Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol. 30, No. 2, pp. 151–155, 1993
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0148-9062/93 $6.00 + 0.00

Technical Note

Determination of Discontinuity Wall Strength by Equotip and Ball Rebound Tests

H. R. G. K. HACK[†]
J. HINGIRA[†]
W. VERWAAL[‡]

INTRODUCTION

Determining the shear strength characteristics of discontinuities requires that the joint wall condition or joint wall strength should be established. Various authors have commented on the influence of the strength of the discontinuity wall on shear strength [1–9]. In virtually all rock masses the "quality" (strength) of the discontinuity wall is lower than the intact rock strength. The decrease in strength may have been caused by weathering features, brought about by chemically charged water percolating through discontinuities which reacted with the wall, etc. The thickness of the layer having a lower strength might range from microscopic thickness up to many centimetres. In shear box tests or triaxial tests the discontinuity wall strength is incorporated in the results. However shear box tests can only be done on samples of a limited size. The strength and thickness of the joint wall is necessary to understand the shear strength test results. A quantitative method of determining discontinuity wall properties would therefore be of great value.

Rebound tests are a method which might be suitable to assess discontinuity wall strength. The most well known rebound test is the Schmidt hammer [9–11] which works on the rebound of a piston activated by a spring. Other rebound measurements are based on a hammer or ball which drops from a certain height on to the surface to be measured [10–13]. The rebound of the piston, hammer or ball after hitting the surface is dependent on the elastic parameters of the tested material and on the strength of the material at the surface of the discontinuity. This latter effect is caused by the crushing of surface asperities and surface material and thus dissipates energy. Most of the rebound tests reported in the literature are not directed to measuring the discontinuity wall strength but to measuring the intact rock strength.

A problem inherent to any type of rebound measuring to obtain surface characteristics is that it is not only influenced by surface characteristics but also by the layer of material directly underneath. The thickness of the layer influencing the rebound depends on the amount of impact energy, the area of the impact point and the elastic and strength characteristics of the material. The standard form of Schmidt hammer releases so much energy over such a large area that in most rocks a layer of up to centimetres depth influences the measurement. The ball rebound [12, 13] and the Equotip [14] devices release considerably less energy and might therefore be better means to establish the discontinuity wall parameters.

To establish a rebound method suitable for measuring discontinuity wall strength tests have been done with the ball rebound and Equotip instruments.

TEST PROCEDURES

Ball rebound

A transparent 52 cm-long square tube is set vertical to the test surface, which has to be horizontal. A metal ball of weight 2.03 g and diameter 7.95 mm is dropped from a standard height of 52 cm and the height (in cm) reached after rebound on the surface is measured. The impact energy is 10 Nmm. The area under impact is theoretically a point but deformation of the ball and rock material increases this area during impact. The size of the area becomes a function of time and of the elastic and strength properties of the ball and the rock material.

Equotip

The Equotip device is based on the same principle as a Schmidt hammer but the amount of energy released and the impact area are far smaller than for the Schmidt hammer. It is an electronic battery-operated spring-based device. The piston moves through a coil and causes a current through the coil. The voltage of the current which is proportional to the velocity of the piston, before impact (V_1) and after impact (V_2) are measured automatically and displayed as a ratio ($V_2/V_1 \times 1000$) which is denoted by the unit: L. Impact energy is approx. 11 Nmm. Impact area is 7.07 mm^2. Multiple types of impact testers (probes) are available for the Equotip. Probe D has been used for all tests in this article.

Tests were done on a series of rock samples. Granite,

[†] ITC (International Institute for Aerospace Survey and Earth Sciences), Kanaalweg 3, 2628 EB Delft, The Netherlands.

[‡] Department Engineering Geology, Delft University of Technology, Faculty of Mining and Petroleum Engineering, Mijnbouwstraat 120, 2628 RX Delft, The Netherlands.

limestone and sandstone blocks were used. The blocks were cubes with sides approx. 20 cm long. Each block contained at least one surface which had been a natural discontinuity wall. The rebound tests were performed on this surface after which the surface was sawn or ground so that a small layer from the surface was removed. The rebound tests were then repeated. This procedure was repeated until the rebound values became constant. It was then assumed that the outer (weathered) wall of the block was completely removed and that the last series of measurements are representative for the intact rock material. Unconfined compressive strength tests with measurement of Young's modulus were done on cores sawn out of the intact rock blocks. This testing procedure allowed measurement of the thickness of the discontinuity wall and an assessment of how the rebound was influenced by the material below the surface.

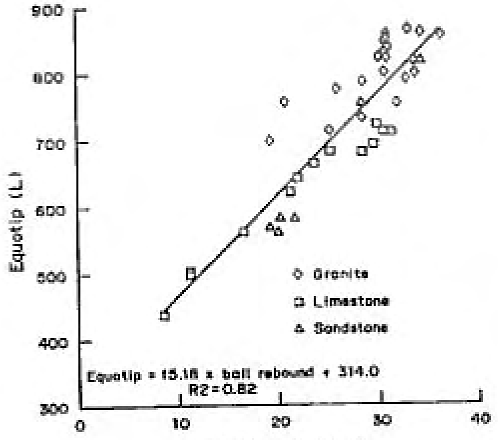

Fig. 1. Ball rebound vs Equotip.

SCATTER OF RESULTS

The rebound value is partly dependent on the material at the impact point. If the radius of the impact point is of the order of the mineral grain sizes then there will be considerable scatter of the measured values. If the impact point is on a "hard" mineral crystal or grain a high rebound value is measured, whereas if on a "soft" mineral a low rebound value is measured. To minimize this influence, multiple tests at slightly different positions were performed in each stage of testing, whereafter the values were averaged.

SURFACE ROUGHNESS

Small-scale surface roughness has an influence on the rebound values. It is clear that a rougher surface offers more asperities for crushing and thus loss of rebound energy. A further influence of surface roughness is that the ball may not rebound perpendicular to the surface and will touch the sides of the tube. This causes friction between the ball and the sides of the tube and thus reduces the ball rebound height. To minimize the influence of small-scale roughness on the tests the natural discontinuity surfaces were therefore very slightly smoothed before testing. Surfaces created by sawing or grinding did not need to be smoothed.

CORRELATION OF THE TEST RESULTS

Ball rebound and Equotip

Correlation between ball rebound and Equotip values have been found to be good (Fig. 1). This good correlation was expected because the tests are of a similar character and both are influenced by the same material properties.

Ball rebound, Equotip and unconfined compressive strength

The unconfined compressive strength (UCS) as a function of ball rebound and Equotip values is shown in Fig. 2, which also shows the relation found by Pool [12] for ball rebound and the relation found by Mulder and Verwaal [15] for the Equotip. The UCS–ball rebound values correlate with the relation found by Pool and the Equotip values correlate with the relation found by

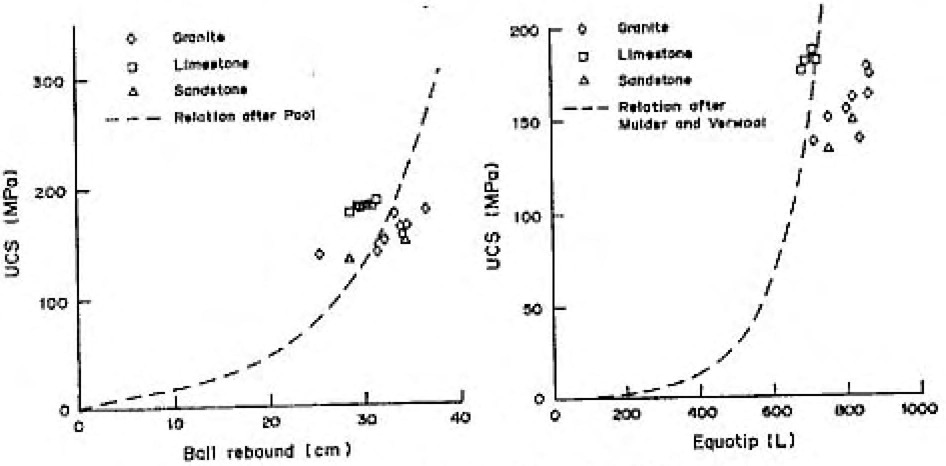

Fig. 2. UCS vs ball rebound and Equotip for fresh rock.

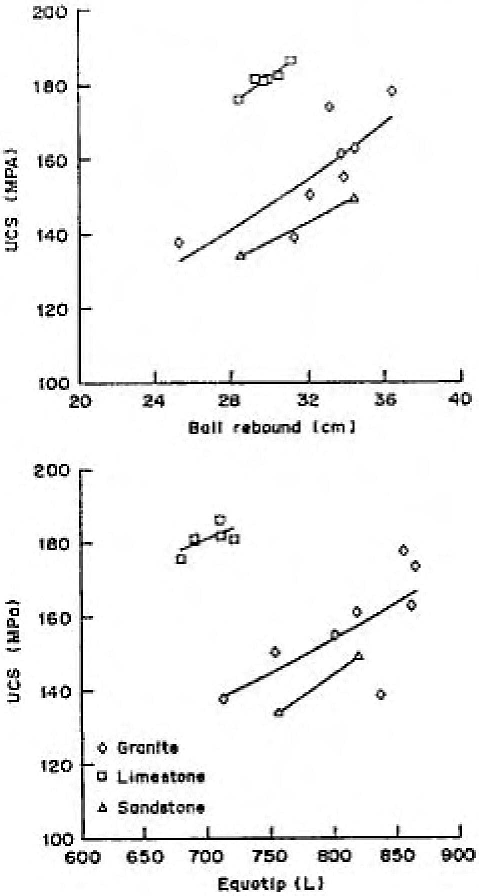

Fig. 3. UCS vs ball rebound and Equotip for fresh rock.

Mulder and Verwaal. In more detail a correlation was obtained per rock type for both ball rebound and Equotip values (Fig. 3). The correlations follow the trend found by Mulder and Verwaal although there seems to be a different correlation for each rock type.

Unit weight

It was expected that unit weight of the rock material would have an influence on the rebound values of both the ball and Equotip devices. Figure 4 shows unit weight vs ball rebound and Equotip. The general trend for all samples appears to be an inverse relation but no clear relation per rock type was found.

Young's modulus

No correlation was found between Young's modulus and either ball or Equotip rebound (Fig. 5). This might indicate that rebound values are influenced more by the crushing of asperities and surface material than by the elastic parameters of the rock material.

Discussion

It seems that the rebound values are more closely related to strength for the specimens tested because visual inspection of the impact points clearly showed surface damage. For stronger rock materials crushing of surface material might be less important and rebound might be more closely related to elastic parameters. Rock grain size may also influence the rebound value.

THE INFLUENCE OF DEPTH

The depth of the material influencing the measurement is estimated to be a maximum of 3 mm for the ball rebound and 5 mm for the Equotip. Figure 6 shows two examples of ball rebound and Equotip vs depth below surface of two weathered discontinuities, one in sandstone, the other in limestone. Each point on the graph represents a rebound measurement on surfaces exposed by the removal of thin layers (± 1 mm thick) by grinding down the weathered wall of a discontinuity to the fresh rock behind. If it is assumed that the weathered wall rock is of more or less uniform strength overlying stronger backing rock and that the rebound number relates to the total strength of rock in the volume influenced by the impact, then a rising impact value indicates the onset of the influence of the backing rock on the rebound value. The depth between the first rise in rebound value and the maximum value on fresh rock is the maximum depth of influence of impact. The difference between depth influences for ball rebound and Equotip suggests that the ball rebound impact area is larger during impact than that of the Equotip, the impact energy per unit area is less and thus the depth influenced smaller.

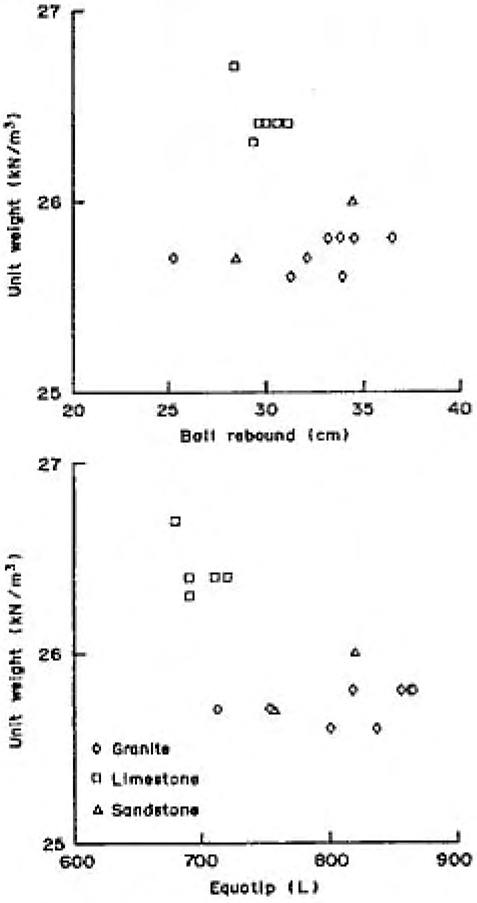

Fig. 4. Unit weight vs ball rebound and Equotip for fresh rock.

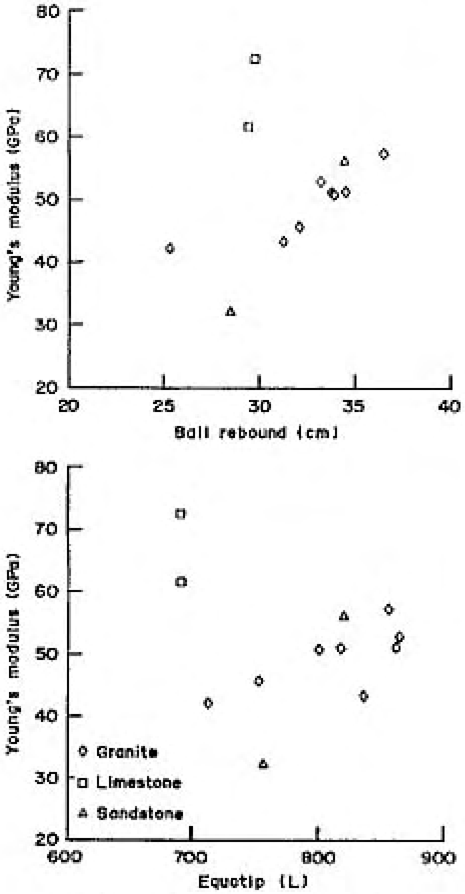

Fig. 5. Young's modulus vs ball rebound and Equotip for fresh rock.

CALCULATING DISCONTINUITY WALL STRENGTH

The objective of the test is to give values of rock wall strength that can be applied to the calculation of discontinuity strength. In the work of various authors as described by Bandis [1], an estimate of the UCS of asperities (the JCS factor) is essential for the estimation of discontinuity shear strength. Estimating discontinuity wall strength has always been a problem. Attempts have been made using the Schmidt hammer [9] but clearly the compressive strength of a thin weak layer backed by a much stronger layer cannot be assessed by this high-impact device. The Equotip seems to be much more suitable.

However, correlations between Equotip rebound and compressive strength suffer from scale effects, the former testing a much smaller volume of rock than the latter. Thus exact correlation is unlikely to be achieved. For the moment, pending yet further work, the authors propose using the correlation graph given in Fig. 2. Thus, in Fig. 6 the near surface compressive strength of the sandstone could be assessed to be about 55 MPa and that of the limestone about 35 MPa in contrast to fresh rock strengths of >200 and 150 MPa, respectively.

CONCLUSIONS

Both ball and Equotip rebound tests present a good alternative to the Schmidt hammer to establish joint wall strength. The layer thickness influencing the rebound is considerably smaller (in the order of millimetres) than that of Schmidt hammer tests and thus better reflects the quality of the discontinuity wall. Impact energy of ball rebound and Equotip are in the order of 10 Nmm compared to the 0.74 Nm impact energy for a Schmidt hammer.

The tests showed that the ball rebound and Equotip values depend more on strength and surface roughness than on density and elastic rock parameters.

The ball rebound test is limited to vertical use only. It can be used in the field or laboratory on horizontally fixed test surfaces only, and field operation is very cumbersome. The results are very sensitive to improper execution of the test. In contrast the battery-operated Equotip can be used in the field or laboratory at any angle and is very easy to use. A correlation table for non-vertical tests is provided by the manufacturer. The flexibility of the Equotip is therefore far larger and use in the field is easy.

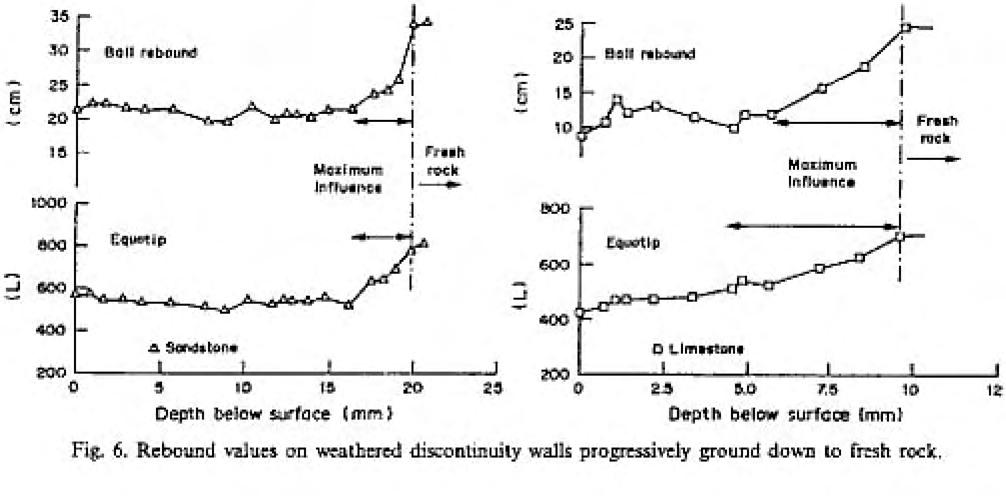

Fig. 6. Rebound values on weathered discontinuity walls progressively ground down to fresh rock.

Accepted for publication 14 December 1992.

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