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TESTS FOR ASSESSING THE DRILLABILITY, CUTTABILITY AND RIPPABILITY OF ROCKS ARE BEING INTERNATIONALLY STANDARDISED

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INTRODUCTION

Reducing geotechnical uncertainty is a major aim of workers in the field of geotechnical engineering and engineering geology. Exploration and investigation techniques can never completely remove uncertainty, except at an economically prohibitive cost. The well-known "S" curve of the economists usually applies, whereby doubling expenditure on investigation may result in halving the risks of encountering unexpected faults, or dykes, or ground water inflows, or too strong or too weak rock. A ten-fold increase in expenditure may still leave appreciable risks.

Improvements in techniques of core drilling, geophysical exploration, and interpretation of photographic imagery, obtained from aircraft or satellites are consistently reducing the risks that a competently planned and carried-out exploration program will not discover latent conditions which may be adverse to machine excavation. Such conditions may be structural geological, or lithological, or hydrological.

There still remains the need for further improvements in techniques of assessing the ability of a particular machine to economically cut rip or dig a particular rock, and to assist in estimating the actual cost of excavation. This will be a function of the rate of consumption or wearing out of the teeth picks or cutters, the rate of penetration or production of the machine, and the proportion of the total working time that the machine is actually cutting or digging.

It would seem to be desirable for there to be one or several internationally-standardized tests or suites of tests, which any machine manufacturer or potential machine-user could use to characterize a rock mass, and assess the feasibility of machine excavation (in terms of the likely production rates and costs).

This desirable state of affairs does not yet exist.

CONTRACTORS' ASSESSMENT AND EXTRAPOLATION OF FULL SIZE PROTOTYPES.

The excavation contractor may tend to have a very complete knowledge of how one or a few machines have performed on one or a few projects. His assessments may be more pessimistic than those of the manufacturers - his memories of the few hours or days when mechanical or geotechnical problems have impeded production will be far more vivid than his memories of the hundreds of hours when the machines worked steadily and monotonously and successfully. In attempting to assess the feasibility of a new excavation project he may, at worst, tend to use his "gut feelings", based on the heft, feel, and scratch hardness of a few lumps of rock from the site or from drill cores, compared with his vague memories of the feel of a few lumps of rock lifted from the ground or from the hoppers or off the conveyor belts on the machines used in his past experience. At best, he may tend to use practices similar to those described in the next two sections.

MACHINE MANUFACTURERS' ASSESSMENT AND EXTRAPOLATION OF PROTOTYPES.

The machine manufacturer will tend to have a more sanguine view of the performance of his machines than will the user of his machines. From seeing his machines take shape in the factory or workshop he knows the amount and quality of workmanship which go into them (whereas the excavation contractor may be darkly suspicious that they are hastily and sloppily assembled, and prove to be fragile and unreliable in use). The few hours during his visits to excavation sites in which he sees the machines working successfully are more vivid in his memory than the even fewer hours in which he hears that the machines were not working.

His assessments of the feasibility of machine excavation on a new project may, like the tunnelling contractors', be based upon his memories of the "feel" of lump samples. However he will have visited many more projects, so his extrapolations based upon past experience will probably be more valid in this respect than those of the contractor.

LABORATORY INDEX TESTS, PERFORMED BY MACHINE MANUFACTURERS.

Some of the major manufacturers of excavation machinery have developed a few of their own special, non-standard tests, to make empirical correlations between the past performances of their machines and the index properties of representative rock samples taken from the sites. The same index tests can be used to make predictions, given representative rock samples from prospective job sites.

Tests used by the different manufacturers include:

(i) subjective hardness and strength estimates, such as Mohs (scratch) hardness, and ease of shattering under the blows of a geological hammer;

(ii) standard strength tests, such as unconfined compressive strength, "Brazilian" tensile strength, or point-load strength index;

(iii) other non-standard tests of rock durability or abrasiveness.

In many cases the test values, and the procedure whereby the manufacturer derives performance predictions from the test results, are confidential, or machine-dependent, or both. A substantial judgement factor is usually involved. Empirical correlations between rock index test values and the performance of particular machines will have to be modified if they are to be extrapolated - used to predict the performance of other machines with different power and different configurations.

LABORATORY INDEX TESTS, PERFORMED BY ACADEMIC RESEARCHERS OR CONSULTANTS.

The academic rock mechanics researcher often starts from a different view-point than the machine manufacturer. Rather than trying to find a special secret or proprietary test which can be used to provide a "magic number" for insertion into his prediction equation, he is interested in studying and quantifying all the relevant properties of a rock. He will, in a spirit of intellectual curiosity, perform a lot of tests at a level of detail which both the contractor and the machine manufacturer may regard as redundant. His justification is simply that he is approaching the problem of predicting rock drillability with an open mind and an enquiring spirit, and sees no particular merit in arbitrarily restricting his knowledge of rock parameters to those which another individual thought adequate in another place at an earlier time.

So he will prefer to measure all the mechanical properties of a rock. In performing drillability and cuttability tests he will use the geological concept of the "method of multiple working hypotheses". While recognizing the desirability of breaking a rock in the laboratory in exactly the same way that it will be broken in the field, he realizes that the field breakage mechanisms are imperfectly understood, and therefore 2 or 3 imperfect tests are better than 1 imperfect test.

While the applied researcher is hopeful that his work will be of practical use to the industry which supports him through their taxes or by more direct grants, he is still more hopeful that his research work will gratify his intellectual curiosity and earn the respect of his peers. The test results coming from such laboratories should be regarded as objective characterizations of the rock properties, and of the empirical correlations with the performance of particular machines.

It should be up to the machine manufacturers to provide the data on machine performance, and to use the empirical correlations for commercial predictive purposes.

GEOTECHNICAL TESTING FOR INVESTIGATION OF EXCAVATION PROJECTS

Geotechnical tests which are performed during the investigation phase of an excavation project may be described under 3 classes:

(i) non-destructive tests, to measure physical properties (e.g. hardness, elastic modulus);

(ii) destructive tests, to measure mechanical properties (e.g. tensile strength, angle of shearing resistance ϕ);

(iii) drillability tests, which are small-scale simulations, performed on small specimens, of the cutting or breaking mechanism of full-size drills or excavating machines.

A further sub-division may be made, into:

(a) tests performed in a laboratory, upon diamond drill cores from exploratory bore holes, or upon lumps or blocks of rock;

(b) tests performed in the field, upon rock outcrops or on the rock in or exposed on the walls of exploratory trenches shafts or adits.

Geotechnical tests which may be performed during the construction phase will include most of those in (i) to (iii) and (a) and (b) above.

Correlation of machine performance parameters with the mechanical properties or drillability indices of the rock can lead to valuable understanding of the mechanisms of rock breakage and penetration, as well as to procedures for refining predictions of machine performance on future projects.

NON-DESTRUCTIVE, PHYSICAL PROPERTY TESTS

While international standards have not yet been formulated to cover these tests, the established practices in most competently-run rock testing laboratories are similar.

The American Society for Testing and Materials (A.S.T.M.) has published several "Standard Methods" (for example, in Part 19 of its 1974 Annual Book of Standards). The International Society for Rock Mechanics, through its Commission on Testing, has been developing a comprehensive series of "Suggested Test Methods", by consensus of the Society's members. In 1980 all the methods agreed upon to date were edited by E. T. Brown and published by Pergamon Press. The Standards Association of Australia, through its

Committee CE/9, has drafted "Australian Standard Methods of Testing Rocks for Engineering Purposes".

The properties measured by the author in his laboratory include:

Density
Moisture Content
Hardness : Sklerograf
: Shore Scleroscope
: Schmidt Rebound Hammer
Ultrasonic Wave Velocities : P-Wave, or Compressional
: S-Wave, or Shear
: Transmitted Amplitude Ratio
Dynamic Elastic Constants : Elastic Modulus
: Poisson's Ratio
Static Elastic Constants : Deformation Modulus
: Poisson's Ratio

DESTRUCTIVE, MECHANICAL PROPERTY TESTS

These may also be regarded as "standard" tests. The properties measured by the author include:

Tensile Strength: "Brazilian" method
Point-Load Strength Index
Shear Strength, or cohesion: Punch method
Unconfined Compressive Strength
Triaxial Compressive Strength
Angle of Shearing Resistance, ϕ

The tests mentioned in the last two sections are described in standard rock mechanics texts and in the A.S.T.M., S.A.A., or I.S.R.M. suggested test methods.

DRILLABILITY TESTS

These tests are generally intended to mimic the mode of breaking rock which is relevant to "real" field situations, such as diamond drilling, drag drilling, percussive drilling, excavation by picks, or breakage by roller cutters or button indenters.

They may be grouped into 3 main types:

(a) abrasion tests, whereby a steel, tungsten carbide or carborundum tool is rubbed over an intact rock surface. The measured depth or volume of removed rock gives a measure of the rock's drillability or toughness; the measured damage done to the rubbing tool gives a measure of the rock's abrasiveness. As a variant of this type of test, a tool may be "stirred" through crushed rock fragments, and the wear produced on the tool gives a measure of the rock's abrasiveness.

(b) static penetration tests, whereby a tool is loaded perpendicular to a surface of rock substance. The tool may be conical, applying a point load; or hemispherical, applying a circular load; or disc-shaped, with the axis of the disc parallel to the rock surface, producing a line load or an elliptical loaded area; or shaped as a frustum of a right wedge, producing a rectangular loaded area. Relationships between force and consequent penetration may be measured to give a measure of the drillability. Alternatively, the volume of the crater or chip of failed rock produced by a standard force and tool geometry may be measured. In the case of the disc cutter, the disc is translated parallel to the rock surface while being loaded normal to the surface. This produces a rolling motion over the rock surface. The test differs from the abrasion tests mentioned in part (a), because there is negligible differential movement (or rubbing) between the tool and individual points on the rock surface.

(c) impact loading tests, whereby a mass falling under the influence of gravity falls onto one or more fragments of rock, and produces rapid crushing or splitting failure. The amount of comminution produced by the application of a certain amount of kinetic energy can be measured (by weighing the proportion of the original mass which will pass through a fine screen). This is a measure of the rock's shatter resistance.

The results from drillability tests can not, in most cases, be used in a "scientific" manner, for the design of drilling or excavating machinery from first principles. Although, as stated earlier, the tests mimic the action of full-scale machinery, there is an inevitable simplification or distortion of such action in the small, light equipment built in the laboratory. The scale effect, which is a well-known factor in the mechanical behavior of rock, must introduce the need for adjustment factors when applying the laboratory test results towards the design of larger equipment. The different rates of application of the forces, in the laboratory and in the field, also counsel caution in extrapolating the laboratory results too far.

It would seem to be more prudent at this stage of the development of the applied sciences of rock mechanics and excavation engineering to treat the laboratory mechanical property and drillability tests as index tests, to quantitatively describe some aspects of the behaviour of the rock substance. These indices should be correlated with the observed and measured performance of field machinery, and any significant correlations found. These correlations can later be used as bases for predictions of performance on future projects. They can also be used to improve the conceptual and physical models for understanding the mechanisms of rock breakage in practical, full-scale situations.

ABRASIVE DRILLABILITY TESTS

(A 1) Drag Drillability: The "Goodrich" Test

This test was modified, following the suggestions of Goodrich (1961) by Singh (1968, 1973), from the test originally suggested by Sievers (1950).

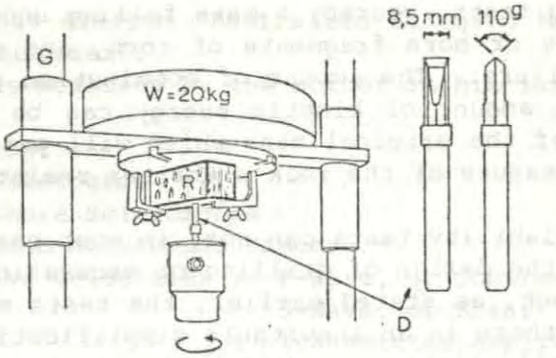
A standard tungsten carbide (9% Cobalt) microbit is used. The bit is 2.4mm thick, with a 90° chisel edge 9.5mm long. It is sharpened on a diamond lap, so that the chisel edge is less than 0.02mm wide, and is then mounted vertically, with the sharp edge uppermost, in a chuck on the drillability machine.

The rock sample is clamped to a steel plate so that it rests on the sharp bit, with gravity inducing a vertical thrust of 200 Newtons. The bit is then rotated 150 revolutions, at a rate of 140r.p.m. As the bit penetrates the rock the cuttings are cleared by falling out of the hole; the rock and its holder can freely slide vertically on teflon bushings.

The depth of the hole, measured with a depth micrometer, gives a measure of the drillability of the rock. The width of the wear flat induced on the chisel edge is measured with a traversing microscope, and this gives the wear factor of the rock.

(A 2) Drag Drillability: The Sievers J-Value Test

There are only minor differences in detail from the Goodrich test, as described above. Figure 1, after Selmer-Olsen and Blindheim (1970) shows the details. In this version of the test the wear number or abrasiveness of the rock is not measured (only the drillability). This seems like a major omission, in neglecting to measure half the data which are available.



G = *guide*

W = *20 kg weight*

D = *miniature drill of tungsten carbide*

R = *sawn rock specimen*

Sievers J-value is found as the depth of the drill holes given in 1/10 mm after 200 revolutions of the miniature drill. The value is given as a medium of minimum 4-8 holes. The bit is resharpened after each test.

FIGURE 1

(A 3) The Taber Abraser Test

A disc of rock is mounted on a revolving horizontal turntable, with its axis parallel to the axis of the turntable. An abrasive wheel (Taber Calibrade H-18), with its axis horizontal, is pressed by a 500 gram weight onto the rock disc, slightly off-centre, so that as the rock disc rotates the abrasive wheel is forced to slowly rotate, by a "scrubbing" action between the 2 surfaces. See Figure 2.

Operational Diagram of the Abraser.

FIGURE 2

Each side of the rock disc is revolved 400 times, with a fresh abrasive wheel on each side. A rock disc and its associated 2 abrasive wheels are weighed before and after the tests, and the abrasive wheels are resurfaced before use.

The mass lost by the rock disc is a measure of the abradability of the rock.

The average mass lost by the abrasive wheels is a measure of the abrasiveness of the rock.

As with the "Goodrich" test, abradability plotted versus abrasiveness can show direct comparisons between different rock types and machines.

(A 4) VOEST-ALPINE Rock Cuttability Index Test

A piece of rock is placed into a cubic mold (side lengths 100mm), which is then filled with cement. After the cement has set the block is sliced in half. The exposed saw cut rock surface of one half is clamped in a horizontal position. A conical steel pick is rotated about a vertical axis under an axial load of 200N, so that the pick cuts a 50mm diameter groove into the rock surface. See Figure 3.

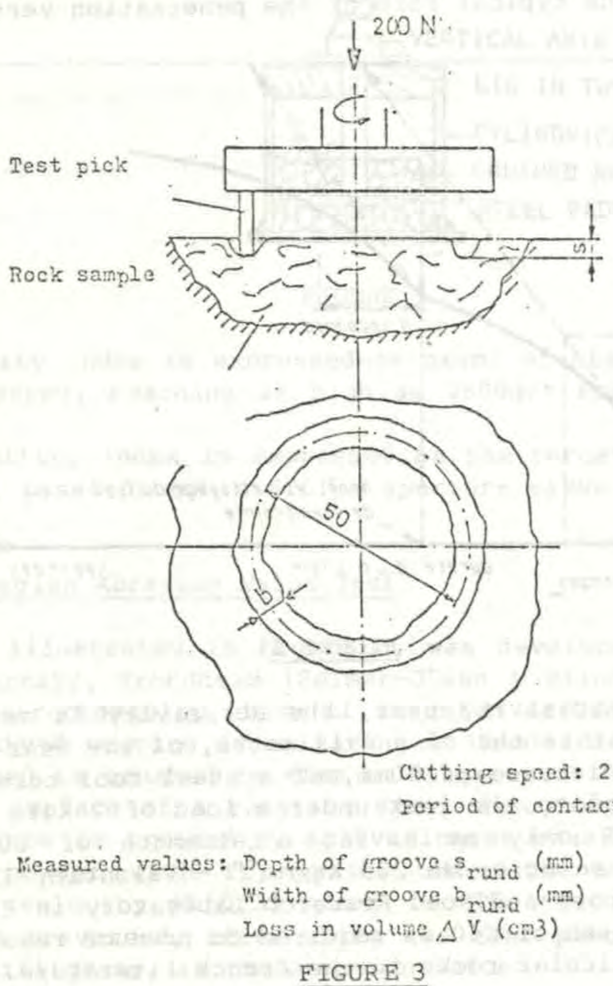


FIGURE 3

The mean depth and width of the groove are measured at 4 different places, spaced 90^o apart. The production rate of an Alpine-Miner AM50 tunnel excavation machine under normal conditions is stated to be equal to 9.172*(mean groove depth)**0.8

Abrasivity of the rock is measured on the matching half block. A steel pin 3.5mm diameter is vertically loaded with a force of 100N onto the rock surface,and rotated along a circular path a sufficient number of revolutions so that the total distance traversed is 3m. 5 different pins are used, each in a different holder, with a different rotation diameter. The largest diameter is 50mm. The total mass (ΔM) lost by the 5 pins over the total traverse distance of 15 metres is used to calculate the coefficient of wear

$$= \frac{\Delta M \text{ (mg/m)}}{15}$$

(A 5) CERCHAR Toughness and Abrasivity

These tests, as standardized by the French coal mining research centre, were described by Valantin (1974). An 8mm diameter tungsten carbide bit, having a 99° dihedral angle is gripped in the chuck of a bench drill press, rotated at 190 revolutions per minute, and forced into a rock sample, under a load of 20 kg. A plot of penetration versus time is made. Due to the inevitable dulling of the bit the slope of the curve (penetration rate) decreases with time. A tangent is drawn to the curve at time = zero (i.e. the initial instantaneous penetration rate) and extrapolated to a penetration of 1 cm. The time, in seconds taken for this apparent penetration, is quoted as the CERCHAR "durete" or toughness.

Figure 4 shows the typical form of the penetration versus time curve.

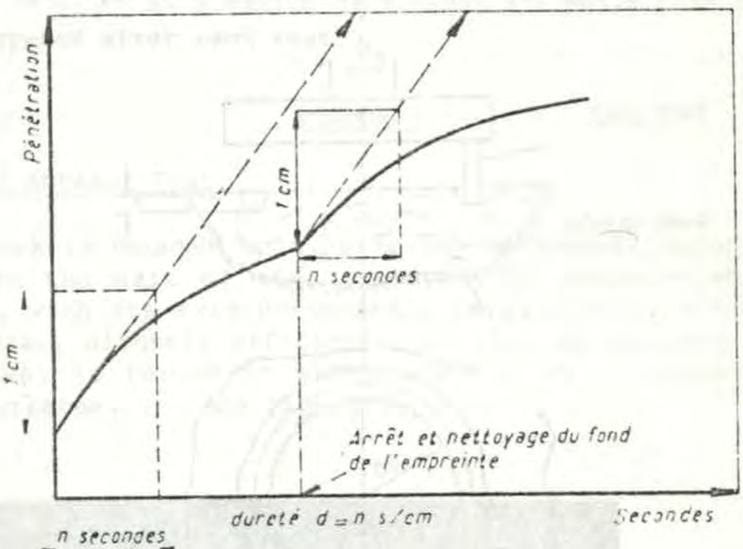


FIGURE 4

In the CERCHAR Abrasivity test, the abrasivity is measured by the diameter, expressed in tenths of a millimetre, of the wear flat produced by the rubbing, over a distance of 10mm, of a steel tool terminated by a 90° conical point, applied to the rock under a load of 7 kgf. The steel is specified by CERCHAR only as having a strength of 200 kg/mm^2 (literally "un foret en acier de 200 kg/mm^2" - Valantin, 1974, p. 91), but G. West of the Transport and Road Research Laboratory in England has found that a Rockwell Hardness of C40 is required to produce results comparable to those quoted for particular rocks in the French literature.

(A 6) Paddle Abrasiveness Test

This test was described by Lewis and Tandanand (1974), pp 90-91. A 400 gram sample of crushed rock, which has passed through a 19mm screen and been retained on a 9.5mm screen is placed into a steel drum. The drum is rotated at 74 revolutions per minute, and a steel paddle, held radially, is rotated concentrically with the outer drum, at 647 r.p.m. The crushed rock is lifted up the side of the rotating drum, and cascades down into the path of the rapidly rotating paddle. The mass lost by the 76 * 25 * 6mm paddle after 15 minutes is quoted as the paddle abrasiveness of the rock.

(A 7) The L.C.P.C. Abrasimeter

This abrasimeter, shown in Figure 5, was designed at the Laboratoire Centrale des Ponts et Chaussees (LCPC) in France. In it the wear piece plays the part of a paddle of stirring and breakage of the abrasive medium. A quantity of crushed rock (normally 500 grams) is placed in a cylindrical pot. The steel paddle (50mm * 25mm * 5mm thick) mounted on the end of a vertical axis of rotation is immersed in the broken rock. The stirring action, as the paddle rotates through the crushed rock, subjects the paddle to wear, and the rock to breakage.

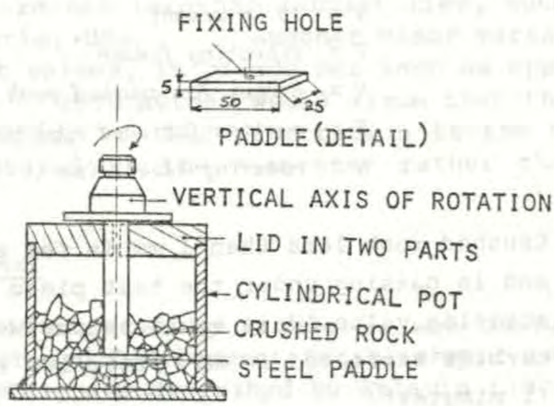


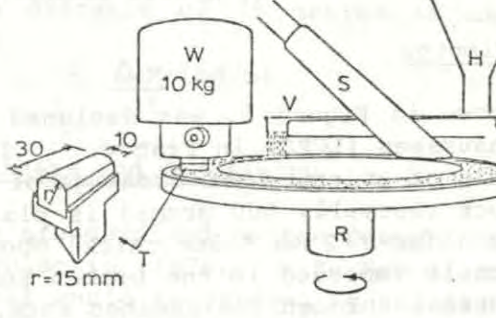
FIGURE 5

The abrasivity index is expressed as grams of steel worn off per tonne of material treated, reaching as high as 2500g/t for extremely abrasive rocks.

The breakability index is expressed as the percentage of the original mass which will pass through a 1.6 mm aperture sieve at the conclusion of the test.

(A 8) The Norwegian Abrasion Value Test

This test, illustrated in Figure 6, was developed at the Norwegian Technical University, Trondheim (Selmer-Olsen & Blindheim, 1970). The wear piece is a rectangular prism of tungsten carbide, 30mm long * 10mm wide, with a curved wearing face, having a 15mm radius of curvature. The rock to be tested is crushed to -1mm in diameter. The rock powder is fed onto the upper surface of a rotating steel disc, onto which the tungsten carbide wear piece is pressed by a 10 kilogram mass. The steel disc, dragging rock powder with it, passes under the work piece at a circumferential velocity of 0.33 m/sec. The test lasts for 5 minutes, i.e. 100 meters traversed, after which the test piece is weighed and the mass loss, in milligrams, is the Abrasion Value.



T = tungsten carbide test piece
W = 10 kg weight
V = vibrating feeder
H = hopper for crushed rock powder
S = suction for used rock powder
R = rotating steel disc

Crushed rock less than 1 mm is fed on the rotating steel disc and is passing under the test piece of tungsten carbide. The abrasion value AV is equal to the weight loss of the tungsten carbide expressed in mg after 100 revolutions of the steel disc (5 minutes).

FIGURE 6

STATIC INDENTATION DRILLABILITY TESTS

In contrast to the great variety of ingenious and complex apparatuses for measuring abrasive wear and drag drillability there are only a limited number of static indentation tests.

(I 1) Button Indentor Penetration - the "Morris" test

A tungsten carbide button compact (90^{o} conical, with a diameter of 11.4mm and radius of 3.2mm at the apex) is mounted on the upper platen of a testing machine. If the rock specimen is diamond drill core it is cut into the shape of a right cylinder, and several hose clips are tightened around it, to provide lateral confinement and prevent failure by splitting during the subsequent test. If the rock specimen is a lump it has one flat face cut on it, and is mounted in a steel ring, filled with an expanding cement mix, with the flat face level with and parallel to the upper surface of the cement. The tungsten carbide button is pressed into the rock surface and the force and the downwards displacement are continually recorded (the latter by L.V.D.T.'s). A linear elastic relationship is characteristically observed between force and displacement, until failure occurs and a chip is formed, whereupon force decreases and displacement suddenly increases. Continued operation of the testing machine may result in reloading of the rock, and formation of another chip, but the force F' and displacement D' at the onset of the first chip formation are the only values used for calculation.

$$\text{Morris Drillability (nanometres/Newton)} = \frac{D'}{F'}$$

This drillability can be correlated with advance rates of drills using button bits and of hard rock tunnel borers and raise borers.

(I 2) Button Indenter Penetration - the "Handewith" test

This test is virtually the same as the Morris test, but with minor variations in interpretation. In the descriptions of the test published by Handewith (1970) and Dollinger (1978) it is stated that rather than stopping the test after the first rock failure, as in the Morris test, they continue reloading until several episodes of rock failure and chip formation have occurred beneath the initially loaded point. A line-of-best-fit is then fitted through the several rock failure points on a force vs penetration plot. The slope of this line does not appear, from their published examples, to be significantly different from the slope of a line joining the origin with the point representing the chip formation. This author therefore concludes that there should be no significant difference between the "Morris" test values as determined in his laboratory and the "Handewith" test values as determined in other laboratories, such as those of The Robbins Company in Seattle, USA. Another minor variation is in the reporting of Handewith test values, in pounds per inch as opposed to the Morris test values in nm/N. This author would argue that the latter is more logical : a force is applied, so that penetration is the dependent variable, and so should be stated as the numerator rather than the denominator.

(I 3) The NCB Cone Indenter Test

This portable test rig, illustrated by Figure 7, was designed and developed at the Mining Research and Development Establishment (MRDE) of the British National Coal Board, (NCB), and described by Szlavin (1974). The test piece is a small piece of rock, about 25mm square by 4 to 6mm thick. A steel cone with a 40° included angle is forced into the rock, which is resting against a flat spring-steel beam. The force transmitted through the cone and the rock causes the beam to deflect. This deflection is measured by a dial gauge, while the movement of the cone is measured by a vernier micrometer. The dial gauge reading (when compared with the spring's calibration) indicates the force; the difference between the vernier micrometer reading and the dial gauge reading indicates the distance that the cone has penetrated into the rock.

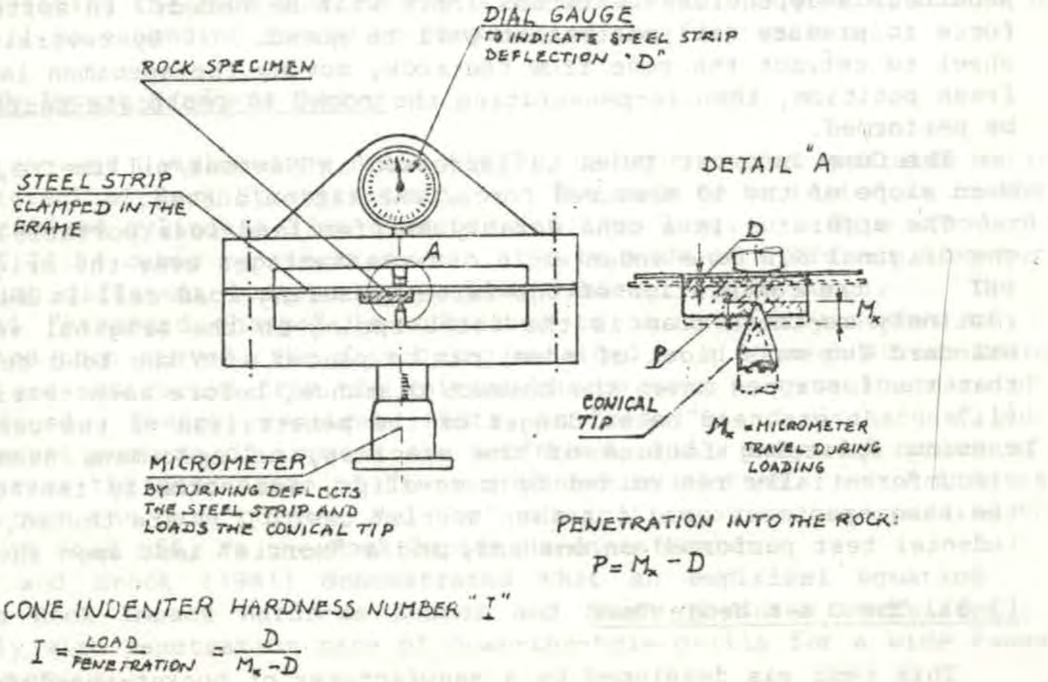


FIGURE 7

The Cone Indenter Hardness is obtained by dividing the force by the amount of deflection which has occurred. In the standard apparatus the vernier micrometer and dial gauge are graduated in units of thousandths of an inch, and 25 units (0.025 inch) deflection of the standard spring represents a force of 40N. A penetration by the cone of one hundredth of an inch (at the standard force of 40N) would therefore be measured by a vernier micrometer reading of (10 + 25) = 35 units, and a dial gauge reading of 25 units. The Cone Indenter Hardness would be $\frac{25}{(35-25)} = 2.5$

This author thought that the apparatus and test procedure could be improved, and therefore designed and constructed the Modified NCB Cone Indenter Test apparatus, described by Bamford & Washusen (1981). One consideration was to make the test results more objective and "scientific", and less apparently method-dependent; another consideration was the suspicion that the beam spring as used in the Standard NCB Cone Indenter apparatus could become deformed and lose its calibration, without this being able to be readily checked before each test; a third consideration was that the small thickness (4 to 6mm) would make the specimens prone to tensile splitting failure, if the rocks were soft and easily penetrable, and the cone therefore penetrated a significant proportion of the sample thickness.

(I 4) The Melbourne-Modified NCB Cone Indenter Test

A hardened steel cone is pressed into the surface of a rock specimen, and the force and displacement measured. A conical tip 6mm long, with an included angle of 40°, is formed on the end of a 4.5mm diameter cylinder, and hardened to a Rockwell C hardness of 65. The rock specimen is cut to the shape of a rectangular prism (if a lump sample) or to a right cylinder (if it is drill core) and is placed on the lower platen of a test rig, which has a load cell attached to it. The cone is mounted on the upper platen and a hand wheel drives a screw feed to push the cone into the rock. An L.V.D.T. measures the downwards displacement of the cone. An X-Y plotter records the force on the load cell on one axis and the L.V.D.T. displacement on the other axis. The cone is pressed into the rock until the force is 40 Newtons or the displacement is 1mm, whichever occurs first. In all but very soft rocks the force criterion will usually apply first, and the penetration depth for 40 Newtons force will be noted; in softer rocks the force to produce 1mm penetration will be noted. By reversing the hand wheel to retract the cone from the rock, moving the specimen laterally to a fresh position, then re-penetrating the rock, 10 replicate tests can quickly be performed.

The Cone Indenter Index is expressed in Newtons/millimetre, and is the mean slope of the 10 measured force/penetration curves.

The apparatus is a considerably stiffer (and less portable) version of the original NCB cone indenter. Two advantages over the original are:

(i) the calibration of the force measuring load cell is much easier to routinely re-check than is the steel spring in the original version; a standard 2kg mass block of steel can be placed upon the load cell, to check that the force pen moves the correct distance, before each testing session.

(ii) there need be no danger of the penetration of the conical point causing splitting failure of the specimen, as specimens 50mm thick, circumferentially restrained by hose-clips, are normally tested - in fact the same specimens used for the "Morris" test (I 1) are tested, with a cone indenter test performed on one end, and a "Morris" test upon the other end.

(I 5) The O & K Wedge Test

This test was developed by a manufacturer of bucket-wheel excavators to determine cutting resistance of hard and compact soils and weak rocks, by measuring the penetration resistance of a bucket knife or tooth in the laboratory. The test tooth is a frustum of a wedge with a 34^o included angle, 5 mm wide and 65 mm long. It is mounted on the upper platen of a compression testing machine and pressed into a 150 mm cube of the material being tested. The force necessary to cut or split the material is divided by the surface area of the failure plane, to give "specific separation force" K_A Inverse parabolic relationships exist between K_A and the production rates of particular bucket wheel excavators. For example, a K_A of greater than 600 kPa has been found at Goonyella by Saunders and Ellery (1981) to indicate "intractable" conditions, requiring extensive ground preparation by blasting before the bucket wheel there is able to remove the material.

DYNAMIC LOADING, OR SHATTER STRENGTH TESTS

There are only 3 tests performed in this category, 2 of them using the same equipment, but with different sample preparation.

(D 1) Coefficient of Rock Strength

This test measures the impact or shatter resistance of rock, and its results have been reliably correlated by the U.S. Bureau of Mines with the performance of percussion drills.

Two fragments of rock, which have passed through a 25.4 mm aperture screen and been retained on a 19.1mm aperture screen, are placed in the hardened steel base of a steel cylinder 660mm long, with an inside diameter of 76mm. A 2.36 kilogram steel weight is allowed to drop 635mm onto the rock fragments an arbitrary number of times. After the required number of impacts have occurred, the rock is removed and placed on a 35 mesh screen (0.5mm aperture) and shaken. The mass retained is subtracted from the initial mass, to indicate the mass of -0.5mm material produced per impact. The coefficient of rock strength is a function of the initial mass multiplied by the number of impacts, divided by the mass of -0.5mm material produced. Fresh pairs of rock fragments are subjected to different numbers of impacts, until a minimum value of the C.R.S. is found. This reflects the fact that a lesser number of impacts than the optimum will still be breaking the rock down to the 0.5mm size, while a greater number of impacts will be expending energy on re-grinding the fine material.

(D 2) Rock Impact Hardness Number

This test was developed by Brook (1977), using the same apparatus as in the Coefficient of Rock Strength test. The rock to be tested is in the form of standard cylinders 25mm diameter and 50mm long. This standard volume, of 24.54 cubic centimetres, can also be made of different diameter cores having different lengths (e.g. 54mm diameter, 11mm long). The cylindrical "standard charge" is subjected to an arbitrary number of impacts, and then sieved, the mass being retained on a 35 mesh screen being recorded, and subtracted from the initial charge mass to give the mass of fines produced. Several replicate tests, on fresh "standard charges" but with different numbers of impacts are performed, and a graph of number of impacts versus the percentage of fines produced is plotted. A line is fitted through the data points, and the number of impacts corresponding to 25% fines is read off, as the Rock Impact Hardness Number.

Rabia and Brook (1981) demonstrated that an empirical equation containing Rock Impact Hardness Number and Shore Hardness correlates excellently with penetration rate of Down-the-hole drills for a wide range of rock types.

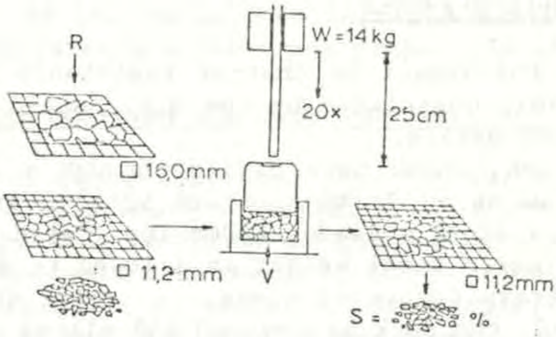
(D 3) Swedish Brittleness Test

This test differs in several significant aspects from the 2 just described, which were derived from the Protod'yakonov test.

(a) the "pestle" or impacting mass does not hit the rock at a high velocity : it sits on top of the rock, and upon being itself hit by a falling mass, transfers the kinetic energy of the falling mass to the rock;

(b) a much smaller size reduction is measured. Instead of measuring the mass of the sample reduced from a diameter of 25mm to a diameter of less than 0.5mm, the Swedish Brittleness test measures the mass which, previously retained on a 11.2mm screen, passes through the same screen after impacts - a much less dramatic size reduction.

The principle of the Swedish Brittleness test is shown in Figure 8. The sample is 500 grams of crushed rock aggregate, which has passed a 16.0mm screen and been retained on a 11.2mm screen. The falling piston weighs 14.5kg, and is allowed to fall 20 times from a height of 250mm. The brittleness value is reported as the percentage mass passing the 11.2mm screen after the 20 impacts.



R = crushed rock sample

W = weight

S = brittleness value

The sample is screened to fraction 16·0-11·2 mm and weighs 500 g if the density is 2·65 Sample weight is corrected to get a constant volume in the mortar if the density is different from 2·65

The brittleness value is the percent of the sample passing the 11·2 mm sieve after the impact of 20 drops, and is determined as the medium value of at least 3-4 parallel tests.

The flakiness number (ratio of average grain width to thickness) is determined and the degree of packing in the mortar is noted in connection with the test, but this is only used as additional information about the rock properties.

FIGURE 8

THE INTERNATIONAL SOCIETY FOR ROCK MECHANICS : COMMISSION ON ROCK BOREABILITY, CUTTABILITY AND DRILLABILITY

This Commission has 3 working groups :

(a) Percussive and rotary drilling
(b) Surface excavation (e.g. ripping, bucket-wheel excavators)
(c) Underground excavation by tunnel boring machines and tunnel excavation machines

It is intended that each of the 3 working groups will produce 4 short reports or position papers (or collaborate in producing joint reports covering the areas of more than one working group, where appropriate) :

(a) complete and clear descriptions of the existing "non-standard" tests for rock drillability testing, to enable other workers to duplicate the test apparatus, or potential users of the results to evaluate them;

(b) summaries of the mechanisms of rock failure under cutting or drilling tools, as proposed by different authors, plus selective bibliography;

(c) case studies of correlations between performances of drills excavating machines and tunnelling machines, on the one hand, and rock physical properties and drillability test results, on the other;

(d) suggested international standard tests for assessing rock boreability, cuttability and drillability.

The Suggested Test Methods to be described under topic (d) would possibly be influenced by the conclusions of the case studies reported under topic (d), and the success or otherwise of currently-used test procedures.

The Chairman of this Commission is also convenor of the "Working Group on Tests for Drilling and Boring", under the I.S.R.M. Commission on Testing Methods.

INTERNATIONAL SOCIETY FOR ROCK MECHANICS : COMMISSION ON TESTING METHODS

This Commission has been one of the most productive activities of the I.S.R.M. Suggested Test Methods covering many procedures in laboratory and field testing of rock substances and rock masses have been drafted by small volunteer working groups, circulated to Commission members and other interested specialists for comment and criticism, and eventually published by the Secretariat of the Society. In 1980 a collection of Suggested Test Methods produced up to that date was published in hard covers by Pergamon Press. There are plans to periodically revise and re-publish this collection.

The Suggested Test Methods have received wide acceptance as being practical and authoratitive. Comments from informed sources in the U.S.A. are to the effect that only a small minority of rock mechanics tests are still being carried out there to A.S.T.M. procedures, as most workers have adopted the I.S.R.M. Suggested Test Methods for their guidance.

The Commission has recently authorised the convenor of the Working Group on Tests for Drilling and Boring to include tests for rippability within his subject area.

Over the next 3 years there will be considerable work done under the aegis of the two Commissions mentioned above, culminating in publication of major reports to coincide with the 1987 Congress of the I.S.R.M. in Montreal, Canada.

The cooperation of all people interested in using objective and internationally accepted tests for assessing the excavation characteristics of rocks to take part in the tasks of drafting, verifying and refining these tests.

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