Suggested Methods for Determining Hardness and Abrasiveness of Rocks

PART 1. INTRODUCTION AND REVIEW

The approach taken in this document is to review and reference those tests which have received recent use. Those tests which have well-established usage are adopted as "Suggested Methods" at the present time. Because of the active research underway, especially in the areas of drillability and machine boreability, it is anticipated that additional methods will be incorporated in the next revision of this document.

DEFINITIONS

The hardness and abrasiveness of rock are dependent on the type and quantity of the various mineral constituents of the rock and the bond strength that exists between the mineral grains. Tests for each property have been developed to simulate or to correlate with field experience. Many of the tests now used for rock have been adapted from highway materials, concrete and metals testing.

Considerable research has been conducted in the past and is now underway regarding these properties of rock. Many tests developed in a research study have not been evaluated by other organizations or have not been used in practical applications. Many tests which have been developed are used by only one commercial firm or governmental organization, or are used only in a limited geographical area.

ABRASION AND ABRASIVENESS

Abrasion tests measure the resistance of rocks to wear. These tests include wear when subject to an abrasive material, wear in contact with metal and wear produced by contact between the rocks. Abrasiveness tests can also measure the wear on metal components (e.g. tunneling machine cutters) as a result of contact with the rock. These tests can be grouped in three categories: (1) abrasive wear impact test; (2) abrasive wear with pressure test; and (3) attrition test.

(1) *Abrasive wear with impact test*

(a) *Los Angeles abrasion test* [1,2]. This test developed for highway aggregates, subjects a graded sample to attrition due to wear between rock pieces and also to impact forces produced by an abrasive charge of steel spheres.

(b) *Sand blast test.* The surface of the test sample is abraded by an air blast containing silica sand or aluminium oxide under specified conditions. The weight loss or depth of abrasion is a measure of the abrasive resistance of the rock. This method has its chief application in the evaluation of building materials [3].

(c) *Burbank test.* This test is designed to determine the relative abrasiveness of a rock sample on metal parts of mining and crushing equipment [4]. A single metal paddle of the test alloy is counter-rotated at 632 rev/min inside a drum containing the rocks which is rotated at 74 rev/min. This produces high-speed impact and rapid wear of the test paddle.

(2) *Abrasive wear with pressure test*

(a) *The Dorry test* [5], *ASTM test C-241-51, and the modified Dorry test* (*British Standard BS-812*). These press the rock specimen against a rotating steel disc. A silica sand or aluminium oxide powder is fed between the rock and steel surface and acts as an abrasive medium.

(b) *Bit wear tests.* Several tests [6–8] have been devised to determine the abrasive resistance of rock by measuring the bit wear of a standard bit drilling for a specified length or time under specified conditions. These tests are also measures of drillability.

(c) The abrasion resistance of a rock and the abrasive effect of the rock on other materials have been determined by use of a modified Taber Abraser Model 143 [9]. Each side of a 6 mm thick disc from an NX core is revolved 400 times under an abrading wheel which is forced against the disc by a 250 g weight. Debris is removed continuously by vacuum. The weight loss of the rock is a measure of its abrasive resistance while the weight loss of the abrading wheel is taken as a measure of the abrasiveness of the rock. These values have been used in conjunction with hardness data to predict tunnel machine boreability [9].

(3) *Attrition tests*

Attrition can be defined as the resistance of one surface to the motion of another surface rubbing over it. The wear is produced without impact, pressure or action of a third element of different and invariably higher hardness. The Deval test in which rock aggregate are tumbled at a slow speed without the abrasive charge of steel spheres used in the Los Angeles test provides a determination of rock attrition. This test is not widely used at present.

HARDNESS

Hardness is a concept of material behaviour rather than a fundamental material property. As such, the quantitative measure of hardness depends on the type of test employed. Three types of tests have been used to measure the hardness of rocks and minerals: (1) indentation tests; (2) dynamic or rebound tests; (3) scratch tests.

(1) *Indentation tests*

The Brinell and Rockwell tests are well-known tests used on metal but are not generally applicable to rock due to its brittle nature. The Knoop [10] and the Vickers [11] tests determine the microhardness of individual rock minerals. A pyramidal-shaped diamond is applied to the surface with a specified force. The area of the permanent residual deformation divided by the applied force is a measure of the hardness. The Knoop test has the ability to determine directional hardness of crystals.

(2) *Dynamic or rebound tests*

These tests employ a moving indenter to strike the test specimen. Any plastic or yielding material behaviour produced by the impact will reduce the elastic energy available to rebound the indenter. The height of rebound is taken as a measure of the hardness of the material.

The Shore scleroscope is a laboratory test device that measures hardness by dropping a small diamond-tipped indenter on the specimen and measuring its rebound height. Because of the small size of the diamond indenter tip and the inhomogeneous nature of most rocks, it is necessary to conduct a large number of rebound tests to obtain an average for a particular material.

The Schmidt impact hammer, originally developed to determine the compressive strength of concrete, has been used for hardness determinations of rock. The device, which has both field and laboratory uses, consists of a spring-loaded piston which is projected against a metal anvil which is in contact with the rock surface. The height of piston rebound is taken as an empirical measure of hardness.

(3) *Scratch tests*

Scratch tests are widely used to determine mineral hardness. The hardness scale proposed by Mohs in 1822 is a scratch test that is still in wide use. In an attempt to provide a more quantitative measure of hardness, scratch sclerometers using a sharp diamond point to scratch the specimen have been developed. The Talmage and Bierbaum devices [12] are among the better-known scatch sclerometers.

REFERENCES

1. ASTM Standard C131-69.
2. ASTM Standard C535-69.
3. ASTM Standard C418-68.
4. Burbank B. B. Measuring the relative abrasiveness of rock minerals and ores. *Pit Quarry*, 114–118. (August 1955).
5. Obert L., Windes S. L. & Duval W. I. Standardized test for determining the physical properties of mine rock. U.S. Bur. Mines Rep. Invest., RI 3891 (1946).
6. Selmer-Olsen R. & Blindheim O. T. On the drillability of rock by percussive drilling. *Proc. 2nd Congr. Int. Soc. Rock Mech.*, Beograd (1970).
7. White C. G. A rock drillability index. *Colo. Sch. Mines Q.* **64**, No. 2, 1–92 (April 1969).
8. Goodrich R. H. Drag bits and machines. *Colo. Sch. Mines Q.* **56**, No. 1, 1–21 (1961).
9. Tarkoy P. J. A study of rock properties and tunnel boring machine advance rates in two mica schist formations. *15th Symp. Rock Mech.*, Custer State Park, South Dakota (September 1973).
10. Winchell H. Observations on orientation and hardness variations. *Am. Miner.* **31**, Nos. 3–4, 149–152 (1946).
11. Das B. Vicker's hardness concept in the light of Vicker's impression. *Int. J. Rock Mech. Min. Sci. & Geomech. Abstr.* **11**, 85–89 (1974).
12. Williams S. R. *Hardness and Hardness Measurements*, 101–132. American Soc. for Metals, Cleveland (1942).

IMPORTANT NOTES

1. The units stated in this document are the modern metric units in accordance with the Systeme International d'Unites (S.I.) which is an extension and refinement of the traditional metric system. The following should be noted:

unit of length—1 meter (m) = 1000 mm;
unit of mass—1 kilogram (kg) = 1000 g;
unit of force—1 newton (N) = kg m/s^2;
unit of stress—1 pascal (Pa) = N/m^2.

2. The comma is used thoughout as the decimal sign.

PART 2. SUGGESTED METHOD FOR DETERMINING THE RESISTANCE TO ABRASION OF AGGREGATE BY USE OF THE LOS ANGELES MACHINE[1]

SCOPE

This method covers procedures for testing aggregate for resistance to abrasion using the Los Angeles testing machine. The abrasive charge and the test sample used are dependent on the aggregate size and grading.

APPARATUS

(a) *Los Angeles Machine*

The Los Angeles abrasion testing machine, conforming in all its essential characteristics to the design shown in Fig. 1 shall be used. The machine shall consist of a hollow steel cylinder, closed at both ends, having an inside diameter of 711 ± 5 mm and an inside length of 508 ± 5 mm. The cylinder shall be mounted on stub shafts attached to the ends of the cylinder but not entering it, and shall be mounted in such a manner

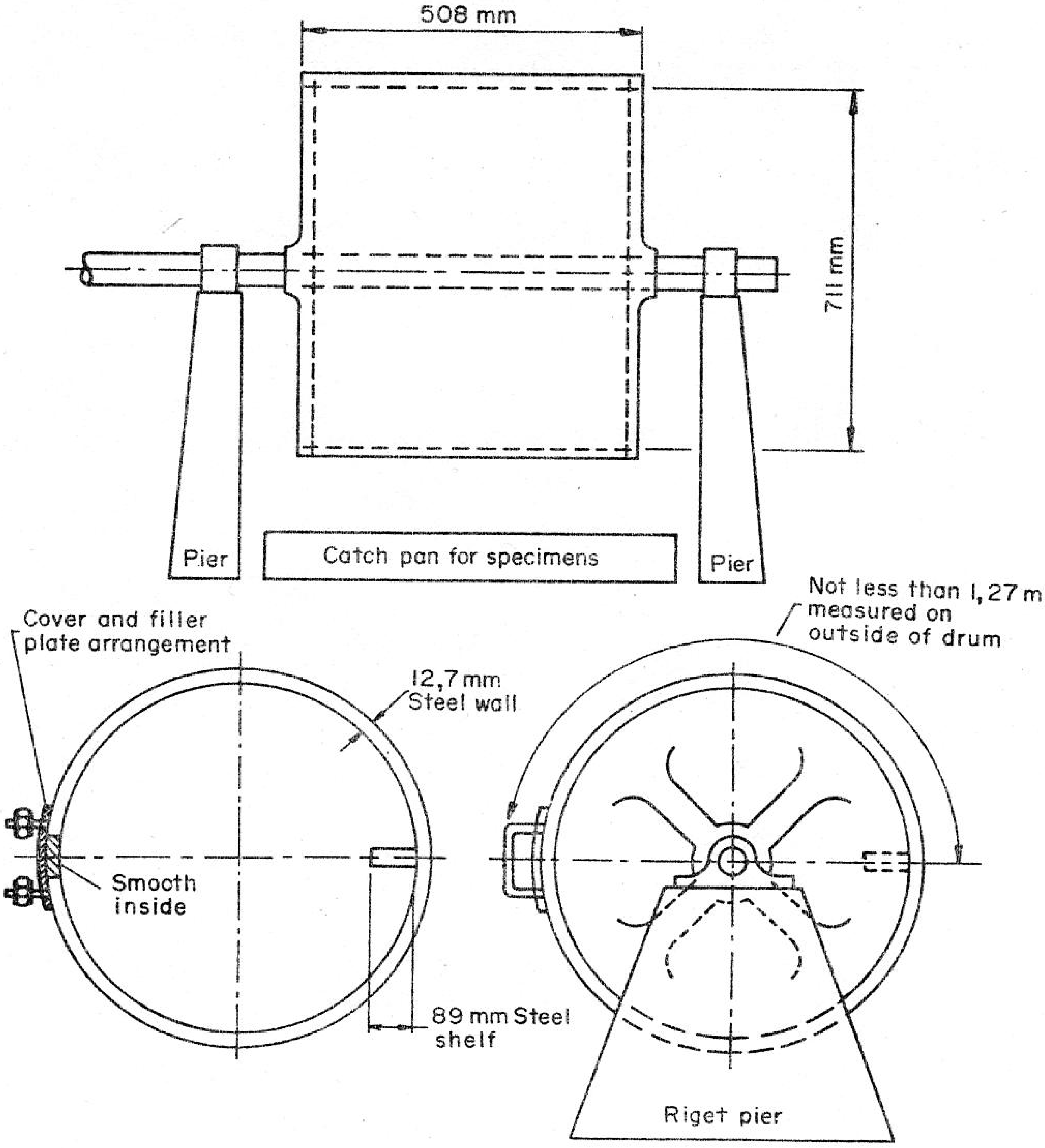

Fig. 1. Los Angeles abrasion testing machine.

that it may be rotated with the axis in a horizontal position within a tolerance in slope of 1 in 100. An opening in the cylinder shall be provided for the introduction of the test sample. A suitable, dust-tight cover shall be provided for the opening with means for bolting the cover in place. The cover shall be so designed as to maintain the cylindrical contour of the interior surface unless the shelf is so located that the charge will not fall on the cover, or come in contact with it during the test. A removable steel shelf extending the full length of the cylinder and projecting inward 89 ± 2 mm shall be mounted on the interior cylindrical surface of the cylinder, or on the inside surface of the cover, in such a way that a plane centred between the large faces coincides with an axial plane. The shelf shall be of such thickness and so mounted, by bolts or other suitable means, as to be firm and rigid. The position of the shelf shall be such that the distance from the shelf to the opening, measured along the outside circumference of the cylinder in the direction of rotation shall be not less than 1,27 m. The shelf shall be made of wear resistant steel and shall be rectangular in cross-section.

(b) *Balance*

A balance or weighing machine accurate within 0,1% of test load over the range required for this test.

TABLE 2. GRADINGS OF TEST SAMPLES*

Sieve size, mm (Square openings)[3]		Weights of indicated sizes, g Grading		
Passing	Retained on	1	2	3
75,0 mm	63,0 mm	2500 ± 50	—	—
63,0 mm	53,0 mm	2500 ± 50	—	—
53,0 mm	38,0 mm	5000 ± 50	5000 ± 50	—
38,0 mm	25,4 mm	—	5000 ± 25	5000 ± 25
25,4 mm	19,0 mm	—	—	5000 ± 25
	Total	10,000 ± 100	10,000 ± 75	10,000 ± 50

* Coarse aggregate larger than 19 mm.

TABLE 3. GRADINGS OF TEST SAMPLES*

Sieve size, mm (Square openings)[3] Passing	Retained on	Weight of indicated sizes, g Grading A	B	C	D
38,0 mm	25,4 mm	1250 ± 25	—	—	—
25,4 mm	19,0 mm	1250 ± 25	—	—	—
19,0 mm	13,2 mm	1250 ± 10	2500 ± 10	—	—
13,2 mm	9,5 mm	1250 ± 10	2500 ± 10	—	—
9,5 mm	5,6 mm	—	—	2500 ± 10	—
5,6 mm	4,7 mm	—	—	2500 ± 10	—
4,7 mm	2,3 mm	—	—	—	5000 ± 10
	Total	5000 ± 10	5000 ± 10	5000 ± 10	5000 ± 10

* Coarse aggregate smaller than 38 mm.

(c) For coarse aggregate smaller than 38 mm the sample shall be recombined and the abrasive charge selected as described in Table 3.

PROCEDURE

(a) Place the test sample and the abrasive charge in the Los Angeles abrasion testing machine and rotate the cylinder at a speed of 30–33 rev/min. The number of revolutions shall be 500 for aggregate smaller than 38 mm and 1000 for aggregate larger than 19 mm. The machine shall be so driven and so counterbalanced as to maintain a substantially uniform peripheral speed.[4] If an angle-shaped steel member is used as the shelf, the direction of rotation shall be such that the charge is caught on the outside surface of the shelf.

(b) After the prescribed number of revolutions, discharge the material from the machine and make a preliminary separation of the sample on a sieve coarser than 1,7 mm (No. 12 US). Sieve the finer portion in a 1,7-mm sieve. Wash the material coarser than the 1,7-mm sieve,[2] oven dry at 105°–110°C to substantially constant weight and weigh to the nearest gramm.

(c) Valuable information concerning the uniformity of the sample under test may be obtained by also determining the loss after 100 revolutions in the case where 500 revolutions is specified or after 200 revolutions in the case where 1000 revolutions is specified. The loss should be determined without washing the material coarser than the 1,7-mm sieve. The ratio of the loss after 100 or 200 revolutions to the loss after 500 or 1000 revolutions, respectively, should not greatly exceed 0,20 for material of uniform hardness. When this determination is made, care should be taken to avoid losing any part of the sample; the entire sample, including the dust of abrasion, shall be returned to the test machine for the final 400 or 800 revolutions required to complete the test.

CALCULATIONS

(a) Express the difference between the original weight and the final weight of the test sample as a percentage of the original weight of the test sample.[1] Report this value as the percentage of wear.

(b) When the procedure described on Procedure Section (c) is followed, the uniformity of wear ratio is the ratio of the loss after 100 or 200 revolutions to the loss after 500 or 1000 revolutions, respectively.

REPORTING OF RESULTS

The report should include the following data:

(a) Source location and geologic description of the sample tested.

(b) Grading of test sample.

(c) Grading of abrasive charge.

(d) The Los Angeles percentage of wear (See Calculations section (a) above).

(e) The Los Angeles uniformity of wear ratio (see Calculations section (b) above) if applicable.

IMPORTANT NOTES

1. This test method combines the essential features of ASTM standard test C131-69 and ASTM standard test C535-69. Aggregate in the size range of 19 mm to 38 mm can be tested by either one of the two procedures described in this Suggested Method. The specific procedure used for this size aggregate shall be reported with the results.

2. If the aggregate is essentially free from adherent coatings and dust, the requirement for washing before and after the test may be waived. Elimination of washing after testing will seldom reduce the percentage wear by more than about 0,2 percentage points.

3. Test sieves shall conform to ISO Standard 56501972 (E) "Test sieves–woven metal wire cloth and perforated plate—nominal sizes of apertures", Series R 40/3.

4. Back-lash or slip in the driving mechanism is very likely to furnish test results which are not duplicated by other Los Angeles abrasion machines producing constant peripheral speed.

PART 3. SUGGESTED METHOD FOR DETERMINATION OF THE SCHMIDT REBOUND HARDNESS[1]

SCOPE

(a) This method is suggested for the use of the Schmidt impact hammer for the hardness determination of rock.

(b) The method is of limited use on very soft or very hard rocks.

APPARATUS

The apparatus shall consist of:

(a) The Schmidt hammer which determines the rebound hardness of a test material. The plunger of the hammer is placed against the specimen and is depressed into the hammer by pushing the hammer against the specimen. Energy is stored in a spring which automatically releases at a prescribed energy level and impacts a mass against the plunger. The height of rebound of the mass is measured on a scale and is taken as the measure of hardness. The device is portable and may be used both in the laboratory and field.

Schmidt hammer models are available in different levels of impact energy. The Type L hammer having an impact energy of 0,74 Nm shall be used with this suggested method.

(b) A steel base of minimum weight of 20 kg to which specimens should be securely clamped. Cored specimens should be tested in a steel 'cradle' with a semicylindrical machined slot of the same radius as the core, or in a steel V-block (Fig. 2).

PROCEDURE

(a) Prior to each testing sequence, the Schmidt hammer should be calibrated using a calibration test anvil supplied by the manufacturer for that purpose. The average of 10 readings on the test anvil should be obtained.

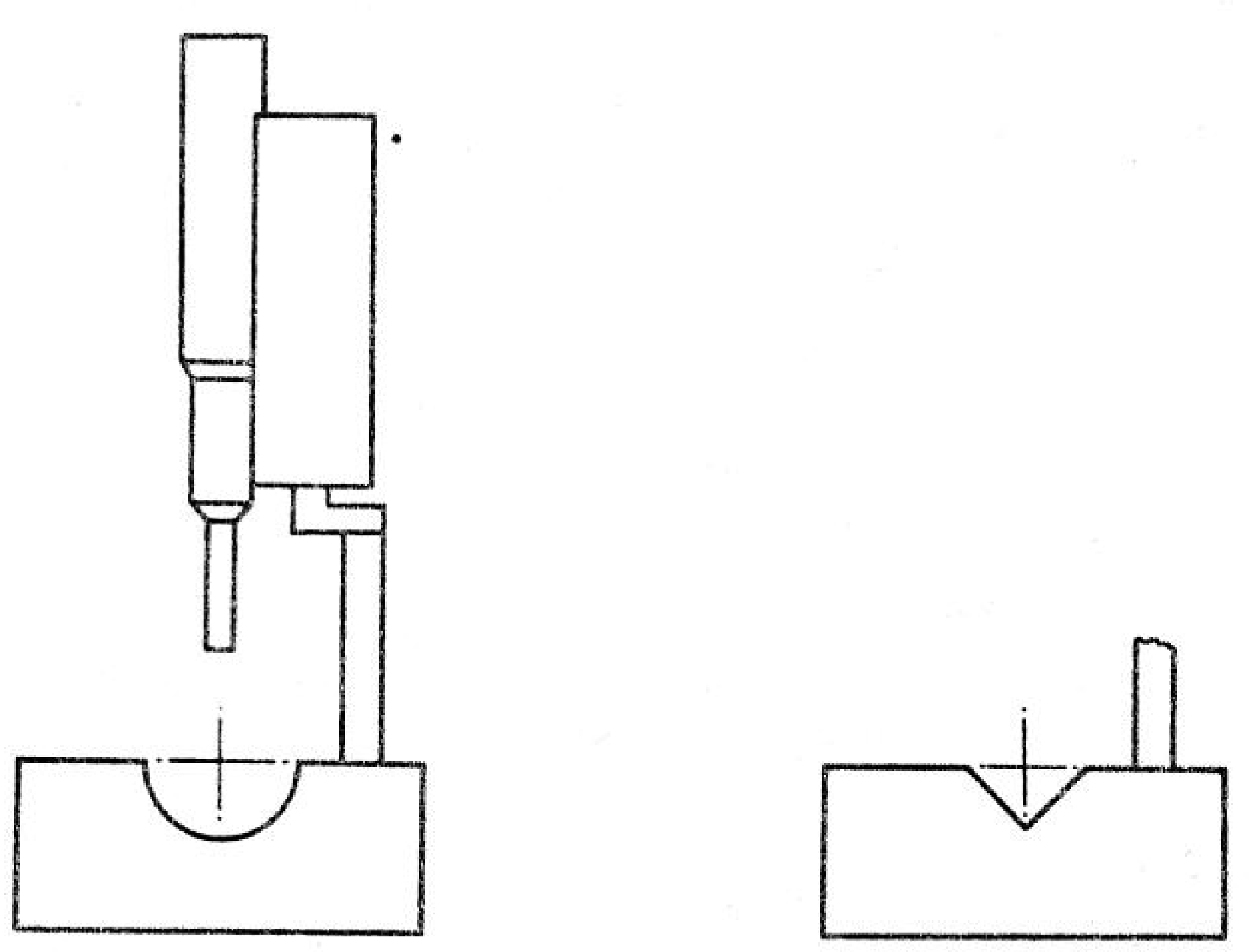

Fig. 2. Core specimen holders.

(b) Specimens obtained for laboratory tests shall be representative of the rock to be studied. When possible, use larger pieces of rock for the Schmidt hardness tests. The Type L hammer should be used on NX or larger core specimens or on block specimens having an edge length of at least 6 cm.

(c) The test surface of all specimens, either in the laboratory or in the field, shall be smooth and flat over the area covered by the plunger. This area and the rock material beneath to a depth of 6 cm shall be free from cracks, or any localized discontinuity of the rock mass.

(d) Small individual pieces of rock, whether tested in the laboratory or in the field, shall be securely clamped to a rigid base to adequately secure the specimen against vibration and movement during the test. The base shall be placed on a flat surface that provides firm support.

(e) The hardness value obtained will be affected by the orientation of the hammer. It is recommended that the hammer be used in one of three positions: vertically upwards, horizontally, or vertically downwards with the axis of the hammer $\pm 5°$ from the desired position. When use of one of the three orientations is not feasible (e.g. *in situ* testing in a circular tunnel), the test should be conducted at the necessary angle and the results corrected to a horizontal or vertical position using the correction curves supplied by the manufacturer. The hammer orientation for the test and any corrections applied to non-vertical or non-horizontal orientations should be recorded and reported in the results.

(f) At least 20 individual tests shall be conducted on any one rock sample. Test locations shall be separated by at least the diameter of the plunger. Any test that causes cracking or any other visible failure shall cause that test and the specimen to be rejected. Errors in specimen preparation and testing technique tend to produce low hardness values.

CALCULATIONS

(a) The correction factor is calculated as:

$$\text{Correction factor} = \frac{\text{Specified standard value of the anvil}}{\text{Average of 10 readings on the calibration anvil}}$$

(b) The measured test values for the sample should be ordered in descending value. The lower 50% of the values should be discarded and the average obtained of the upper 50% values. This average shall be multiplied by the correction factor to obtain the Schmidt Rebound Hardness.

REPORTING OF RESULTS

The following information shall be reported:

(a) Lithologic description of the rock. Source of sample, including: geographic location, depth and orientations.

[1] As manufactured or licensed by E. Schmidt, Basel, Switzerland.

(b) Type of specimen (core, blasted or broken sample, *in situ*). Size and shape of core or block specimen.

(c) Date of sampling, date of testing and condition of storage (i.e. exposure to temperature extremes, air drying, moisture, etc.).

(d) Orientation of the hammer axis in the test.

(e) Method of clamping sample (V-block or clamps).

(f) The Schmidt Hardness value obtained as in the Calculations section above.

PART 4. SUGGESTED METHOD FOR DETERMINATION OF THE SHORE SCLEROSCOPE[1] HARDNESS

SCOPE

This laboratory method is suggested for the hardness determination of rock minerals using the Shore scleroscope[1] and for the verification of other scleroscope hardness instruments. Rock hardness may be obtained as an average of readings taken at random on individual mineral grains.

APPARATUS

The instrument used for determining scleroscope hardness numbers is supplied in two models designated Model C and Model D. Model C-2 is recommended for use with rock.

(a) The Scleroscope Model C-2 consists of a vertically-disposed barrel containing a precision bore glass tube. A scale graduated from 0 to 140, is set behind the barrel and is visible through the glass tube. A pneumatic actuating head affixed to the top of the barrel, is manually operated by a rubber bulb and tube. A hammer drops from a specified height and rebounds within the glass tube. The hammer for Model C-2 shall have the following dimensions:

Diameter	5,94 mm
Mass	2,300 ± 0,500 g
Overall length	20,7 to 21,3 mm
Distance hammer falls	251,2 + 0,13 − 0,38 mm

(b) The diamond must be shaped to produce a correct reading on reference bars of known hardness. In profile, the diamond is convex, having a radius terminated by a flat striking surface, as shown in Fig. 3. The flat striking surface is approximately circular and from 0,1 to 0,4 mm in diameter, depending on the hardness and other physical characteristics of the diamond.

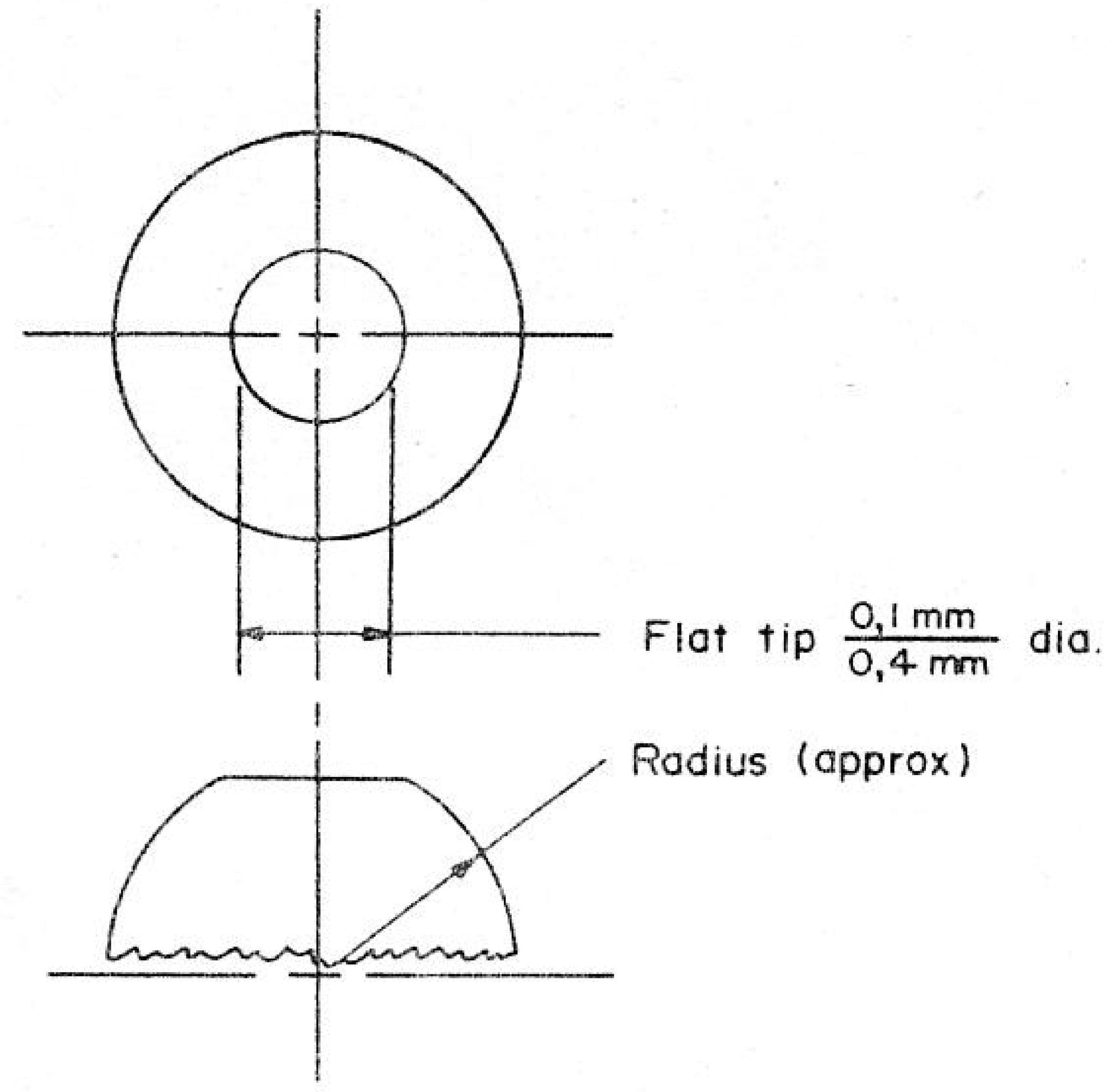

Fig. 3. Profile of scleroscope diamond showing range of diameters of flat tip.

PROCEDURE

(a) Before each days use, make at least five hardness readings on the standard test block furnished by the manufacturer at the hardness level at which the machine is being used. If the values fall within the range of the standardized hardness test block the instrument may be regarded as satisfactory; if not the machine should be verified using procedures recommended by the manufacturer.

(b) Tests shall be made on flat surfaces ground smooth using a No. 1800 grade aluminium oxide abrasive powder. An excessively coarse surface will yield low and erratic readings.

(c) Specimens should have a minimum test surface of 10 cm^2 and a minimum thickness of 1 cm. Small specimens should be clamped securely with the flat test surface perpendicular to the scleroscope axis.

(d) To perform a test hold or set the instrument in a vertical position with the bottom of the barrel in firm contact with the test specimen and normal to the surface of the specimen. Bring the hammer to the elevated position by squeezing the rubber bulb and then allow it to fall and strike the test surface and measure the height of rebound. The height to which the hammer rebounds on the first bounce indicates the hardness of the material.

(e) To prevent errors resulting from misalignment the instrument must be set or held in a vertical position, using the plumb bob or spirit level on the instrument to determine verticality. The most accurate readings of the scleroscope are obtained with the instrument mounted in a clamping stand. Lateral vibrations must be avoided since they tend to cause the free fall of the hammer to be impeded and, hence, cause the instrument to read low.

(f) An error may result if the indentations are spaced too closely together. Space indentations at least 5 mm apart and make only one test at the same spot. At least 20 hardness determinations should be taken.

[1] Registered trade mark of the Shore Instrument and Mfg. Co., Inc., Jamaica, New York, U.S.A.

CALCULATIONS

The Shore Scleroscope Hardness shall be the average of not less than 20 measurements made on the same specimen, using the above method.

REPORTING OF RESULTS

The report should include the following information on each specimen tested:

(a) Lithologic description of the rock. Source of the sample, including: geographic location, depth and orientations.

(b) Approximate mineral composition and grain sizes of the rock specimen.

(c) Date of sampling, date of testing, storage conditions, and specimen preparation procedures.

(d) Orientation of the test surface with respect to bedding or foliation planes when these are significant characteristics of the rock.

(e) The number of tests conducted and the average Shore Hardness.

INTRODUCTION

The Commission on Standardization of Laboratory and Field Tests on Rock was appointed in 1967. Subsequent to its first meeting in Madrid in October 1968, the Commission circulated a questionnaire to all the members of the International Society for Rock Mechanics, the answers received clearly showing a general desire for standardized testing procedures. At a further meeting in Oslo in September 1969, tests were categorized and a priority for their standardization was agreed upon, as given in Table 1.

It was also decided that research tests, including many of the rock physics tests, were beyond the scope of standardization. Subsequent meetings were held in Belgrade in September 1970, in Nancy in October 1971, in Lucerne in September 1972, in Katowice in October 1973, in Denver in September 1974, in Minneapolis in September 1975 and in Salzburg in October 1976. At the Lucerne meeting the Commission was subdivided into two committees, one on standardization of laboratory tests and the second on the standardization of field tests.

The present document has been produced by the Committee on Standardization of Laboratory Tests. The present document covers Category I (4) in Table 1.

It should be emphasized that the purpose of these "Suggested Methods" is to specify rock testing procedures and to achieve some degree of standardization without inhibiting the development or improvement of techniques.

Any person interested in these recommendations and wishing to suggest additions or modifications should address his remarks to: The Secretary General, International Society for Rock Mechanics, Laboratório Nacional de Engenharia Civil, Avenida do Brasil, Lisboa, Portugal.

Acknowledgements—The following persons contributed in the drafting of these "Suggested Methods": R. H. Atkinson (U.S.A.), W. E. Bamford (Australia), E. Broch (Norway), D. U. Deere (U.S.A.), J. A. Franklin (U.K.), C. Nieble (Brazil), F. Rummel (Germany), P. J. Tarkoy (U.S.A.) and H. van Duyse (Belgium).

TABLE 1. TEST CATEGORIES FOR STANDARDIZATION

Category I: Classification and Characterization
Rock material (laboratory tests)
(1) Density, water content, porosity, absorption.*
(2) Strength and deformability in uniaxial compression; point load strength.*
(3) Anisotropy indices.
(4) Hardness, abrasiveness.*
(5) Permeability.
(6) Swelling and slake-durability.*
(7) Sound velocity.*
(8) Micro-petrographic descriptions.*
Rock mass (field observations)
(9) Joint systems: orientation, spacing, openness, roughness, geometry, filling and alteration.*
(10) Core recovery, rock quality designation and fracture spacing.
(11) Seismic tests for mapping and as a rock quality index.
(12) Geophysical logging of boreholes.*
Category II: Engineering Design Tests
Laboratory
(1) Determination of strength envelope (triaxial and uniaxial compression and tensile tests).*
(2) Direct shear tests.*
(3) Time-dependent and plastic properties.
In situ
(4) Deformability tests.*
(5) Direct shear tests.*
(6) Field permeability, ground-water pressure and flow monitoring; water sampling.
(7) Rock stress determination.*
(8) Monitoring of rock movements, support pressures, anchor loads, rock noise and vibrations.
(9) Uniaxial, biaxial and triaxial compressive strength.
(10) Rock anchor testing.*

* Asterisks indicate that final drafts on these tests have been prepared.

Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol. 15, pp. 89–97
0020-7624/78/0601-0089$02.00/0

INTERNATIONAL SOCIETY FOR ROCK MECHANICS

COMMISSION ON
STANDARDIZATION OF LABORATORY AND FIELD TESTS

SUGGESTED METHODS FOR DETERMINING HARDNESS AND ABRASIVENESS OF ROCKS