	Considerably weakened & discoloured, but larger pieces cannot be broken by hand. (Rock Quality Designation, RQD is generally >0, but RQD should not be used as the major criterion for assessment).
IV	Core can be broken by hand or consists of gravel size pieces. Generally highly to very highly fractured, but majority of sample consists of lithorelics. (RQD generally = 0, but RQD should not be used as the major guide for assessment). For siltstone, shale, sandstone, quartzite and conglomerate, the slake test can be used to differentiate between Grade V (slakes) and Grade IV (does not slake).
V	Rock weathered down to soil-like material, but bedding intact. Material slakes in water.
VI	Bedding destroyed

3. Checklist for Identification of Rocks with Weathering Grade III or Better

Based on the collective experience in Singapore local practices, a checklist has been developed to assist the project parties to identify rocks with weathering classification Grade III (moderately weathered) or better, for igneous rocks and sedimentary rocks.

The checklist is attached in Appendix 1. It contains 7 criteria for the examination of rock samples retrieved from pile bore. In order to be classified as rock with weathering Grade III or better, the rock samples need to fulfil all 7 criteria positively.



A brief description of each criterion is given in the subsequent sub-sections, in accordance to the sequence adopted in the checklist.

3.1 Criterion 1: Close Correlation to Nearby Boreholes

The Qualified Person shall have a good overall understanding of the ground condition of the site based on the available site investigation data. The information of particular interest includes type of rocks, weathering grade with respect to depth, and variability of rock-head levels across the entire site.

Reference shall be made to the nearby boreholes when evaluating the rock sample from the pile bore. The retrieved sample must show close resemblance to the description of the rock in the nearby boreholes. As a minimum, the nearest borehole must show the presence of similar lithology with weathering grade III or better. This can happen at similar depth or similar stratum, if the rock-head profile is known to be undulating in the particular site. Qualified Persons will need to exercise their engineering judgement to determine what constitutes reasonable variation of rock-head levels at the particular site.

3.2 Criterion 2: Use of Rock Coring Tools

The right tools should be used to perform the right job in order to accomplish the rock drilling work in a proper and productive manner. In view of the relatively higher strength of rocks with weathering Grade III or better as compared to that of lower grade, deployment of rock coring tools for drilling into rock is appropriate and essential. Figure 1 shows the examples of rock coring tool commonly used in Singapore.

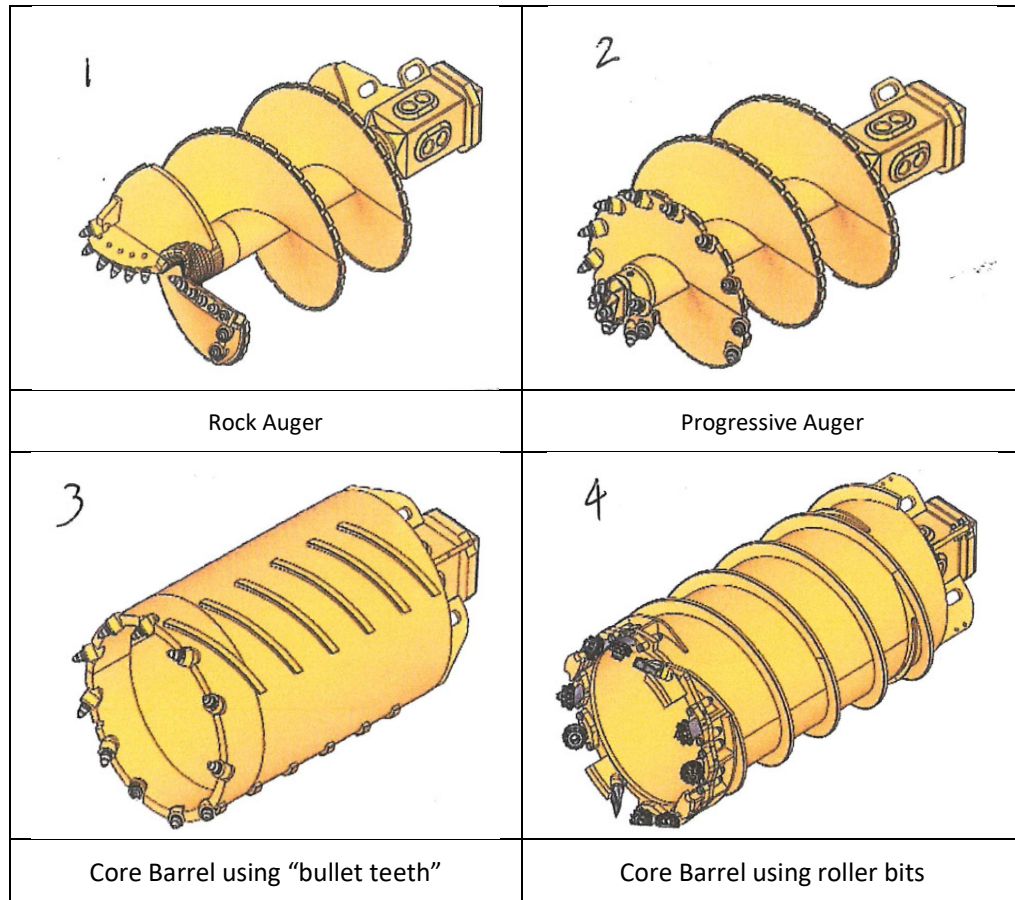


Figure 1 Examples of Rock Coring Tools

3.3 Criterion 3: Size of Rock Samples from Pile Bore

Rock Quality Designation (RQD) is often used as an indicator for assessment of weathering grade of rocks. RQD is defined as the sum of all sound rock pieces, each with minimum length of 100mm, divided by the total length of the core run, expressed as a percentage.

For the purpose of this checklist, the rock cores from the pile bore shall contain samples with size larger than 100 mm in all 3 dimensions to be qualified as rocks with weathering Grade III or better. The more rock samples from the same pile bore that satisfy this criterion, the more certain will be the rock classification.

The Qualified Person may exercise their engineering judgement and discretion in setting the minimum dimension proposed for this criterion, taking into consideration the possible rock crushing and fracture caused by the coring tools.

3.4 Criterion 4: Rock Samples Cannot Be Broken by Hand

It is evident from Tables 2 and 3 that to be considered as rock with weathering grade III or better, the rock samples retrieved from the pile bore shall fail to be broken by hand. This applies for both igneous rocks and sedimentary rocks. This assessment can be carried out easily and quickly on site. It acts as a simple and quick assessment of the minimum threshold of rock strength to be classified as rocks with weathering grade III or better.

3.5 Criterion 5: Sample Angularity

Rocks with weathering Grade IV or lower are highly to completely weathered. Due to the extensive weathering process, the edges of the rock samples are typically more rounded.

On the other hand, rocks with weathering Grade III or better is larger in size in its natural state. However, due to the coring process, the rock mass may be crushed or fractured by the rock tools, resulting is rock samples that is smaller in size. However, in comparison to rocks with weathering Grave IV or lower, the edges shall be angular in shape. The rock samples of rocks with weathering Grade III or better often contain sharp edges and distinct fresh rock surface on the fractured plane. Figure 2 illustrates the distinction between rock samples with angular and rounded edges. To fulfil the requirement of the checklist, the rock cores from the pile bore shall contain samples with angular edges instead of rounded edges.

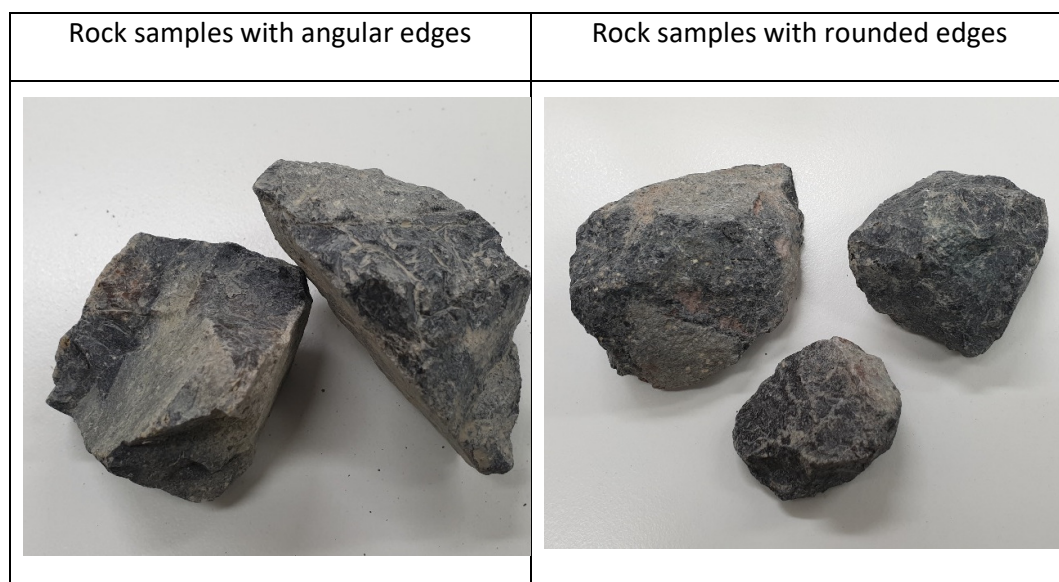


Figure 2 Angularity of Rock Sample

3.6 Criterion 6: Slake in Water

Table 2 and Table 3 show that Grade IV rocks do not slake in water. Hence, it is a compulsory criterion for rocks of weathering Grade III or better not to slake in water.

A simple slake test can be performed using a small rock specimen from the pile bore to determine whether the sample degrades or disintegrates when soaked in water. Figure 3 shows a slake test performed conveniently using a simple apparatus. The specimen shall not degrade or disintegrate after 5 minutes, even after it has been agitated a few times.



Figure 3 A Simple Slake Test Showing No Disintegrated Soil at Bottom of Cup

3.7 Criterion 7: Point Load Test Index

3.7.1 Establish correlation between UCS and $I_{s(50)}$ of rocks at site

Table 4 presents the uniaxial compressive strength (UCS) of rock based on BS EN ISO 14689. Combining the indicators in Tables 2, 3 and 4, rocks with weathering Grade III or better shall have a strength grade of moderately strong with UCS of at least 12.5MPa.

Table 4: Unconfined Compressive Strength of Rock Material (BS EN ISO 14689)

Term	Identification by hand test	Unconfined compressive strength MPa
Extremely weak	Scratched by thumbnail, gravel size lumps can be crushed between finger and thumb	0,6 to 1
Very weak	Scratched by thumbnail, lumps can be broken by heavy hand pressure, can be peeled easily by a pocket knife, crumbles under firm blows with point of geological hammer	1 to 5
Weak	Thin slabs, corners or edges can be broken off with hand pressure, can be peeled by a pocket knife with difficulty, easily scratched by pocket knife, shallow indentations made by firm blow with point of geological hammer	5 to 12,5
Moderately weak	Thin slabs, corners or edges can be broken off with heavy hand pressure, can be scratched with difficulty by pocket knife, hand-held specimen can be broken with single firm blow of geological hammer	12,5 to 25
Medium strong	Cannot be scraped or peeled with a pocket knife, specimen on a solid surface can be fractured with single firm blow of geological hammer	25 to 50
Strong	Specimen requires more than one blow of geological hammer to fracture it	50 to 100
Very strong	Specimen requires many blows of geological hammer to fracture it	100 to 250
Extremely strong	Specimen can only be chipped with geological hammer	Greater than 250

The Qualified Person shall establish the actual UCS of the rocks used in the bored pile design by testing the rock core samples retrieved from the site investigation. Both uniaxial compressive test (UCS) and point load test ($I_{s(50)}$) shall be carried out on the same rock core. A correlation between UCS test results and point load test results can be obtained by plotting UCS against $I_{s(50)}$ and drawing a best fit linear line in the plot. Examples of such plots for igneous rocks and sedimentary rocks are shown in Figure 4 and Figure 5 respectively.

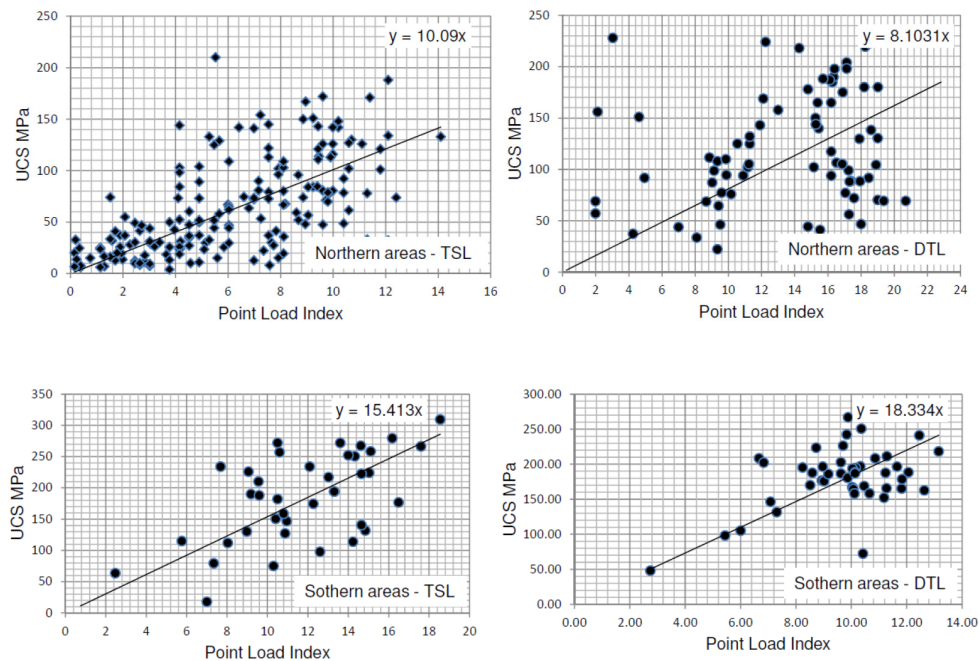


Figure 4 Example of correlation between UCS and I_{s50} for Granite (Veeresh et al. 2016)

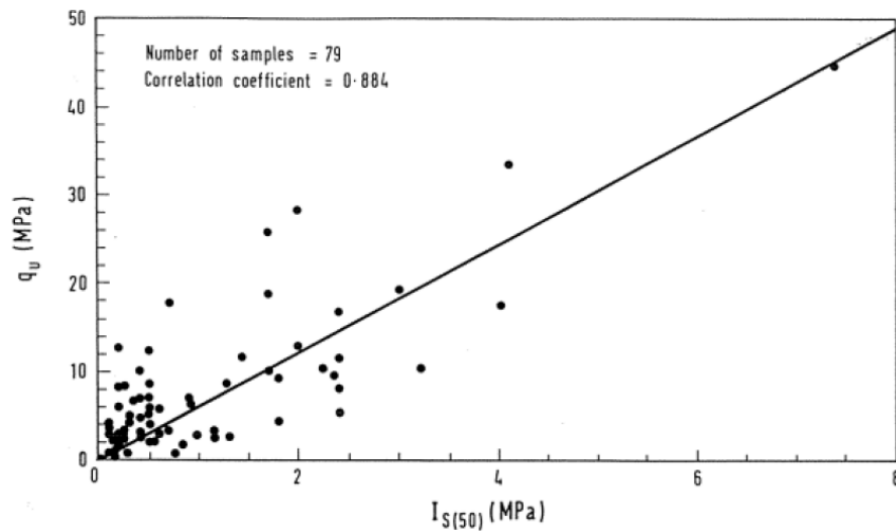


Figure 5 Example of correlation between UCS and I_{s50} for weathered sedimentary rock (Leung and Radhakrishnan, 1990)

3.7.2 Point Load test on rock samples from pile bores

Once the correlation of UCS and $I_{s(50)}$ is established, point load test can be used at site to estimate the compressive strength of the rock samples retrieved from pile bores. The point load test provides a more objective approach to evaluate strength of rock samples as compared to Criterion 4. It is also portable and more convenient as compared to the uniaxial compressive test for application at project site. The point load test procedure is fast, so that can be used to test large number of rock samples.

The point load test apparatus has to be calibrated by an accredited laboratory in Singapore, minimally once a year. The apparatus has to be regularly maintained and checked for its proper functionality prior to use.

The test shall be conducted in compliance with the relevant code of practice, for instance "ISRM Suggested Method for Determining Point Load Strength" recommended in SS EN 1997-2 Annex W.2. Figure 6 shows a point load test apparatus located in a project site office. It includes a hydraulic ram mounted inside a protection cage with digital readout display. The rock sample is placed between the two conical platens in the cage. Pressure is provided by a hand operated pump until rock sample ruptures.

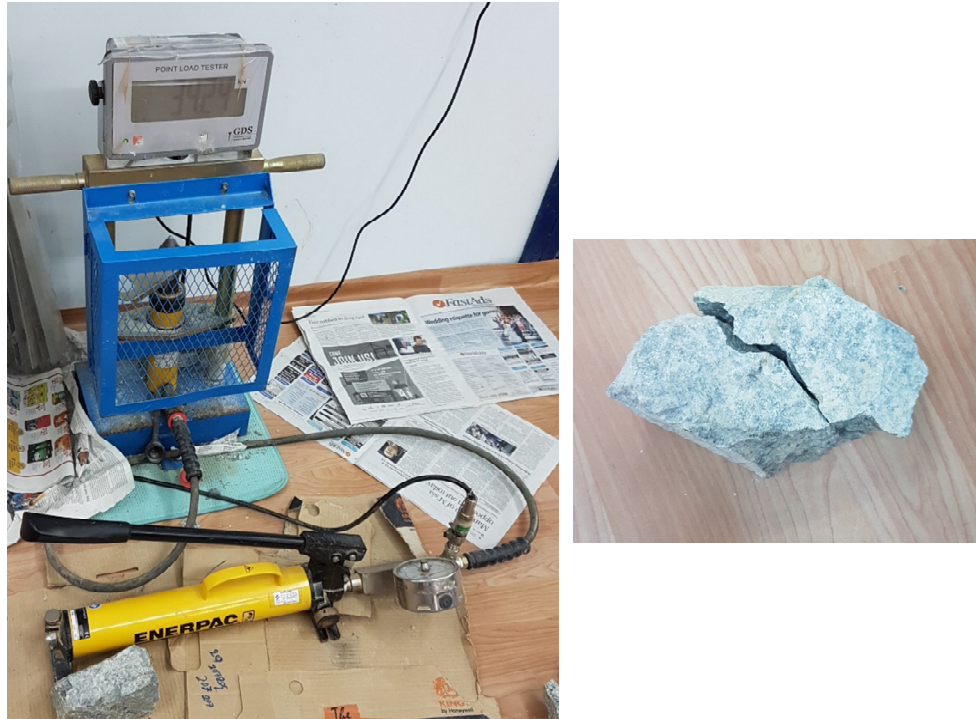


Figure 6 Point load test apparatus and rock sample after test

The strength value determined from the test is referred to as the point load test index, I_s .

$$I_s = P/D_e^2$$

where

P = Force needed to rupture the rock sample,

D_e = Equivalent rock core diameter

Considering the rock samples retrieved from pile bore are irregular in shape, size correction will need to be applied to obtain a unique strength value, $I_{s(50)}$ corresponding to the standard test on cylindrical sample with diameter, $D = 50\text{mm}$.

For test on lump rock sample, the size of the specimen is ideally $50 \pm 35\text{mm}$ with D/W between 0.3 and 1.0. The definition of D and W are given in Figure 7.

A template calculation sheet to compute $I_{s(50)}$ is provided in Appendix 2.

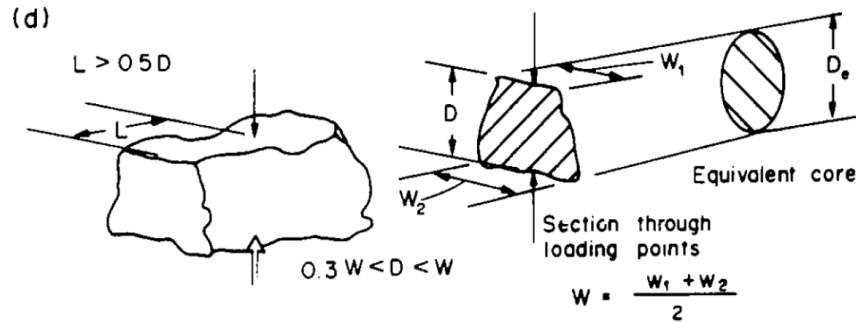


Figure 7 Block and lump rock sample for point load test

$$I_{s(50)} = F \times I_s, \quad \text{where } F = (D_e/50)^{0.45}; \quad D_e = \sqrt{(4A/\pi)}$$

$I_{s(50)}$ value specified in Criterion 7 shall be determined by QP based on the expected minimum UCS of the rocks used in the bored pile design and the correlation factor between UCS and $I_{s(50)}$ established as described in section 3.7.1. For the guidelines, $I_{s(50)} > 2$ MPa is recommended as a guide to QP.

3.7.3 Recommended frequency of Point load tests

In terms of test frequency, it is recommended that a minimum of two (2) sets of point load tests shall be conducted for each bored pile, i.e. one set at the beginning depth of rock, and the another set at the pile toe level. For piles with substantial rock socket, it is also proposed that one (1) set of point load test to be carried out at every one (1.0) meter rock socket interval.

Each set of point load tests shall consist of minimum three (3) rock specimens to be selected by the Resident Engineer (RE) and/or Resident Technical Officer (RTO) from the most representative rock samples recovered for each rock core. The average $I_{s(50)}$ value from the 3 tests shall then be compared with the $I_{s(50)}$ value specified in Criterion 7.

The test procedure for point load test shall be witnessed and verified by RE/RTO.

4. Application of guidelines at piling site involving rock drilling

The industry is strongly encouraged to adopt the guidelines for piling projects involving rock drilling, as they provide a more objective assessment procedure for the project parties involved in bored pile construction to identify the beginning depth of rock stratum using a simple checklist containing 7 criteria.

The Qualified Person should determine the pile design criteria and specify the parameters in the checklist. The design criteria and procedure to use this checklist shall be communicated clearly to the Builder.

The Builder should then take the ownership of this checklist and submit request for inspection to the Supervision Team whenever the beginning depth of the rock stratum is encountered. Adequate number of representative rock specimens from every pile bore should be selected for testing and verification of the criteria. Site engineer engaged by the Builder shall check and confirm all 7 criteria specified in the checklist. The Supervision Team shall witness the conduct of tests and verify the checklist on the fulfilment of all the criteria. The checklist shall then be vetted and signed by QP to be kept at site.

References

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APPENDIX 1

CHECKLIST FOR IDENTIFICATION OF ROCKS WITH WEATHERING GRADE III OR BETTER

Project Title:			
Location/Block No:		Date & Time of Boring:	
Pile Reference No:		Reference BH:	
Rock Type:	*Igneous Rocks (Granite) /Sedimentary Rocks	Depth where samples are taken (mBGL):	

S/N	Criteria	Yes	No	Remarks
1	The nearest borehole shows similar lithology with weathering grade III or better, at similar depth or similar stratum?			
2	Type of piling equipment used, e.g. Rock Auger, Core Barrel with “bullet teeth” or roller bits?			
3	Sample size larger than 100mm on all sides?			
4	Sample cannot be broken by hand?			
5	Sample contain angular and sharp edges instead of rounded edges?			
6	Sample does not slake in water?			
7	Point load test index $I_{s(50)} > \underline{\text{*2.0}}$ MPa * This value serves as a guide. QP should assess and determine whether 2 MPa is appropriate based on the tests conducted to establish the correlation between UCS and $I_{s(50)}$.			
Conclusion: The sample is classified as rock: weather grade III or better <i>(Note: the reply to Criteria 1 to 7 should be “Yes” for sample to be classified as weathering Grade III or better)</i>				

Prepared by (Site Engineer):	Witnessed by (*RE/RTO):	Vetted by (QP):
Name and Signature Date & Time	Name and Signature Date & Time	Name and Signature Date & Time

* Delete where applicable.

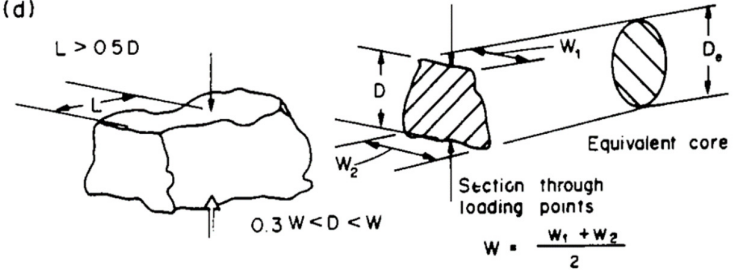
Generally, rock is defined as weathering grade III or better for igneous rocks (Granite) and sedimentary rocks. This list is not exhaustive and serves as a guide only.

APPENDIX 2

POINT LOAD TEST ON IRREGULAR ROCK LUMP

Project Title:			
Location/Block No:		Date & Time of Boring:	
Pile Reference No:		Reference BH:	
Rock Type:	*Igneous Rocks (Granite) /Sedimentary Rocks	Depth where samples are taken (mBGL):	

(d)



$W = \frac{W_1 + W_2}{2}$

- Size of specimen: 50 ± 35mm
- D/W: 0.3 ~ 1.0 (preferred)
- L > 0.5D
- Specimens of this size and shape may be selected if available, or may be prepared by trimming larger pieces by saw- or chisel-cutting
- The load is to be increased steadily such that failure occurs within 10-60 sec and the failure load P is recorded

Calculations:

Uncorrected Point Load Strength $I_s = P/D_e^2$, where D_e is the equivalent core diameter.

$D_e^2 = 4A/\pi$ for test on rock lump, $A = WD$ = minimum cross sectional area of a plane through the platen contact points.

$I_{s(50)} = F \times I_s$; where $F = (D_e/50)^{0.45}$; $D_e = \sqrt{4A/\pi}$

Reference: ISRM Suggested Method for Determining Point Load Strength - 1985

No.	W (mm)	D (mm)	P (kN)	D_e^2 (mm ²)	D_e (mm)	I_s (MPa)	F	$I_{s(50)}$ (MPa)
1								
2								
3								
Average:								

Prepared by (Site Engineer):	Witnessed by (*RE/RTO):	Vetted by (QP):
Name and Signature Date & Time	Name and Signature Date & Time	Name and Signature Date & Time