Technical Report

Title: ***Field Geomechanical Testing of DGR-1 and DGR-2 Core***

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DGR Site Characterization Document
Intera Engineering Project 06-219

Intera Engineering DGR Site Characterization Document		
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1 Introduction

Intera Engineering Ltd. has been contracted by Ontario Power Generation (OPG) to implement the Geoscientific Site Characterization Plan (GSCP) for the Bruce site located on Lake Huron, Ontario. The purpose of this site characterization work is to assess the suitability of the Bruce site to construct a Deep Geologic Repository (DGR) to store low-level and intermediate-level radioactive waste. The GSCP is described by Intera Engineering Ltd., (2006).

This report summarizes the results of the geomechanical field testing program of DGR-1 and DGR-2 core completed as part of Phase I of the GSCP. Field geomechanical testing included: point load testing, slake durability testing and ultrasonic pulse velocity (P- and S-wave) measurements.

Work described in this Technical Report was completed in accordance with Test Plan TP-06-09 – DGR-1 & DGR-2 Core Photography and Logging (Intera Engineering Ltd., 2007a) and Test Plan TP-06-13 – Geomechanical Field Testing of DGR-1 & DGR-2 Core (Intera Engineering Ltd., 2007b), which were prepared following the general requirements of the DGR Project Quality Plan (Intera Engineering Ltd., 2007c).

2 Background

Phase 1 GSCP investigations included a deep bedrock drilling program of two vertical 152 mm diameter continuously cored boreholes (DGR-1 and DGR-2) to depths of approximately 462 and 862 meters below ground surface (mBGS). Both of these boreholes were drilled at one location at the Bruce site (Site 1) as shown on Figure 1.

The field geomechanical testing program was conducted concurrently with the drilling of DGR-1 and DGR-2 in the period January to August, 2007. Core samples were collected by Intera Engineering Ltd. following the core testing frequency requirements as well as collection and preservation requirements outlined in Test Plan TP-06-13 – Geomechanical Field Testing of DGR-1 & DGR-2 Core (Intera Engineering Ltd., 2007b) and Test Plan TP-06-10 – DGR-1 & DGR-2 Core Sampling and Distribution for Laboratory Testing (Intera Engineering Ltd., 2007d), respectively. The following sections give a brief description of each of the three field testing methodologies.

2.1 Point Load Testing

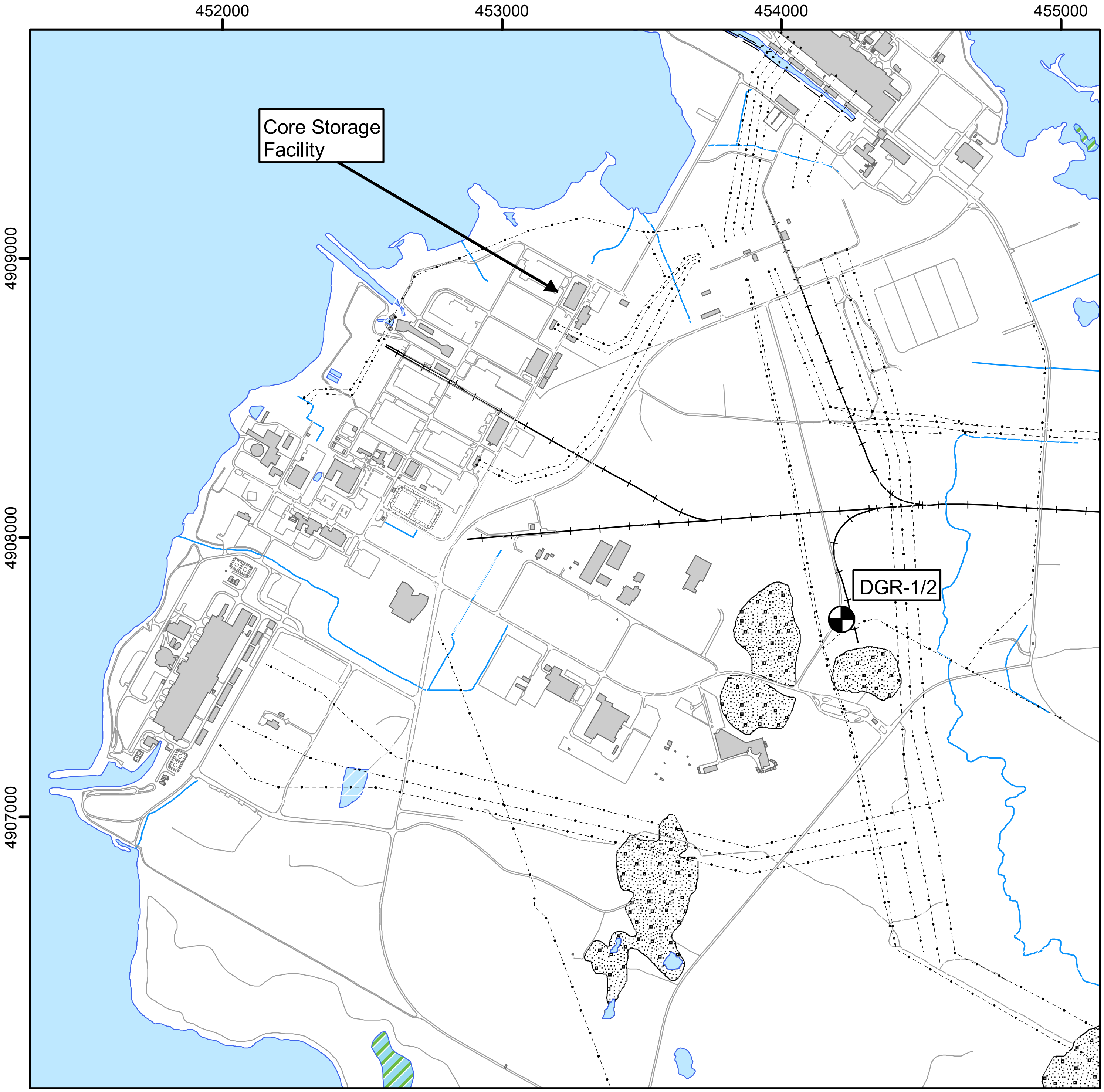
Point load testing, a form of indirect tensile strength testing, provides data on the point load strength index of rocks encountered throughout the stratigraphic column beneath the Bruce site, to the depth of the proposed DGR. This is an index test, and is intended to be used as an aid in classifying and characterizing the rock materials with respect to strength.

2.2 Slake Durability Testing

Slake durability testing is a form of short-term durability testing that provides index values of the susceptibility of rock materials to degradation when exposed to weathering due to wetting and drying cycles. These tests generally apply only to rock materials with significant clay content, and as such, shaley and argillaceous units were targeted for sampling.

2.3 Ultrasonic Pulse Velocity (P- and S-wave) Measurements

Ultrasonic pulse velocity measurements use both compression (P) waves and shear (S) waves to provide information on the dynamic elastic constants of the rock. These measurements may also provide a relative index measurement of increasing damage that tends to occur with increasing borehole depth due to stress relief of the recovered core.



OPG DGR
Site Characterization Plan

Legend

- Location of DGR-1/2
- Buildings
- Roads
- Railway
- Transmission Line
- Pits or Landfills
- Stream or Drainage

Location of DGR-1 and DGR-2 at the Bruce Site

Figure 1

N

Scale 1:20,000 (approx.)

0 130 260 520 780 1,040 Meters

Date: 17/10/2007
Drawn: NKP
Project: 06-219
Checked: SNS
P:/Projects/2006/06-219/QMS_DGR/TM_Working Files/TM-07-05/06-219_Site Location.mxd

Projection: UTM NAD 83 Zone 17

Data Credits:
NRVIS/OBM, MNR, Ontario Power Generation, Bruce Power

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3 Sample Collection

Samples collected for field geomechanical analysis were identified as XXXX-mmm.mm, where XXXX is the borehole name (e.g., DGR1) and mmm.mm is the distance in meters from the borehole reference datum (ground surface) to the sample interval midpoint. Samples were generally collected and preserved within 30 minutes of core arriving at surface. In most cases field testing was completed within 24 hours of sample collection.

Table 1 provides a summary of the samples collected for field geomechanical core testing based on Formation age (i.e., Devonian, Silurian, Upper and Middle Ordovician). Tables A.1, A.2 and A.3 of Appendix A summarize the minimum, maximum and arithmetic mean for point load, slake durability and P- and S-wave test results on a formation by formation basis. Individual sample results, including a brief description of sample lithology, are located in Tables B.1 to B.4 of Appendix B, together with other pertinent information collected for point load testing (axial), point load testing (diametral), slake durability testing and P- and S-wave testing.

Table 1 Summary of Samples Collected for Field Geomechanical Testing

Test	***Devonian & Silurian***	***Upper Ordovician***	***Middle Ordovician***	***Total***
Point Load – Axial	81	46	35	162
Point Load – Diametral	80	36	30	146
Slake Durability	11	13	6	30
P- and S-wave	24	41	40	105

The identification of gradational formation contacts was imprecise in the field and was not finalized until after completion of the testing described in this Technical Report. Consequently some samples were collected from stratigraphically similar formations located slightly above and below the Formations originally targeted for sampling. As a result, the number of samples collected from each formation may differ somewhat compared to the collection requirements outlined in Test Plan TP-06-13.

4 Methodology and Testing Procedures

4.1 Point Load Testing

Point load testing was conducted according to American Society for Testing Materials (ASTM) Standard Testing Method D 5731-05 *Standard Test Method for Determination of the Point Load Strength Index of Rock* (approved November 1, 2005). ASTM D 5731-05 is reproduced in Appendix D of this Technical Report for reference.

Samples for point load testing were selected approximately every 5 m of core length and/or at horizons of significant lithological change. Specimens were preserved in vacuum sealed 3-mil polyethylene bags or plastic freezer bags to maintain in-situ moisture conditions between the time of sample collection and the time of analysis. Tests were conducted both axially (parallel to drilling direction) and diametrally (transverse to drilling direction). In order to meet ASTM requirements, the total core length to diameter ratio for axial testing is between 0.3 and 1, and for diametral testing the ratio is greater than 1.

Point load testing was completed using the Roctest Telemax PIL-07 (Intera Measurement and Test Equipment [MTE] ID: PLT-01), where the peak load pressure (MPa) following failure was recorded from the digital pressure gauge mounted on the Roctest apparatus as shown in Figure 2a. Scientific Notebook, SN-06-13-1, was used to record the dimensions of the sample as well as the peak load pressure applied at failure.

Figure 2a. Point Load Testing Apparatus

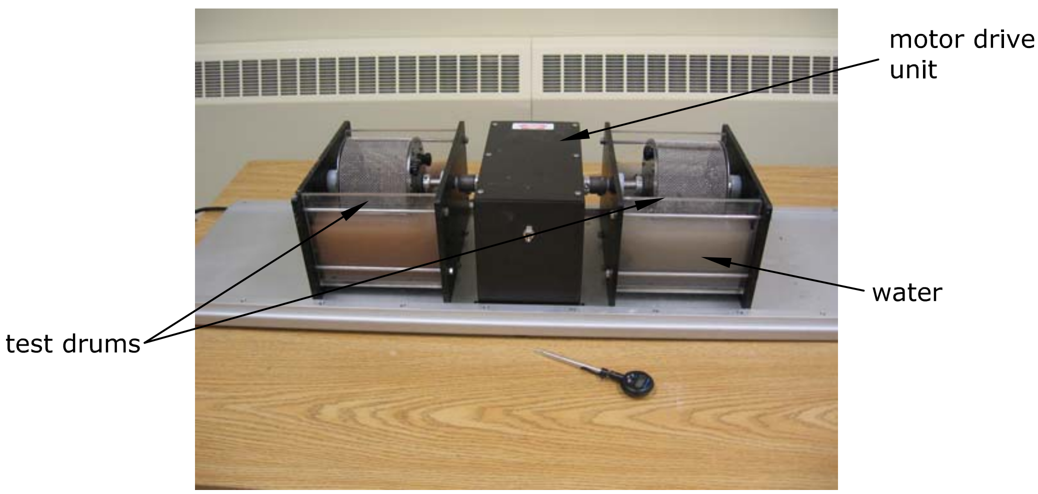


Figure 2b. Slake Durability Testing Apparatus

Figure 2c. P- and S-wave Testing Apparatus

Field Geomechanical Testing Equipment Set-up		Prepared by: SNG Reviewed by: SNS
FIGURE 2	Doc. No.: TR-07-07_Geomechanical Apparatus_R1.dwg	Date: 13-Feb-09

The following calculations were followed to determine the size-corrected point load strength, $I_{s(50)}$:

Uncorrected Point Load Strength Index:

$$I_s = \frac{P}{De^2} \tag{1}$$

where: I_s = uncorrected point load strength index (MPa)
P = failure load (equal to recorded peak load multiplied by the test platen area (9.48 x 10^{-4} m^2))
D_e^2 = square of equivalent core diameter

Size-corrected Point Load Strength Index:

$$I_{s(50)} = I_s \times F \tag{2}$$

where: $I_{s(50)}$ = size corrected point load strength index (MPa)
I_s = uncorrected point load strength index (MPa)
F = size correction factor

The anisotropic index, $I_{a(50)}$, which is the ratio of strength measured parallel and perpendicular to the horizontal planes of weakness was also determined. Further details of the applicable calculations and equations are found in the relevant ASTM standard.

A detailed summary of the point load testing data is provided in Appendix B. A point load test was considered valid if the failure resulted in a break completely through the specimen and parallel to the applied load. Conversely, a test was considered invalid if the failure resulted in a break that did not completely penetrate the specimen (i.e. chipped off one side). Photographs of each rock specimen were taken prior to testing and following failure. Sample photographs showing examples of valid and invalid breaks are provided in Appendix C, with remaining photographs available upon request.

4.2 Slake Durability Testing

Slake durability testing was conducted according to ASTM Standard Test Method D 4644-04 *Standard Method for Slake Durability of Shales and Similar Weak Rocks* (approved February 1, 2004). ASTM D 4644-04 is reproduced in Appendix D of this Technical Report for reference.

Sampling for slake durability testing targeted argillaceous rock units (i.e. rocks containing a significant content of clay minerals) that are most at risk for adverse slaking behaviour. Specimens selected for testing were preserved in vacuum sealed 3-mil polyethylene bags to maintain in-situ moisture conditions between the time of sample collection and the time of analysis. For testing purposes the specimen was broken into 10 roughly equal sized fragments weighing between 40 and 60 g each.

Prior to slake durability testing, the moisture content of each sample was determined following ASTM Standard D 2216-05, using a field lab drying oven and an Apex 4001 top loading lab balance manufactured by Denver Instruments (capacity = 4000 g, accuracy = 0.1 g) (MTE ID: TLB-01). ASTM D 2216-05 *Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass* (approved March 1, 2005) is reproduced in Appendix D of this Technical Report for reference.

Slake durability testing was completed using a slake durability apparatus manufactured by Hoskin Scientific (MTE ID: SD-01), as shown in Figure 2b, to determine the resistance of rock samples to weaken and disintegrate when subjected to changes in water content. The equipment consists of a base-mounted, motor drive unit which rotated two specimen test drums at a speed of 20 revolutions per minute. Each drum is approximately 100 mm in length and 140 mm in diameter with a 2.0 mm mesh exterior. Two cycles, consisting of 12 hours of oven drying followed by 10 minutes of tumbling in water, were conducted on the samples.

The slake durability index, I_d, represents the percentage by dry mass of the sample retained on the 2.0 mm sieve following the wetting and drying cycles. Due to the length of time required for each slake durability test, and multiple samples collected from closely spaced shale units, testing was generally completed within 48 hours of sample collection.

Scientific notebook, SN-06-13-2, as well as supplementary notebook sheets were used to record all parameters required to calculate the water content and slake durability index, as well as a qualitative description of the rock fragments remaining in the 2.0 mm sieve. A detailed summary of the slake durability testing results is found in Appendix B. Photographs of the rock specimens were taken before and after testing. Sample photographs are presented in Appendix C, with the remainder of the photographs available upon request.

4.3 Ultrasonic Pulse Velocity (P- and S-wave) Measurements

The P-wave (compressive) and S-wave (shear) ultrasonic pulse velocity measurements were conducted according to ASTM Standard Test Method D 2845-05 *Standard Test Method for Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock* (approved June 1, 2005). ASTM D 2845-05 is reproduced in Appendix D of this Technical Report for reference.

Samples for ultrasonic pulse velocity measurements were selected at regular intervals throughout DGR-1 and DGR-2. The specimens were prepared for testing by cutting the ends of the core using a rock saw to produce flat end surfaces that are planar and parallel within the limits stated by the reference ASTM standard. Following cutting, the samples were preserved using vacuum sealed 3-mil polyethylene bags or plastic freezer bags to maintain in-situ moisture conditions prior to testing.

Ultrasonic pulse velocity measurements were completed using a low-frequency Portable Ultrasonic Non-destructive Digital Indicating Tester (PUNDIT) equipped with two 1 MHz transducers, manufactured by CNS Farnell Ltd. (model: PUNDIT plus) (MTE ID: UVM-01) as shown in Figure 2c, to determine the transit time of a sound wave through the length of rock core. For both compression and shear waves, this equipment measures ultrasonic pulse velocity (range = 1 to 9999 m/s; accuracy = 1 m/s), ultrasonic wave transit time (range = 0.1 to 9999 μs; accuracy = 0.1 μs), and the calculated dynamic elastic modulus (range = up to 999.9 GN/m^2; accuracy = 0.1 GN/m^2).

The PUNDIT plus equipment was calibrated and operated as per manufacturer's recommendations. For testing, a honey coupling medium (Laser Fast Industrial Couplant) was used between the transducers and the rock specimen to minimize signal loss from the transducers through to the rock.

Scientific Notebook, SN-06-13-3, was used to record the sample dimensions, as well as the P- and S-wave transit times used to calculate the ultrasonic wave velocities and dynamic properties. The P- and S-wave velocities were determined by dividing the sample length by the ultrasonic wave travel time though the sample.

The dynamic properties were calculated using the following equations as outlined in the ASTM standard:

Dynamic Young's Modulus:

$$E_d = \frac{\rho V_s^2 \left(3V_p^2 - 4V_s^2\right)}{V_p^2 - V_s^2} \quad (3)$$

where: E_d = dynamic Young's modulus
V_s = shear wave velocity
V_p = compressive wave velocity
ρ = bulk density of specimen

Dynamic Shear Modulus:

$$G_d = \rho V_s^2 \quad (4)$$

where: G_d = dynamic shear modulus
V_s = shear wave velocity
ρ = bulk density of specimen

Poisson's Ratio (based on velocity data):

$$\nu_d = \frac{V_p^2 - 2V_s^2}{2\left(V_p^2 - V_s^2\right)} \quad (5)$$

where: ν_d = Poisson's Ratio
V_s = shear wave velocity
V_p = compressive wave velocity

A detailed summary of ultrasonic pulse velocity results (including dynamic properties for each sample) is found in Appendix B. Sample photographs are presented in Appendix C, with the remainder of the photographs available upon request.

5 Results and Conclusions

The results for point load testing, slake durability testing and ultrasonic pulse velocity measurements are summarized in Tables A.1, A.2 to A.3, respectively. The data are summarized by formation, with the Lucas and Amherstburg Formations being grouped together based on geologic age and similar lithologies. The Salina Formation was subdivided into a dolostone component comprised of A, B, D, E and G Units, and a more shaley component consisting of the C and F Units. The Guelph, Goat Island, Gasport, Lions Head and Fossil Hill Formations were also grouped together based on geologic age and similar lithologies, in addition to the gradational contacts between the Formations and the fact they are all relatively thin units.

A summary of bedrock stratigraphy is presented in Table 2 and illustrated in Figure 3. The rational for identifying each bedrock formation and the contact depths can be found in Technical Report TR-07-05 – Bedrock Formations in DGR-1 and DGR-2 (Intera Engineering Limited, 2009a).

Detailed information collected from the field, including specimen dimensions and lithological descriptions, as well as subsequent calculations are included in Tables B.1 to B.4.

Table 2 Formation Summary and Bedrock Stratigraphy

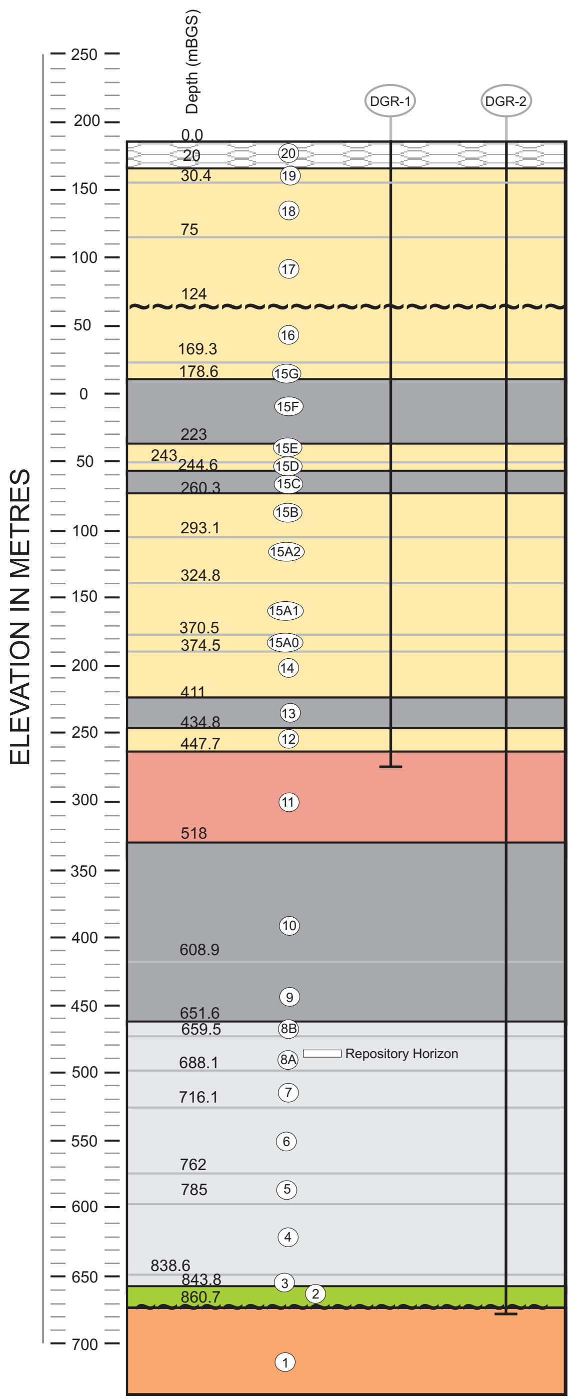
Formation	***Bedrock Stratigraphy***
Devonian & Silurian	
Lucas/Amherstburg	Brown-Grey Dolostone
Bois Blanc	Brown-Grey Dolostone with Shale and Chert
Bass Islands	Brown Fine-Grained Dolostone
Salina (Units G, E, D, B and A)	Dolostone/Dolomitic Shale/Anhydritic Dolostone
Salina (Units F and C)	Dolomitic Shale and Shale
Guelph, Goat Island, Gasport, Lions Head and Fossil Hill	Dolostone and Dolomitic Limestone
Cabot Head	Green and Grey Shale
Manitoulin	Cherty Dolostone and Minor Shale
Upper Ordovician	
Queenston	Red Shale
Georgian Bay	Greenish-Grey Shale
Blue Mountain	Dark Grey Shale
Middle Ordovician	
Cobourg	Shale and Argillaceous Limestone
Sherman Fall	Shaley and Argillaceous Limestone
Kirkfield	Argillaceous Limestone
Coboconk	Fine Grained Bioturbated Limestone
Gull River	Lithographic Limestone

5.1 Point Load Testing

Point load testing was conducted at roughly equal intervals along the entire stratigraphic column encountered in DGR-1 and DGR-2 underlying the Bruce site. A total of 162 (140 valid) axial tests and 148 (143 valid) diametral tests were completed. Only a relatively small number of tests were considered invalid due to the fracture surface not passing all the way through the sample. For those samples that did not fail within the ASTM recommended time (10 to 60 seconds with a steadily applied load), the majority of these failed before 10 seconds and occurred during diametral testing. These tests were considered valid, as a reflection of the effects of relatively weak horizontal (bedding) planes within the sedimentary rocks.

Table A.1 summarizes by geologic age and Formation, the number of samples tested, minimum value, maximum value, and arithmetic mean value of strength index, $I_{s(50)}$ for both axial and diametral tests. In addition, the average anisotropic index, $I_{a(50)}$, is summarized in Table A.1. Sample descriptions, recorded peak load, index strength parameters and validity of the tests are listed in Table B.1 and B.2 for axial and diametral point load tests, respectively.

The average corrected axial point load strength indices, $I_{s(50)}$, varied from 1.35 MPa for the Blue Mountain Formation to 5.37 MPa for the Guelph, Goat Island, Lion’s Head and Fossil Hill Formations. Similarly, the average corrected diametral point load strength indices varied between 0.54 MPa and 4.79 MPa for the Blue Mountain and Guelph, Goat Island, Lion’s Head and Fossil Hill Formations, respectively. The results for both axial and diametral testing indicate that there is significant variation of strength indices within each formation.



LEGEND - BRUCE SITE STRATIGRAPHY

PLEISTOCENE
20 SURFICIAL DEPOSITS

MIDDLE DEVONIAN
19 LUCAS FORMATION - DOLOSTONE
18 AMHERSTBURG FORMATION - DOLOSTONE

LOWER DEVONIAN
17 BOIS BLANC FORMATION - CHERTY DOLOSTONE
~~~~~~ SILURIAN / DEVONIAN DISCONTINUITY

UPPER SILURIAN
16 BASS ISLANDS FORMATION - DOLOSTONE
15 SALINA FORMATION
15G G UNIT - ARGILLACEOUS DOLOSTONE
15F F UNIT - DOLOMITIC SHALE
15E E UNIT - BRECCIATED DOLOSTONE AND DOLOMITIC SHALE
15D D UNIT - ANHYDRITIC DOLOSTONE
15C C UNIT - DOLOMITIC SHALE AND SHALE
15B B UNIT - ARGILLACEOUS DOLOSTONE AND ANHYDRITE
15A2 A2 UNIT - DOLOSTONE AND ANHYDRITIC DOLOSTONE
15A1 A1 UNIT - ARGILLACEOUS DOLOSTONE AND ANHYDRITIC DOLOSTONE
15A0 A0 - BITUMINOUS DOLOSTONE

MIDDLE SILURIAN
14 GUELPH, GOAT ISLAND, GASPORT, LIONS HEAD AND FOSSIL HILL FORMATIONS - DOLOSTONE AND DOLOMITIC LIMESTONE

LOWER SILURIAN
13 CABOT HEAD FORMATION - SHALE
12 MANITOULIN FORMATION - CHERTY DOLOSTONE AND MINOR SHALE

UPPER ORDOVICIAN
11 QUEENSTON FORMATION - RED SHALE
10 GEORGIAN BAY FORMATION - GREY SHALE
9 BLUE MOUNTAIN FORMATION - DARK GREY SHALE

MIDDLE ORDOVICIAN
8 COBOURG FORMATION
8B COLLINGWOOD MEMBER - BLACK CALCAREOUS SHALE AND ARGILLACEOUS LIMESTONE
8A LOWER MEMBER - ARGILLACEOUS LIMESTONE
7 SHERMAN FALL FORMATION - ARGILLACEOUS LIMESTONE
6 KIRKFIELD FORMATION - ARGILLACEOUS LIMESTONE
5 COBOCONK FORMATION - BIOTURBATED LIMESTONE
4 GULL RIVER FORMATION - LITHOGRAPHIC LIMESTONE
3 SHADOW LAKE FORMATION - SILTSTONE AND SANDSTONE

CAMBRIAN
2 CAMBRIAN SANDSTONE
~~~~~~ CAMBRIAN / PRECAMBRIAN UNCOMFORMITY

PRECAMBRIAN
1 PRECAMBRIAN BASEMENT - GRANITIC GNEISS

NOTE:
1. SUBSURFACE STRATIGRAPHIC NOMENCLATURE AFTER ARMSTRONG AND CARTER (2006)

Interpreted Bedrock Stratigraphy at Bruce Site from DGR-1 and DGR-2		Prepared by: ADG Reviewed by: KGR
FIGURE 3	Doc. No.: TR-07-07_Figure 3-Bedrock Stratigraphy_R1.cdr	Date: 23-Jan-09

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In general, the average size corrected point load strength index was greater for tests parallel to drilling direction (axial) compared to the tests conducted perpendicular to the drilling direction (diametral). This suggests that the major planes of weakness are in the horizontal direction, which was consistent with the field observations of horizontal bedding planes and horizontal shale stringers or interbeds in many of the Formations. The degree of anisotropy, $I_{a(50)}$, which is a measure of the ratio between the strength perpendicular and parallel to the planes of weakness, ranges from 0.85 in the Bois Blanc Formation to 5.08 in the Manitoulin Formations, respectively. With the exception of the Bois Blanc Formation, all other Formations had an anisotropic index of greater than or equal to one.

5.2 Slake Durability Testing

Slake durability testing was conducted on 30 specimens collected from DGR-1 and DGR-2. Table A.2 summarizes by geologic age and Formation, the number of samples tested, minimum value, maximum value and arithmetic mean value for water content and slake durability index. Table B.3 provides pertinent information for each individual sample, including a brief geologic description, water content, slake durability index and a description of the rock fragments categorized into Type I (virtually unchanged), Type II (large and small) or Type III (exclusively small) as outlined in ASTM Standard D 4644-04.

The average slake durability index ranged from a low of 62% from the samples collected from the Salina Formation (C and F Units) to a high of 99% in both the Lucas/Amherstburg and Coboconk Formations. The results are consistent with the expected values based on the lithology of the specimens and indicate that the competent limestone/dolostone units have index values close to 100% (i.e. no material loss), while the the more argillaceous or shaley limestone units have index values less than 90%.

The average water content generally decreased with depth and varied from less than 2% in the Middle Ordovician limestones between 650-840 mBGS, approximately 2% in the Upper Ordovician shales (450-650 mBGS) and greater than 5% in the shallow formations (Devonian and Silurian between 20-450 mBGS).

5.3 Ultrasonic Pulse Velocity (P- and S-wave) Measurements

A total of 105 samples were collected from DGR-1 and DGR-2 for ultrasonic pulse velocity measurements. Thirty-five of these samples were also submitted to CANMET Laboratories for further laboratory strength testing (Intera Engineering Limited, 2009b).

Based on the P- and S-wave velocities measured in the field, the dynamic elastic constants, Young's Modulus (E_d), shear modulus (G_d) and Poisson's ratio (v_d) were calculated. These calculations are inherently unreliable using this method because small errors in the velocity measurements are propagated through the respective formulas and can result in large errors in the final determination of dynamic elastic constants. It should be noted that dynamic shear modulus, G_d, is generally considered to be the most reliable of the constants calculated because of the relatively straightforward relationship with the measured S-wave velocity.

The testing conducted by CANMET was under controlled laboratory conditions and the results may be considered more accurate than the field results. The results of field testing are summarized by geologic age and Formation in Table A.3, which includes the number of samples tested, minimum, maximum and average P- and S-wave velocities, as well as average values for the dynamic properties of the units. Table B.4 provides a summary of relevant information for each individual P- and S-wave velocity (V_p and V_s), dynamic Young's modulus (E_d), dynamic shear modulus (G_d) and Poisson's ratio (v_d) result.

For comparison purposes the P- and S-wave velocity results of the field samples are presented with the corresponding CANMET sample in Table A.4. Field measured P- and S-wave velocities varied between being both greater than and less than CANMET lab measured velocities.

Forty-three of the field pulse velocity measurements were deemed to be unreliable because subsequent calculations of dynamic Young's modulus (E_d) and/or Poisson's ratio (v_d) were not within the range of expected values based on the results of CANMET testing. When at least one of the dynamic elastic constants was out of range the remaining calculations for the sample were considered suspect and not included in summary calculations.

Based on the results of 62 samples with P- and S-wave velocity measurements in the expected range based on CANMET analyses, the following variability of elastic constants were observed in DGR-1 and DGR-2 samples. Dynamic Young's modulus ranges from an average of approximately 17 GPa in the Salina F-member to approximately 75 GPa in the Cobourg and Lucas/Amherstburg Formations. The dynamic shear modulus ranges from approximately 7 GPa in the Salina F-member to approximately 31 GPa in the Cobourg and Lucas/Amherstburg Formations. Values of Poisson's ratio vary between 0.07 in the Sherman Fall Formation to approximately 0.35 in the Bass Island, Cabot Head and Manitoulin Formations, each with only one valid sample result.

6 Data Quality and Use

Results of field geomechanical testing of DGR-1 and DGR-2 core described in this Technical Report are based on testing conducted in accordance with well established and well defined ASTM testing procedures and following the general requirements of the DGR Project Quality Plan and TP-06-13. Consequently, the results presented in this Technical Report are suitable for assessing the general range of geomechanical strength, elastic and slaking degradation properties of bedrock formations intersected by DGR-1 and DGR-2. These data will assist in the development of descriptive geomechanical models of the Bruce DGR site

The results of field geomechanical testing show a range of results reflecting natural lithological and stratigraphic variability of the bedrock formations encountered. However, the results generated from field geomechanical testing described in this Technical Report are generally consistent with expectations based on experience in geomechanical testing of bedrock formations elsewhere (Lam et al., 2007) and related DGR laboratory geomechanical core testing programs (Intera Engineering Ltd., 2007b).

7 References

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APPENDIX A

Summary Tables of Phase I Field Geomechanical Test Results

Table A.1 Summary of Point Load Testing Results

Formation	Strength Index (Axial), $I_{s(50)}$				Strength Index (Diametral), $I_{s(50)}$				Average Anisotropic Index, $I_{a(50)}$
	# of Samples (Valid/Total)	Min	Max	Avg.	# of Samples (Valid/Total)	Min	Max	Avg	
Devonian & Silurian									
Lucas/Amherstberg	8/9	2.39	7.12	4.75	8/9	3.20	6.16	4.60	1.03
Bois Blanc	7/8	0.15	6.81	3.51	9/10	2.25	6.10	4.11	0.85
Bass Islands	6/6	1.70	6.48	4.30	6/6	0.39	10.33	3.16	1.36
Salina (A, B, D, E and G Units)	25/28	0.28	8.03	3.05	28/28	0.16	4.99	1.63	1.88
Salina (C and F Units)	10/12	0.41	4.54	2.10	13/13	0.07	2.40	0.96	2.18
Guelph, Goat Island, Gasport, Lions Head and Fossil Hill	10/10	3.64	7.71	5.37	8/9	2.50	6.66	4.79	1.12
Cabot Head	4/6	1.15	4.63	2.56	4/4	0.16	2.33	0.84	3.05
Manitoulin	2/2	3.30	4.98	4.14	1/1	--	--	0.82	5.08
Upper Ordovician									
Queenston	13/14	1.68	4.90	2.30	15/15	0.31	3.71	1.60	1.43
Georgian Bay	14/22	0.70	5.82	2.08	15/15	0.03	6.90	1.80	1.16
Blue Mountain	6/10	0.22	2.65	1.35	5/5	0.02	1.87	0.54	2.53
Middle Ordovician									
Cobourg	5/5	3.04	4.27	3.69	5/5	3.47	3.95	3.69	1.00
Sherman Fall	5/5	3.26	6.28	4.25	5/5	0.75	4.40	2.53	1.68
Kirkfield	8/8	2.46	5.04	3.70	7/7	0.41	4.47	1.93	1.91
Coboconk	5/5	2.88	4.62	3.33	5/6	0.30	3.66	1.53	2.18
Gull River	12/12	2.59	5.35	3.88	9/10	0.75	5.26	2.70	1.44

Table A.2 Summary of Slake Durability Testing

Formation	# of samples	Water Content (%)			Slake Durability Index		
		Min	Max	Avg	Min	Max	Avg
Devonian & Silurian							
Lucas/Amherstberg	1	n/a	n/a	4.0	n/a	n/a	99.0
Bois Blanc	0	--	--	--	--	--	--
Bass Islands	3	3.1	7.3	5.5	35.8	97.4	73.5
Salina (A,B,D,E and G Units)	0	--	--	--	--	--	--
Salina (C and F Units)	4	4.6	9.4	7.0	51.5	78.9	61.7
Guelph, Goat Island, Gasport, Lions Head and Fossil Hill	0	--	--	--	--	--	--
Cabot Head	3	2.6	3.6	3.2	41.5	85.9	65.3
Manitoulin	0	--	--	--	--	--	--
Upper Ordovician							
Queenston	4	1.4	2.2	1.9	84.5	95.1	89.4
Georgian Bay	6	1.8	2.6	2.2	63.8	87.8	76.3
Blue Mountain	3	1.7	2.5	2.2	85.1	98.2	92.8
Middle Ordovician							
Cobourg	0	--	--	--	--	--	--
Sherman Fall	2	1.3	1.3	1.3	83.8	93.2	88.5
Kirkfield	1	n/a	n/a	0.6	n/a	n/a	98.4
Coboconk	1	n/a	n/a	0.2	n/a	n/a	99.1
Gull River	2	0.7	0.9	0.8	95.9	98.5	97.2

Notes:
-- = no data
n/a = not applicable

Table A.3 Summary of Ultrasonic Pulse Velocity Measurements

Formation	# of samples (valid/total)	P-Wave Velocity, Vp (km/s)			S-Wave Velocity, Vs (km/s)			Dynamic Young's Modulus, E_d (GPa)	Dynamic Shear Modulus, G_d (GPa)	Poisson's Ratio, v_d
		Min	Max	Avg	Min	Max	Avg	Avg	Avg	Avg
Devonian & Silurian										
Lucas/Amherstberg	3/4	5.55	5.83	5.64	3.39	3.65	3.48	74.60	31.31	0.19
Bois Blanc	1/2	n/a	n/a	5.42	n/a	n/a	3.08	62.77	24.86	0.26
Bass Islands	1/1	n/a	n/a	3.95	n/a	n/a	1.95	25.37	9.47	0.34
Salina (A,B and G Units)	3/5	2.85	5.52	4.13	1.86	3.20	2.45	43.22	17.56	0.21
Salina (F Unit)	4/4	2.25	4.32	3.34	1.23	1.97	1.59	17.40	6.51	0.33
Guelph, Goat Island, Gasport, Lions Head and Fossil Hill	3/3	3.97	5.68	5.10	2.10	3.36	2.92	59.22	23.76	0.26
Cabot Head	1/1	n/a	n/a	3.96	n/a	n/a	1.81	23.76	8.69	0.37
Manitoulin	1/2	n/a	n/a	5.90	n/a	n/a	2.92	63.63	23.78	0.34
Upper Ordovician										
Queenston	18/23	3.70	5.63	4.34	1.86	3.33	2.47	41.66	16.70	0.26
Georgian Bay	6/18	3.44	6.10	4.94	1.97	3.56	2.72	51.96	21.00	0.25
Blue Mountain	0/0	--	--	--	--	--	--	--	--	--
Middle Ordovician										
Cobourg	10/10	5.42	6.02	5.78	3.26	3.52	3.40	76.85	31.11	0.23
Sherman Fall	1/8	n/a	n/a	3.65	n/a	n/a	2.49	35.27	16.55	0.07
Kirkfield	0/7	--	--	--	--	--	--	--	--	--
Coboconk	0/2	--	--	--	--	--	--	--	--	--
Gull River	10/13	3.73	6.23	5.48	2.12	3.40	2.95	61.73	24.29	0.28

Notes:

-- = no data

n/a = not applicable

Table A.4 - Comparison between INTERA and CANMET Ultrasonic Pulse Velocity Measurements

Sample ID	INTERA		CANMET[(1)]		RPD (%)	
	P-Wave Velocity, Vp (km/s)	S-Wave Velocity, Vs (km/s)	P-Wave Velocity, Vp (km/s)	S-Wave Velocity, Vs (km/s)	P-Wave Velocity, Vp	S-Wave Velocity, Vs
DGR1-070.84	5.83	3.65	5.72	2.96	2	21
DGR1-108.62	2.47*	2.30*	3.86	2.46	36	7
DGR1-171.14	3.95	1.95	4.29	2.21	8	13
DGR1-183.60	2.25	1.40	4.23	2.40	61	53
DGR1-206.55	3.68	1.78	4.04	1.98	9	11
DGR1-286.69	1.59*	1.53*	4.20	1.99	62	23
DGR1-314.88	4.01	2.30	4.93	2.49	21	8
DGR1-367.06	5.52	3.20	5.55	2.71	0.5	16
DGR1-386.55	5.68	3.30	5.51	2.84	3	15
DGR1-415.16	3.96	1.81	2.54	1.05	44	53
DGR1-438.10	1.78*	2.15*	4.83	2.56	63	16
DGR1-455.22	3.87	1.86	3.87	2.03	0	9
DGR1-460.41	4.15	2.34	1.94	0.92	73	87
DGR2-474.71	4.39	2.73	4.25	2.34	3	16
DGR2-491.32	2.43*	2.06*	3.94	2.29	38	10
DGR2-502.78	5.18	3.10	4.85	3.21	7	4
DGR2-519.61	2.35*	2.08*	4.48	2.39	48	13
DGR2-533.94	5.57	3.56	5.66	3.30	2	8
DGR2-606.50	0.97*	1.90*	3.34	1.85	71	3
DGR2-654.97	5.42	3.29	4.53	2.65	18	22
DGR2-660.68	6.02	3.42	5.94	3.15	1	8
DGR2-661.61	5.89	3.47	5.70	3.13	3	10
DGR2-666.79	5.91	3.52	5.43	2.81	8	22
DGR2-668.46	5.87	3.43	5.35	2.75	9	22
DGR2-673.26	5.53	3.26	4.95	2.65	11	21
DGR2-674.11	5.90	3.43	5.41	2.99	9	14
DGR2-676.75	5.96	3.44	5.46	2.95	9	15
DGR2-679.83	5.65	3.35	4.79	2.64	16	24
DGR2-683.02	5.60	3.37	4.59	2.62	20	25
DGR2-688.22	1.62*	2.13*	4.25	2.38	62	11
DGR2-694.11	1.56*	2.38*	5.51	2.70	72	12
DGR2-695.15	3.65	2.49	5.95	2.91	48	16
DGR2-704.47	1.09*	2.22*	3.49	1.80	69	23
DGR2-710.29	0.95*	2.01*	4.38	2.07	78	3
DGR2-719.38	1.65*	2.26*	2.73	1.59	40	42

Notes:

RPD = Relative Percent Difference

(1) = Intera Engineering Ltd., 2007f. Laboratory Geomechanical Strength Testing of DGR-1 & DGR-2 Core, TR-07-03, Revision 1, November 9, 2007, Ottawa.

***** = INTERA data leading to anomalous elastic constant results

APPENDIX B

Field Geomechanical Testing Results

Table B.1 Results of Point Load Testing (Axial) of DGR-1 and DGR-2 Core Samples

Sample ID	Sample Desciption	Date Tested	Diameter (mm)	Length (mm)	Peak Load (MPa)	$Is_{(50)}$ (MPa)	Notes
Lucas Formation (20-30.4 mBGS)							
Amherstburg Formation (30.4-75 mBGS)							
DGR1-030.39	light grey/tan dolostone	26-Jan-07	67	60	10.98	2.39	Valid
DGR1-033.92	light grey/tan dolostone /w clasts of fossils	26-Jan-07	67	59	18.20	4.04	Invalid (break)
DGR1-039.05	brown dolostone	30-Jan-07	67	52	10.08	2.47	Valid
DGR1-044.47	brown dolostone	1-Feb-07	67	44	25.08	6.94	Valid
DGR1-049.28	light brown dolostone	3-Feb-07	67	53	13.36	3.22	Valid
DGR1-056.04	grey/brown dolostone	3-Feb-07	67	62	21.46	4.58	Valid
DGR1-060.60	light brown/grey dolostone	4-Feb-07	67	42	19.52	5.60	Valid
DGR1-066.42	light brown/grey dolostone	4-Feb-07	67	34	21.06	7.12	Valid
DGR1-070.23	medium brown/grey dolostone /w chert clast	7-Feb-07	67	42	19.90	5.71	Valid
Bois Blanc Formation (75-124 mBGS)							
DGR1-075.66	brown/grey dolostone /w mudstone clast	17-Feb-07	67	55	18.16	4.23	Valid
DGR1-079.21	grey/brown dolostone	17-Feb-07	67	67	24.78	4.95	Valid
DGR1-087.45	grey/brown cherty dolostone	19-Feb-07	67	52	15.12	3.68	Valid
DGR1-096.47	grey/brown cherty dolostone	22-Feb-07	67	39	14.58	4.43	Valid
DGR1-100.05	grey cherty dolostone	22-Feb-07	76	51	0.66	0.15	Valid
DGR1-110.60	light grey cherty dolostone	22-Feb-07	76	50	7.88	1.79	Invalid (break)
DGR1-115.61	grey/brown cherty dolostone	24-Feb-07	76	54	31.78	6.81	Valid
DGR1-123.12	grey cherty dolostone /w mudstone clasts	24-Feb-07	76	61	1.72	0.34	Valid
Bass Islands Formation (124-169.3 mBGS)							
DGR1-124.09	light grey/tan dolostone	24-Feb-07	76	67	35.74	6.48	Valid
DGR1-129.33	grey/brown dolostone	25-Feb-07	76	51	7.60	1.70	Valid
DGR1-132.49	grey/brown dolostone	27-Feb-07	67	43	16.54	4.66	Valid
DGR1-134.57	grey dolomitized shale	27-Feb-07	67	40	18.00	5.36	Valid
DGR1-144.67	light brown/grey dolostone	1-Mar-07	67	60	25.86	5.66	Valid
DGR1-161.19	grey/brown angular and rounded clastic dolostone	2-Mar-07	67	65	9.44	1.93	Valid
Salina G Unit (169.3-178.6 mBGS)							
DGR1-169.45	medium grey argillaceous dolostone /w anhydrite veins	2-Mar-07	67	46	3.38	0.90	Valid
DGR1-171.61	3.3cm anhydrite layer /w medium grey argillaceous dolostone	2-Mar-07	67	42	1.52	0.44	Valid
DGR1-178.20	grey argillaceous dolostone	2-Mar-07	67	32	5.76	2.04	Valid
Salina F Unit (178.6-223 mBGS)							
DGR1-180.25	medium/dark grey argillaceous dolostone /w anhydrite veins	2-Mar-07	67	34	5.92	2.00	Valid
DGR1-181.89	medium/dark grey argillaceous dolostone /w anhydrite veins and laminations	2-Mar-07	67	36	5.10	1.65	Valid
DGR1-185.62	reddish/brown dolomitic shale /w anhydrite veins	26-Mar-07	76	60	9.80	1.93	Valid
DGR1-193.64	reddish/brown dolomitic shale /w anhydrite veins	27-Mar-07	76	54	10.16	2.18	Valid
DGR1-195.18	grey/green dolomitic shale /w anhydrite veins	27-Mar-07	76	58	22.40	4.54	Valid
DGR1-198.66	grey/green dolomitic shale /w anhydrite veins	27-Mar-07	76	64	16.28	3.06	Invalid (break)
DGR1-202.15	grey/green dolomitic shale /w thick anhydrite layers and veins	27-Mar-07	76	58	17.54	3.55	Valid
DGR1-204.14	grey/green dolomitic shale /w anhydrite veins	27-Mar-07	76	52	4.20	0.93	Invalid (break)
DGR1-213.42	grey/green dolomitic shale /w minor anhydrite veins	27-Mar-07	76	48	7.90	1.85	Valid
DGR1-220.50	tan/brown brecciated dolostone /w anhydrite veins and layers	27-Mar-07	76	61	12.24	2.38	Valid
Salina E Unit (223-243 mBGS)							
DGR1-227.09	tan/grey brecciated dolostone /w grey/green dolomitic shale and anhydrite veins	27-Mar-07	76	35	2.78	0.83	Valid
DGR1-228.92	tan/grey brecciated dolostone /w grey/green dolomitic shale and anhydrite veins	27-Mar-07	76	38	2.64	0.74	Valid
DGR1-242.12	medium grey dolomitic shale	28-Mar-07	76	36	2.24	0.66	Valid

Table B.1 Results of Point Load Testing (Axial) of DGR-1 and DGR-2 Core Samples

Sample ID	Sample Desciption	Date Tested	Diameter (mm)	Length (mm)	Peak Load (MPa)	$Is_{(50)}$ (MPa)	Notes
Salina D Unit (243.0-244.6 mBGS)							
Salina C Unit (244.6-260.3 mBGS)							
DGR1-249.52	light orange anhydrite layer	28-Mar-07	76	26	1.40	0.53	Valid
DGR1-257.15	grey/green and red dolomitic shale /w anhydrite veins and nodules	28-Mar-07	76	51	1.84	0.41	Valid
Salina B Unit (260.3-293.1 mBGS)							
DGR1-262.04	grey/green argillaceous dolostone /w minor anhydrite nodules	28-Mar-07	76	45	1.12	0.28	Valid
DGR1-267.60	grey/green argillaceous dolostone /w minor anhydrite veins	28-Mar-07	76	32	1.84	0.59	Valid
DGR1-273.48	grey/green argillaceous dolostone /w anhydrite veins and nodules	28-Mar-07	76	58	2.12	0.43	Valid
DGR1-275.49	grey/green argillaceous dolostone /w minor anhydrite veins	28-Mar-07	76	38	3.64	1.02	Valid
DGR1-282.11	grey/green argillaceous dolostone	29-Mar-07	76	53	2.92	0.63	Valid
DGR1-290.37	grey/brown argillaceous dolostone	30-Mar-07	76	71	25.54	4.42	Valid
Salina A Unit (293.1-374.5 mBGS)							
DGR1-294.95	grey/brown dolostone	30-Mar-07	76	29	8.00	2.77	Valid
DGR1-298.37	medium grey dolostone	30-Mar-07	76	47	11.90	2.84	Valid
DGR1-307.08	grey dolomitic shale and light grey argillaceous dolostone	31-Mar-07	76	67	1.82	0.33	Valid
DGR1-311.14	tan/grey argillaceous dolostone	31-Mar-07	76	27	11.66	4.27	Valid
DGR1-315.17	tan/grey dolostone	31-Mar-07	76	50	20.72	4.71	Valid
DGR1-320.83	grey/blue anhydritic dolostone	31-Mar-07	76	34	22.62	6.93	Valid
DGR1-324.16	grey/blue anhydritic dolostone	31-Mar-07	76	42	21.40	5.57	Valid
DGR1-329.70	grey/brown argillaceous dolostone	31-Mar-07	76	53	17.52	3.81	Valid
DGR1-336.17	grey argillaceous dolostone /w anhydrite veins	31-Mar-07	76	60	29.54	5.83	Invalid (break)
DGR1-340.62	grey argillaceous dolostone	31-Mar-07	76	51	26.10	5.84	Invalid (break)
DGR1-346.55	grey argillaceous dolostone	1-Apr-07	76	68	41.62	7.45	Valid
DGR1-351.37	grey argillaceous dolostone	1-Apr-07	76	40	17.80	4.81	Valid
DGR1-357.42	grey argillaceous dolostone /w horizontal bituminous laminations	1-Apr-07	76	28	14.36	5.12	Valid
DGR1-359.97	grey argillaceous dolostone /w horizontal bituminous laminations	1-Apr-07	76	39	5.54	1.53	Invalid (break)
DGR1-367.65	light grey/blue anhydritic dolostone	1-Apr-07	76	49	28.42	6.56	Valid
DGR1-370.14	light grey/blue anhydritic dolostone	1-Apr-07	76	48	34.22	8.03	Valid
Guelph Formation (374.5-378.6mBGS)							
DGR1-375.26	brown vuggy sucrosic dolostone	2-Apr-07	76	55	20.72	4.37	Valid
Goat Island Formation (378.6-397.4 mBGS)							
DGR1-380.47	medium grey dolostone	2-Apr-07	76	44	30.72	7.71	Valid
DGR1-383.28	medium grey dolostone	2-Apr-07	76	58	25.56	5.18	Valid
DGR1-386.28	medium grey dolostone	2-Apr-07	76	49	24.32	5.62	Valid
DGR1-391.24	medium grey dolostone	3-Apr-07	76	43	21.02	5.37	Valid
DGR1-394.66	medium grey dolostone	3-Apr-07	76	58	29.00	5.88	Valid
DGR1-395.20	medium grey dolostone	3-Apr-07	76	30	15.42	5.21	Valid
Gasport Formation (397.4-404.25 mBGS)							
DGR1-401.35	light to medium grey dolomitic limestone	3-Apr-07	76	63	28.28	5.37	Valid
Lions Head Formation (404.25-408.7 mBGS)							
DGR1-406.95	tan/grey dolostone	3-Apr-07	76	50	16.02	3.64	Valid
Fossil Hill Formation (408.7-411.0 mBGS)							
DGR1-410.33	tan grey dolostone	3-Apr-07	76	73	31.74	5.38	Valid

Table B.1 Results of Point Load Testing (Axial) of DGR-1 and DGR-2 Core Samples

Sample ID	Sample Desciption	Date Tested	Diameter (mm)	Length (mm)	Peak Load (MPa)	$Is_{(50)}$ (MPa)	Notes
Cabot Head Formation (411.0-434.8 mBGS)							
DGR1-416.95	red/maroon massive non-calcareous shale	3-Apr-07	76	50	7.34	1.67	Valid
DGR1-417.01	grey/green and red/maroon non-calcareous shale	3-Apr-07	76	44	8.20	2.05	Invalid (break)
DGR1-422.29	red/maroon non-calcareous shale	3-Apr-07	76	39	4.18	1.15	Valid
DGR1-429.33	medium grey fossiliferous dolostone	3-Apr-07	76	57	22.56	4.63	Valid
DGR1-430.92	dark grey dolomitic shale	4-Apr-07	76	32	4.08	1.31	Invalid (break)
DGR1-432.20	light/medium grey dolomitic shale and cherty dolostone	4-Apr-07	76	40	10.26	2.77	Valid
Manitoulin Formation (434.8-447.7 mBGS)							
DGR1-437.58	medium/dark grey cherty dolostone	4-Apr-07	76	41	18.80	4.98	Valid
DGR1-446.40	finely laminated grey/green shale	4-Apr-07	76	60	16.74	3.30	Valid
Queenston Formation (447.7-518 mBGS)							
DGR1-449.37	massive red/maroon calcareous shale with minor grey/green calcareous shale	4-Apr-07	76	61	10.48	2.04	Valid
DGR1-457.57	massive red/maroon calcareous shale	4-Apr-07	76	30	5.78	1.95	Valid
DGR2-458.56	massive red/maroon calcareous shale	30-May-07	76	25	58.76	22.86	Invalid (break)
DGR1-462.49	massive red/maroon calcareous shale	4-Apr-07	76	57	11.30	2.32	Valid
DGR2-473.76	massive red/maroon calcareous shale	29-May-07	76	40	6.62	1.80	Valid
DGR2-479.28	massive red/maroon calcareous shale	30-May-07	76	40	8.20	2.22	Valid
DGR2-483.78	massive grey/green calcareous shale	30-May-07	76	35	5.56	1.68	Valid
DGR2-484.69	massive grey/green calcareous shale	30-May-07	76	30	5.52	1.86	Valid
DGR2-491.21	massive grey/green shale	30-May-07	76	39	17.90	4.90	Valid
DGR2-498.72	massive grey/green shale	31-May-07	76	35	5.56	1.68	Valid
DGR2-503.45	interbedded green shale and fossiliferous limestone	31-May-07	76	40	8.20	2.22	Valid
DGR2-508.26	massive red/maroon grey/green shale	31-May-07	76	32	7.44	2.39	Valid
DGR2-511.53	massive red/maroon shale	31-May-07	76	41	9.44	2.52	Valid
DGR2-514.90	massive red/maroon shale	31-May-07	76	40	8.62	2.33	Valid
Georgian Bay Formation (518-608.9 mBGS)							
DGR2-520.15	grey/green interbedded shale and limestone	31-May-07	76	40	7.36	1.99	Valid
DGR2-521.57	grey/green interbedded shale and limestone	31-May-07	76	51	10.12	2.27	Valid
DGR2-530.16	grey/green shale	31-May-07	76	35	2.34	0.70	Valid
DGR2-535.70	grey/green shale /w minor interbeds of limestone	31-May-07	76	52	6.60	1.46	Valid
DGR2-540.81	grey/green interbedded shale and limestone	31-May-07	76	23	32.24	13.38	Invalid (break)
DGR2-548.21	grey/green interbedded shale and limestone	1-Jun-07	76	33	7.54	2.37	Valid
DGR2-548.49	grey/green interbedded shale and limestone	1-Jun-07	76	72	6.90	1.18	Invalid (break)
DGR2-549.18	grey/green shale	1-Jun-07	76	45	12.70	3.13	Invalid (break)
DGR2-555.20	grey/green interbedded shale and limestone	1-Jun-07	76	35	5.36	1.61	Invalid (break)
DGR2-558.42	grey/green shale /w minor interbeds of limestone	1-Jun-07	76	45	2.44	0.60	Invalid (break)
DGR2-565.66	grey/green interbedded shale and limestone	1-Jun-07	76	43	6.14	1.57	Valid
DGR2-568.03	grey/green interbedded shale and limestone	1-Jun-07	76	42	10.14	2.64	Valid
DGR2-575.67	grey/green interbedded shale and limestone	1-Jun-07	76	34	4.26	1.31	Valid
DGR2-576.31	grey/green shale	3-Jun-07	76	34	4.70	1.44	Invalid (break)
DGR2-581.45	grey/green shale /w minor interbeds of limestone	3-Jun-07	76	48	2.56	0.60	Invalid (break)
DGR2-587.90	grey/green shale	3-Jun-07	76	53	8.22	1.78	Invalid (break)
DGR2-590.99	grey/green shale	3-Jun-07	76	43	9.44	2.41	Valid
DGR2-592.49	grey/green shale /w minor interbeds of limestone	3-Jun-07	76	40	5.12	1.38	Valid
DGR2-597.77	grey/green shale	3-Jun-07	76	36	7.30	2.14	Valid

Table B.1 Results of Point Load Testing (Axial) of DGR-1 and DGR-2 Core Samples

Sample ID	Sample Desciption	Date Tested	Diameter (mm)	Length (mm)	Peak Load (MPa)	$Is_{(50)}$ (MPa)	Notes
DGR2-603.87	grey/green shale	3-Jun-07	76	28	4.94	1.76	Valid
DGR2-607.43	grey fossiliferous sandstone	3-Jun-07	76	40	21.54	5.82	Valid
DGR2-608.85	grey/green shale	3-Jun-07	76	42	5.18	1.35	Valid
Blue Mountain Formation (608.9-651.6 mBGS)							
DGR2-611.27	grey/green shale	3-Jun-07	76	53	10.42	2.26	Valid
DGR2-618.43	grey/blue shale	3-Jun-07	76	58	9.32	1.89	Valid
DGR2-623.97	grey/blue shale	3-Jun-07	76	53	1.02	0.22	Valid
DGR2-630.59	grey shale	3-Jun-07	76	60	0.22	0.04	Invalid (break)
DGR2-633.24	grey shale	3-Jun-07	76	42	1.70	0.44	Invalid (break)
DGR2-639.41	grey shale	3-Jun-07	76	75	2.08	0.35	Valid
DGR2-639.50	grey shale	3-Jun-07	76	34	2.62	0.80	Invalid (break)
DGR2-644.85	grey shale	3-Jun-07	76	52	2.74	0.60	Invalid (break)
DGR2-650.38	grey shale	4-Jun-07	76	39	9.68	2.65	Valid
DGR2-651.55	grey shale	4-Jun-07	76	42	2.88	0.75	Valid
Cobourg Formation (651.6-688.1 mBGS)							
DGR2-656.65	grey/brown limestone	11-Jun-07	76	42	14.40	3.77	Valid
DGR2-665.12	grey/brown argillaceous limestone	11-Jun-07	76	35	13.24	3.99	Valid
DGR2-672.15	grey/brown argillaceous limestone	11-Jun-07	76	25	8.82	3.40	Valid
DGR2-678.55	grey/brown argillaceous limestone	11-Jun-07	76	27	11.64	4.27	Valid
DGR2-683.49	grey argillaceous limestone	11-Jun-07	76	23	7.26	3.04	Valid
Sherman Fall Formation (688.1-716.1 mBGS)							
DGR2-689.78	grey argillaceous fossiliferous limestone	12-Jun-07	76	45	13.20	3.26	Valid
DGR2-696.50	grey argillaceous limestone	12-Jun-07	76	46	25.90	6.28	Valid
DGR2-701.87	grey argillaceous limestone	12-Jun-07	76	55	20.62	4.35	Valid
DGR2-709.47	dark grey shale	13-Jun-07	76	39	12.54	3.46	Valid
DGR2-714.97	grey/green interbedded shale and limestone	14-Jun-07	76	31	11.84	3.90	Valid
Kirkfield Formation (716.1-762 mBGS)							
DGR2-719.98	grey argillaceous limestone	14-Jun-07	76	39	13.36	3.70	Valid
DGR2-726.76	grey/green interbedded shale and limestone	14-Jun-07	76	33	15.94	5.04	Valid
DGR2-729.98	grey/green interbedded shale and limestone	14-Jun-07	76	38	8.80	2.46	Valid
DGR2-735.61	grey/green interbedded shale and limestone	15-Jun-07	76	34	11.52	3.53	Valid
DGR2-743.05	grey/green interbedded shale and limestone	15-Jun-07	76	30	10.84	3.66	Valid
DGR2-749.32	medium grey argillaceous limestone	15-Jun-07	76	37	16.40	4.71	Valid
DGR2-753.50	grey/green interbedded shale and limestone	15-Jun-07	76	43	15.56	3.98	Valid
DGR2-760.66	dark grey/green shale	15-Jun-07	76	45	10.14	2.50	Valid
Coboconk Formation (762-785 mBGS)							
DGR2-762.86	dark grey/green shale	15-Jun-07	76	49	12.58	2.90	Valid
DGR2-765.16	grey limestone	17-Jun-07	76	30	9.50	3.21	Valid
DGR2-768.35	grey limestone	17-Jun-07	76	45	11.66	2.88	Valid
DGR2-775.41	medium grey limestone /w thin shale layer	18-Jun-07	76	55	21.90	4.62	Valid
DGR2-777.22	grey limestone with styolites	18-Jun-07	76	42	11.62	3.02	Valid

Table B.1 Results of Point Load Testing (Axial) of DGR-1 and DGR-2 Core Samples

Sample ID	Sample Desciption	Date Tested	Diameter (mm)	Length (mm)	Peak Load (MPa)	$Is_{(50)}$ (MPa)	Notes
Gull River Formation (785-838.6 mBGS)							
DGR2-788.21	dark grey/brown limestone /w styolites	19-Jun-07	76	55	14.58	3.08	Valid
DGR2-788.29	medium grey limestone /w styolites	19-Jun-07	76	55	14.62	3.09	Valid
DGR2-794.90	medium grey limestone /w styolites	20-Jun-07	76	50	18.48	4.20	Valid
DGR2-800.59	dark grey fossiliferous limestone	22-Jun-07	76	45	18.50	4.56	Valid
DGR2-806.58	medium grey limestone /w styolite layer	22-Jun-07	76	50	12.48	2.84	Valid
DGR2-806.66	medium grey limestone /w styolite layers	22-Jun-07	76	50	19.88	4.52	Valid
DGR2-813.32	medium grey limestone /w styolites	22-Jun-07	76	45	19.90	4.91	Valid
DGR2-816.60	light grey/brown limestone /w styolites	22-Jun-07	76	50	17.84	4.06	Valid
DGR2-819.02	medium grey limestone /w styolites	22-Jun-07	76	45	18.22	4.49	Valid
DGR2-824.19	medium grey limestone /w styolites	22-Jun-07	76	52.5	24.46	5.35	Valid
DGR2-835.02	dark grey limestone	23-Jun-07	76	35	8.64	2.59	Valid
DGR2-838.52	dark grey limestone	23-Jun-07	76	38	10.24	2.88	Valid

Table B.2 Results of Point Load Testing (Diametral) of DGR-1 and DGR-2 Core Samples

Sample ID	Sample Description	Date Tested	Time Tested	Initials of Tester	Diameter (mm)	Length (mm)	L:D	Peak Load (MPa)	P (MN)	De^2 (m^2)	De (m)	F	Is (MPa)	$Is_{(50)}$ (MPa)	Notes
Lucas Formation (20-30.4 mBGS)															
DGR1-029.65	grey/tan dolostone	26-Jan-07	21:00	SNS	67	190	2.8	22.94	0.022	0.0045	0.067	1.14	4.84	5.53	Valid
Amherstburg Formation (30.4-75 mBGS)															
DGR1-034.01	light grey/brown fossiliferous dolostone	26-Jan-07	10:35	MDN	67	106	1.6	18.06	0.017	0.0045	0.067	1.14	3.81	4.35	Valid
DGR1-038.95	light grey/brown dolostone	30-Jan-07	7:40	MDN	67	103	1.5	13.28	0.013	0.0045	0.067	1.14	2.80	3.20	Valid
DGR1-045.18	light grey/brown dolostone	1-Feb-07		MDN	67	127	1.9	16.60	0.016	0.0045	0.067	1.14	3.51	4.00	Valid
DGR1-049.36	light grey/brown fossiliferous dolostone	3-Feb-07	10:05	TLJ	67	105	1.6	25.56	0.024	0.0045	0.067	1.14	5.40	6.16	Valid
DGR1-056.17	light grey/brown dolostone	7-Feb-07	15:20	TLJ	67	90	1.3	17.30	0.016	0.0045	0.067	1.14	3.65	4.17	Valid
DGR1-060.04	light grey/brown dolostone	4-Feb-07		MAM	67	118	1.8	23.88	0.023	0.0045	0.067	1.14	5.04	5.75	Valid
DGR1-068.03	light grey/brown dolostone	4-Feb-07		MAM	67	120	1.8	34.70	0.033	0.0045	0.067	1.14	7.33	8.36	Invalid (break)
DGR1-070.66	light grey/brown dolostone /w mudstone clasts	7-Feb-07		MAM	67	122	1.8	15.26	0.014	0.0045	0.067	1.14	3.22	3.68	Valid
Bois Blanc Formation (75-124 mBGS)															
DGR1-075.09	light grey/brown dolostone /w mudstone clasts	17-Feb-07	19:05	NKP	67	132	2.0	31.10	0.029	0.0045	0.067	1.14	6.57	7.49	Invalid (break)
DGR1-078.82	light grey/brown fossiliferous dolostone with two large fossils (>3cm)	17-Feb-07	19:40	NKP	67	122	1.8	9.36	0.009	0.0045	0.067	1.14	1.98	2.25	Valid
DGR1-087.19	light grey cherty dolostone /w mudstone clasts	19-Feb-07		MAM	67	95	1.4	24.70	0.023	0.0045	0.067	1.14	5.22	5.95	Valid
DGR1-096.72	light grey cherty dolostone /w mudstone clasts	22-Feb-07		SNG	76	96	1.3	16.96	0.016	0.0058	0.076	1.21	2.78	3.36	Valid
DGR1-100.30	light grey cherty dolostone /w mudstone clasts	22-Feb-07		SNG	76	80	1.1	26.60	0.025	0.0058	0.076	1.21	4.37	5.27	Valid
DGR1-104.69	light grey cherty dolostone /w mudstone clasts	22-Feb-07		SNG	76	115	1.5	30.76	0.029	0.0058	0.076	1.21	5.05	6.10	Valid
DGR1-110.23	light grey cherty dolostone /w mudstone clasts	22-Feb-07		SNG	76	95	1.3	17.96	0.017	0.0058	0.076	1.21	2.95	3.56	Valid
DGR1-115.61	light grey cherty dolostone /w mudstone clasts	24-Feb-07	8:05	NKP	76	141	1.9	15.08	0.014	0.0058	0.076	1.21	2.48	2.99	Valid
DGR1-118.28	light grey cherty dolostone /w mudstone clasts	24-Feb-07		NKP	76	206	2.7	19.16	0.018	0.0058	0.076	1.21	3.14	3.80	Valid
DGR1-121.32	light grey cherty dolostone /w mudstone clasts	25-Feb-07	3:55	NKP	76	95	1.2	18.61	0.018	0.0058	0.076	1.21	3.05	3.69	Valid
Bass Islands Formation (124-169.3 mBGS)															
DGR1-124.09	light grey/tan dolostone	24-Feb-07	17:00	SNS	76	114	1.5	52.12	0.049	0.0058	0.076	1.21	8.55	10.33	Valid
DGR1-132.77	grey/brown dolostone	27-Feb-07	5:30	NKP	67	78	1.2	20.88	0.020	0.0045	0.067	1.14	4.41	5.03	Valid
DGR1-146.38	grey/brown dolostone	28-Feb-07		NKP	67	77	1.1	4.28	0.004	0.0045	0.067	1.14	0.90	1.03	Valid
DGR1-162.86	grey/brown dolostone /w blue anhydrite clasts	2-Mar-07		SNG	67	119	1.8	1.92	0.002	0.0045	0.067	1.14	0.41	0.46	Valid
DGR1-163.21	grey/brown dolostone /w blue anhydrite clasts	2-Mar-07		SNG	67	91	1.4	1.62	0.002	0.0045	0.067	1.14	0.34	0.39	Valid
DGR1-165.08	grey/brown dolostone	2-Mar-07		SNG	67	78	1.2	7.24	0.007	0.0045	0.067	1.14	1.53	1.74	Valid
Salina G Unit (169.3-178.6 mBGS)															
DGR1-169.45	medium grey argillaceous dolostone /w anhydrite veins	2-Mar-07		SNG	67	86	1.3	0.66	0.001	0.0045	0.067	1.14	0.14	0.16	Valid
DGR1-171.61	medium grey argillaceous dolostone /w 1.5 and 3.3cm anhydrite layers and veins	2-Mar-07		SNG	67	87	1.3	6.92	0.007	0.0045	0.067	1.14	1.46	1.67	Valid
DGR1-178.20	grey argillaceous dolostone	2-Mar-07		SNG	67	77	1.1	3.18	0.003	0.0045	0.067	1.14	0.67	0.77	Valid
Salina F Unit (178.6-223 mBGS)															
DGR1-180.25	medium/dark grey argillaceous dolostone /w anhydrite veins	2-Mar-07		SNG	67	85	1.3	9.96	0.009	0.0045	0.067	1.14	2.10	2.40	Valid
DGR1-181.89	medium/dark grey argillaceous dolostone /w anhydrite veins and laminations	2-Mar-07		SNG	67	93	1.4	0.28	0.000	0.0045	0.067	1.14	0.06	0.07	Valid
DGR1-186.88	grey/green dolomitic shale /w reddish/brown discolouration and anhydrite veins/nodules	26-Mar-07	20:15	MDN	76	191	2.5	8.50	0.008	0.0058	0.076	1.21	1.40	1.68	Valid
DGR1-193.64	reddish/brown dolomitic shale /w anhydrite veins	27-Mar-07	7:50	KER	76	125	1.6	3.38	0.003	0.0058	0.076	1.21	0.55	0.67	Valid
DGR1-195.18	grey/green dolomitic shale /w anhydrite veins	27-Mar-07	8:15	KER	76	149	2.0	1.28	0.001	0.0058	0.076	1.21	0.21	0.25	Valid
DGR1-198.66	grey/green dolomitic shale /w anhydrite layers and veins	27-Mar-07	8:40	KER	76	145	1.9	7.92	0.008	0.0058	0.076	1.21	1.30	1.57	Valid
DGR1-202.15	grey/green dolomitic shale /w thick anhydrite layers and veins	27-Mar-07	9:00	KER	76	122	1.6	6.82	0.006	0.0058	0.076	1.21	1.12	1.35	Valid
DGR1-204.14	grey/green dolomitic shale /w reddish/brown discolouration and anhydrite veins	27-Mar-07	9:20	KER	76	90	1.2	3.66	0.003	0.0058	0.076	1.21	0.60	0.73	Valid
DGR1-209.80	grey/green dolomitic shale /w reddish/brown discolouration and anhydrite veins	27-Mar-07	9:30	KER	76	168	2.2	2.84	0.003	0.0058	0.076	1.21	0.47	0.56	Valid
DGR1-213.57	grey/green dolomitic shale /w reddish/brown discolouration and anhydrite veins	27-Mar-07	20:35	MDN	76	183	2.4	5.04	0.005	0.0058	0.076	1.21	0.83	1.00	Valid
DGR1-219.45	tan/brown brecciated dolostone /w significant anhydrite infilling	27-Mar-07	20:45	MDN	76	99	1.3	9.34	0.009	0.0058	0.076	1.21	1.53	1.85	Valid

Table B.2 Results of Point Load Testing (Diametral) of DGR-1 and DGR-2 Core Samples

Sample ID	Sample Description	Date Tested	Time Tested	Initials of Tester	Diameter (mm)	Length (mm)	L:D	Peak Load (MPa)	P (MN)	De^2 (m^2)	De (m)	F	Is (MPa)	$Is_{(50)}$ (MPa)	Notes
Salina E Unit (223-243 mBGS)															
DGR1-226.48	tan/grey brecciated dolostone /w grey/green dolomitic shale and anhydrite veins and layers	27-Mar-07	21:00	MDN	76	115	1.5	3.60	0.003	0.0058	0.076	1.21	0.59	0.71	Valid
DGR1-228.81	tan/grey brecciated dolostone /w grey/green dolomitic shale and anhydrite veins and nodules	27-Mar-07	21:10	MDN	76	140	1.8	4.18	0.004	0.0058	0.076	1.21	0.69	0.83	Valid
DGR1-235.94	tan/grey brecciated dolostone /w grey/green dolomitic shale and anhydrite nodules	28-Mar-07	8:20	KER	76	145	1.9	2.64	0.003	0.0058	0.076	1.21	0.43	0.52	Valid
DGR1-242.12	medium grey dolomitic shale	28-Mar-07	8:35	KER	76	95	1.3	2.02	0.002	0.0058	0.076	1.21	0.33	0.40	Valid
Salina D Unit (243.0-244.6 mBGS)															
Salina C Unit (244.6-260.3 mBGS)															
DGR1-245.92	grey/green dolomitic shale /w anhydrite veins	28-Mar-07	9:00	KER	76	103	1.4	1.00	0.001	0.0058	0.076	1.21	0.16	0.20	Valid
DGR1-257.65	grey/green and red dolomitic shale /w anhydrite veins and nodules	28-Mar-07	20:50	MDN	76	145	1.9	1.00	0.001	0.0058	0.076	1.21	0.16	0.20	Valid
Salina B Unit (260.3-293.1 mBGS)															
DGR1-261.68	grey/green argillaceous dolostone /w anhydrite veins and nodules	28-Mar-07	20:40	MDN	76	206	2.7	1.70	0.002	0.0058	0.076	1.21	0.28	0.34	Valid
DGR1-264.71	grey/green argillaceous dolostone /w anhydrite veins and nodules	28-Mar-07	20:45	MDN	76	180	2.4	1.84	0.002	0.0058	0.076	1.21	0.30	0.36	Valid
DGR1-273.35	grey/green brecciated argillaceous dolostone /w anhydrite veins and nodules	28-Mar-07	20:55	MDN	76	200	2.6	1.78	0.002	0.0058	0.076	1.21	0.29	0.35	Valid
DGR1-274.59	grey/green brecciated argillaceous dolostone /w anhydrite veins and nodules	28-Mar-07	21:15	NKP	76	189	2.5	1.24	0.001	0.0058	0.076	1.21	0.20	0.25	Valid
DGR1-282.11	grey/green brecciated argillaceous dolostone /w anhydrite veins and nodules	29-Mar-07	13:15	MAM	76	130	1.7	1.82	0.002	0.0058	0.076	1.21	0.30	0.36	Valid
DGR1-285.89	grey/green argillaceous dolostone /w anhydrite veins and nodules	29-Mar-07	14:45	MAM	76	137	1.8	4.20	0.004	0.0058	0.076	1.21	0.69	0.83	Valid
DGR1-290.48	grey/brown argillaceous dolostone	30-Mar-07	19:40	NKP	76	116	1.5	5.90	0.006	0.0058	0.076	1.21	0.97	1.17	Valid
Salina A Unit (293.1-374.5 mBGS)															
DGR1-294.70	grey/brown dolostone	30-Mar-07	20:05	NKP	76	102	1.3	8.16	0.008	0.0058	0.076	1.21	1.34	1.62	Valid
DGR1-298.45	tan/grey dolostone	30-Mar-07	19:15	NKP	76	115	1.5	13.02	0.012	0.0058	0.076	1.21	2.14	2.58	Valid
DGR1-307.08	grey dolomitic shale and light grey argillaceous dolostone	31-Mar-07	7:25	SNG	76	150	2.0	2.58	0.002	0.0058	0.076	1.21	0.42	0.51	Valid
DGR1-311.14	tan/grey argillaceous dolostone	31-Mar-07	7:35	SNG	76	200	2.6	25.18	0.024	0.0058	0.076	1.21	4.13	4.99	Valid
DGR1-315.17	tan/grey dolostone	31-Mar-07	7:15	SNG	76	140	1.8	16.20	0.015	0.0058	0.076	1.21	2.66	3.21	Valid
DGR1-320.83	grey/blue anhydritic dolostone	31-Mar-07	7:45	SNG	76	138	1.8	19.60	0.019	0.0058	0.076	1.21	3.22	3.88	Valid
DGR1-324.09	grey/blue anhydritic dolostone	31-Mar-07	19:00	NKP	76	110	1.4	16.34	0.015	0.0058	0.076	1.21	2.68	3.24	Valid
DGR1-329.85	grey argillaceous dolostone	1-Apr-07	0:38	SNG	76	115	1.5	6.58	0.006	0.0058	0.076	1.21	1.08	1.30	Valid
DGR1-336.08	grey argillaceous dolostone /w anhydrite veins	31-Mar-07	19:15	NKP	76	113	1.5	10.30	0.010	0.0058	0.076	1.21	1.69	2.04	Valid
DGR1-340.69	grey argillaceous dolostone /w minor anhydrite veins	31-Mar-07	19:30	NKP	76	101	1.3	18.76	0.018	0.0058	0.076	1.21	3.08	3.72	Valid
DGR1-346.55	grey argillaceous dolostone /w one 1cm anhydrite layer	1-Apr-07	0:35	TLJ	76	184	2.4	13.86	0.013	0.0058	0.076	1.21	2.27	2.75	Valid
DGR1-351.37	grey argillaceous dolostone	1-Apr-07	7:15	TLJ	76	95	1.3	2.20	0.002	0.0058	0.076	1.21	0.36	0.44	Valid
DGR1-367.56	light grey/blue anhydritic dolostone	1-Apr-07	18:45	MAM	76	124	1.6	12.42	0.012	0.0058	0.076	1.21	2.04	2.46	Valid
DGR1-370.22	light grey/blue anhydritic dolostone	1-Apr-07	19:00	MAM	76	168	2.2	20.48	0.019	0.0058	0.076	1.21	3.36	4.06	Valid
Guelph Formation (374.5-378.6 mBGS)															
DGR1-375.36	brown vuggy sucrosic dolostone	2-Apr-07		MAM	76	145	1.9	17.58	0.017	0.0058	0.076	1.21	2.89	3.48	Invalid (break)
Goat Island Formation (378.6-397.4 mBGS)															
DGR1-380.38	medium grey dolostone	2-Apr-07		MAM	76	121	1.6	32.88	0.031	0.0058	0.076	1.21	5.40	6.52	Valid
DGR1-383.28	medium grey dolostone	2-Apr-07		MAM	76	107	1.4	23.98	0.023	0.0058	0.076	1.21	3.94	4.75	Valid
DGR1-386.19	medium grey dolostone	2-Apr-07		MAM	76	142	1.9	21.70	0.021	0.0058	0.076	1.21	3.56	4.30	Valid
DGR1-391.24	medium grey dolostone	3-Apr-07	6:35	TLJ	76	150	2.0	33.62	0.032	0.0058	0.076	1.21	5.52	6.66	Valid
DGR1-394.66	medium grey dolostone	3-Apr-07	6:50	TLJ	76	115	1.5	24.60	0.023	0.0058	0.076	1.21	4.04	4.87	Valid
Gasport Formation (397.4-404.25 mBGS)															
DGR1-401.35	light to medium grey dolomitic limestone	3-Apr-07	7:40	TLJ	76	130	1.7	27.64	0.026	0.0058	0.076	1.21	4.54	5.48	Valid
Lions Head Formation (404.25-408.7 mBGS)															
DGR1-406.95	tan/grey dolostone	3-Apr-07	20:35	SNS	76	105	1.4	22.86	0.022	0.0058	0.076	1.21	3.75	4.53	Valid
Fossil Hill Formation (408.7-411.0 mBGS)															
DGR1-410.33	tan grey dolostone	3-Apr-07	20:40	SNS	76	139	1.8	12.64	0.012	0.0058	0.076	1.21	2.07	2.50	Valid

Table B.2 Results of Point Load Testing (Diametral) of DGR-1 and DGR-2 Core Samples

Sample ID	Sample Description	Date Tested	Time Tested	Initials of Tester	Diameter (mm)	Length (mm)	L:D	Peak Load (MPa)	P (MN)	De^2 (m^2)	De (m)	F	Is (MPa)	$Is_{(50)}$ (MPa)	Notes
Cabot Head Formation (411.0-434.8 mBGS)															
DGR1-416.09	red/maroon massive non-calcareous shale	3-Apr-07	20:50	SNS	76	101	1.3	0.80	0.001	0.0058	0.076	1.21	0.13	0.16	Valid
DGR1-421.90	red/maroon non-calcareous shale	3-Apr-07	21:15	SNS	76	101	1.3	2.76	0.003	0.0058	0.076	1.21	0.45	0.55	Valid
DGR1-429.33	medium grey fossiliferous dolostone	3-Apr-07	21:20	SNS	76	116	1.5	11.78	0.011	0.0058	0.076	1.21	1.93	2.33	Valid
DGR1-432.20	light/medium grey dolomitic shale and cherty dolostone	4-Apr-07	8:30	SNG	76	82	1.1	1.56	0.001	0.0058	0.076	1.21	0.26	0.31	Valid
Manitoulin Formation (434.8-447.7 mBGS)															
DGR1-437.58	medium/dark grey cherty dolostone	4-Apr-07	8:15	SNG	76	95	1.3	4.12	0.004	0.0058	0.076	1.21	0.68	0.82	Valid
Queenston Formation (447.7-518 mBGS)															
DGR1-449.37	massive red/maroon calcareous shale with minor grey/green calcareous shale interbed	4-Apr-07	21:25	SNG	76	142	1.9	10.70	0.010	0.0058	0.076	1.21	1.76	2.12	Valid
DGR1-457.57	massive red/maroon calcareous shale	4-Apr-07	21:35	SNG	76	92	1.2	9.48	0.009	0.0058	0.076	1.21	1.56	1.88	Valid
DGR1-462.49	massive red/maroon calcareous shale	4-Apr-07	21:45	SNG	76	140	1.8	9.86	0.009	0.0058	0.076	1.21	1.62	1.95	Valid
DGR2-458.62	massive red/maroon calcareous shale with minor grey/green calcareous shale interbeds	29-May-07	11:30	SNG	76	105	1.4	18.70	0.018	0.0058	0.076	1.21	3.07	3.71	Valid
DGR2-461.36	massive red/maroon calcareous shale with minor grey/green calcareous shale interbeds	29-May-07	11:40	MDN	76	100	1.3	2.92	0.003	0.0058	0.076	1.21	0.48	0.58	Valid
DGR2-468.08	massive red/maroon calcareous shale with minor grey/green calcareous shale interbeds	29-May-07	11:50	DCS	76	160	2.1	5.76	0.005	0.0058	0.076	1.21	0.95	1.14	Valid
DGR2-473.76	massive red/maroon calcareous shale	29-May-07	11:58	DCS	76	174	2.3	6.14	0.006	0.0058	0.076	1.21	1.01	1.22	Valid
DGR2-479.28	massive red/maroon calcareous shale	29-May-07	12:07	MDN	76	137	1.8	7.52	0.007	0.0058	0.076	1.21	1.23	1.49	Valid
DGR2-483.49	interbedded green calcareous shale and fossiliferous limestone	29-May-07	12:21	DCS	76	80	1.1	5.78	0.005	0.0058	0.076	1.21	0.95	1.15	Valid
DGR2-484.76	interbedded green calcareous shale and fossiliferous limestone	30-May-07	12:32	MDN	76	113	1.5	6.54	0.006	0.0058	0.076	1.21	1.07	1.30	Valid
DGR2-491.12	fossiliferous limestone /w minor green shale content	30-May-07	12:38	DCS	76	141	1.9	16.8	0.016	0.0058	0.076	1.21	2.76	3.33	Valid
DGR2-497.33	interbedded green shale and fossiliferous limestone	31-May-07	9:35	DCS	76	115	1.5	3.48	0.003	0.0058	0.076	1.21	0.57	0.69	Valid
DGR2-508.26	massive red/maroon shale /w grey/green shale interbeds	31-May-07	10:20	DCS	76	145	1.9	6.98	0.007	0.0058	0.076	1.21	1.15	1.38	Valid
DGR2-511.53	massive red/maroon shale /w grey/green shale interbeds	31-May-07	11:30	DCS	76	110	1.4	9.18	0.009	0.0058	0.076	1.21	1.51	1.82	Valid
DGR2-517.67	massive red/maroon shale /w grey/green shale interbeds	31-May-07	11:51	DCS	76	132	1.7	1.56	0.001	0.0058	0.076	1.21	0.26	0.31	Valid
Georgian Bay Formation (518-608.9 mBGS)															
DGR2-520.30	grey/green interbedded shale and limestone	31-May-07	12:05	DCS	76	149	2.0	1.34	0.001	0.0058	0.076	1.21	0.22	0.27	Valid
DGR2-522.50	grey/green interbedded shale and limestone	31-May-07	12:15	DCS	76	115	1.5	26.78	0.025	0.0058	0.076	1.21	4.40	5.31	Valid
DGR2-529.64	grey/green interbedded shale and limestone	31-May-07	12:35	DCS	76	118	1.6	22.46	0.021	0.0058	0.076	1.21	3.69	4.45	Valid
DGR2-531.64	grey/green shale	31-May-07	12:50	DCS	76	87	1.1	0.14	0.000	0.0058	0.076	1.21	0.02	0.03	Valid
DGR2-548.03	grey/green interbedded shale and limestone	1-Jun-07	21:35	KER	76	95	1.3	0.40	0.000	0.0058	0.076	1.21	0.07	0.08	Valid
DGR2-555.81	grey/green interbedded shale and limestone	1-Jun-07	21:00	KER	76	99	1.3	1.64	0.002	0.0058	0.076	1.21	0.27	0.32	Valid
DGR2-558.50	grey fossiliferous limestone /w anhydrite nodules	1-Jun-07	21:45	KER	76	139	1.8	34.84	0.033	0.0058	0.076	1.21	5.72	6.90	Valid
DGR2-562.35	grey/green interbedded shale and fossiliferous limestone	1-Jun-07		KER	76	135	1.8	3.96	0.004	0.0058	0.076	1.21	0.65	0.78	Valid
DGR2-568.03	grey/green interbedded shale and limestone	1-Jun-07	20:15	KER	76	96.7	1.3	23.06	0.022	0.0058	0.076	1.21	3.78	4.57	Valid
DGR2-587.81	grey/green shale	3-Jun-07	3:30	NKP	76	78	1.0	0.72	0.001	0.0058	0.076	1.21	0.12	0.14	Valid
DGR2-589.28	grey/green shale	3-Jun-07	3:46	NKP	76	140	1.8	5.04	0.005	0.0058	0.076	1.21	0.83	1.00	Valid
DGR2-591.82	grey/green shale	3-Jun-07	3:37	NKP	76	89	1.2	2.94	0.003	0.0058	0.076	1.21	0.48	0.58	Valid
DGR2-597.77	grey/green shale	3-Jun-07	4:10	NKP	76	76	1.0	6.58	0.006	0.0058	0.076	1.21	1.08	1.30	Valid
DGR2-603.87	grey/green shale	3-Jun-07	4:01	NKP	76	102	1.3	5.34	0.005	0.0058	0.076	1.21	0.88	1.06	Valid
DGR2-611.27	grey/green shale	3-Jun-07	4:20	NKP	76	81	1.1	1.22	0.001	0.0058	0.076	1.21	0.20	0.24	Valid
Blue Mountain Formation (608.9-656.1 mBGS)															
DGR2-618.03	grey/blue shale	3-Jun-07	3:42	NKP	76	94	1.2	0.22	0.000	0.0058	0.076	1.21	0.04	0.04	Valid
DGR2-624.05	grey/blue shale	3-Jun-07	16:15	KER	76	110	1.4	3.16	0.003	0.0058	0.076	1.21	0.52	0.63	Valid
DGR2-633.30	grey shale	3-Jun-07	16:40	KER	76	93	1.2	0.10	0.000	0.0058	0.076	1.21	0.02	0.02	Valid
DGR2-639.41	grey shale	3-Jun-07	16:45	KER	76	95	1.3	0.62	0.001	0.0058	0.076	1.21	0.10	0.12	Valid
DGR2-652.52	grey shale	4-Jun-07	0:16	MDN	76	99.7	1.3	9.42	0.009	0.0058	0.076	1.21	1.55	1.87	Valid

Table B.2 Results of Point Load Testing (Diametral) of DGR-1 and DGR-2 Core Samples

Sample ID	Sample Description	Date Tested	Time Tested	Initials of Tester	Diameter (mm)	Length (mm)	L:D	Peak Load (MPa)	P (MN)	De^2 (m^2)	De (m)	F	Is (MPa)	$Is_{(50)}$ (MPa)	Notes
Cobourg Formation (656.1-688.1mBGS)															
DGR2-656.65	grey/brown limestone	11-Jun-07	22:45	DCS	76	154.7	2.0	17.64	0.017	0.0058	0.076	1.21	2.90	3.50	Valid
DGR2-665.46	grey/brown argillaceous limestone /w styolites	11-Jun-07	20:25	DCS	76	94.3	1.2	17.5	0.017	0.0058	0.076	1.21	2.87	3.47	Valid
DGR2-672.07	grey/brown argillaceous limestone /w styolites	11-Jun-07	20:35	DCS	76	134.7	1.8	19.92	0.019	0.0058	0.076	1.21	3.27	3.95	Valid
DGR2-676.89	grey/brown argillaceous limestone /w styolites	11-Jun-07	20:55	DCS	76	100.3	1.3	18.96	0.018	0.0058	0.076	1.21	3.11	3.76	Valid
DGR2-685.10	grey/brown argillaceous limestone /w styolites	11-Jun-07	21:20	DCS	76	90	1.2	19.16	0.018	0.0058	0.076	1.21	3.14	3.80	Valid
Sherman Fall Formation (688.1-716.1 mBGS)															
DGR2-689.78	grey argillaceous fossiliferous limestone	12-Jun-07	5:15	DCS	76	86.7	1.1	13.26	0.013	0.0058	0.076	1.21	2.18	2.63	Valid
DGR2-696.50	grey argillaceous limestone	12-Jun-07	5:35	DCS	76	110	1.4	20.7	0.020	0.0058	0.076	1.21	3.40	4.10	Valid
DGR2-701.87	grey argillaceous limestone	12-Jun-07	10:05	SNG	76	115	1.5	22.18	0.021	0.0058	0.076	1.21	3.64	4.40	Valid
DGR2-708.80	grey/green interbedded fossiliferous shale and argillaceous limestone	13-Jun-07	19:45	NKP	76	117	1.5	4.00	0.004	0.0058	0.076	1.21	0.66	0.79	Valid
DGR2-714.97	grey/green interbedded shale and argillaceous limestone	14-Jun-07	16:50	DCS	76	117.7	1.5	3.78	0.004	0.0058	0.076	1.21	0.62	0.75	Valid
Kirkfield Formation (716.1-762 mBGS)															
DGR2-719.98	grey argillaceous limestone	14-Jun-07	17:10	DCS	76	117.7	1.5	22.56	0.021	0.0058	0.076	1.21	3.70	4.47	Valid
DGR2-726.86	grey argillaceous fossiliferous limestone	14-Jun-07	17:30	DCS	76	171.3	2.3	17.34	0.016	0.0058	0.076	1.21	2.85	3.44	Valid
DGR2-730.08	grey/green interbedded shale and argillaceous limestone	14-Jun-07	17:42	DCS	76	161.7	2.1	4.56	0.004	0.0058	0.076	1.21	0.75	0.90	Valid
DGR2-735.45	grey/green interbedded fossiliferous shale and argillaceous	15-Jun-07	14:20	DCS	76	94	1.2	5.88	0.006	0.0058	0.076	1.21	0.97	1.17	Valid
DGR2-743.05	grey argillaceous fossiliferous limestone	15-Jun-07	14:45	DCS	76	124	1.6	2.06	0.002	0.0058	0.076	1.21	0.34	0.41	Valid
DGR2-749.32	grey argillaceous limestone	15-Jun-07	15:00	DCS	76	88	1.2	12.34	0.012	0.0058	0.076	1.21	2.03	2.45	Valid
DGR2-753.50	grey/green interbedded shale and limestone	15-Jun-07	15:17	DCS	76	131	1.7	3.56	0.003	0.0058	0.076	1.21	0.58	0.71	Valid
Coboconk Formation (762-785 mBGS)															
DGR2-762.70	grey limestone /w occasional shale layers	15-Jun-07	16:00	DCS	76	170	2.2	5.42	0.005	0.0058	0.076	1.21	0.89	1.07	Invalid (break)
DGR2-764.95	grey limestone /w shale interbeds	17-Jun-07		DMP	76	110	1.4	2.52	0.002	0.0058	0.076	1.21	0.41	0.50	Valid
DGR2-768.35	grey limestone	17-Jun-07	11:55	DMP	76	110	1.4	5.44	0.005	0.0058	0.076	1.21	0.89	1.08	Valid
DGR2-775.41	medium grey limestone /w thin shale layer	18-Jun-07	15:17	DMP	76	120	1.6	10.64	0.010	0.0058	0.076	1.21	1.75	2.11	Valid
DGR2-777.22	medium grey limestone /w styolites	18-Jun-07	15:38	DMP	76	100	1.3	1.50	0.001	0.0058	0.076	1.21	0.25	0.30	Valid
DGR2-782.55	medium grey limestone /w styolites	19-Jun-07	15:15	DMP	76	100	1.3	18.48	0.018	0.0058	0.076	1.21	3.03	3.66	Valid
Gull River Formation (785-838.6 mBGS)															
DGR2-788.29	medium grey limestone /w styolites	19-Jun-07	15:40	DMP	76	95	1.3	7.22	0.007	0.0058	0.076	1.21	1.19	1.43	Valid
DGR2-794.90	medium grey limestone /w styolites	20-Jun-07	18:05	DMP	76	120	1.6	26.54	0.025	0.0058	0.076	1.21	4.36	5.26	Valid
DGR2-800.59	medium grey limestone /w styolites	22-Jun-07		DMP	76	110	1.4	7.70	0.007	0.0058	0.076	1.21	1.26	1.53	Valid
DGR2-806.66	medium grey limestone /w styolites	22-Jun-07		DMP	76	100	1.3	3.76	0.004	0.0058	0.076	1.21	0.62	0.75	Valid
DGR2-813.32	medium grey limestone /w styolites	22-Jun-07		DMP	76	100	1.3	24.28	0.023	0.0058	0.076	1.21	3.99	4.81	Valid
DGR2-816.60	light grey/brown limestone /w styolites	22-Jun-07		DMP	76	140	1.8	8.80	0.008	0.0058	0.076	1.21	1.44	1.74	Valid
DGR2-819.02	medium grey limestone /w styolites	22-Jun-07		DMP	76	100	1.3	27.76	0.026	0.0058	0.076	1.21	4.56	5.50	Invalid (break)
DGR2-824.19	medium grey limestone /w styolites	22-Jun-07		MJD	76	120	1.6	10.98	0.010	0.0058	0.076	1.21	1.80	2.18	Valid
DGR2-834.78	medium grey limestone	23-Jun-07	10:11	SJP	76	--	--	25.50	0.024	0.0058	0.076	1.21	4.19	5.05	Valid
DGR2-838.43	medium grey limestone	23-Jun-07		SJP	76	142	1.9	7.82	0.007	0.0058	0.076	1.21	1.28	1.55	Valid

Notes:

The following samples were collected, but not tested because they broke prior to testing:

DGR1-357.42
DGR1-446.40
DGR2-535.70
DGR2-579.35
DGR2-605.39
DGR2-630.53
DGR2-760.74

Table B.3 Results of Slake Durability Testing of DGR-1 and DGR-2 Core Samples

Sample ID	Sample Description	Mass of Moist Specimen (g)	Mass of Dry Specimen (g)	Water Content (%)	Final Mass of Specimen (g)	Slake Durability Index	Description of Rock Fragments
Lucas Formation (30.4-75 mBGS)							
Amherstburg Formation (30.4-75 mBGS)							
DGR1-034.81	light grey/brown fossiliferous dolostone	527.1	505.9	4.0	500.8	99.0	Type I - virtually unchanged
Bois Blanc Formation (75-124 mBGS)							
Bass Islands Formation (124-169.3 mBGS)							
DGR1-134.27	light grey dolostone	491.8	476.4	3.1	464.2	97.4	Type I - virtually unchanged
DGR1-169.23	medium grey argillaceous dolostone	484.8	449.3	7.3	160.9	35.8	Type II - large and small
DGR1-178.09	medium grey argillaceous dolostone	498.3	467.9	6.1	407.7	87.1	Type I - virtually unchanged
Salina G Unit (169.3-178.6 mBGS)							
Salina F Unit (178.6-223 mBGS)							
DGR1-179.93	grey/green dolomitic shale /w anhydrite veins	487.9	465.6	4.6	367.5	78.9	Type II - large and small
Salina E Unit (223-243 mBGS)							
Salina D Unit (243.0-244.6 mBGS)							
Salina C Unit (244.6-260.3 mBGS)							
DGR1-251.43	grey/green and red dolomitic shale /w anhydrite veins	516.9	481.8	6.8	265.5	55.1	Type II - large and small
DGR1-253.40	grey/green dolomitic shale /w anhydrite veins	474.3	439.2	7.4	226	51.5	Type II - large and small
DGR1-255.58	grey/green and red dolomitic shale /w anhydrite veins	526.1	476.5	9.4	292.6	61.4	Type I - virtually unchanged
Salina B Unit (260.3-293.1 mBGS)							
Salina A Unit (293.1-374.5 mBGS)							
Guelph Formation (374.5-378.6 mBGS)							
Goat Island Formation (378.6-397.4 mBGS)							
Gasport Formation (397.4-404.25 mBGS)							
Lions Head Formation (404.25-408.7 mBGS)							
Fossil Hill Formation (408.7-411.0 mBGS)							
Cabot Head Formation (411.0-434.8 mBGS)							
DGR1-411.94	massive red/maroon non-calcareous shale	537.9	520.1	3.3	446.6	85.9	Type II - large and small
DGR1-424.18	massive grey/green non-calcareous shale	459.5	447.5	2.6	185.8	41.5	Type II - large and small
DGR1-434.24	grey/blue dolomitic fossiliferous shale	523.1	504.2	3.6	344.9	68.4	Type I - virtually unchanged
Manitoulin Formation (434.8-447.7 mBGS)							
Queenston Formation (447.7-518 mBGS)							
DGR1-461.91	massive calcareous red/maroon and grey/green calcareous shale	520.4	510.6	1.9	485.7	95.1	Type I - virtually unchanged
DGR2-467.17	massive red/maroon calcareous shale	493	482.2	2.2	446.3	92.6	Type II - large and small
DGR2-482.94	massive grey/green calcareous shale	523.6	513.3	2.0	433.7	84.5	Type II - large and small
DGR2-503.87	interbedded green shale and light/medium grey fossiliferous limestone	524.4	517	1.4	441.3	85.4	Type II - large and small
Georgian Bay Formation (518-608.9 mBGS)							
DGR2-519.93	massive grey/green shale /w one fossiliferous interbed	521.5	512.3	1.8	449.6	87.8	Type I - virtually unchanged
DGR2-528.15	massive dark grey/green shale	503.6	493.5	2.0	362.8	73.5	Type II - large and small
DGR2-540.95	massive dark grey/green shale	496.6	486	2.1	365.9	75.3	Type II - large and small
DGR2-553.70	massive light/medium grey shale	518.9	505.6	2.6	322.6	63.8	Type III - exclusively small
DGR2-573.39	massive grey/green shale	518.6	507.4	2.2	374.4	73.8	Type II - large and small
DGR2-592.80	massive grey/green shale	486.8	474.4	2.5	395.6	83.4	Type II - large and small

Table B.3 Results of Slake Durability Testing of DGR-1 and DGR-2 Core Samples

Sample ID	Sample Description	Mass of Moist Specimen (g)	Mass of Dry Specimen (g)	Water Content (%)	Final Mass of Specimen (g)	Slake Durability Index	Description of Rock Fragments
Blue Mountain Formation (608.9-651.6 mBGS)							
DGR2-617.59	massive grey shale	527	513.9	2.5	437.2	85.1	n/a
DGR2-635.18	massive dark grey shale	496.8	485.6	2.3	461.3	95.0	Type II - large and small
DGR2-647.59	massive grey/green shale	524.4	515.4	1.7	506.3	98.2	n/a
Cobourg Formation (651.6-688.1 mBGS)							
Sherman Fall Formation (688.1-716.1mBGS)							
DGR2-702.47	medium grey argillaceous limestone and grey/green shale	536.4	529.3	1.3	443.7	83.8	Type II - large and small
DGR2-722.67	medium grey argillaceous limestone	513.3	506.4	1.3	471.8	93.2	Type II - large and small
Kirkfield Formation (716.1-762 mBGS)							
DGR2-745.08	interbedded argillaceous limestone and grey/green interbeds	521.1	517.8	0.6	509.7	98.4	Type I - virtually unchanged
Coboconk Formation (762-785 mBGS)							
DGR2-776.50	medium grey limestone	526.9	525.8	0.2	521.3	99.1	Type I - virtually unchanged
Gull River Formation (785-838.6 mBGS)							
DGR2-791.81	medium grey limestone	489.8	486.3	0.7	466.5	95.9	Type II - large and small
DGR2-809.44	medium grey limestone	501.0	496.5	0.9	488.9	98.5	Type I - virtually unchanged

Table B.4 - Results of Ultrasonic Pulse Velocity Testing of DGR-1 and DGR-2 Core Samples

Sample ID	Sample Description	Diameter (mm)	Length (mm)	Mass (g)	Density (g/mm^3)	P-Wave Transit Time (µs)	S-Wave Transit Time (µs)	P-Wave Velocity, Vp (km/s)	S-Wave Velocity, Vs (km/s)	Dynamic Young's Modulus, E_d (GPa)	Dynamic Shear Modulus, G_d (GPa)	Poisson's Ratio, v_d	CANMET Sample
Lucas Formation (20-30.4 mBGS)													
Amherstburg Formation (30.4-75 mBGS)													
DGR1-038.50	brown dolostone	67	178	1699.2	0.0027	32.1	52.2	5.55	3.41	75.31	31.48	0.20	
DGR1-052.13	light brown/grey dolostone	67	174	1597.7	0.0026	51.5	72.1	3.38	2.41	29.70	15.17	-0.02*	
DGR1-064.18	brown/grey dolostone /w coral and mudstone clasts	67	176	1562.7	0.0025	31.7	51.9	5.55	3.39	69.65	28.96	0.20	
DGR1-070.84	grey/brown dolostone	67	176	1558.7	0.0025	30.2	48.2	5.83	3.65	78.83	33.49	0.18	X
Bois Blanc Formation (75-124 mBGS)													
DGR1-102.66	grey/brown cherty dolostone	76	160	1855.8	0.0026	29.5	52.0	5.42	3.08	62.77	24.86	0.26	
DGR1-108.62	grey/brown cherty dolostone /w chert and mudstone clasts	76	188	2161.0	0.0027	76.2	81.6	2.47	2.30	-54.11*	14.19	-2.91*	X
Bass Islands Formation (124-169.3 mBGS)													
DGR1-171.14	grey dolomitic shale /w anhydrite	67	165	1452.2	0.0025	41.8	84.7	3.95	1.95	25.37	9.47	0.34	X
Salina G Unit (169.3-178.6 mBGS)													
Salina F Unit (178.6-223 mBGS)													
DGR1-182.76	medium to dark grey dolomitic shale /w minor anhydrite	67	220	1950.5	0.0025	70.4	179.0	3.13	1.23	10.70	3.80	0.41	
DGR1-183.60	grey/green dolomitic shale /w minor anhydrite	76	250	2549.17	0.0022	111.0	178.5	2.25	1.40	10.45	4.41	0.18	X
DGR1-193.87	grey/green dolomitic shale /w anhydrite	76	180	2084.49	0.0026	41.7	91.6	4.32	1.97	27.00	9.86	0.37	
DGR1-206.55	grey/green dolomitic shale /w anhydrite	76	195	2220.17	0.0025	53.0	109.4	3.68	1.78	21.48	7.97	0.35	X
Salina E Unit (223-243 mBGS)													
DGR1-227.24	tan/grey brecciated dolostone /w minor anhydrite	76	198	2277.55	0.0025	69.4	106.4	2.85	1.86	19.84	8.78	0.13	
DGR1-236.32	tan/grey brecciated dolostone /w minor anhydrite	76	190	2373.56	0.0028	53.7	75.0	3.54	2.53	34.43	17.67	-0.03*	
Salina D Unit (243.0-244.6 mBGS)													
Salina C Unit (244.6-260.3 mBGS)													
Salina B Unit (260.3-293.1 mBGS)													
DGR1-286.69	tan/grey brecciated dolostone /w anhydrite	76	178	1999.8	0.0025	112.3	116.5	1.59	1.53	-58.53*	5.78	-6.06*	X
Salina A Unit (293.1-374.5 mBGS)													
DGR1-314.88	tan/grey argillaceous dolostone	76	172	2057.23	0.0026	42.9	74.9	4.01	2.30	34.92	13.90	0.26	X
DGR1-340.82	tan/grey argillaceous dolostone	76	175	2125.0	0.0027	68.8	74.6	2.54	2.35	-39.64*	14.73	-2.35*	
DGR1-354.02	grey argillaceous dolostone	76	199	2401.6	0.0027	173.4	101.8	1.15	1.95	46.01	10.17	1.26*	
DGR1-367.06	grey argillaceous dolostone	76	179	2383.61	0.0029	32.4	56.0	5.52	3.20	74.88	29.99	0.25	X
Guelph Formation (374.5-378.6mBGS)													
Goat Island Formation (378.6-397.4 mBGS)													
DGR1-386.55	grey dolostone	76	175	2121.4	0.0027	30.8	53.0	5.68	3.30	72.54	29.13	0.25	X
DGR1-394.83	grey dolostone	76	175	2181.3	0.0027	31.0	52.1	5.65	3.36	76.01	31.00	0.23	
Gasport Formation (397.4-404.25 mBGS)													
Lions Head Formation (404.25-408.7 mBGS)													
DGR1-406.32	tan/grey dolostone	76	186	2124.1	0.0025	46.8	88.4	3.97	2.10	29.09	11.14	0.31	
Fossil Hill Formation (408.7-411.0 mBGS)													
Cabot Head Formation (411.0-434.8 mBGS)													
DGR1-415.16	massive non-calcareous red shale	76	171	2053.6	0.0026	43.2	94.4	3.96	1.81	23.76	8.69	0.37	X
Manitoulin Formation (434.8-447.7 mBGS)													
DGR1-438.10	grey dolostone /w shale layers	76	178	2164.83	0.0027	99.8	82.7	1.78	2.15	76.90	12.42	2.10*	X
DGR1-443.10	tan/grey dolostone	76	170	2149.32	0.0028	28.8	58.2	5.90	2.92	63.63	23.78	0.34	
Queenston Formation (447.7-518 mBGS)													
DGR2-452.10	massive grey/green calcareous shale	76	190	2171.1	0.0025	41.6	70.8	4.57	2.68	44.86	18.14	0.24	
DGR1-455.22	massive red/maroon calcareous shale	76	172	2098.8	0.0027	44.5	92.4	3.87	1.86	25.15	9.32	0.35	X
DGR2-457.21	massive red/maroon calcareous shale /w minor grey/green calcareous shale layers	76	180	2186.53	0.0027	41.9	84.2	4.30	2.14	32.68	12.24	0.34	
DGR2-458.46	massive red/maroon calcareous shale	76	120	1439.16	0.0026	26.3	49.5	4.56	2.42	40.50	15.54	0.30	
DGR1-460.41	massive red/maroon calcareous shale	76	175	2096.8	0.0026	42.2	74.8	4.15	2.34	36.62	14.46	0.27	X
DGR2-462.60	massive red/maroon calcareous shale	76	186	2259.92	0.0027	42.8	74.5	4.35	2.50	41.86	16.69	0.25	
DGR2-465.44	massive red/maroon calcareous shale	76	199	2411.25	0.0027	48.1	79.7	4.14	2.50	40.42	16.65	0.21	
DGR2-470.02	massive red/maroon calcareous shale	76	190	2312.49	0.0027	42.6	71.9	4.46	2.64	46.07	18.74	0.23	

Table B.4 - Results of Ultrasonic Pulse Velocity Testing of DGR-1 and DGR-2 Core Samples

Sample ID	Sample Description	Diameter (mm)	Length (mm)	Mass (g)	Density (g/mm^3)	P-Wave Transit Time (μs)	S-Wave Transit Time (μs)	P-Wave Velocity, Vp (km/s)	S-Wave Velocity, Vs (km/s)	Dynamic Young's Modulus, E_d (GPa)	Dynamic Shear Modulus, G_d (GPa)	Poisson's Ratio, v_d	CANMET Sample
DGR2-473.41	massive red/maroon calcareous shale	76	103	1253.98	0.0027	23.0	28.8	4.48	3.58	42.54	34.33	-0.38*	
DGR2-474.71	massive red/maroon calcareous shale	76	210	2547.2	0.0027	47.8	76.8	4.39	2.73	47.33	19.99	0.18	X
DGR2-477.69	grey/green calcareous shale /w minor siltstone	76	186	2291.52	0.0027	85.3	96.7	2.18	1.92	-5.10*	10.05	-1.25*	
DGR2-479.81	massive red/maroon calcareous shale	76	191	2322.81	0.0027	46.6	78.0	4.10	2.45	39.30	16.07	0.22	
DGR2-485.14	red/maroon calcareous shale /w grey/green calcareous shale	76	177	2161.57	0.0027	43.0	74.8	4.12	2.37	37.78	15.07	0.25	
DGR2-485.69	massive red/maroon calcareous shale	76	190	2317.89	0.0027	46.0	77.5	4.13	2.45	39.70	16.16	0.23	
DGR2-489.29	green shale	76	192	2356.66	0.0027	46.7	77.5	4.11	2.48	40.35	16.61	0.21	
DGR2-491.32	green shale /w interbedded light grey limestone	76	181	2225.28	0.0027	74.6	87.8	2.43	2.06	4.65	11.52	-0.80*	X
DGR2-492.84	light to medium grey fossiliferous limestone	76	175	2173.13	0.0027	31.1	52.5	5.63	3.33	74.80	30.42	0.23	
DGR2-499.84	green shale /w interbedded light grey limestone and a 4.5cm bioclastic limestone layer	76	146	1782.73	0.0027	169.1	80.5	0.86	1.81	38.01	8.85	1.15*	
DGR2-502.78	light to medium grey limestone	76	184	2252.2	0.0027	35.5	59.4	5.18	3.10	63.28	25.89	0.22	X
DGR2-505.15	light to medium grey limestone	76	102	1257.68	0.0027	24.9	44.9	4.10	2.27	35.85	14.03	0.28	
DGR2-508.05	massive red/maroon shale	76	191	2321.72	0.0027	45.4	88.7	4.21	2.15	32.86	12.42	0.32	
DGR2-511.92	red/maroon and green shale thinly interbedded	76	196	2402.18	0.0027	53.0	92.6	3.70	2.12	30.41	12.10	0.26	
DGR2-517.33	red/maroon and green shale thinly interbedded	76	125	1544.81	0.0027	44.6	55.2	2.80	2.26	15.64	13.97	-0.44*	
Georgian Bay Formation (518-608.9 mBGS)													
DGR2-518.78	grey siliceous sandstone/siltstone/limestone	76	131	1624.19	0.0027	36.8	49.6	3.56	2.64	33.85	19.06	-0.11*	
DGR2-519.61	green shale /w thin interbeds of fossiliferous grey limestone	76	178	2199.63	0.0027	75.8	85.7	2.35	2.08	-6.98*	11.75	-1.30*	X
DGR2-523.67	green shale	76	128	1559.63	0.0027	24.6	45.7	5.20	2.80	54.62	21.07	0.30	
DGR2-525.41	interbedded green shale and fossiliferous grey limestone	76	114	1418.17	0.0027	33.1	47.5	3.44	2.40	32.48	15.80	0.03	
DGR2-526.44	grey siliceous sandstone/siltstone/limestone /w minor green shale	76	100	1238.92	0.0027	19.6	25.2	5.10	3.97	63.16	43.01	-0.27*	
DGR2-531.95	green shale /w minor interbeds of grey siliceous sandstone/siltstone/limestone	76	107	1317.48	0.0027	81.6	68.3	1.31	1.57	42.23	6.66	2.17*	
DGR2-533.94	grey/green fossiliferous limestone	76	195	2312.9	0.0026	35.0	54.7	5.57	3.56	76.65	33.23	0.15	X
DGR2-541.30	grey/green interbedded shale and light grey limestone	76	148	1756.4	0.0026	63.0	72.2	2.35	2.05	-2.10*	10.99	-1.10*	
DGR2-541.63	grey limestone/siltstone	76	110	1316.4	0.0026	49.4	69.7	2.23	1.58	13.08	6.57	-0.005*	
DGR2-546.21	grey/green fossiliferous limestone	76	116	1462.85	0.0028	54.8	61.3	2.12	1.89	-9.75*	9.95	-1.49*	
DGR2-546.61	fossiliferous grey limestone	76	120	1474.78	0.0027	87.1	69.9	1.38	1.72	46.38	7.98	1.90*	
DGR2-560.38	grey/green interbedded shale and light grey limestone	76	127	1567.82	0.0027	26.9	64.6	4.72	1.97	29.35	10.52	0.40	
DGR2-561.12	grey/green shale interbedded /w grey sandstone/siltstone/limestone and fossiliferous light grey limestone	76	87	1212.77	0.0031	15.6	21.2	5.58	4.10	94.14*	51.75	-0.09*	
DGR2-577.03	fossiliferous grey sandstone/siltstone/limestone	76	153	2011.33	0.0029	25.1	46.5	6.10	3.29	81.22	31.37	0.29	
DGR2-584.80	dark grey/green shale	76	107	1311.02	0.0027	23.3	47.0	4.59	2.28	37.43	14.00	0.34	
DGR2-596.90	dark grey/green shale	76	119	1369.7	0.0025	75.2	77.9	1.58	1.53	-63.24*	5.92	-6.34*	
DGR2-599.89	dark grey/green shale	76	115	1389.1	0.0027	89.7	74.4	1.28	1.55	39.47	6.36	2.10*	
DGR2-606.50	dark grey/green shale /w minor layers of limestone/sandstone	76	178	2204.07	0.0027	182.6	93.7	0.97	1.90	42.92	9.85	1.18*	X
Blue Mountain Formation (608.9-651.6mBGS)													
Cobourg Formation (651.6-688.1 mBGS)													
DGR2-654.97	grey/brown limestone fossiliferous layers (abundant bivalves)	76	180	2190.29	0.0027	33.2	54.7	5.42	3.29	70.20	29.05	0.21	X
DGR2-660.68	light grey to tan argillaceous limestone	76	180	2174.8	0.0027	29.9	52.6	6.02	3.42	78.68	31.19	0.26	X
DGR2-661.61	light grey to tan argillaceous limestone	76	179	2170.3	0.0027	30.4	51.6	5.89	3.47	79.39	32.16	0.23	X
DGR2-666.79	medium to light grey argillaceous limestone	76	188	2288.14	0.0027	31.8	53.4	5.91	3.52	81.49	33.25	0.23	X
DGR2-668.46	medium to light grey argillaceous limestone	76	178	2193.93	0.0027	30.3	51.9	5.87	3.43	79.35	31.96	0.24	X
DGR2-673.26	medium to light grey argillaceous limestone	76	177	2181.5	0.0027	32.0	54.3	5.53	3.26	71.24	28.87	0.23	X
DGR2-674.11	medium to light grey argillaceous limestone	76	180	2205.32	0.0027	30.5	52.5	5.90	3.43	79.07	31.75	0.25	X

Table B.4 - Results of Ultrasonic Pulse Velocity Testing of DGR-1 and DGR-2 Core Samples

Sample ID	Sample Description	Diameter (mm)	Length (mm)	Mass (g)	Density (g/mm^3)	P-Wave Transit Time (µs)	S-Wave Transit Time (µs)	P-Wave Velocity, Vp (km/s)	S-Wave Velocity, Vs (km/s)	Dynamic Young's Modulus, E_d (GPa)	Dynamic Shear Modulus, G_d (GPa)	Poisson's Ratio, v_d	CANMET Sample
DGR2-676.75	medium to light grey argillaceous limestone	76	177	2164.52	0.0027	29.7	51.5	5.96	3.44	79.66	31.84	0.25	X
DGR2-679.83	medium to light grey argillaceous limestone	76	178	2203.73	0.0027	31.5	53.2	5.65	3.35	75.16	30.55	0.23	X
DGR2-683.02	medium to light grey argillaceous limestone	76	187	2280.6	0.0027	33.4	55.5	5.60	3.37	74.23	30.52	0.22	X
Sherman Fall Formation (688.1-716.1 mBGS)													
DGR2-688.22	medium to light grey argillaceous limestone	76	191	2297.2	0.0027	117.9	89.7	1.62	2.13	64.60	12.02	1.69*	X
DGR2-689.90	medium to light grey argillaceous limestone	76	185	2233.8	0.0027	175.2	153.1	1.06	1.21	28.10	3.89	2.62*	
DGR2-694.11	light to dark grey argillaceous limestone	76	190	2325.3	0.0027	121.9	79.9	1.56	2.38	72.51	15.26	1.38*	X
DGR2-695.15	light to dark grey argillaceous limestone	76	186	2258	0.0027	51.0	74.8	3.65	2.49	35.27	16.55	0.07	X
DGR2-704.47	light grey argillaceous limestone /w minor dark grey/green shale interbeds	76	185	2221.3	0.0026	170.1	83.4	1.09	2.22	56.22	13.02	1.16*	X
DGR2-708.57	light grey argillaceous fossiliferous limestone /w minor dark grey/green shale interbeds	76	160	1888.4	0.0026	80.8	71.7	1.98	2.23	99.82*	12.96	2.85*	
DGR2-710.29	medium to light grey argillaceous limestone	76	191	2314.46	0.0027	201.2	95.2	0.95	2.01	46.11	10.75	1.14*	X
DGR2-713.97	medium to light grey argillaceous limestone	76	162	1966.6	0.0027	140.2	196.0	1.16	0.83	3.57	1.83	-0.02*	
Kirkfield Formation (716.1-762 mBGS)													
DGR2-719.38	medium to light grey argillaceous limestone	76	191	2325.93	0.0027	115.6	84.7	1.65	2.26	70.42	13.65	1.58*	X
DGR2-723.59	medium to light grey argillaceous limestone	76	150	1828.08	0.0027	122.5	104.8	1.22	1.43	37.04	5.50	2.36*	
DGR2-732.97	medium to light grey argillaceous limestone	76	154	1875.48	0.0027	60.2	55.4	2.56	2.78	197.72*	20.74	3.77*	
DGR2-737.16	medium to light grey argillaceous limestone /w dark grey/green shale interbeds /w calcite nodules	76	200	2646.05	0.0029	107.8	89.6	1.86	2.23	90.60*	14.53	2.12*	
DGR2-744.86	medium to light grey argillaceous limestone /w dark grey/green shale interbeds /w calcite nodules	76	150	1842.57	0.0027	230.1	172.5	0.65	0.87	10.82	2.05	1.64*	
DGR2-751.38	medium to light grey argillaceous limestone /w dark grey/green shale interbeds /w calcite nodules	76	170	2053.2	0.0027	247.1	145.2	0.69	1.17	16.52	3.65	1.26*	
DGR2-757.13	medium to light grey argillaceous limestone	76	150	1871.69	0.0028	95.3	68.5	1.57	2.19	66.86	13.19	1.53*	
Coboconk Formation (762-785 mBGS)													
DGR2-767.05	grey limestone	76	185	2246.9	0.0027	132.2	80.6	1.40	2.30	64.76	14.10	1.30*	
DGR2-769.61	medium grey/brown limestone	76	180	2451.58	0.0030	71.4	68.7	2.52	2.62	339.60*	20.61	7.24*	
Gull River Formation (785-838.6 mBGS)													
DGR2-779.64	light to medium grey limestone	76	180	2244.38	0.0027	77.5	70.4	2.32	2.56	156.68*	17.97	3.36*	
DGR2-784.77	light to medium grey limestone	76	185	2301.61	0.0027	30.2	57.4	6.13	3.22	74.56	28.49	0.31	
DGR2-788.44	light to medium grey limestone	76	185	2287.5	0.0027	33.1	62.3	5.59	2.97	62.65	24.03	0.30	
DGR2-790.50	dark grey limestone	76	180	2295.19	0.0028	48.2	68.5	3.73	2.63	39.19	19.41	0.01	
DGR2-796.96	medium grey limestone	76	180	2738.36	0.0034	95.0	100.3	1.89	1.79	-61.77*	10.80	-3.86*	
DGR2-798.73	medium to dark grey limestone	76	180	2152.31	0.0026	31.0	53.5	5.81	3.36	74.43	29.84	0.25	
DGR2-803.88	light to dark grey limestone	76	190	2305.9	0.0027	34.7	64.8	5.48	2.93	59.75	23.00	0.30	
DGR2-809.66	light to dark grey limestone	76	180	2255.36	0.0028	93.4	91.0	1.93	1.98	245.43*	10.81	10.36*	
DGR2-816.42	medium to dark grey limestone	76	180	2182.34	0.0027	33.2	78.7	5.42	2.29	38.92	13.98	0.39	
DGR2-819.77	grey limestone	76	180	2262.4	0.0028	28.9	53.8	6.23	3.35	80.46	31.01	0.30	
DGR2-821.19	light grey/tan limestone	76	180	2258.34	0.0028	29.5	55.3	6.10	3.25	76.25	29.30	0.30	
DGR2-828.26	light grey/tan limestone /w styolites	76	181	2265.19	0.0028	31.5	53.3	5.75	3.40	78.36	31.81	0.23	
DGR2-833.79	grey/green mudstone	76	219	2656.91	0.0027	48.0	103.3	4.56	2.12	32.75	12.02	0.36	

Notes:

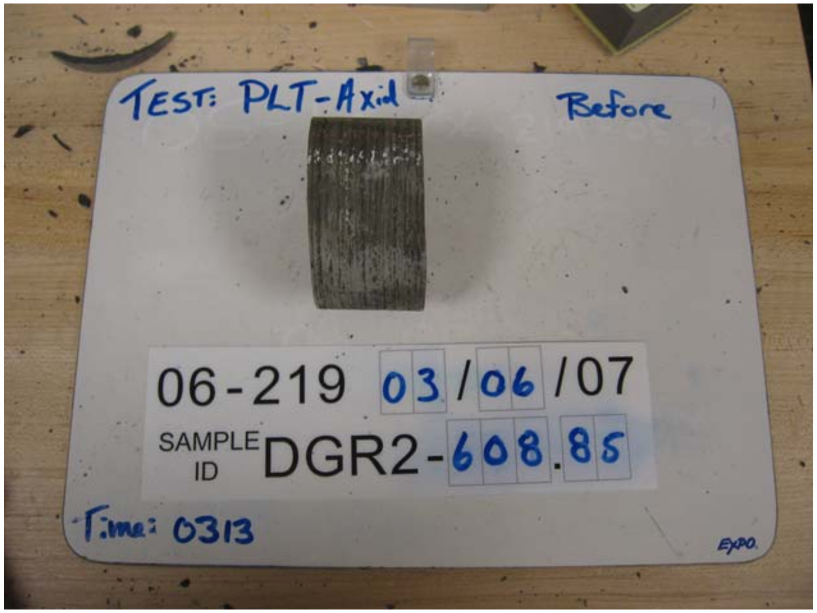
* = indicated data not within range of expected values based on CANMET testing {*E* (0-90 Gpa) and *v* (0-0.7)}

APPENDIX C

Selected Sample Photographs

DGR1-096.47 (Before)

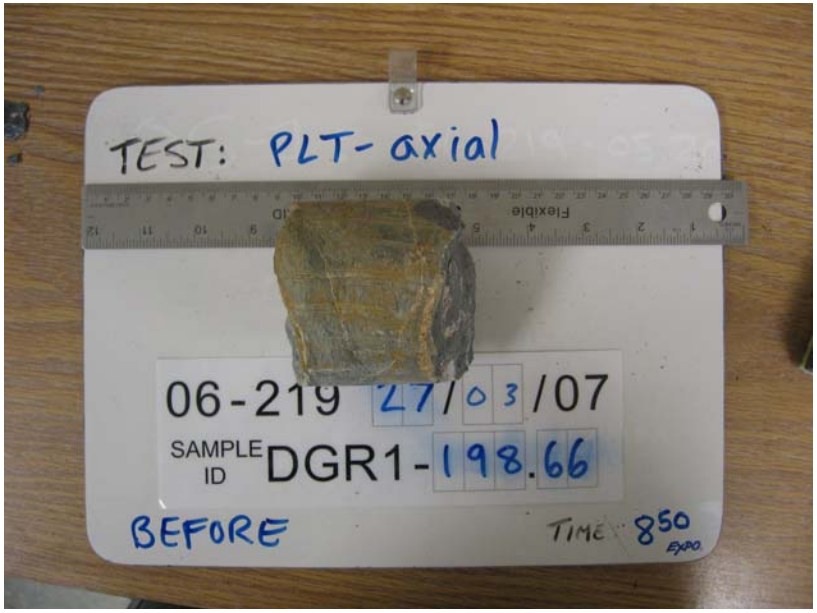
DGR1-096.47 (After)



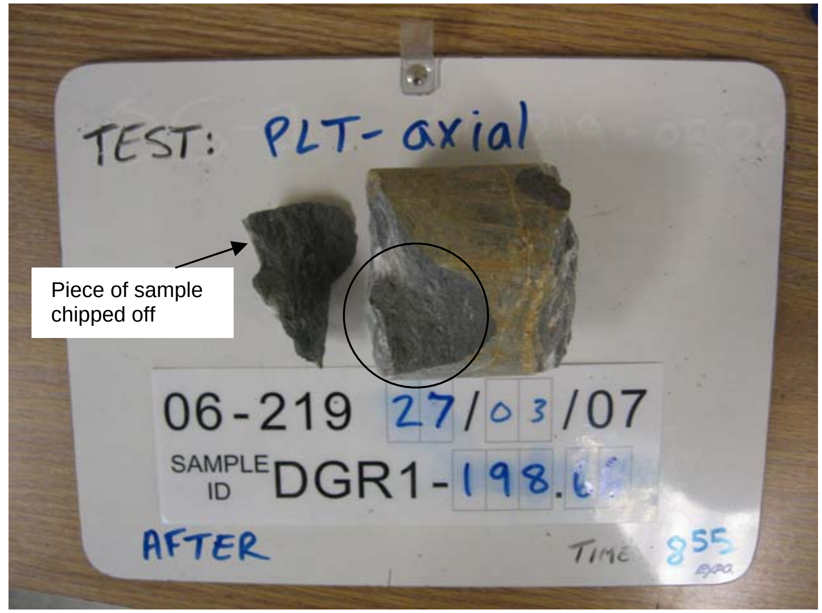
DGR2-608.85 (Before)

DGR2-608.85 (After)

TR-07-07: Point Load Testing (axial) – Valid Tests



DGR1-198.66 (Before)



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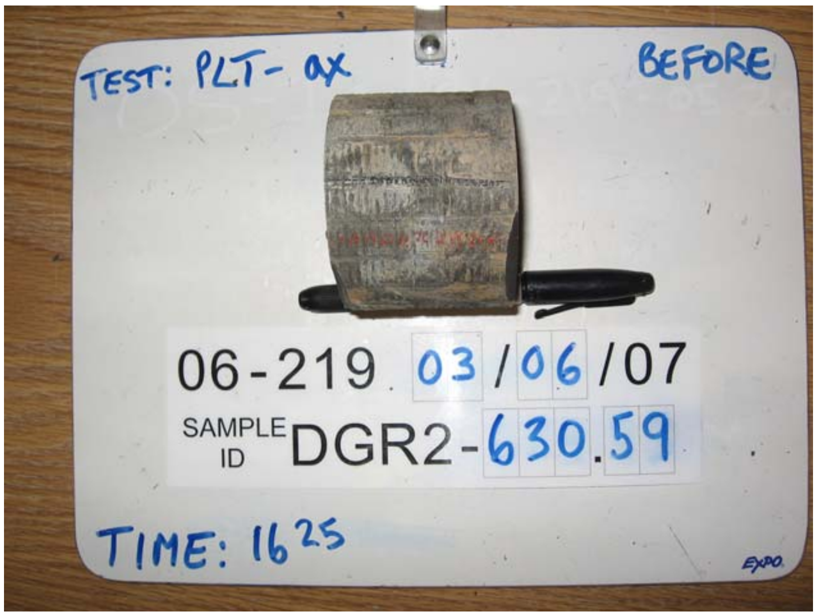
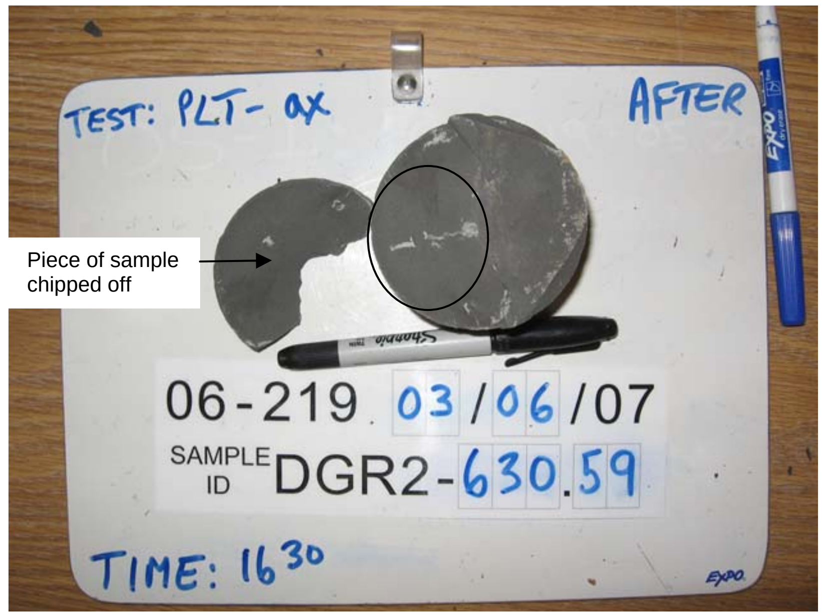
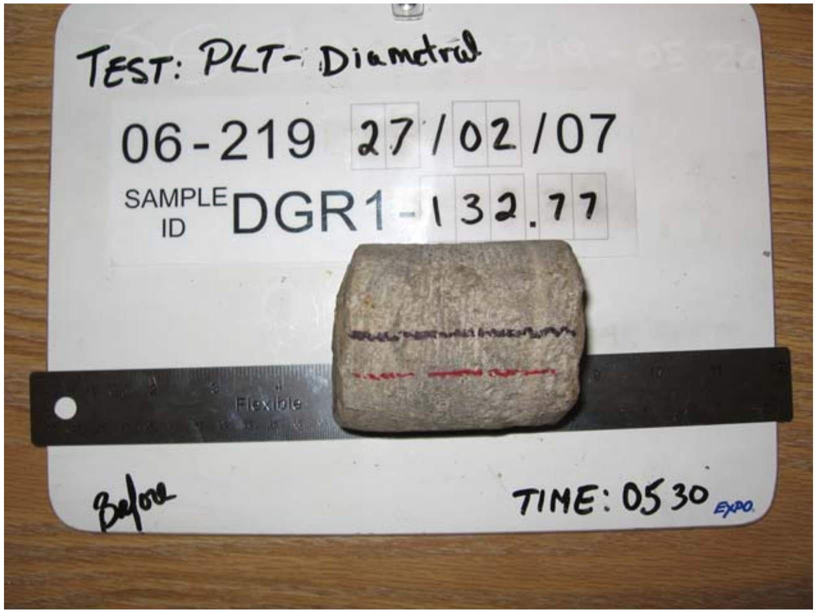


DGR2-630.59 (Before)



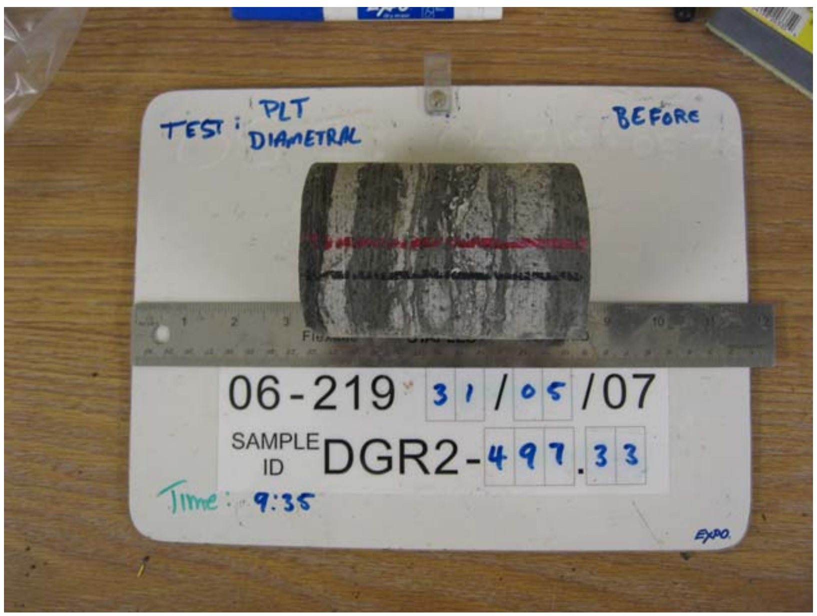
DGR2-630.59 (After)

TR-07-07: Point Load Testing (axial) – Invalid Tests



DGR1-132.77 (Before)

DGR1-132.77 (After)

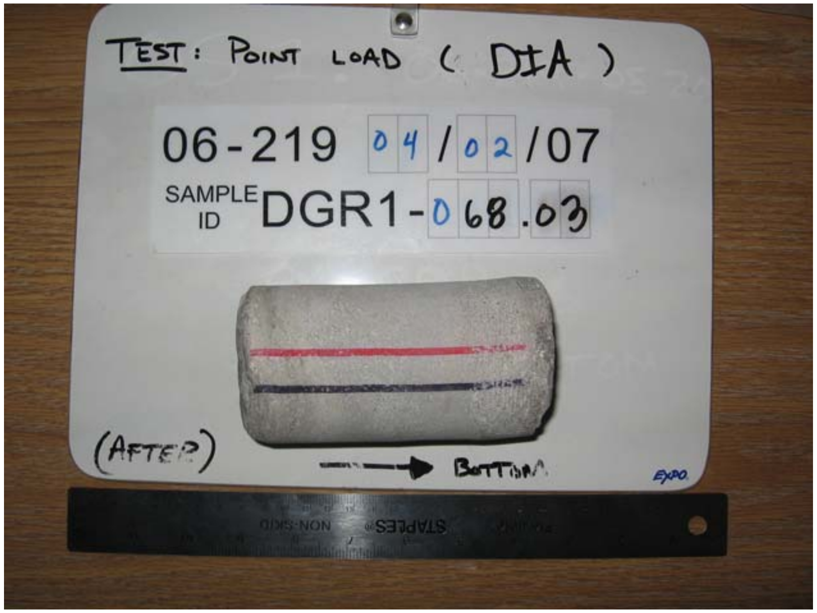


DGR2-497.33 (Before)

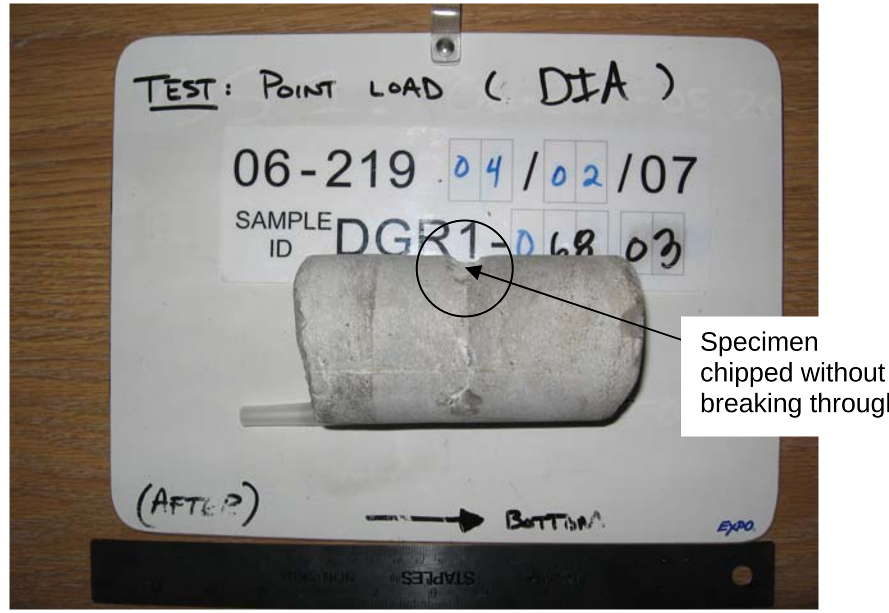
DGR2-497.33 (After)

TR-07-07: Point Load Testing (diametral) – Valid Tests

INTERA



DGR1-068.03 (Before)



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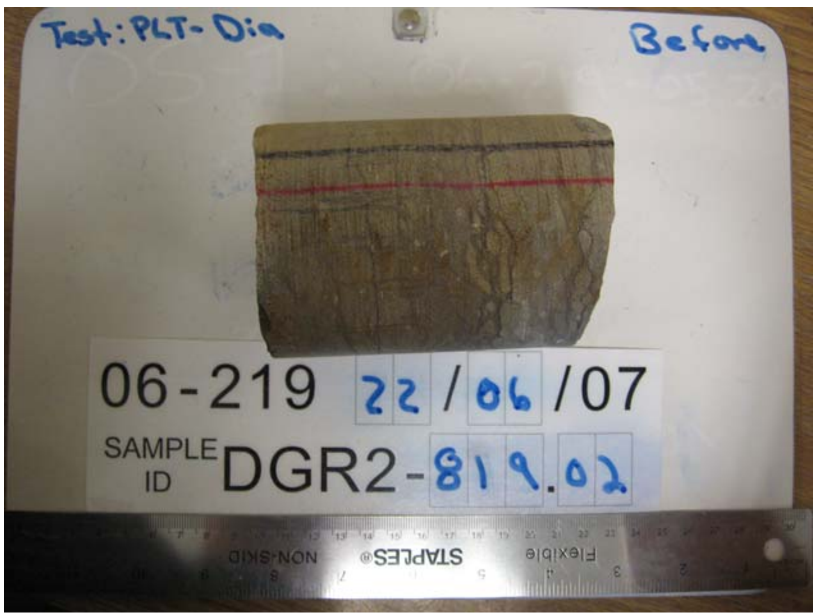
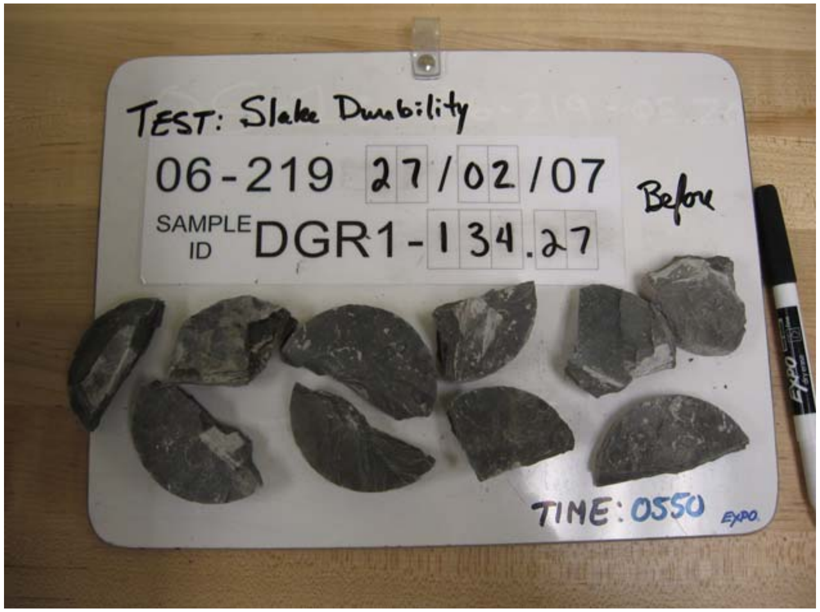


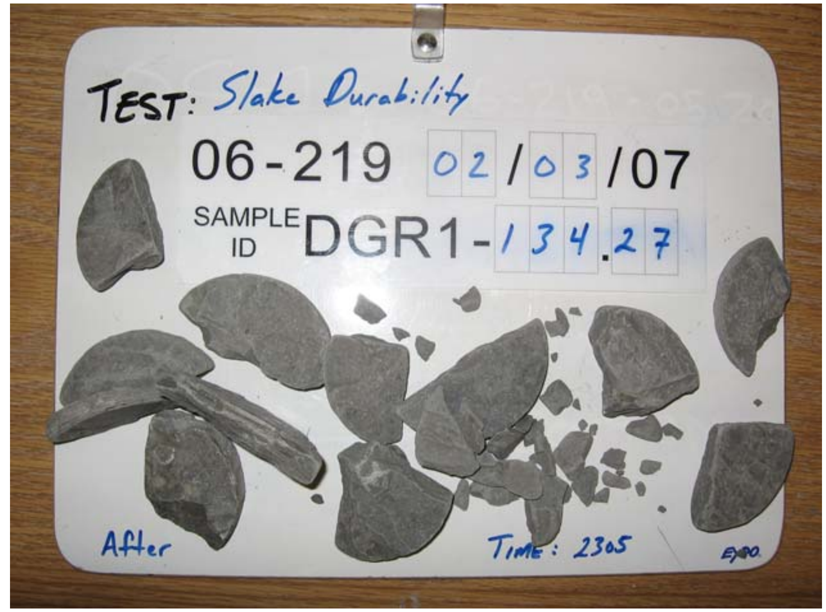
DGR2-819.02 (Before)

DGR2-819.02 (After)

TR-07-07: Point Load Testing (diametral) – Invalid Tests



DGR1-134.27 (Before)



DGR1-134.27 (After) – Type I (virtually unchanged)

DGR2-424.18 (Before)

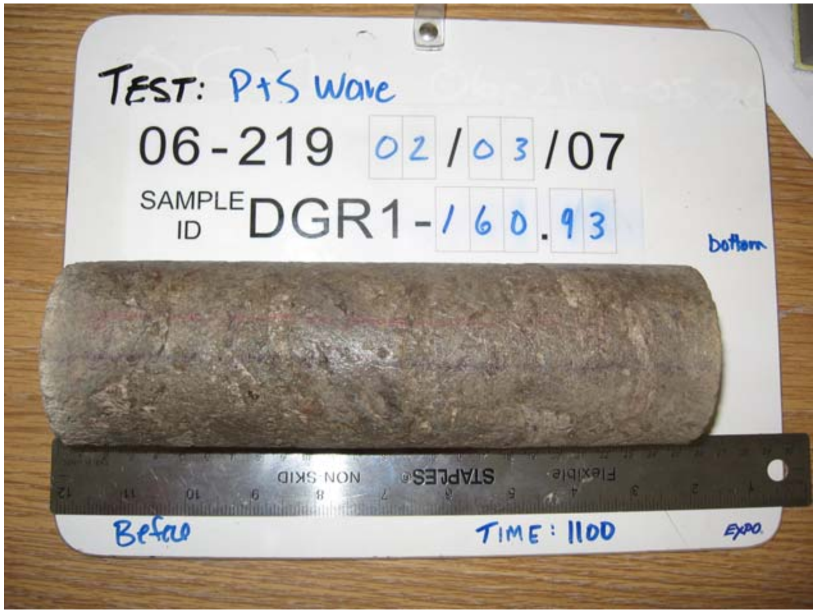
DGR2-424.18 (After) – Type II (large and small)

DGR1-553.70 (Before)

DGR1-553.70 (After) – Type III (exclusively small)

DGR2-809.44 (Before)

DGR2-809.44 (After) – Type I (virtually unchanged)



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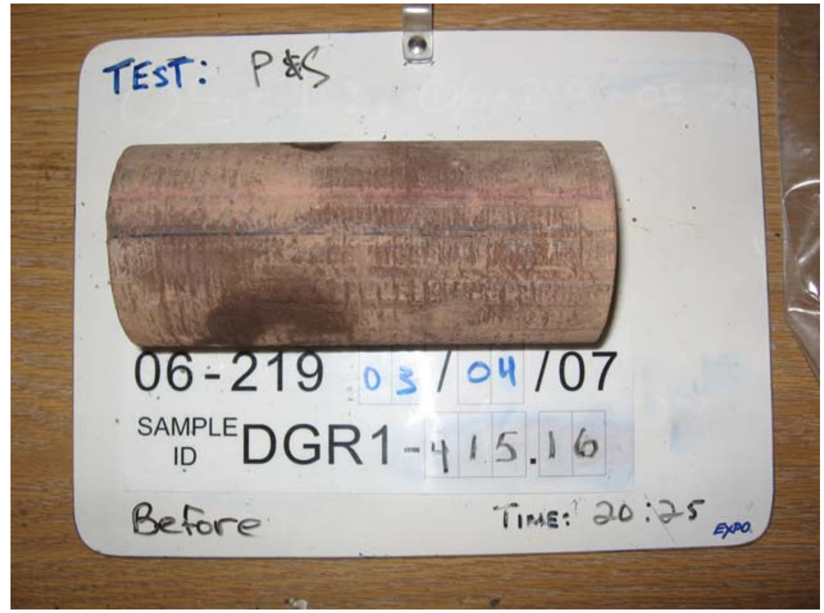

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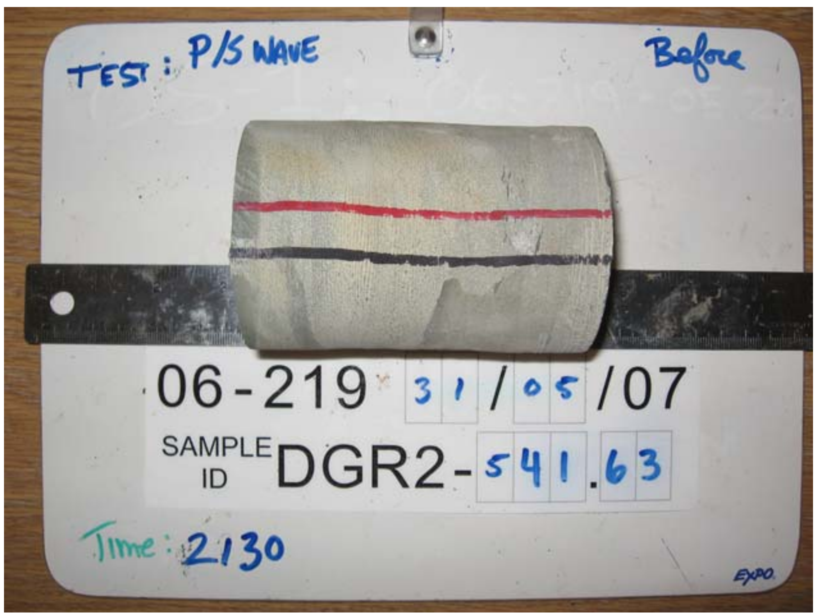

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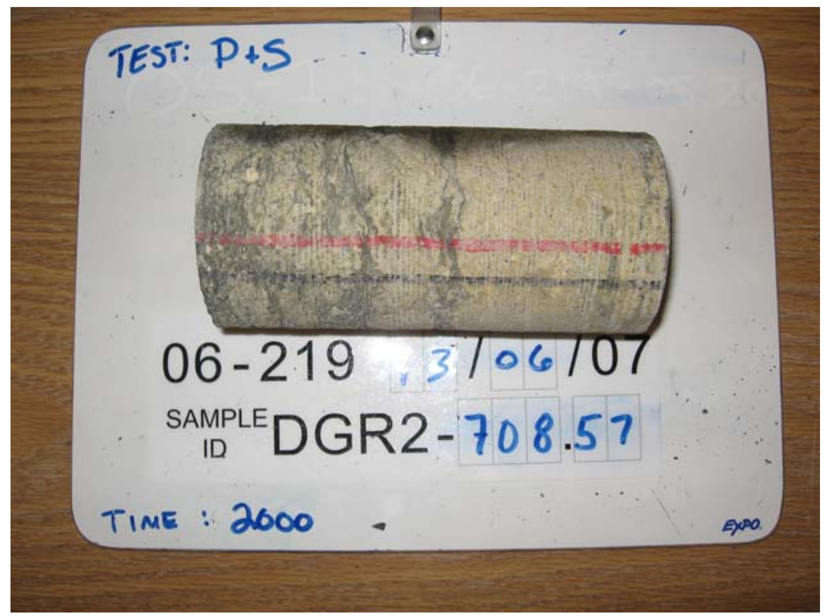

DGR2-708.57

APPENDIX D

Copies of ASTM Standards

ASTM Standard Test Method D 5731-05 *Standard Test Method for Determination of the Point Load Strength Index of Rock* (approved Nov.1, 2005).

ASTM Standard Test Method D 4644-04 *Standard Test Method for Slake Durability of Shales and Similar Weak Rocks* (approved Feb.1, 2004).

ASTM Standard Test Method D 2845-05 *Standard Test Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock* (approved June 1, 2005).

ASTM Standard Test Method D 2216-05 *Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass* (approved March 1, 2005).

Designation: D 5731 – 05

Standard Test Method for Determination of the Point Load Strength Index of Rock[1]

This standard is issued under the fixed designation D 5731; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers the guidelines, requirements, and procedures for determining the point load strength index of rock. Specimens in the form of rock cores, blocks, or irregular lumps can be tested by this test method. This test method can be performed in the field or laboratory because the testing machine is portable. This is an index test and is intended to be used to classify and characterize rock.

1.2 This test method applies to hard rock (compressive strength over 15 MPa (2200 psi)).

1.3 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.3.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.4 The values stated in the SI units are to be regarded as standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D 5079 Practices for Preserving and Transporting Rock Core Samples

D 6026 Practice for Using Significant Digits in Geotechnical Data

D 7012 Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens Under Varying States of Stress and Temperatures

E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials

2.2 *ISRM Standard:*

Suggested Methods for Determining Point Load Strength[3]

3. Terminology

3.1 For definitions of terms used in this test method refer to Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *point load strength index*—an indicator of strength (see 9.1) obtained by subjecting a rock specimen to an increasingly concentrated point load, applied through a pair of truncated, conical platens, until failure occurs.[3]

4. Summary of Test Method

4.1 This index test is performed by subjecting a rock specimen to an increasingly concentrated load until failure occurs by splitting the specimen. The concentrated load is applied through coaxial, truncated conical platens. The failure load is used to calculate the point load strength index and to estimate the uniaxial compressive strength.

5. Significance and Use

5.1 The uniaxial compression test (see Test Method D 7012) is used to determine compressive strength of rock specimens, but it is a time-consuming and expensive test that requires specimen preparation. When extensive testing is required for preliminary and reconnaissance information, alternative tests such as the point load test can be used in the field to reduce the time and cost of compressive strength tests.

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[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved Nov. 1, 2005. Published November 2005. Originally approved in 1995. Last previous edition approved in 2002 as D 5731–02.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] "Suggested Methods for Determining Point Load Strength", International Society for Rock Mechanics Commission on Testing Methods, *Int. J. Rock. Mech. Min. Sci. and Geomechanical Abstr.*, Vol 22, No. 2, 1985, pp. 51–60.

***A Summary of Changes section appears at the end of this standard.**

5.2 The point load strength test is used as an index test for strength classification of rock materials. The test results should not be used for design or analytical purposes.

5.3 This test method is performed to determine the point load strength index ($I_s(50)$) of rock specimens, and the point load strength anisotropy index ($I_a(50)$) that is the ratio of point load strengths on different axes that result in the greatest and least values.

5.4 Rock specimens in the form of either core (the diametral and axial tests), cut blocks (the block test), or irregular lumps (the irregular lump test) are tested by application of concentrated load through a pair of truncated, conical platens. Little or no specimen preparation is required. However, the results can be highly influenced by how the specimem is treated from the time it is obtained until the time it is tested. Therefore, it may be necessary to handle specimens in accordance with Practice D 5079.

NOTE 1—The quality of the result produced by this standard is dependent upon the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing and sampling. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *General*—A point load tester (see Fig. 1) consists of a loading system typically comprised of a loading frame, platens, a measuring system for indicating load, *P*, (required to break the specimen), and a means for measuring the distance, *D*, between the two platen contact points. The equipment shall be resistant to shock and vibration so that the accuracy of readings is not adversely affected by repeated testing.

6.2 *Loading System*:

6.2.1 The loading system shall have a loading frame with a platen-to-platen clearance that allows testing of rock specimens in the required size range. Typically, this range is within 30 to 85 mm so that an adjustable distance is available to accommodate both small and large specimens.

6.2.2 The loading capacity shall be sufficient to break the largest and strongest specimens to be tested.

6.2.3 The test machine shall be designed and constructed so that it does not permanently distort during repeated applications of the maximum test load, and so that the platens remain coaxial within ±0.2 mm throughout testing. No spherical seat or other nonrigid component is permitted in the loading system. Loading system rigidity is essential to avoid slippage when specimens of irregular geometry are tested.

6.2.4 Truncated, conical platens, as shown on Fig. 2, are to be used. The 60° cone and 5-mm radius spherical platen tip shall meet tangentially. The platens shall be of hard material (Rockwell 58 HRC, as explained in Test Method E 18) such as tungsten carbide or hardened steel so they remain undamaged during testing.

6.3 *Load Measuring System*:

6.3.1 A load measuring system, for example a load cell or a hydraulic pressure gage, that will indicate failure load, *P*, required to break specimen. The system should conform to the requirements of 6.3.2-6.3.4.

6.3.2 Measurements of failure load, *P*, shall be to a precision of ±5 % or better of full-scale load-measuring system, irrespective of the size and strength of specimen that is tested.

6.3.3 Failure is often sudden and a peak load indicator is required so the failure load can be recorded after each test.

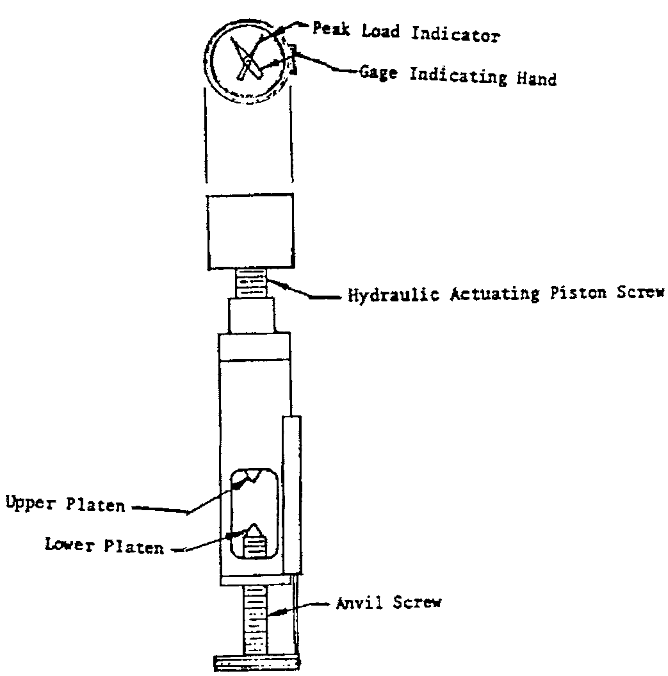


FIG. 1 An Example of a Loading System

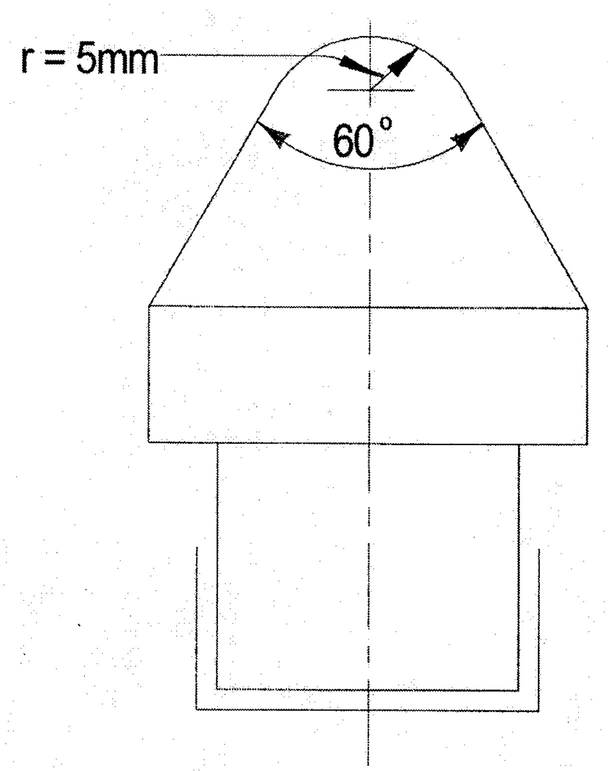


FIG. 2 Platen Dimensions

6.3.4 The system should be capable of using interchangeable measuring devices in order to be consistent with the estimated strength of rock (point load strength of rock is usually an order of magnitude lower than the compressive strength of rock).

6.4 *Distance Measuring System*:

6.4.1 The distance measuring system, a vernier direct reading scale, should connect to the loading frame for measuring the distance, *D*, between specimen-platen contact points and conform to requirements 6.4.2 and 6.4.3.

6.4.2 Measurements of *D* shall be to an accuracy of ±2 % or better of distance between contact points, irrespective of the size and strength of specimen that is tested.

6.4.3 The measuring system shall allow a check of the" zero displacement" value when the two platens are in contact and should include a zero adjustment.

6.4.4 An instrument such as a caliper or a steel rule is required to measure the width, *W*, (with an accuracy of ±5 %) of specimens for all but the diametral test.

6.5 *Miscellaneous Items*—Diamond saw, chisels, towels, marking pens, and plotting paper.

7. Test Specimens

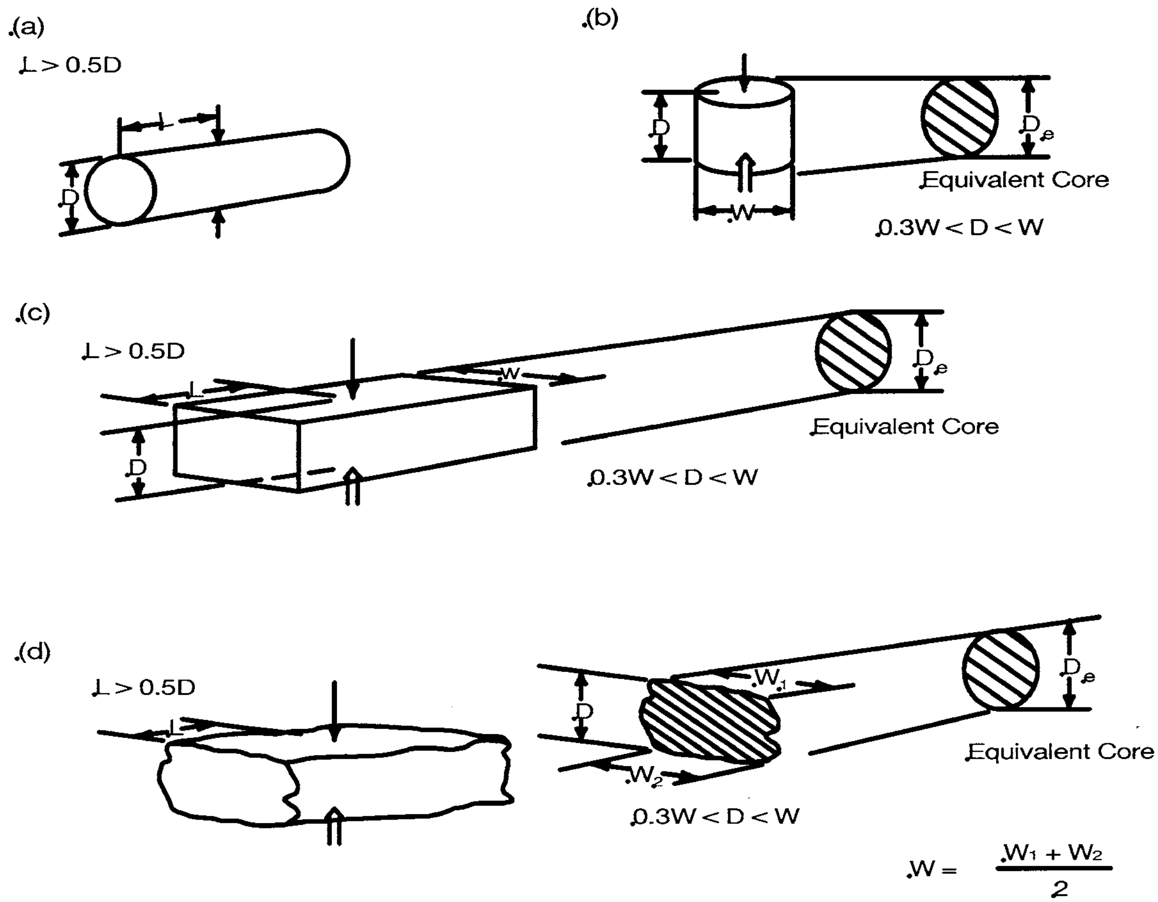
7.1 *Sampling*—Rock samples are grouped on the basis of both rock type and estimated strength. When testing core or block specimens at least ten specimens are selected. When testing irregular-shaped specimens obtained by other means at least 20 specimens are selected. Specimens in the form of core are preferred for a more precise classification.

7.2 *Dimensions*—The specimen's external dimensions shall not be less than 30 mm and not more than 85 mm with the preferred dimension about 50 mm.

7.3 *Size and Shape*—The size and shape requirements for diametral, axial, block, or irregular lump testing shall conform with the recommendations shown on Fig. 3. The sides of the specimens shall be free from abrupt irregularities that can generate stress concentrations. No specimen preparation is required.

7.4 *Water Content*—Using Test Method D 2216, determine the water content of each specimen after testing since it can affect the value of the point load strength.

7.5 *Marking and Measuring Specimens*—The specimens shall be properly marked and measured.



NOTE 1—Legend: L = length, W = width, D = depth or diameter, and D_e = equivalent core diameter (see 9.1).

FIG. 3 Load Configurations and Specimen Shape Requirement for (a) the Diametral Test, (b) the Axial Test, (c) the Block Test, and (d) the Irregular Lump Test[3]

7.5.1 *Marking*—The desired test orientation of the specimen shall be indicated by marking lines on the specimen. These lines are used for centering the specimen in the testing machine, and to ensure proper orientation during testing. These lines may also be used as reference lines for measuring thickness and diameter.

7.5.2 *Measuring*—Measure each dimension of a specimen at three different places, and calculate the averages.

8. Procedure

8.1 *Diametral Test*:

8.1.1 Core specimens with length/diameter ratio greater than one are suitable for diametral testing.

8.1.2 Insert a specimen in the test device and close the platens to make contact along a core diameter. Ensure that the distance, *L*, between the contact points and the nearest free end is at least 0.5 times the core diameter (see Fig. 3(*a*)).

8.1.3 Determine and record the distances *D* and *L* (see Fig. 3).

8.1.4 Steadily increase the load such that failure occurs within 10 to 60 s, and record failure load, *P*. The test should be rejected if the fracture surface passes through only one platen loading point (see Fig. 4(*d*)).

8.1.5 The procedures in 8.1.2-8.1.4 are repeated for each specimen of the rock type.

8.2 *Axial Test*:

8.2.1 Core specimens with length/diameter ratio of ⅓ to 1 are suitable for axial testing (see Fig. 3(*b*)). Suitable specimens can be obtained by saw-cutting or chisel-splitting.

8.2.2 Insert a specimen in the test machine and close the platens to make contact along a line perpendicular to the core end faces (in the case of isotropic rock, the core axis, but see 8.4 for anisotropic rock).

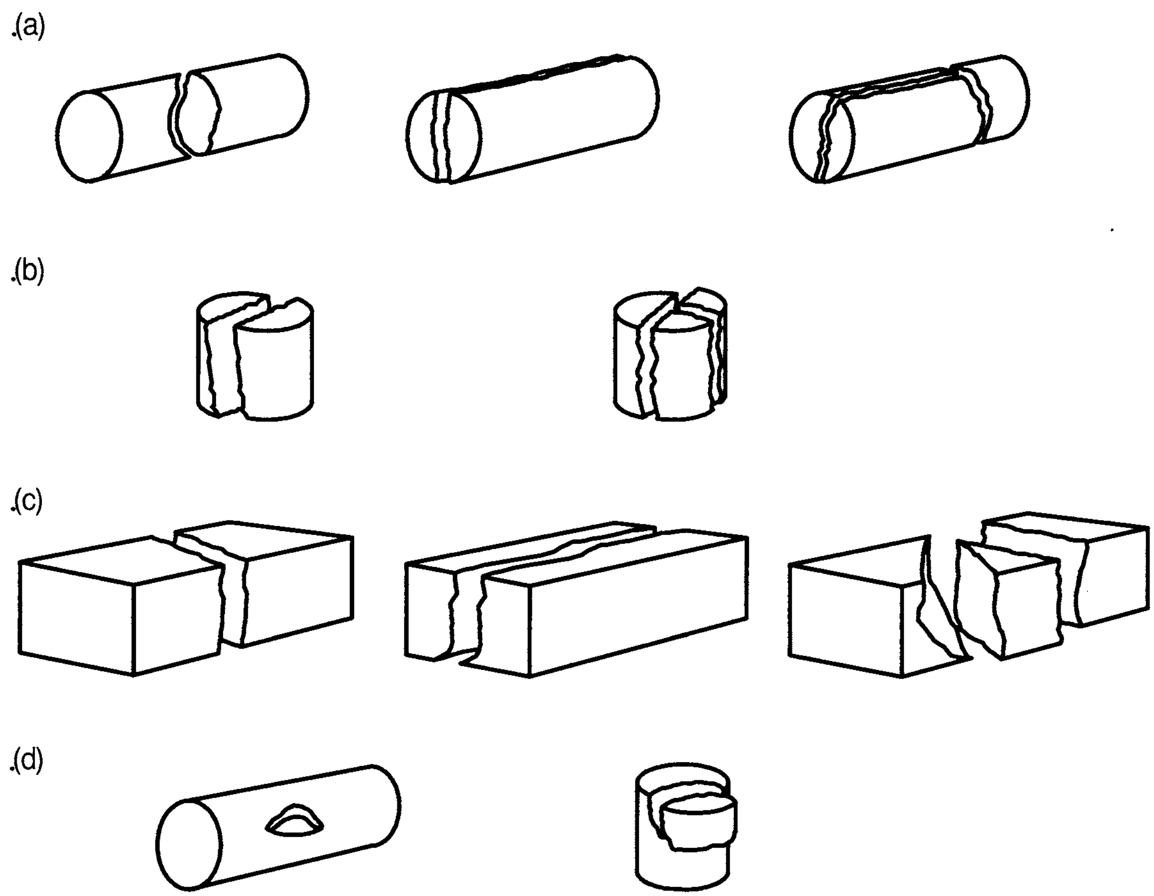
8.2.3 Record the distance, *D*, between platen contact points (see Fig. 3). Record the specimen width, *W*, perpendicular to the loading direction, with an accuracy of ±5 %.

8.2.4 Steadily increase the load such that failure occurs within 10 to 60 s, and record the failure load, *P*. The test should be rejected if the fracture surface passes through only one loading point (see Fig. 4(*e*)).

8.2.5 Procedures 8.2.2-8.2.4 are repeated for each test specimen of the rock type.

8.3 *Block and Irregular Lump Tests*:

8.3.1 Rock blocks or lumps, 30 to 85 mm, and of the shape shown in Fig. 3(*c*) and (*d*) are suitable for the block and the



NOTE 1—(a) Valid diametral tests; (b) valid axial tests; (c) valid block tests; (d) invalid core test; and (e) invalid axial test (point load strength index test).

FIG. 4 Typical Modes of Failure for Valid and Invalid Tests[3]

irregular lump tests. The ratio, D/W, should be between ⅓ and 1, preferably close to 1. The distance L should be at least 0.5 W.

8.3.2 Insert a specimen in the testing machine and close the platens to make contact with the smallest dimension of the lump or block, away from edges and corners (see Fig. 3(*c*) and (*d*).

8.3.3 Record the distance D between platen contact points. Record the smallest specimen width, W, perpendicular to the loading direction. If the sides are not parallel, then calculate W as $(W_1 + W_2)/2$ as shown on Fig. 3. This width, W, is used in calculating point load strength index irrespective of the actual mode of failure (see Fig. 3 and Fig. 4).

8.3.4 Steadily increase the load such that failure occurs within 10 to 60 s, and record the failure load, P. The test should be rejected if the fracture surface passes through only one loading point (see examples for other shapes in Fig. 4(*d*) or (*e*).

8.3.5 Procedures 8.3.2-8.3.4 are repeated for each test specimen in the sample.

8.4 *Anisotropic Rock*:

8.4.1 When a rock sample is shaly, bedded, schistose, or otherwise observably anisotropic, it should be tested in directions that will give the greatest and least strength values, in general, parallel and normal to the planes of anisotropy.

8.4.2 If the sample consists of core drilled through weakness planes, a set of diametral tests may be completed first, spaced at intervals that will yield pieces that can then be tested axially.

8.4.3 Strongest test results are obtained when the core axis is perpendicular to the planes of weakness; therefore, when possible, the core should be drilled in this direction. The angle between the core axis and the normal to the direction of least strength should preferably not exceed 30°.

8.4.4 For measurement of the point load strength index (I_s) value in the direction of least strength, ensure that load is applied along a single weakness plane. Similarly, when testing for the I_s value in the direction of greatest strength, ensure that the load is applied perpendicular to the direction of least strength.

8.4.5 If the sample consists of blocks or irregular lumps, it should be tested as two subsamples, with load first applied perpendicular to, then along the observable planes of weakness. Again, the required minimum strength value is obtained when the platens make contact and are loaded to failure along a single plane of weakness.

8.5 If significant platen penetration occurs, the dimension D to be used in calculating point load strength should be the value D' measured at the instant of failure, that will be smaller than the initial value suggested in 8.1.3, 8.2.3, and 8.3.3. The error in assuming D to be its initial value is negligible when the specimen is large or strong. The dimension at failure may always be used as an alternative to the initial value and is preferred.

8.6 *Water Content*—Follow Test Method D 2216 to determine the water content of each rock specimen and report the moisture condition (see Section 10).

9. Calculation

9.1 *Uncorrected Point Load Strength Index*—The uncorrected point load strength I_s is calculated as:

$$I_s = P/D_e^2, \text{ MPa} \quad (1)$$

where:
P = failure load, N,
D_e = equivalent core diameter = D for diametral tests (see Fig. 3), m, and is given by:
D_e^2 = D^2 for cores, mm^2, or
D_e^2 = $4A/\pi$ for axial, block, and lump tests, mm^2;

where:
A = WD = minimum cross-sectional area of a plane through the platen contact points (see Fig. 3).

NOTE 2—If significant platen penetration occurs in the test, such as when testing weak sandstones, the value of D should be the final value of the separation of the loading points, D'. Measurements of core diameter, D, or specimen width, W, made perpendicular to the line joining the loading points are not affected by this platen penetration and should be retained at the original values. The modified values of D_e can be calculated from:

$$D_e^2 = D \times D' \text{ for cores } = 4/\pi\ W \times D' \text{ for other shapes} \quad (2)$$

9.2 *Size Correction Factor*:

9.2.1 I_s varies as a function of D in the diametral test, and as a function of D_e in axial, block, and irregular lump tests, so that a size correction must be applied to obtain an unique point load strength value for the rock sample and one that can be used for purposes of rock strength classification.

9.2.2 The size-corrected point load strength index, $I_{s(50)}$, of a rock specimen is defined as the value of I_s that would have been measured by a diametral test with $D = 50$ mm.

9.2.3 When a precise rock classification is essential, the most reliable method of obtaining $I_{s(50)}$ is to conduct diametral tests at or close to $D = 50$ mm. Size correction is then unnecessary. For example, in case of diametral tests on NX, core diameter = 54 mm and size correction to $D = 50$ mm is not necessary. Most point load strength tests are in fact performed using other specimen sizes or shapes. In such cases, the size correction described in 9.2.4 or 9.2.5 must be applied.

9.2.4 The most reliable method of size correction is to test the specimen over a range of D or D_e values and to plot graphically the relation between P and D_e. If a log-log plot is used, the relation is a straight line (see Fig. 5). Points that deviate substantially from the straight line may be disregarded (although they should not be deleted). The value of $I_{s(50)}$ corresponding to $D_e^2 = 2500$ mm^2 ($D_e = 50$ mm) can be obtained by interpolation and use of the size-corrected point load strength index calculated as shown in 9.2.5.

9.2.5 When neither 9.2.3 nor 9.2.4 is practical (for example when testing single-sized core at a diameter other than 50 mm or if only a few small pieces are available), size correction may be accomplished using the formula:

$$I_{s(50)} = F \times I_s \quad (3)$$

The "Size Correction Factor F" can be obtained from the chart in Fig. 6, or from the expression:

$$F = (D_e/50)^{0.45} \quad (4)$$

For tests near the standard 50-mm size, only slight error is introduced by using the approximate expression:

$$F = \sqrt{(D_e/50)} \quad (5)$$

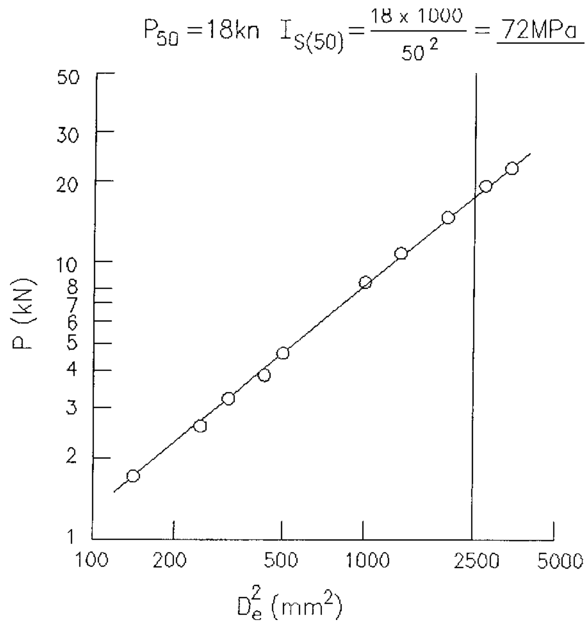


FIG. 5 Procedure for Graphical Determination of $I_{s(50)}$ from a Set of Results at D_e Values Other Than 50 mm [3]

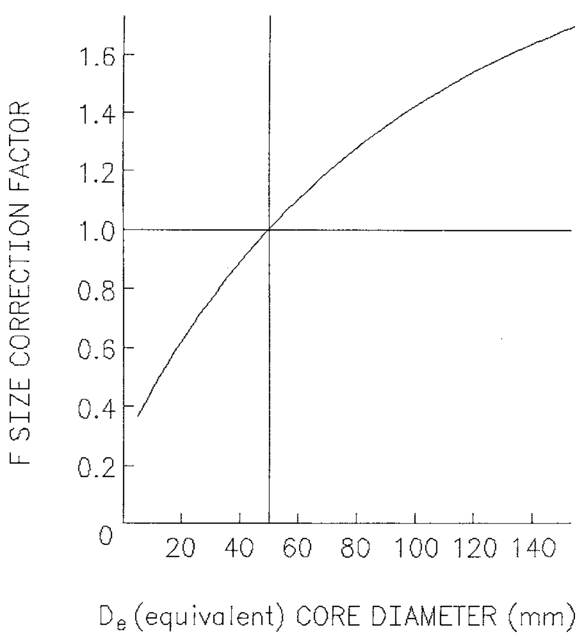


FIG. 6 Size Correction Factor Chart [3]

instead of using the procedure outlined on Fig. 5.

9.3 *Mean Value Calculation*:

9.3.1 Mean values of $I_{s(50)}$, as defined in 9.3.2, are to be used when classifying samples with regard to their point load strength and point load strength anisotropy indices.

9.3.2 The mean value of $I_{s(50)}$ is to be calculated by deleting the two highest and two lowest values from the ten, or more, valid tests, and calculating the mean of the remaining values. If significantly fewer specimens are tested, only the highest and lowest values are to be deleted and the mean calculated from those remaining.

9.4 *Point Load Strength Anisotropy Index*—The strength anisotropy index $I_{a(50)}$ is defined as the ratio of mean $I_{s(50)}$ values measured perpendicular and parallel to planes of weakness, that is, the ratio of greatest to least point load strength indices.See Fig. 7[4].

9.5 *Estimation of Compressive Strength*—The estimated uniaxial compressive strength can be obtained by using Fig. 6 or using the following formula:

$$\delta_{uc} = C\, I_{s(50)} \tag{6}$$

where:

δ_{uc} = uniaxial compressive strength,
C = factor that depends on site-specific correlation between δ_{uc} and $I_{s(50)}$, and
$I_{s(50)}$ = corrected point load strength index.

9.5.1 If site-specific correlation factor "*C*" is not available, use the generalized value of "*C*" shown in Table 1.

TABLE 1 Generalized Value of "C"[A]

Core Size, mm	Value of "C" (Generalized)
20	17.5
30	19
40	21
50	23
54	24
60	24.5

[A] From ISRM Suggested Methods.[3]

9.5.2 If any specimen in a rock type gives a value 20 % under the average, it should be examined for defects.

10. Report

10.1 A typical report (example shown in Fig. 8) may include the following:

10.1.1 Source of sample including project name, location, and, if known, storage environment. The location may be specified in terms of borehole number and depth of specimen from the collar of the hole,

10.1.2 Physical description of sample including rock type and location and orientation of discontinuities, such as, apparent weakness planes, bedding planes, schistosity, or large inclusions, if any,

10.1.3 Date of sampling and testing,

10.1.4 General indication of the moisture condition of test specimens at the time of testing, such as, saturated, as received, laboratory air dry, or oven dry. In some cases, it may be necessary to report the actual water content as determined in accordance with Test Method D 2216,

10.1.5 Average thickness and average diameter of the test specimen,

10.1.6 The maximum applied load "*P*",

10.1.7 The distance "*D*" or *D'*, or both, if required,

10.1.8 Direction of loading (parallel to or normal to plane of weakness),

10.1.9 The number of specimens tested,

10.1.10 The calculated uncorrected (I_s) and corrected $I_{s(50)}$ point load strength index values,

[4] D'Andrea, D.V., Fisher, R.L., and Fogelson, D.E., Prediction of Compressive Strength of Rock from Other Rock Properties, *U.S. Bureau of Mines Rep. Invest.,*, 6702, 1965.

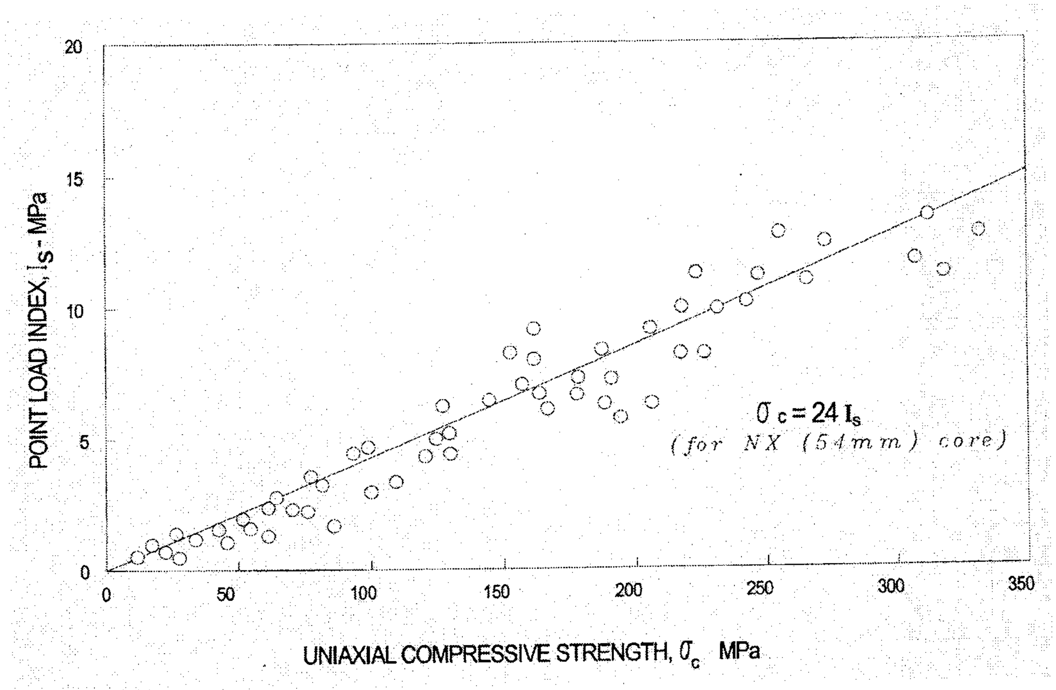


FIG. 7 Relationship Between Point Load Strength Index and Uniaxial Compressive Strength from 125 Tests On Sandstone, Quartzite, Marikana, Norite, and Belfast Norite[4]

10.1.11 The estimated value of uniaxial compressive strength (δ_{uc}),

10.1.12 The calculated value of strength anisotropy index ($I_{a(50)}$), and

10.1.13 Type and location of failure, including any photographs of the tested specimens before and after the test.

11. Precision and Bias

11.1 *Precision*—Due to the nature of rock materials tested by this test method, multiple specimens that have uniform physical properties have not been produced for testing. Since specimens that would yield the same test results have not been tested, Subcommittee D18.12 cannot determine the variation between tests since any variation observed is just as likely to be due to specimen variation as to operator or testing variation. Subcommittee D18.12 welcomes proposals to resolve this problem and would allow for development of a valid precision statement.

11.2 *Bias*—There is no accepted reference value for this test method; therefore, bias cannot be determined.

12. Keywords

12.1 compressive strength; index test; point load; rock

Sample Details **Point Load Test** **Date 11/17/83**

1 block sample from Gamblethorpe Opencast site.

Fine grained pale grey Coal Measures sandstone with numerous coaly streaks along horizontal bedding planes.

Specimens 1-6 chisel cut blocks, air-dried 2 weeks;
7-10 sawn blocks, air-dried 2 weeks;
11-15 cores, air-dried 2 weeks;
16-20 cores, air-dried 2 weeks;
- tested in laboratory.

No.	Type	W (mm)	D(mm)	P (kN)	D_e^2(mm2)	D_e (mm)	I_s	F	$I_{s(50)}$
1	i ⊥	30.4	17.2	2.687	666	25.8	4.03	0.75	
2	i ⊥	16	8	0.977	163	12.8	5.99	0.54	3.24
3	i ⊥	19.7	15.6	1.962	391	19.8	5.02	0.66	3.31
4	i ⊥	35.8	18.1	3.641	825	28.7	4.41	0.765	3.46
5	i ⊥	42.5	29	6.119	1569	39.6	3.90	0.875	3.49
6	i ⊥	42	35	7.391	1872	43.3	3.95	0.935	
7	b ⊥	44	21	4.600	1176	34.3	3.91	0.84	
8	b ⊥	40	30	5.940	1528	39.1	3.88	0.89	
9	b ⊥	19.5	15	2.040	372	19.3	5.48	0.655	
10	b ⊥	33	16	2.87	672	25.9	4.27	0.75	
11	d //	-	49.93	5.107	-	-	-	-	
12	d //	-	49.88	4.615	-	-	-	-	
13	d //	-	49.82	5.682	-	-	-	-	
14	d //	-	49.82	4.139	-	-	-	-	
15	d //	-	49.86	4.546	-	-	-	-	1.83
16	d //	-	25.23	1.837	-	-	2.89	0.74	2.14
17	d //	-	25.00	1.891	-	-	3.02	0.735	2.22
18	d //	-	25.07	2.118	-	-	3.37	0.735	
19	d //	-	25.06	1.454	-	-	2.32	0.735	
20	d //	-	25.04	1.540	-	-	2.46	0.735	1.81

d = diametral;
a = axial;
b = block;
i = irregular lump test;
⊥ = perpendicular;
// = parallel to planes of weakness.

Mean $I_{s(50)}$ ⊥	3.38
Mean $I_{s(50)}$ //	1.98
$I_{s(50)}$	1.71

FIG. 8 Test Record[3]

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (2002) that may impact the use of this standard.

(1) Deleted Test Method D 2938 in Section 2 and 5.1 and replaced with Test Method D 7012

Designation: D 4644 – 04

Standard Test Method for Slake Durability of Shales and Similar Weak Rocks[1]

This standard is issued under the fixed designation D 4644; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers the determination of the slake durability index of a shale or other similar rock after two drying and wetting cycles with abrasion.

1.2 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.2.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are provided for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 2113 Practice for Diamond Core Drilling for Site Investigation

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Rock and Soil

D 3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D 5079 Practices for Preserving and Transporting Rock Core Samples

D 6026 Practice for Using Significant Digits in Geotechnical Data

E 11 Specification for Wire Cloth and Sieves for Testing Purposes

3. Terminology

3.1 For terminology used in this test method, refer to Terminology D 653

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *slake durability index*—the percentage by dry mass retained of a collection of shale pieces on a 2.00 mm (No. 10) sieve after two cycles of oven drying and 10 min of soaking in water with a standard tumbling and abrasion action.

4. Significance and Use

4.1 The test method is used to estimate qualitatively the durability of weak rocks in the service environment.**(1-7)**[3].

4.2 This test method is used to assign quantitative durability values to weak rocks. A primary example is the Franklin Rating System **(1).**

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing, sampling, inspection, and so forth. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

5. Apparatus

5.1 *Slake Durability Device*—The drum (Fig. 1) shall be made of 2.00 mm (No. 10) square-mesh, woven-wire cloth, conforming to the requirements of Specification E 11. It shall be cylindrical in shape, with a diameter of 140 mm (5.5 in.) and a length of 100 mm (3.9 in.). The ends shall be rigid plates, with one removable end. It must be sufficiently strong to retain its shape during use, but neither the exterior of the mesh nor the interior of the drum shall be obstructed by a support. The drum shall be able to withstand a temperature of 110 ± 5°C (230 ± 9°F). A trough shall support the drum in a horizontal manner such that the drum is free to rotate about its axis. The trough shall be capable of being filled with slaking fluid to 20 mm (0.8 in.) below the drum axis, and shall allow at least 40 mm (1.6 in.) unobstructed clearance between the trough and the bottom

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved Feb. 1, 2004. Published February 2004. Originally approved in 1987. Last previous edition approved in 1998 as D 4644 – 87 (1998).

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The boldface numbers in parentheses refer to the list of references at the end of this standard.

***A Summary of Changes section appears at the end of this standard.**

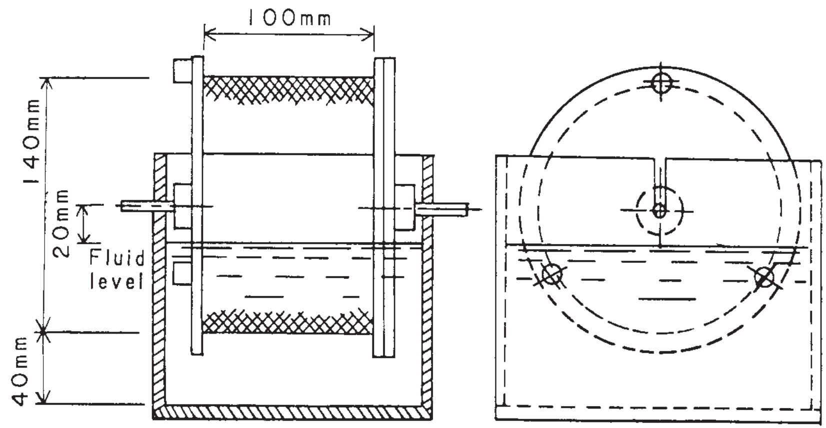


FIG. 1 Critical Dimensions of Slake Durability Device Showing Critical Dimensions

of the mesh. The drum shall be rotated by a motor capable of maintaining a speed of 20 rpm, constant to within 5 %, for a period of 10 min. Devices conforming to these requirements are commercially available.

5.2 *Drying Oven*, thermostatically controlled, capable of maintaining a temperature of 110 ± 5°C (230 ± 9°F).

5.3 *Balance*, sensitive to 1 g and having a 2000-g capacity.

5.4 *Miscellaneous Apparatus*, including a brush and hammer.

5.5 *Distilled Water*.

6. Test Sample and Specimen—

6.1 Collect, transport, and store test samples and test specimens in such a manner as to retain the natural water content using the guidelines in Practices D 2113 and D 5079 and Test Method D 2216.

6.2 The test specimen shall consist of ten representative, intact, roughly equidimensional shale fragments weighing 40 g to 60 g each. These fragments may be naturally occurring or may be produced by breaking with a hammer. Such fragments may be obtained from rock cores or from test pits, and their sizes will vary with the method of sampling. Break off any sharp corners, if possible, and remove any dust by brushing the fragment just prior to weighing. The total test specimen shall weigh 450 to 550 g.

7. Procedure

7.1 Photograph specimen prior to placement in drum.

7.2 *Water Content*—Using Test Method D 2216, determine the water content of each test specimen before testing. This shall be done with the shale fragments in the drum to be used for the actual testing.

7.3 Mount the drum in the trough and couple to the motor. Fill the trough with distilled water at room temperature to 20 mm (0.8 in.) below the drum axis. Rotate the drum at 20 rpm for a period of 10 min. Record the water temperature at the beginning and end of the run.

7.4 Remove the drum from the trough immediately after the rotation period is complete and dry the drum and the specimen retained in the oven the same as in 7.2 and obtain the oven-dried mass.

7.5 Repeat 7.3 and 7.4 to obtain a final oven-dried mass for the second cycle.

7.6 Photograph specimen retained and file a copy of the photo with the laboratory report, or record standard verbal descriptions, as follows:

7.6.1 *Type I*—Retained specimen remain virtually unchanged.

7.6.2 *Type II*—Retained specimen consist of large and small fragments.

7.6.3 *Type III*—Retained specimen is exclusively small fragments.

7.7 See Fig. 2 for representative photographs of the three types.

8. Calculations

8.1 Calculate the slake durability index (second cycle), as follows:

$$I_d(2) = [(W_F - C)/(B - C)] \times 100 \quad (1)$$

where:

$I_d(2)$ = slake durability index (second cycle),
B = mass of drum plus oven-dried specimen before the first cycle, g,
W_F = mass of drum plus oven-dried specimen retained after the second cycle, g, and
C = mass of drum, g.

9. Report

9.1 The report shall include the following:

9.1.1 Description of the specimen and where it was obtained.

9.1.2 Slake durability index (second cycle) to the nearest 0.1 %.

9.1.3 Range and average value of the water temperature.

9.1.4 Natural water content.

9.1.5 Description of the appearance of the fragments retained in the drum (see 7.6).

10. Precision and Bias

10.1 Test data on precision is not presented due to the nature of shale and other similar rock tested by this test method. It is either not feasible or too costly at this time to produce multiple specimens which have uniform physical properties. Any variation observed on the data is just as likely to be due to specimen

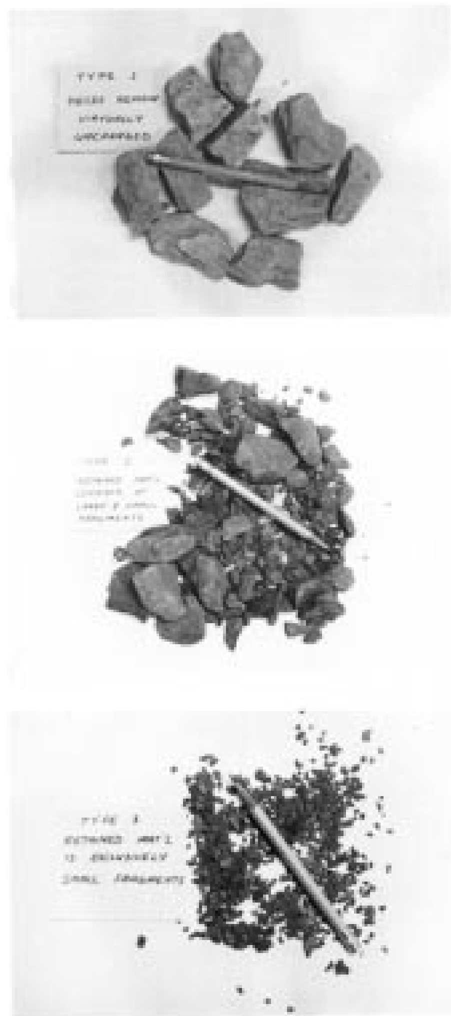


FIG. 2 Illustration of Fragment Types Retained

variation as to operator or laboratory testing variation: Subcommittee D18.12 welcomes proposals that would allow for development of a valid precision statement. There is no accepted reference value of shale or weak rock for this test method; therefore, bias cannot be determined.

11. Keywords

11.1 abrasion resistance; shale; slake durability; weak rocks

REFERENCES

(**1**) Franklin Trow Associates, "Field Evaluation of Shales for Construction Projects," Research and Development Project No. 1404, Ministry of Transportation and Communications, Research and Development Branch, Downsview, Ontario, March 1979.

(**2**) Chapman, D. R., "Shale Classification Tests and Systems: A Comparative Study," MSCE Thesis and Joint Highway Research Project No. 75-11, Purdue University, West Lafayette, IN, June 1975, 90 pp.

(**3**) Deo, P., "Shales as Embankment Materials," Ph.D. Thesis and Joint Highway Research Project No. 45, Purdue University, West Lafayette, IN, December 1972, 202 pp.

(**4**) International Society for Rock Mechanics, "Suggested Methods for Determining Slake-Durability Index Properties," Commission on Standardization of Laboratory and Field Tests, November 1972.

(**5**) Lutton, R. J., "Design and Construction of Compacted Shale Embankments, Volume 3, Slaking Indexes for Design," Report No. FHWA-RD-77-1, Federal Highway Administration, Washington, DC, February 1977.

(**6**) Surendra, M., "Additives to Control Slaking in Compacted Shales," Ph.D. Thesis and Joint Highway Research Project No. 80-6, Purdue University, West Lafayette, IN, May 1980, 277 pp.

(**7**) Oakland, M. W., and Lovell, C. W., "Classification and Other Standard Tests for Shale Embankment," Joint Highway Research Project No. 82-4, Purdue University, West Lafayette, IN, February 1982, 171 pp.

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (D 4644 – 87 (1998)) that may impact the use of this standard.

(1) As required, a footnote about Summary of Changes was added to the title of Section 1.
(2) Added standard paragraphs for significant digits and rounding established by Practice D 6026
(3) Added Terminology D 653 , Practice D 2113, Test Method D 2216, Practice D 3740, Practice D 5079, Practice D 6026.
(4) Added 3.1 referencing Terminology D 653, and renumbered section accordingly.
(5) Added Note 1 referencing Practice D 3740.
(6) Moved 6.2 up to 6.1 and added reference to Practice D 2113, Test Method D 2216, and Practice D 5079.
(7) Section 7. Changed all reference to material to specimen and changed pieces to fragments.
(8) Added 7.1 about photographing test specimen before testing and renumbered accordingly.
(9) Took out section in 7.1 on calculating initial water content and referred user to Test Method D 2216 for determining water content.
(10) Reworded 7.3 and 7.4 to remove instructions contained in Test Method D 2216.
(11) Changed sample to specimen in 8.1.
(12) The word "material" was changed to "specimen" in 9.1.1.
(13) Section 10 was re-worded to conform with the D18 standards preparations manual.
(14) Added Summary of Changes section.

INTERNATIONAL

Designation: D 2845 – 05

Standard Test Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock[1]

This standard is issued under the fixed designation D 2845; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method describes equipment and procedures for laboratory measurements of the pulse velocities of compression waves and shear waves in rock (**1**)[2] and the determination of ultrasonic elastic constants (Note 1) of an isotropic rock or one exhibiting slight anisotropy.

NOTE 1—The elastic constants determined by this test method are termed ultrasonic since the pulse frequencies used are above the audible range. The terms sonic and dynamic are sometimes applied to these constants but do not describe them precisely (**2**). It is possible that the ultrasonic elastic constants may differ from those determined by other dynamic methods.

1.2 This test method is valid for wave velocity measurements in both anisotropic and isotropic rocks although the velocities obtained in grossly anisotropic rocks may be influenced by such factors as direction, travel distance, and diameter of transducers.

1.3 The ultrasonic elastic constants are calculated from the measured wave velocities and the bulk density. The limiting degree of anisotropy for which calculations of elastic constants are allowed and procedures for determining the degree of anisotropy are specified.

1.4 The values stated in inch-pounds are to be regarded as the standard. The SI values given in parenthesis are provided for information purposes only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [3]

D 653 Terminology Relating to Rock, Soil, and Contained Fluids
D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D 6026 Practice for Using Significant Digits in Geotechnical Data
E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 For common definitions of terms in this standard, refer to Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *compression wave velocity*—the dilational wave velocity which is the propagation velocity of a longitudinal wave in a medium that is effectively infinite in lateral extent. It is not to be confused with bar or rod velocity.

4. Summary of Test Method

4.1 Details of essential procedures for the determination of the ultrasonic velocity, measured in terms of travel time and distance, of compression and shear waves in rock specimens include requirements of instrumentation, suggested types of transducers, methods of preparation, and effects of specimen geometry and grain size. Elastic constants may be calculated for isotropic or slightly anisotropic rocks, while anisotropy is reported in terms of the variation of wave velocity with direction in the rock.

5. Significance and Use

5.1 The primary advantages of ultrasonic testing are that it yields compression and shear wave velocities, and ultrasonic values for the elastic constants of intact homogeneous isotropic rock specimens (**3**). Elastic constants are not to be calculated for rocks having pronounced anisotropy by procedures described in this test method. The values of elastic constants often do not agree with those determined by static laboratory methods or the *in situ* methods. Measured wave velocities likewise may not agree with seismic velocities, but offer good approximations. The ultrasonic evaluation of rock properties is

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved June 1, 2005. Published July 2005. Originally approved in 1969. Last previous edition approved in 2000 as D 2845 – 00.

[2] The boldface numbers in parentheses refer to the list of references at the end of this test method.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard.**

useful for preliminary prediction of static properties. The test method is useful for evaluating the effects of uniaxial stress and water saturation on pulse velocity. These properties are in turn useful in engineering design.

5.2 The test method as described herein is not adequate for measurement of stress-wave attenuation. Also, while pulse velocities can be employed to determine the elastic constants of materials having a high degree of anisotropy, these procedures are not treated herein.

NOTE 2—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing and sampling. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *General*—The testing apparatus (Fig. 1) should have impedance matched electronic components and shielded leads to ensure efficient energy transfer. To prevent damage to the apparatus allowable voltage inputs should not be exceeded.

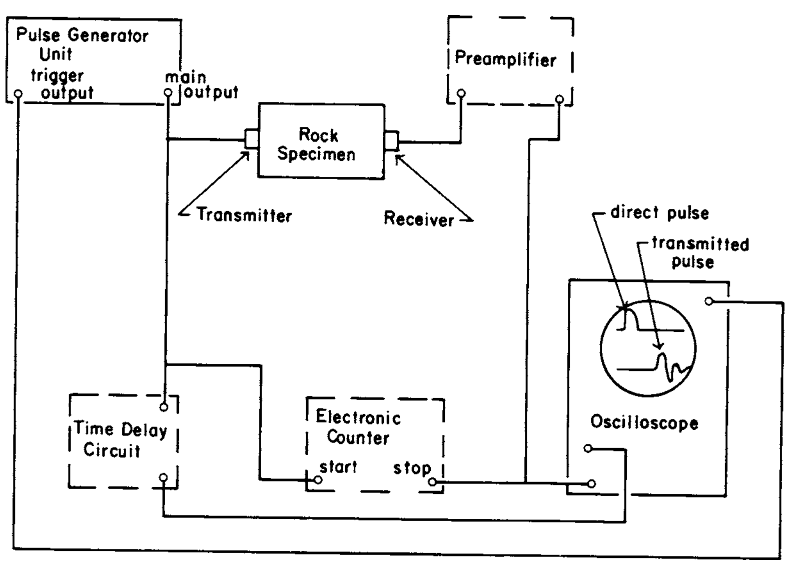
6.2 *Pulse Generator Unit*—This unit shall consist of an electronic pulse generator and external voltage or power amplifiers if needed. A voltage output in the form of either rectangular pulse or a gated sine wave is satisfactory. The generator shall have a voltage output with a maximum value after amplification of at least 50 V into a 50-Ω impedance load. A variable pulse width, with a range of 1 to 10μ *s* is desirable. The pulse repetition rate may be fixed at 60 repetitions per second or less although a range of 20 to 100 repetitions per second is recommended. The pulse generator shall also have a trigger-pulse output to trigger the oscilloscope. There shall be a variable delay of the main-pulse output with respect to the trigger-pulse output, with a minimum range of 0 to 20 μ*s*.

6.3 *Transducers*—The transducers shall consist of a transmitter that converts electrical pulses into mechanical pulses and a receiver that converts mechanical pulses into electrical pulses. Environmental conditions such as ambient temperature, moisture, humidity, and impact should be considered in selecting the transducer element. Piezoelectric elements are usually recommended, but magnetostrictive elements may be suitable. Thickness-expander piezoelectric elements generate and sense predominately compression-wave energy; thickness-shear piezoelectric elements are preferred for shear-wave measurements. Commonly used piezoelectric materials include ceramics such as lead-zirconate-titanate for either compression or shear, and crystals such as a-c cut quartz for shear. To reduce scattering and poorly defined first arrivals at the receiver, the transmitter shall be designed to generate wavelengths at least 3 × the average grain size of the rock.

NOTE 3—Wavelength is the wave velocity in the rock specimen divided by the resonance frequency of the transducer. Commonly used frequencies range from 75 kHz to 3 MHz.

6.3.1 In laboratory testing, it may be convenient to use unhoused transducer elements. But if the output voltage of the receiver is low, the element should be housed in metal (grounded) to reduce stray electromagnetic pickup. If protection from mechanical damage is necessary, the transmitter as well as the receiver may be housed in metal. This also allows special backings for the transducer element to alter its sensitivity or reduce ringing **(4)**. The basic features of a housed element are illustrated in Fig. 2. Energy transmission between the transducer element and test specimen can be improved by (*1*) machining or lapping the surfaces of the face plates to make them smooth, flat, and parallel, (*2*) making the face plate from a metal such as magnesium whose characteristic impedance is close to that of common rock types, (*3*) making the face plate as thin as practicable, and (*4*) coupling the transducer element to the face plate by a thin layer of an electrically conductive adhesive, an epoxy type being suggested.

6.3.2 Pulse velocities may also be determined for specimens subjected to uniaxial states of stress. The transducer housings in this case will also serve as loading platens and should be



NOTE 1—Components shown by dashed lines are optional, depending on method of travel-time measurement and voltage sensitivity of oscilloscope.

FIG. 1 Schematic Diagram of Typical Apparatus

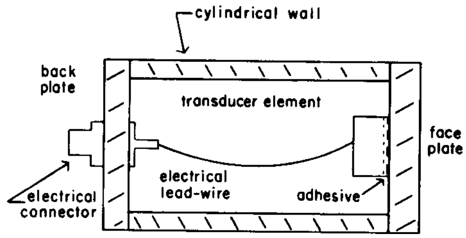


FIG. 2 Basic Features of a Housed Transmitter or Receiver

designed with thick face plates to assure uniform loading over the ends of the specimen (**5**).

NOTE 4—The state of stress in many rock types has a marked effect on the wave velocities. Rocks *in situ* are usually in a stressed state and therefore tests under stress have practical significance.

6.4 *Preamplifier*—A voltage preamplifier is required if the voltage output of the receiving transducer is relatively low or if the display and timing units are relatively insensitive. To preserve fast rise times, the frequency response of the preamplifier shall drop no more than 2 dB over a frequency range from 5 kHz to 4 × the resonance frequency of the receiver. The internal noise and gain must also be considered in selecting a preamplifier. Oscilloscopes having a vertical-signal output can be used to amplify the signal for an electronic counter.

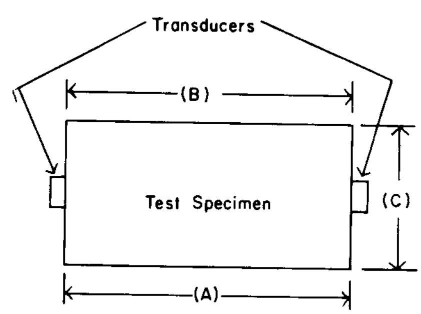
6.5 *Display and Timing Unit*—The voltage pulse applied to the transmitting transducer and the voltage output from the receiving transducer shall be displayed on a cathode-ray oscilloscope for visual observation of the waveforms. The oscilloscope shall have an essentially flat response between a frequency of 5 kHz and 4 × the resonance frequency of the transducers. It shall have dual beams or dual traces so that the two waveforms may be displayed simultaneously and their amplitudes separately controlled. The oscilloscope shall be triggered by a triggering pulse from the pulse generator. The timing unit shall be capable of measuring intervals between 2 µs and 5 ms to an accuracy of 1 part in 100. Two alternative classes of timing units are suggested, the respective positions of each being shown as dotted outlines in the block diagram in Fig. 1: (*1*) an electronic counter with provisions for time interval measurements, or (*2*) a time-delay circuit such as a continuously variable-delay generator, or a delayed-sweep feature on the oscilloscope. The travel-time measuring circuit shall be calibrated periodically with respect to its accuracy and linearity over the range of the instrument. The calibration shall be checked against signals transmitted by the National Institute of Standards and Technology radio station WWV, or against a crystal controlled time-mark or frequency generator that can be referenced back to the signals from WWV periodically. It is recommended that the calibration of the time measuring circuit be checked at least once a month and after any severe impact that the instrument may receive.

7. Test Specimens

7.1 *Preparation*—Exercise care in core drilling, handling, sawing, grinding, and lapping the test specimen to minimize the mechanical damage caused by stress and heat. It is recommended that liquids other than water be prevented from contacting the specimen, except when necessary as a coupling medium between specimen and transducer during the test. The surface area under each transducer shall be sufficiently plane that a feeler gage 0.001 in. (0.025 mm) thick will not pass under a straightedge placed on the surface. The two opposite surfaces on which the transducers will be placed shall be parallel to within 0.005 in./in. (0.1 mm/20 mm) of lateral dimension (Fig. 3). If the pulse velocity measurements are to be made along a diameter of a core, the above tolerance then refers to the parallelism of the lines of contact between the transducers and curved surface of the rock core. Moisture content of the test specimen can affect the measured pulse velocities. Pulse velocities may be determined on the velocity test specimen for rocks in the oven-dry state (0 % saturation), in a saturated condition (100 % saturation), or in any intermediate state. If the pulse velocities are to be determined with the rock in the same moisture condition as received or as exists underground, care must be exercised during the preparation procedure so that the moisture content does not change. In this case it is suggested that both the sample and test specimen be stored in moisture-proof bags or coated with wax and that dry surface-preparation procedures be employed. If results are desired for specimens in the oven-dried condition, refer to Test Method D 2216. The specimen shall remain submerged in water up to the time of testing when results are desired for the saturated state.

7.2 *Limitation on Dimensions*—It is recommended that the ratio of the pulse-travel distance to the minimum lateral dimension not exceed 5. Reliable pulse velocities may not be measurable for high values of this ratio. The travel distance of the pulse through the rock shall be at least 10 × the average grain size so that an accurate average propagation velocity may be determined. The grain size of the rock sample, the natural resonance frequency of the transducers, and the minimum lateral dimension of the specimen are interrelated factors that affect test results. The wavelength corresponding to the dominant frequency of the pulse train in the rock is approximately related to the natural resonance frequency of the transducer and the pulse-propagation velocity, (compression or shear) as follows:

$$\Lambda \approx V/f, \quad (1)$$



NOTE 1—(A) must be within 0.1 mm of (B) for each 20 mm of width (C).

FIG. 3 Specification for Parallelism

where:
Λ = dominant wavelength of pulse train, in. (or m),
V = pulse propagation velocity (compression or shear), in./s (or m/s), and
f = natural resonance frequency of transducers, Hz.

The minimum lateral dimension of the test specimen shall be at least 5 × the wavelength of the compression wave so that the true dilational wave velocity is measured (Note 5), that is,

$$D \geq 5\Lambda, \tag{2}$$

where:
D = minimum lateral dimension of test specimen, in. (or m).

The wavelength shall be at least 3 × the average grain size (See 6.3) so that

$$\Lambda \geq 3d, \tag{3}$$

where:
d = average grain size, in. (or m).

Eq 1, Eq 2, and Eq 3 can be combined to yield the relationship for compression waves as follows:

$$D \geq 5(V_p/f) \geq 15\ d, \tag{4}$$

where:
V_p = pulse propagation velocity (compression), in./s (or m/s).

Since V_p and d are inherent properties of the material, f and D shall be selected to satisfy Eq 4 (Fig. 4) for each test specimen. For any particular value of V_p/f the permissible values of specimen diameter D lie above the diagonal line in Fig. 4, while the permissible values of grain size d lie below the diagonal line. For a particular diameter, the permissible values for specimen length L lie to the left of the diagonal line.

NOTE 5—Silaeva and Shamina (**6**) found the limiting ratio of diameter to wavelength to be about 2 for metal rods. Data obtained by Cannady (**3**) on rock indicate the limiting ratio is at least 8 for a specimen length-to-diameter ratio of about 8.

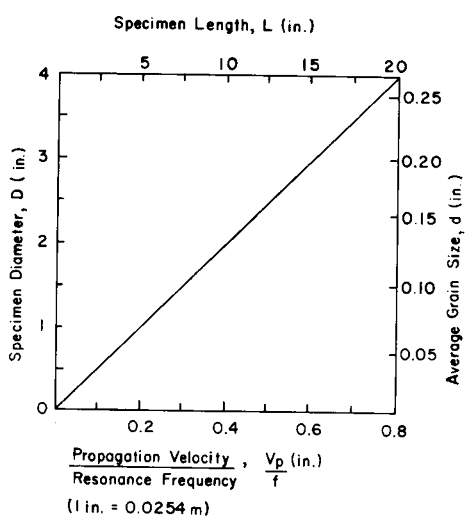


FIG. 4 Graph Showing Allowable Values of Specimen Diameter, Specimen Length and Average Grain Size Versus the Ratio of Compression Propagation Velocity to Resonance Frequency

8. Procedure

8.1 *Determination of Travel Distance and Density*—Mark off the positions of the transducers on the specimen so that the line connecting the centers of the transducer contact areas is not inclined more than 2° (approximately 0.1 in. in 3 in. (1 mm in 30 mm)) with a line perpendicular to either surface. Then measure the pulse-travel distance from center to center of the transducer contact area to within 0.1 %. The density of the test specimen is required in the calculation of the ultrasonic elastic constants (see 8.2). Determine the density of the test specimen from measurements of its mass and its volume calculated from the average external dimensions. Determine the mass and average dimensions within 0.1 %. Calculate the density as follows:

$$\rho = m/V$$

where:
ρ = density, lb sec^2/in.^{4}(or kg/m^3),
m = mass of test specimen, lb sec^2/386.4 in. (or kg), and
V = volume of test specimen, in^3(or m^3).

8.2 *Moisture Condition*—The moisture condition of the sample shall be noted and reported as explained in 10.1.3.

8.3 *Determination of Pulse-Travel Time*:

8.3.1 Increase the voltage output of the pulse generator, the gain of the amplifier, and the sensitivity of the oscilloscope and counter to an optimum level, giving a steeper pulse front to permit more accurate time measurements. The optimum level is just below that at which electromagnetic noise reaches an intolerable magnitude or triggers the counter at its lowest triggering sensitivity. The noise level shall not be greater than one tenth of the amplitude of the first peak of the signal from the receiver. Measure the travel time to within 1 part in 100 for compression waves and 1 part in 50 for shear waves by (*1*) using the delaying circuits in conjunction with the oscilloscope (see section 8.3.1.1) or (*2*) setting the counter to its highest usable precision, (see section 8.3.1.2).

8.3.1.1 The oscilloscope is used with the time-delay circuit to display both the direct pulse and the first arrival of the transmitted pulse, and to measure the travel time. Characteristically, the first arrival displayed on the oscilloscope consists of a curved transition from the horizontal zero-voltage trace followed by a steep, more or less linear, trace. Select the first break in a consistent manner for both the test measurement and the zero-time determination. Select it either at the beginning of the curved transition region or at the zero-voltage intercept of the straight line portion of the first arrival.

8.3.1.2 The counter is triggered to start by the direct pulse applied to the transmitter and is triggered to stop by the first arrival of the pulse reaching the receiver. Because a voltage change is needed to trigger the counter, it can not accurately detect the first break of a pulse. To make the most accurate time interval measurements possible, increase the counter's triggering sensitivity to an optimum without causing spurious triggering by extraneous electrical noise.

8.3.2 Determine the zero time of the circuit including both transducers and the travel-time measuring device and apply the correction to the measured travel times. This factor remains constant for a given rock and stress level if the circuit characteristics do not change. Determine the zero time accordingly to detect any changes. Determine it by (*1*) placing the transducers in direct contact with each other and measuring the delay time directly, or (*2*) measuring the apparent travel time of some uniform material (such as steel) as a function of length, and then using the zero-length intercept of the line through the data points as the correction factor.

8.3.3 Since the first transmitted arrival is that of the compression wave, its detection is relatively easy. The shear-wave arrival, however, may be obscured by vibrations due to ringing of the transducers and reflections of the compression wave. The amplitude of the shear wave relative to the compression wave may be increased and its arrival time determined more accurately by means of thickness shear-transducer elements. This type of element generates some compressional energy so that both waves may be detected. Energy transmission between the specimen and each transducer may be improved by using a thin layer of a coupling medium such as phenyl salicylate, high-vacuum grease, or resin, and by pressing the transducer against the specimen with a small seating force.

8.3.4 For specimens subjected to uniaxial stress fields, first arrivals of compression waves are usually well defined. However, the accurate determination of shear-wave first arrivals for specimens under stress is complicated by mode conversions at the interfaces on either side of the face plate and at the free boundary of the specimen **(4)**. Shear-wave arrivals are therefore difficult to determine and experience is required for accurate readings.

8.4 *Ultrasonic Elastic Constants*—The rock must be isotropic or possess only a slight degree of anisotropy if the ultrasonic elastic constants are to be calculated (Section 9). In order to estimate the degree of anisotropy of the rock, measure the compression-wave velocity in three orthogonal directions, and in a fourth direction oriented at 45° from any one of the former three directions if required as a check. Make these measurements with the same geometry, that is, all between parallel flat surfaces or all across diameters. The equations in 9.2 for an isotropic medium shall not be applied if any of the three compression-wave velocities varies by more than 2 % from their average value. The error in *E* and *G* (see 9.2) due to both anisotropy and experimental error will then normally not exceed 6 %. The maximum possible error in μ, λ, and *K* depends markedly upon the relative values of V_p and V_s as well as upon testing errors and anisotropy. In common rock types the respective percent of errors for μ, λ, and *K* may be large as or even higher than 24, 36, and 6. For greater anisotropy, the possible percent of error in the elastic constants would be still greater.

9. Calculation

9.1 Calculate the propagation velocities of the compression and shear waves, V_p and V_s respectively, as follows:

$$V_p = L_p/T_p$$

$$V_s = L_s/T_s$$

where:

V = pulse-propagation velocity, in./s (or m/s),
L = pulse-travel distance, in. (or m),
T = effective pulse-travel time (measured time minus zero time correction), s,

and subscripts $_p$ and $_s$ denote the compression wave and shear wave, respectively.

9.2 If the degree of velocity anisotropy is 2 % or less, as specified in 8.4, calculate the ultrasonic elastic constants as follows:

$$E = [\rho V_s^2(3V_p^2 - 4V_s^2)]/(V_p^2 - V_s^2)$$

where:

E = Young's modulus of elasticity, psi (or Pa), and
ρ = density, lb/in.^{3} (or kg/m^3);

$$G = \rho V_s^2$$

where:

G = modulus of rigidity or shear modulus, psi (or Pa);

$$\mu = (V_p^2 - 2V_s^2)/[2(V_p^2 - V_s^2)]$$

where:

μ = Poisson's ratio;

$$\lambda = \rho\,(V_p^2 - 2V_s^2)$$

where:

λ = Lamé's constant, psi (or Pa); and

$$K = \rho(3V_p^2 - 4V_s^2)/3$$

where:

K = bulk modulus, psi (or Pa).

9.3 All calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

10. Report

10.1 The report shall include the following:

10.1.1 Identification of the test specimen including rock type and location,

10.1.2 Density of test specimen,

10.1.3 General indication of moisture condition of sample at time of test such as as-received, saturated, laboratory air dry, or oven dry. It is recommended that the moisture condition be more precisely determined when possible and reported as either water content or degree of saturation.

10.1.4 Degree of anisotropy expressed as the maximum percent deviation of compression-pulse velocity from the average velocity determined from measurements in three directions,

10.1.5 Stress level of specimens,

10.1.6 Calculated pulse velocities for compression and shear waves with direction of measurement,

10.1.7 Calculated ultrasonic elastic constants (if desired and if degree of anisotropy is not greater than specified limit),

10.1.8 Coupling medium between transducers and specimen, and

10.1.9 Other data such as physical properties, composition, petrography, if determined.

10.2 For purposes of comparing measured or calculated values with specified limits, the measured or calculated values shall be rounded to the nearest decimal given in the specification limits in accordance with the provisions of Practice D 6026.

11. Precision and Bias

11.1 An interlaboratory study of longitudinal and transverse pulse velocity (LPV and TPV) of intact specimens of four rock types was conducted in accordance with Practice E 691 in six laboratories with five replications per rock type. The results of this study are reported in ISR Research Report No. PS D18.12-R01, 1992, and its Addendum, 1994.

11.2 The repeatability and reproducibility statistics reported in Table 1 refer to within-laboratory and between-laboratory precision, respectively. Each entry in the tables has the dimensions of km/s.

11.3 The probability is approximately 95 % that two test results obtained in the same laboratory on the same material will not differ by more than the repeatability limit *r*. Likewise, the probability is approximately 95 % that two test results obtained in different laboratories on the same material will not differ by more than the reproducibility limit *R*. The precision statistics are calculated from:

$$r = 2\sqrt{2s_r}$$

where:
s_r = the repeatability standard deviation, and

$$r = 2\sqrt{2s_R}$$

where:
s_R = the reproducibility standard deviation.

11.4 It should be noted here that the anisotropy for TPV in Barre Granite is about 5 %, depending on the orientation of the plane of polarization for shear waves. The data presented here are“ average” results.

11.5 *Bias*—There is no accepted reference value for this test method; therefore bias cannot be determined.

12. Keywords

12.1 compression testing; anisotropy; ultrasonic testing; velocity-pulse

TABLE 1 Repeatability and Reproducibility Statistics

	Barre Granite	Berea Sandstone	Salem Limestone	Tennessee Marble
		LPV, km/s		
Mean *x*	3.47	2.28	4.15	6.15
Repeatability limit *r*	0.22	0.15	0.27	0.44
Reproducibility limit *R*	0.48	0.30	0.58	0.45
		TPV, km/s		
Mean *x*	2.37	1.45	2.30	3.33
Repeatability limit *r*	0.14	0.07	0.21	0.25
Reproducibility limit *R*	0.80	0.58	0.61	0.55

REFERENCES

(**1**) Simmons, Gene, "Ultrasonics in Geology," *Proceedings, Inst. Electrical and Electronic Engineers,* Vol 53, No. 10, 1965, pp. 1337–1345.

(**2**) Whitehurst, E. A., *Evaluation of Concrete Properties from Sonic Tests,* Am. Concrete Inst., Detroit, Mich., and the Iowa State Univ. Press, Ames, Iowa, 1966, pp. 1–2.

(**3**) Cannaday, F. X., "Modulus of Elasticity of a Rock Determined by Four Different Methods," *Report of Investigations U.S. Bureau of Mines 6533,* 1964.

(**4**) Thill, R. E., McWilliams, J. R., and Bur, T. R.," An Acoustical Bench for an Ultrasonic Pulse System," *Report of Investigations U.S. Bureau of Mines 7164,* 1968.

(**5**) Gregory, A. R., "Shear Wave Velocity Measurements of Sedimentary Rock Samples under Compression," *Rock Mechanics,* Pergamon Press, New York, N.Y., 1963, pp. 439–471.

(**6**) Silaeva, O. I., and Shamina, O. G., "The Distribution of Elastic Pulses in Cylindrical Specimens," *USSR Academy of Sciences (Izvestiya), Geophysics Series,* 1958, pp. 32–43, (English ed., Vol 1, No. 1, 1958, pp. 17–24).

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (2000) that may impact the use of the standard.

(1) Changes section references in 8.3.1. In the last sentence changes section 7.1.1 to 8.3.1.1 and section 6.3.2 to 8.3.1.2
(2) Deleted Note 2 and renumbered other notes
(3) Reworded section 1.4 caveat.
(4) Inserted Practice D 6026 reference under section 2.1
(5) Corrected spelling of anisotropy in section 1.3
(6) Corrected spelling in section 8.4, first sentence.
(7) Inserted Practice D 6026 reference under section 9.2.
(8) Inserted Practice D 6026 reference under section 10.2.
(9) Corrected spelling of anisotropy in section 12
(10) Corrected rho density symbol in section 8.1.
(11) Corrected referral in 8.2.
(12) Added new section 9.3.
(13) Deleted (7.2) in 7.1.
(14) Under Equation 1 changed (Note 6) to (Note 5).

Designation: D 2216 – 05

Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass[1]

This standard is issued under the fixed designation D 2216; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 These test methods cover the laboratory determination of the water (moisture) content by mass of soil, rock, and similar materials where the reduction in mass by drying is due to loss of water except as noted in 1.4, 1.5, and 1.7. For simplicity, the word "material" shall refer to soil, rock or aggregate whichever is most applicable.

1.2 Some disciplines, such as soil science, need to determine water content on the basis of volume. Such determinations are beyond the scope of this test method.

1.3 The water content of a material is defined in 3.2.1.

1.4 The term "solid material" as used in geotechnical engineering is typically assumed to mean naturally occurring mineral particles of soil and rock that are not readily soluble in water. Therefore, the water content of materials containing extraneous matter (such as cement etc.) may require special treatment or a qualified definition of water content. In addition, some organic materials may be decomposed by oven drying at the standard drying temperature for this method (110°C). Materials containing gypsum (calcium sulfate dihydrate) or other compounds having significant amounts of hydrated water may present a special problem as this material slowly dehydrates at the standard drying temperature (110°C) and at very low relative humidity, forming a compound (such as calcium sulfate hemihydrate) that is not normally present in natural materials except in some desert soils. In order to reduce the degree of dehydration of gypsum in those materials containing gypsum or to reduce decomposition in highly/fibrous organic soils, it may be desirable to dry the materials at 60°C or in a desiccator at room temperature. Thus, when a drying temperature is used which is different from the standard drying temperature as defined by this test method, the resulting water content may be different from the standard water content determined at the standard drying temperature of 110°C.

NOTE 1—Test Method D 2974 provides an alternate procedure for determining water content of peat materials.

1.5 Materials containing water with substantial amounts of soluble solids (such as salt in the case of marine sediments) when tested by this method will give a mass of solids that includes the previously soluble dissolved solids. These materials require special treatment to remove or account for the presence of precipitated solids in the dry mass of the specimen, or a qualified definition of water content must be used. For example, see Test Method D 4542 regarding information on marine sediments.

1.6 This test standard requires several hours for proper drying of the water content specimen. Test Methods D 4643, D 4944 and D 4959 provide less time-consuming processes for determining water content. See Gilbert[2] for details on the background of Test Method D 4643.

1.7 Two test methods are provided in this standard. The methods differ in the significant digits reported and the size of the specimen (mass) required. The method to be used may be specified by the requesting authority; otherwise Method A shall be performed.

1.7.1 *Method A*—The water content by mass is recorded to the nearest 1 %. For cases of dispute, Method A is the referee method.

1.7.2 *Method B*—The water content by mass is recorded to the nearest 0.1 %.

1.8 This standard requires the drying of material in an oven. If the material being dried is contaminated with certain chemicals, health and safety hazards can exist. Therefore, this standard should not be used in determining the water content of contaminated soils unless adequate health and safety precautions are taken.

1.9 *Units*—The values stated in SI units shall be regarded as standard excluding the Alternative Sieve Sizes listed in Table 1. No other units of measurement are included in this test method.

1.10 Refer to Practice D 6026 for guidance concerning the use of significant figures that shall determine whether Method, A or B is required. This is especially important if the water content will be used to calculate other relationships such as moist mass to dry mass or vice versa, wet unit weight to dry

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

Current edition approved March 1, 2005. Published April 2005. Originally approved in 1963. Last previous edition approved in 1998 as D 2216 – 98.

[2] Gilbert, P.A., "Computer Controlled Microwave Oven System for Rapid Water Content Determination", Tech. Report GL-88–21, Department of the Army, Waterways Experiment Station, Corps of Engineers, Vicksburg, MS, November 1988.

*A Summary of Changes section appears at the end of this standard.

TABLE 1 Minimum Requirements for Mass of Test Specimen, and Balance Readability

Maximum Particle Size (100 % Passing)		Method A Water Content Recorded to ±1 %		Method B Water Content Recorded to ±0.1 %	
SI Unit Sieve Size	Alternative Sieve Size	Specimen Mass	Balance Readability (g)	Specimen Mass (g)	Balance Readability (g)
75.0 mm	3 in	5 kg	10	50 kg	10
37.5 mm	1-½ in.	1 kg	10	10 kg	10
19.0 mm	¾ in.	250 g	1	2.5 kg	1
9.5 mm	⅜ in.	50 g	0.1	500 g	0.1
4.75 mm	No. 4	20 g	0.1	100 g	0.1
2.00 mm	No. 10	20 g	0.1	20 g	0.01

unit weight or vice versa, and total density to dry density or vice versa. For example, if four significant digits are required in any of the above calculations, then the water content has to be recorded to the nearest 0.1 %. This occurs since 1 plus the water content (not in percent) will have four significant digits regardless of what the value of the water content is; that is, 1 plus 0.1/100 = 1.001, a value with four significant digits. While, if three significant digits are acceptable, then the water content can be recorded to the nearest 1 %.

1.11 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [3]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 2974 Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D 4220 Practices for Preserving and Transporting Soil Samples

D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

D 4542 Test Method for Pore-Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer

D 4643 Test Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method

D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

D 4944 Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester Method

D 4959 Test Method for Determination of Water (Moisture) Content of Soil By Direct Heating Method

D 5079 Practices for Preserving and Transporting Rock Core Samples

D 6026 Practice for Using Significant Digits in Calculating and Reporting Geotechnical Test Data

E 145 Specification for Gravity-Convection and Forced-Ventilation Ovens

3. Terminology

3.1 Refer to Terminology D 653 for standard definitions of terms.

3.2 *Definitions:*

3.2.1 *water content by mass (of a material)*—the ratio of the mass of water contained in the pore spaces of soil or rock material, to the solid mass of particles in that material, expressed as a percentage. A standard temperature of 110 ± 5°C is used to determine these masses.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *constant dry mass (of a material)*—the state that a water content specimen has attained when further heating causes, or would cause, less than 1 % or 0.1 % additional loss in mass for Method A or B respectively. The time required to obtain constant dry mass will vary depending on numerous factors. The influence of these factors generally can be established by good judgement, and experience with the materials being tested and the apparatus being used.

4. Summary of Test Method

4.1 A test specimen is dried in an oven at a temperature of 110 ± 5°C to a constant mass. The loss of mass due to drying is considered to be water. The water content is calculated using the mass of water and the mass of the dry specimen.

5. Significance and Use

5.1 For many materials, the water content is one of the most significant index properties used in establishing a correlation between soil behavior and its index properties.

5.2 The water content of a material is used in expressing the phase relationships of air, water, and solids in a given volume of material.

5.3 In fine-grained (cohesive) soils, the consistency of a given soil type depends on its water content. The water content of a soil, along with its liquid and plastic limits as determined by Test Method D 4318, is used to express its relative consistency or liquidity index.

NOTE 2—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself ensure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Drying Oven*—Vented, thermostatically-controlled, preferably of the forced-draft type, meeting the requirements of Specification E 145 and capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber.

6.2 *Balances*—All balances must meet the requirements of Specification D 4753 and this section. A Class GP1 balance of 0.01 g readability is required for specimens having a mass of up to 200 g (excluding mass of specimen container) and a Class GP2 balance of 0.1 g readability is required for specimens having a mass over 200 g. However, the balance used may be controlled by the number of significant digits needed (see 1.10).

6.3 *Specimen Containers*—Suitable containers made of material resistant to corrosion and change in mass upon repeated heating, cooling, exposure to materials of varying pH, and cleaning. Unless a dessicator is used, containers with close-fitting lids shall be used for testing specimens having a mass of less than about 200 g; while for specimens having a mass greater than about 200 g, containers without lids may be used (see Note 3). One uniquely numbered (identified) container or number-matched container and lid combination as required is needed for each water content determination.

NOTE 3—The purpose of close-fitting lids is to prevent loss of moisture from specimens before initial mass determination, and to prevent absorption of moisture from the atmosphere following drying and before final mass determination.

6.4 *Desiccator (Optional)*—A desiccator cabinet or large desiccator jar of suitable size containing silica gel or anhydrous calcium sulfate. It is preferable to use a desiccant that changes color twhen it needs to be reconstituted.

NOTE 4—Anhydrous calcium sulfate is sold under the trade name Drierite.

6.5 *Container Handling Apparatus*, gloves, tongs, or suitable holder for moving and handling hot containers after drying.

6.6 *Miscellaneous*, knives, spatulas, scoops, quartering cloth, wire saws, etc., as required.

7. Samples

7.1 Soil samples shall be preserved and transported in accordance with Practice D 4220 Section 8 Groups B, C, or D soils. Rock samples shall be preserved and transported in accordance with Practice D 5079 section 7.5.2, Special Care Rock. Keep the samples that are stored prior to testing in non-corrodible airtight containers at a temperature between approximately 3 and 30°C and in an area that prevents direct contact with sunlight. Disturbed samples in jars or other containers shall be stored in such a way as to reduce moisture condensation on the insides of the containers.

7.2 The water content determination should be done as soon as practicable after sampling, especially if potentially corrodible containers (such as thin-walled steel tubes, paint cans, etc.) or plastic sample bags are used.

8. Test Specimen

8.1 For water contents being determined in conjunction with another ASTM method, the specimen mass requirement stated in that method shall be used if one is provided. If no minimum specimen mass is provided in that method then the values given below shall apply. See Howard[4] for background data for the values listed.

8.2 The minimum specimen mass of moist material selected to be representative of the total sample is based on visual maximum particle size in the sample and the Method (Method A or B) used to record the data. Minimum specimen mass and balance readability shall be in accordance with Table 1.

8.3 Using a test specimen smaller than the minimum indicated in 8.2 requires discretion, though it may be adequate for the purposes of the test. Any specimen used not meeting these requirements shall be noted on the test data forms or test data sheets.

8.4 When working with a small (less than 200 g) specimen containing a relatively large gravel particle, it is appropriate not to include this particle in the test specimen. However, any discarded material shall be described and noted on the test data form/sheet.

8.5 For those samples consisting entirely of intact rock or gravel-size aggregate, the minimum specimen mass shall be 500 g. Representative portions of the sample may be broken into smaller particles. The particle size is dictated by the specimen mass, the container volume and the balance being used to determine constant mass, see 10.4. Specimen masses as small as 200 g may be tested if water contents of only two significant digits are acceptable.

9. Test Specimen Selection

9.1 When the test specimen is a portion of a larger amount of material, the specimen must be selected to be representative of the water condition of the entire amount of material. The manner in which the test specimen is selected depends on the purpose and application of the test, type of material being tested, the water condition, and the type of sample (from another test, bag, block, etc.).

9.2 For disturbed samples such as trimmings, bag samples, etc; obtain the test specimen by one of the following methods (listed in order of preference):

9.2.1 If the material is such that it can be manipulated and handled without significant moisture loss and segregation, the material should be mixed thoroughly. Select a representative portion using a scoop of a size that no more than a few scoopfuls are required to obtain the proper size of specimen defined in 8.2. Combine all the portions for the test specimen.

9.2.2 If the material is such that it cannot be thoroughly mixed or mixed and sampled by a scoop, form a stockpile of the material, mixing as much as possible. Take at least five

[4] Howard, A. K., "Minimum Test Specimen Mass for Moisture Content Determination", *Geotechnical Testing Journal,* ASTM., Vol. 12, No. 1, March 1989, pp. 39-44.

portions of material at random locations using a sampling tube, shovel, scoop, trowel, or similar device appropriate to the maximum particle size present in the material. Combine all the portions for the test specimen.

9.2.3 If the material or conditions are such that a stockpile cannot be formed, take as many portions of the material as practical, using random locations that will best represent the moisture condition. Combine all the portions for the test specimen.

9.3 Intact samples such as block, tube, split barrel, etc, obtain the test specimen by one of the following methods depending on the purpose and potential use of the sample:

9.3.1 Using a knife, wire saw, or other sharp cutting device, trim the outside portion of the sample a sufficient distance to see if the material is layered, and to remove material that appears more dry or more wet than the main portion of the sample. If the existence of layering is questionable, slice the sample in half. If the material is layered, see 9.3.3.

9.3.2 If the material is not layered, obtain the specimen meeting the mass requirements in 8.2 by: *(1)* taking all or one-half of the interval being tested; *(2)* trimming a representative slice from the interval being tested; or *(3)* trimming the exposed surface of one-half or from the interval being tested.

NOTE 5—Migration of moisture in some cohesionless soils may require that the entire sample be tested.

9.3.3 If a layered material (or more than one material type is encountered), select an average specimen, or individual specimens, or both. Specimens must be properly identified as to location, or what they represent, and appropriate remarks entered on the test data forms or test data sheets.

10. Procedure

10.1 Determine and record the mass of the clean and dry specimen container and its lid, if used along with its identification number.

10.2 Select representative test specimens in accordance with Section 9.

10.3 Place the moist test specimen in the container and, if used, set the lid securely in position. Determine the mass of the container and moist specimen using a balance (see 8.2 and Table 1) selected on the basis of the specimen mass. Record this value.

NOTE 6—To assist in the oven drying of large test specimens, they should be placed in containers having a large surface area (such as pans) and the material broken up into smaller aggregations.

10.4 Remove the lid (if used) and place the container with the moist specimen in the drying oven. Dry the specimen to a constant mass. Maintain the drying oven at 110 ± 5°C unless otherwise specified (see 1.4). The time required to obtain constant mass will vary depending on the type of material, size of specimen, oven type and capacity, and other factors. The influence of these factors generally can be established by good judgment and experience with the materials being tested and the apparatus being used.

10.4.1 In most cases, drying a test specimen overnight (about 12 to 16 h) are sufficient, especially for forced draft ovens. In cases where there is doubt concerning the adequacy of drying to a constant dry mass, see 3.3.1 and check for additional loss in mass with additional oven drying over an adequate time period, for a minimum time period of two hours, however, increasing drying time with increasing specimen mass. A rapid check to see if a relatively large specimen (> than about 100 g of material) is dry; place a small strip of torn paper on top of the material while it is in the oven or just upon removal from the oven, if the paper strip curls the material is **not** dry. Specimens of sand may often be dried to constant mass in a period of about 4 h, when a forced-draft oven is used.

10.4.2 Since some dry materials may absorb moisture from drying specimens, dried specimens shall be removed before placing moist specimens in the same oven; unless they are being dried overnight.

10.5 After the specimen has dried to constant mass, remove the container from the oven (and replace the lid if used). Allow the specimen and container to cool to room temperature or until the container can be handled comfortably with bare hands and the operation of the balance will not be affected by convection currents and/or its being heated. Determine the mass of the container and oven-dried specimen using the same type/capacity balance used in 10.3. Record this value. Tight fitting lids shall be used if it appears that the specimen is absorbing moisture from the air prior to determination of its dry mass.

10.5.1 Cooling in a desiccator is acceptable in place of tight fitting lids since it greatly reduces absorption of moisture from the atmosphere during cooling.

10.6 A copy of a sample data sheet is shown in Appendix X1. Any data sheet can be used, provided the form contains all the required data.

11. Calculation

11.1 Calculate the water content of the material as follows:

$$w = [(M_{cms} - M_{cds})/(M_{cds} - M_c)] \times 100 = (M_w/M_s) \times 100 \quad (1)$$

where:

w = water content, %,
M_{cms} = mass of container and moist specimen, g,
M_{cds} = mass of container and oven dry specimen, g,
M_c = mass of container, g,
M_w = mass of water ($M_w = M_{cms} - M_{cds}$), g, and
M_s = mass of oven dry specimen ($M_s = M_{cds} - M_c$), g.

12. Report: Test Data Form/Sheet

12.1 The method used to specify how data are recorded on the test data sheets or forms, as given below, is the industry standard, and are representative of the significant digits that should be retained. These requirements do not consider in situ material variation, use of the data, special purpose studies, or any considerations for the user's objectives. It is common practice to increase or reduce significant digits of reported data commensurate with these considerations. It is beyond the scope of the standard to consider significant digits used in analysis method for engineering design.

12.1.1 Test data forms or test data sheets shall include the following:

12.1.2 Identification of the sample (material) being tested, such as boring number, sample number, test number, container number etc.

12.1.3 Water content of the specimen to the nearest 1 % for Method A or 0.1 % for Method B, as appropriate based on the minimum mass of the specimen. If this method is used in concert with another method, the water content of the specimen should be reported to the value required by the test method for which the water content is being determined. Refer to Practice D 6026 for guidance concerning significant digits, especially if the value obtained from this test method is to be used to calculate other relationships such as unit weight or density. For instance, if it is desired to express dry unit weight to the nearest 0.1 lbf/f^3 (0.02 kN/m^3), it may be necessary to use a balance with a greater readability or use a larger specimen mass to obtain the required significant digits the mass of water so that the water content can be determined to the required significant digits. Also, the significant digits in Practice D 6026 may need to be increased when calculating phase relationships requiring four significant digits.

12.1.4 Indicate if test specimen had a mass less than the minimum indicated in 8.2.

12.1.5 Indicate if test specimen contained more than one material type (layered, etc.).

12.1.6 Indicate the drying temperature if different from 110 ± 5°C.

12.1.7 Indicate if any material (size and amount) was excluded from the test specimen.

12.2 When reporting water content in tables, figures, etc., any data not meeting the requirements of this test method shall be noted, such as not meeting the mass, balance, or temperature requirements or a portion of the material is excluded from the test specimen.

13. Precision and Bias

13.1 *Statements on Precision*:

13.1.1 *Precision*—Test data on precision is not presented due to the nature of the soil or rock materials tested by this test method. It is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation.

13.1.2 Subcommittee D18 is seeking any data from the users of this test method that might be used to make a limited statement on precision.

13.1.3 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

14. Keywords

14.1 aggregate; consistency; index property; laboratory; moisture analysis; moisture content; soil; water content

APPENDIX

(Nonmandatory Information)

X1. WATER CONTENT OF SOIL AND ROCK SAMPLE DATA SHEET

Project Name: ___________________ Project Number: ___________________

Test Method: __X__ Method A
_____ Method B

Laboratory Number	04-725-S	04-726-S	04-727-S		
Boring Number	B-1	B-2	B-2		
Field Number	SPT-1	SPT-2	SPT-2a		
Container / Lid Number	725	726	727		
Container Mass, g M_c	770.1	731.7	770.6		
Container+Moist Specimen Mass, g M_{cms}	1895.3	2008.4	1827.9		
Date / Time In Oven	8/20/2004 0700	8/20/2004 0700	8/20/2004 0700		
Initial Container+Oven Dry Specimen Mass, g	1721.4	1872.1	1707.6		
Date / Time Out of Oven	8/20/2004 1200	8/20/2004 1200	8/20/2004 1200		
Secondary Container+Oven Dry Specimen Mass, g	1721.4	1801.2	1660.8		
Date / Time Out of Oven	--	8/20/2004 1600	8/20/2004 1600		
Final Container+Oven Dry Specimen Mass, g, M_{cds}	1721.4	1801.2	1660.8		
Date / Time Out of Oven	--	8/21/2004 0700	8/21/2004 0700		
Mass of Water, g, $M_w = M_{cms} - M_{cds}$	173.9	207.2	167.1		
Mass of Solids, g, $M_s = M_{cds} - M_c$	951.3	1069.5	890.2		
Water Content, %, $w = (M_w/M_s) \times 100$	18	19	19		
Unified Soil Classification Group Symbol (Visual)	GC	GC	GC		
Bold Approximate Maximimum Grain Size (Visual)	3 in., 1½ in., **¾ in.**, ⅜ in., #4, #10, < #10	3 in., 1½ in., **¾ in.**, ⅜ in., #4, #10, < #10	3 in., 1½ in., **¾ in.**, ⅜ in., #4, #10, < #10	3 in., 1½ in., ¾ in., ⅜ in., #4, #10, < #10	3 in., 1½ in., ¾ in., ⅜ in., #4, #10, < #10
Oven Temperature if Other Than 110°C	—	—	—		

Remarks: ____

____

Tested By: ____________________ Date: ______________ Checked By: ____________________

Dry Mass By: __________________ Date: ______________ Spot Checked: __________________

Calculated By: _________________ Date: ______________ Reviewed By: ___________________

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (D 2216 – 98) that may impact the use of this standard.

(*1*) Footnote 2 was replaced with reference to Test Method D 4542. Subsequent footnotes were renumbered where necessary for sequential identification.
(*2*) Two new ASTM referenced documents were included in 1.6 to inform the user that less time-consuming processes are available.
(*3*) A new 1.7 was added to establish that two test methods (Method A and Method B) are provided in this standard. Subsequent Sections were renumbered where necessary for sequential identification.
(*4*) A new 1.9 was added to clarify the use of SI units as standard, and to conform to D18 Standards Preparation Manual Section 4.3.3. Subsequent Sections were renumbered where necessary for sequential identification.
(*5*) A new 1.10 was added as an information reference to Practice D 6026, and to conform to D18 Standards Preparation Manual Section 4.3.6. Subsequent Sections were renumbered where necessary for sequential identification.
(*6*) Five new ASTM referenced documents were added to, and one existing ASTM referenced document was deleted from section 2.1.
(*7*) Section 3.2 was renamed "Definitions of Terms."
(*8*) In section 3.2.1 the term "water content by mass" was redefined to correspond with its current definition in Terminology D 653.
(*9*) Section 3.3 "Definitions of Terms Specific to This Standard" was added.
(*10*) Section 3.3.1 was added, the term "constant dry mass" was defined to correspond with C 566, section 7.4.
(*11*) A new Note 2, referencing Practice D 3740, was added to Section 5 to conform to D18 Standards Preparation Manual section 4.3.5. Subsequent Notes were renumbered where necessary for sequential identification.
(*12*) Section 7.1 was revised to clarify the differences between the preservation and transportation of soil and rock samples.
(*13*) An information reference to Practice D 5079 was included in 7.1.
(*14*) Section 8.2 was revised, and Table 1 added to clarify specimen mass and balance readability requirements for Method A and Method B.
(*15*) Section 9.2.1 was revised to improve clarity.
(*16*) Section 10.4.1 was added incorporating former Note 7 as required text. This was revised to provide the user with guidelines for rapidly determining possible specimen dryness.
(*17*) Section 10.4.2 was added incorporating former Note 8 as required text.
(*18*) Section 10.5.1 was added incorporating former Note 9 as required text. It was edited to improve clarity, and to conform to section 10.5.
(*19*) Section 10.6 was added to indicate the addition of Appendix X1.
(*20*) The radical M_{cs} in Eq 1, and in the Eq 1 nomenclature legend was revised to M_{cds} to be consistent with the nomenclature used in the equations for calculating the values M_w and M_s.
(*21*) Section 12.1 was revised to follow the style and approach of ASTM D 854.
(*22*) Sections 13.1.1, 13.1.2 and 13.1.3 were revised to conform to D18 Standards Preparation Manual Table 3, Section 11.
(*23*) Appendix X1 (Water Content of Soil and Rock Sample Data Sheet) was added to conform to D18 Standards Preparation Manual 4.3.9.
(*24*) The Summary of Changes statement was updated to conform to D18 Standards Preparation Manual 9.9.1.