A Field Classification for Uniaxial Strength of Diamond Drill Core Using Simple Field Index Tests

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1. A number of classifications of core uniaxial strength have been published since 1964. In recent years, three groups (CANMET, ISRM, Geol. Soc.) have summarized the classifications developed and to provide simple field index tests from which the uniaxial strength of core can be broadly assessed. However, experience by the authors in using the systems has indicated that, despite some commonality in the field indices or descriptions, the assigned strengths are widely variable between the different classifications. Furthermore, for medium to strong rocks typical of underground metalliferous mine environments, the classifications rely heavily on the number of hammer blows required to break a core specimen. This test has been found to give widely varying results due to specimen geometry and the influence of different operators.

On the basis of this experience, a small programme of field index tests and uniaxial compression tests was undertaken. This test programme aimed to clearly define each index test procedure and to determine the strength range for which each index test shows widely variable results. A system for classifying core strength is proposed using these index tests. This classification sets the limits between strength descriptions based on the field index tests and not on arbitrary limits.

2. PUBLISHED CLASSIFICATIONS

The classifications published by the International Society for Rock Mechanics (Ref. 1), Canada Centre for Mineral and Energy Technology (Ref. 2) and the Geological Society Engineering Group Working Party (Ref. 3) use only two or three index tests to determine a specimen's compressive strength. These index test procedures are:

(i) the number of blows to fracture the specimen,

(ii) the effect of hitting the sample with he sharp end of a geological pick, and

(iii) scraping the specimen with fingernail and penknife.

The classifications are summarized in Table 1.

The uniaxial compressive strength limits associated with the classifications are summarized in Table 2. Also included in this table is a classification published by Attewell & Farmer (Ref. 4) which summarizes all the classifications published prior to 1968.

Both tables indicate that whilst there is a reasonable degree of uniformity in most test descriptions, the index test involving the number of hammer blows can give a wide variation in strength class. For example, a single blow can yield a classification of medium strong (Ref. 1 and 2) or strong rock (Ref. 2). Table 2 shows that the classifications cover a wide range in strengths, even for the same index test descriptions. For example a single fracturing blow can estimate strengths between 25-50 MPa (Ref. 1), 10-25 MPs (Ref. 2) and 50-100 MPa (Ref. 3).

3. TEST PROGRAMME

A set of 60 core lengths representing a range in rock type from soft sedimentary materials to metamorphosed granites. For each specimen the uniaxial compressive strength was determined using standard techniques as recommended by the ISRM (Ref. 5) along with the density and dynamic modulus. Core diameters varied from 38 mm to 60 mm.

3.1 Proposed Index Tests

Based on the authors' experience and the classifications published previously, six index tests were chosen and each was undertaken on the trimmed off end pieces of the 60 compression test specimens. A set of procedures, set out in Table 3, was then prepared for each index test. The published classifications do not propose any standard procedures other than a recommendation to use a hand size specimen. This may, in part, explain some of the differences in strength classification obtained by different personnel logging core.

3.2 Results for Index Tests

The previously published classifications rely heavily on the number of hammer blows to fracture a specimen. For rocks above medium strength, this test forms the only index used for classification. The results for this index test for the 60 specimens in Fig. 1 and indicate a wide scatter. This variation is particularly noticeable where 2 or 3 blows are required to fracture a specimen. This correlates with strength estimates, in excess of 50 MPa (Ref. 1); 80 MPa (Ref. 2); and 100 MPa (Ref. 3) from the published classifications. For these tests over 70% of the specimens which required 2 or 3 blows had compressive strengths of less than 50 MPa.

TABLE 1

FIELD CLASSIFICATION OR ROCK STRENGTH -
COMPARISON OF PUBLISHED CLASSIFICATIONS

ISRM (Ref. 1)	CANMET (Ref. 2)	GEOL. SOC. (Ref. 3)
Extremely weak: Indented by thumbnail		Very weak: Broken by hand with difficulty.
Very weak: Crumbles under firm blows with point of geological hammer; can be peeled by a pocket knife.	R1: Crumbles under firm blows with point of geological hammer; can be peeled by a pocket knife.	Weak: Material crumbles under blows with the sharp end of a geol-ogical pick.
Weak: Can be peeled by a pocket knife with difficulty; shallow indentations made by firm blow with point of geological hammer.	R2: Can be peeled by a pocket knife with difficulty; shallow indentations made by firm blow with point of geological hammer.	Moderately Weak: Too hard to cut by hand into a triaxial specimen.
Medium Strong: Cannot be scraped or peeled with a pocket knife; specimen can be fractured with a single firm blow of a geological hammer.	R3: Cannot be scraped or peeled with a pocket knife; specimen can be fractured with a single firm blow of hammer or end of geological pick.	Moderately Strong: 5mm indentations with sharp end of pick.
Strong: Specimen requires more than one blow of geological hammer to fracture.	R4: Specimen requires more than one blow of geological pick to fracture.	Strong: Hand held specimen can be broken with single blow of geological hammer.
Very Strong: Specimen requires many blows of geological hammer to fracture it.	R5: Specimen requires many blows of hammer end of geological pick to fracture it.	Very Strong: More than one blow of geological hammer required to break specimen.
Extremely Strong: Specimen can only be chipped with geological hammer.		

Reliance on this index alone to assess the strength would obviously lead to large errors.

In summary, the results for the six index tests are presented below:

Index 1 - Thumbnail scratch test

The cores could be scratched easily with a fingernail where the strength was below 3 MPa, and with difficulty for strength up to 30 MPa. Beyond this value the test fails. This index is very useful in the classification of weak rock and is not included in any of the publications classifications.

Index 2 - Crumble test

The core specimens could be crumbled where the strength was less than 3 MPa although some bedded material of up to 8 MPa could be crumbled with difficulty. This is in general agreement with the limits set by the ISRM & CANMET.

Index 3 - Peel test

The core edges may be peeled only where strengths are below 5 MPa. Beyond this limit the cores may crack or no impression will be made by the knife blade other than a scratch. This result differs with the ISRM & CANMET index test where strengths to 25 MPa can be classified by this test.

TABLE 2

UNIAXIAL COMPRESSIVE STRENGTH
COMPARISON OF PUBLISHED CLASSIFICATIONS

UNCONFINED COMPRESSIVE STRENGTH (MPa)

3 10 30 100 300 1000

Classification						
INTERN SOC FOR ROCK MECHANICS (Ref. 1)	R1: VERY WEAK	R2: WEAK	R3: MEDIUM STRONG	R4: STRONG	R5: VERY STRONG	R6: EXTREMELY STRONG
CANMET (Ref. 2)	R1	R2	R3	R4	R5	
GEOL. SOC. ENG. GRP WORKING PARTY (Ref. 3)	WEAK	MODERATELY WEAK	MODERATELY STRONG	STRONG	VERY STRONG	EXTREMELY STRONG
ATTEWELL & FARMER (Ref. 4)	VERY WEAK	WEAK	MEDIUM	STRONG	VERY STRONG	

Index 4 - Penknife scratch test

The cores can be scratched easily to a strength limit of 8 MPa and moderately to a strength limit of 50 MPa. Beyond this limit it is hard to scratch the surface. Both ISRM & CANMET classifications state only that after 25 MPa the core cannot be scraped. This may be different to scratching. This test is useful in classifying weak rock from strong rock.

Index 5 - Point indentation test

The diameter (and appearance) of the indentation produced by the point of a geological hammer is very sensitive to rock strength. Below 5 MPa strength, a large full diameter indentation is made. Beyond this strength the indentation diameter reduces progressively to 2mm at 30 MPa and 1mm above 40 MPa. This test, if repeated at varying locations on the core surface, can identify strength variations. If these variations occur the largest indentation, representative of the weakest material, should be recorded.

4. The test series outlined above has highlighted many inconsistencies in the previously published classifications. While the proposed test series is not exhaustive, it does indicate that, by combining two or more of the index tests used in this series, a better classification of the uniaxial compressive strength of rock cores can be made. Details of proposed classification system are summarized in Table 4.

The accuracy of the proposed classification is indicated in Table 5 which summarizes the actual and predicted strengths by class for the sixty cores tested. Overall, 67% of the predicted strength classes were accurate, with much higher accuracies for the very strong and very weak rock classes. By way of comparison, using the classification in Ref. 2, only 40% of the predictions were accurate.

5. CONCLUSIONS

Experiences with the previously published field index tests for the assignment of the uniaxial strength of rock cores, coupled with a controlled series of tests reported here, indicate that the published classifications can yield large errors in the strength estimates of moderate to strong rocks and do not entirely agree on the strength limits of many of the strength classes they propose. A new classification is proposed which extends the simple field tests used by the published classifications in the following ways:

(i) test results are recorded in a more quantitative manner, and

(ii) index tests are combined to define each classification category.

The classification concentrates on the resolution of the classification of weak to strong rock (i.e. to 100 MPa). Beyond this strength value it is felt that more direct tests of strength (for example the point load test) are more relevant.

TABLE 3

PROCEDURE FOR PROPOSED FIELD INDEX TESTS OF ROCK CORE STRENGTH

INDEX TESTS	PROCEDURE
1. Thumbnail Scratch	Using moderate pressure attempt to scratch side of core - record as: easy - a deep indentation difficult - surface damage only fail - no mark made on core
2. Crumble	Using a hand size specimen attempt to crush the core in one hand - record as: easy - specimen breaks into small chips difficult - requires two hands fail - cannot be broken by hand
3. Penknife Peel	Using a penknife with a hardened blade attempt to peel off a corner of the core at its end - record as: pass: a deep incision made fail: cannot be cut or core chips break off
4. Penknife Scratch	Using the hardened point of a penknife blade cut into the sides of core - record as: easy - a deep (1 mm) incision is made usually with little rock dust and ridging either side of the cut mod - a shallow but sharp-sided incision usually with rock dust hard - only just scratches surface creating lots of rock dust
5. Point of Geol-ogical Pick (approx. 5mm diameter point)	Holding a specimen in one hand let the point of a geological pick fall freely onto the flat edge of the specimen from a height of approximately 100mm (4 inches) record from five repeat tests; record approiximate average diameter of indentation: 5mm: full diameter indentation usually 2-3mm deep and with ridges at rim of indentation 2mm: shallow half-diameter indentation, may be associated with surface cracking of specimen 1mm: well defined indentation 0mm no effect
6. Hammer Blow	Holding a specimen, with length equal to twice the core diameter, in one hand strike across a diameter of the core aiming for a central section of core, i.e. away from core ends. Hardest hit should not sting the hand. Record number of blows to crack the sample across the diameter.

TABLE 4

PROPOSED FIELD INDEX TEST CLASSIFICATION
OF CORE UNIAXIAL STRENGTH

CLASSIFICATION	INDEX TEST	APPROX. UNIAXIAL STRENGTH (MPa)
Very weak rock	Can be scratched by fingernail and penknife and crumbled by hand. The point of a geological pick makes a 5mm diameter indentation. The core can be browkn by a single blow of a geological hammer.	0-3
Weak rock	Cannot be crumbled but is scratched with difficulty by a fingernail. Cannot be peeled but is scratched easily by penknife. Hammer point makes 3-4mm diameter indentation. One or two blows are required to break the core.	3-10
Medium strong rock	Can be scratched by thumbnail only with difficulty but moderately easily by penknife. A hammer point makes a small (2-3mm) diameter indentation. Multiple hammer blows may be required to break the core.	10-30
Strong rock	Can be scratched with moderate difficulty by penknife. Hammer point makes 1-2mm diameter indentation. Multiple hammer blows may be required to break the core.	30-50
Very strong rock	Can be scratched with difficulty by a penknife. Hammer point causes only superficial surface damage. Multiple hammer blows are required to break the core.	50

TABLE 5

CORRELATION OF ACTUAL & PREDICTED STRENGTHS BY CLASS

ACTUAL STRENGTH		PREDICTION		
CLASS	No.	CLASS	No.	accuracy of assessment
0-3 MPa	6	0-3 MPA >3 MPa	5 1	83%
3-10 MPa	15	<3 MPa 3-10 MPa >10 MPa	2 10 3	67%
10-30 MPa	9	<10 MPa 10-30 MPa >30 MPa	2 6 1	67%
30-50 MPa	12	<30 MPa 30-50 MPa >50 MPa	2 7 3	58%
>50 MPa	18	<50 MPa >50 MPa	4 14	77%

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7. REFERENCES

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