RESULTS OF AN EXPERIMENTAL CAMPAIGN FOR PLOTTING THE CORRELATION CURVES FOR THE ROCK REBOUND HAMMER

By **Michele Massaccesi**
DRC Development & Research Centre of Ancona

With the collaboration of **Giovanni Menditto, Stefano Bufarini, Vincenzo D'Aria**
Università Politecnica delle Marche – Department of Architecture, Construction and Structures

1. Introduction

In technical applications, there is often a need both in the planning and execution phase to provide even general indications as to the state of the rock mass regarding which supporting or deep works are to be carried out.
To this end, the rebound hammer for L-type rocks is generally used, whilst the most complete method of evaluation of the superficial hardness of natural rocks is currently to be found in the ASTM D 5873-00 "*Standard test method for determination of rock hardness by rebound hammer method" American Society for Testing and Materials*.
For general indications relative to the principles, equipment, procedure and results of the rebound hardness test method, we recommend referring to UNI standard EN 12504-2:2001 (*Non-destructive testing - Determination of rebound number*).
This work features a presentation of the regression curves that correlate the values of the rebound hardness numbers with the probable value of the rock's mechanical strength, regardless of its specific nature. Thus a fundamental element is made available to the designer, both for structural purposes as well as for scaling works of a temporary nature or provisional coverings as is the case with tunnels.

2. Aim, limitations and field of application

The rebound hardness number determined by means of this method can principally be used for in situ tests carried out for engineering, design or construction purposes, and in particular for:

a. qualitative surveys into the degree of homogenisation of rock materials;
b. the extent of the strength of rock materials with an evaluation of the unconfined uniaxial compressive strength;
c. an evaluation of the state of alteration of rock materials through the relationship between the rebound numbers respectively on the walls of the joints (discontinuities where marked slips cannot be seen between the faces) and a fresh surface of the same rock obtained by means of segregation;
d. the evaluation of the JCS coefficient (*Joint wall compressive strength*);
e. the prediction of penetration rates for tunnel boring machines.

The rebound hardness test should not be seen as an alternative for determining the compressive strength of rock material, but with suitable correlation it can provide an estimate of the strength that will be encountered in situ.
The test is based on the correspondence between the unit compression breaking load and the superficial hardness of the rock material by measuring the remaining elastic energy (*rebound method*).
It should in any case be noted that in rock masses, the local state of stress is that of "confined elements" and thus pluriaxial ones, so that we generally need to have further correlation curves between the uniaxial and pluriaxial tension states if we are to obtain a correct interpretation of the rock rebound numbers.

3. How the rebound hammer works

The instrument's functioning revolves around the principle that a mass hurled from a spring strikes a piston in contact with the surface, and the result of the test is expressed in terms of the mass' rebound distance.
The apparatus is composed of a mobile mass featuring a certain amount of initial kinetic energy which strikes the surface of a mass of natural rock. After the impact, there is a redistribution of the initial kinetic energy; this is partly absorbed by the material in the form of plastic deformation energy, and is partly returned to the mobile mass; this rebounds over a distance which is proportional to the available residual energy. An essential condition of this distribution of energy is that the mass of material being tested should be virtually infinite compared to the mass of the mobile equipment; should this not be the case, a part of the initial energy, depending on the relative masses of the two bodies in collision, would be transferred to the rock in the form of kinetic energy. The rock is given infinite mass by using very small impact masses.
In order to obtain the necessary energy for impact, a spring-loaded system is used. The rebound distance is determined by the energy of the rebound following impact with the material being tested, along with the characteristics of the spring-loaded system.
All the testing devices that are based on using the results of the impact energy must feature calibration checking as, after prolonged use, the elastic constants of the springs become altered.

4. Characteristics of the instrumentation used for the experiments

The experimental campaign was conducted using a mechanical L-type rebound hammer called the "GEOHAMMER" (photo no. 1) produced by Eurosit s.r.l. of Ancona, with an impact energy of 0.735 N×m; the results of the experiments are presented herewith.
In the absence of any specific EC regulations, or of any guidelines, work was carried out along the lines of what had been gleaned on the concrete rebound hammer (N-type).
The steel calibration anvil (photo no. 2), on which checks on the hammer were carried out, has the following technical characteristics:

Hardness:	> 60 HRC
Mass:	16 Kg
Diameter:	147 mm

Photo no. 1

Photo no. 2

The calibration test was divided up into the following phases:

- operation of the instrument at least three times before beginning to take the readings from the calibration anvil, so as to ensure that its mechanical functioning is correct;
- insertion of the rebound hammer in the anvil's guide ring (figure no. 1) and execution of a series of impacts (no. ≥ 10);
- check that the average of the rebound numbers of the rebound tests carried out with the GEOHAMMER at the calibration anvil was equal to **70±2**, as prescribed by the manufacturer.

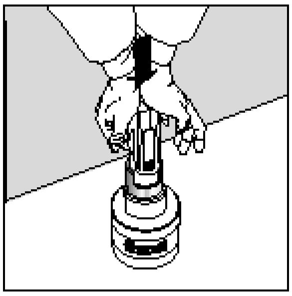


Figure no. 1

DRC srl
Via Montesicuro snc 60131 Ancona – Italy
Tel +39 071 8036077 FAX +39 178 2205318
C.F. e P.IVA 02478810423
info@drcitalia.it www.drcitalia.it

5. Nature of the surfaces to be tested in situ

The surfaces of the rock masses to be tested in situ, including natural outcrops or prepared surfaces such as the tunnel walls or floors, shall have a smooth and flat test area at least 15cm in diameter.
Where surface outcrops are concerned, avoid sampling or testing any material which has been weakened by weathering or alteration or which for some reason is deemed not representative of the material of interest. The testing surface for all the specimens, whether in the field or in the laboratory, shall be smooth to the touch and free of joints, fractures or other localised discontinuities, up to a depth of at least 6 cm. The rock in situ must be flat and free of surface grit in the area covered by the plunger.
If the testing surface is heavily textured, grind it smooth using the abrasive stone supplied with the instrument.

6. Regression and experimentation curves

A correct application of the rebound hardness method would require the plotting of correlation curves with reference to the construction material. As this operation cannot be put into practice owing to the enormous variety of natural rocks in existence, we are limited to plotting the regression curves based on cubic specimens of rock belonging to determined “types”; in particular, the most commonly occurring rock masses such as those shown in table no. 1 have been surveyed:

Name	Type	Area of origin
Porphyry	Porphyry	Porphyry quarry of Valtellina
Calcareous sandstone	Sandstone	Fiorenzuola (FI)
Travertine	Travertine	Tivoli (RM)
Lecce rock	Soft Limestone	Lecce
Trani (Apricena)	Compact Limestone	Apricena
Marbles	Marbles	San Pietro Mussolini (VI)
Tuff	Tuff	Tuff quarries (Lazio)

Table no. 1

Only an approximate estimate can be made as to the strength of the material if there is an experimental calibration curve that correlates the strength of that particular material with the rebound number.
In its absence, it is possible to use a more general curve which is the one supplied as a support by the rebound hammer's manufacturer.
The aim of the experimental campaign thus executed was to subject 60 cubic specimens, 75mm per side, of a selected natural rock shown in table no. 1 (photo no. 3) to destructive tests (crushing in a cradle) and non-destructive tests (rebound hammer tests) in accordance with the following standards:

- UNI EN 12670: 2003 *"Natural stone - Terminology"*;
- UNI EN 1926:2000 *"Natural stone test methods – Determination of compressive strength"*.

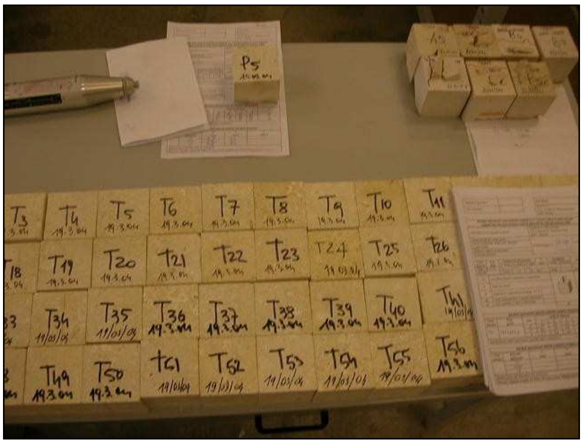


Photo no. 3

Each cubic specimen was subjected to:
- thorough dimensional checks and relative weighing;
- execution of rebound tests.

In order to render the results of the rebound testing as independent of the operator as possible, Eurosit has designed and built a piece of equipment named the ATHR (*Alfa Test Hammer Robot* – patent no. AN2002A000028, photo no. 4) which consents the cubic specimens to be gripped automatically between the two plates of a cradle with stress of 1 N/mm², so that they are held firmly, impeding any movement during impact. In this way, it was possible to carry out a sequence of four rebound tests per side, observing them with a video camera and external monitor, where the instrument's conditions of inclination were $\alpha = -90°$, 0° and +90° (where α is the angle that the axis of the rebound hammer forms with the horizontal axis).
- Crushing of the test specimens (photo no.° 5).

A scattergram of experimental points between surface hardness and unit breaking load was obtained: the data gathered was examined for the most reliable correlation curves in accordance with the principle of maximum likelihoood.

Hypothesising a correlation of the following type between the rebound number (I) and compressive strength on the rock cube (R)

$$Rcub. = a \times I^{b}$$

(**a**, **b** constants),

based on the data gathered and with the use of a statistical processing programme, the application of the method of least squares consented constants a and b to be determined and the following relationships were attained (figure no. 2):

$$Rcub. = 0.0775 \times I^{1.9823} \quad (N/mm^2)$$

for = -90° with a correlation coefficient equal to 0.9396 (figure no. 3);

$$Rcub. = 0.0232 \times I^{2.2637} \quad (N/mm^2)$$

For = 0° with a correlation coefficient equal to 0.9278 (figure no. 4);

$$Rcub. = 0.0074 \times I^{2.5172} \quad (N/mm^2)$$

For = +90° with a correlation coefficient equal to 0.9192 (figure no. 5).

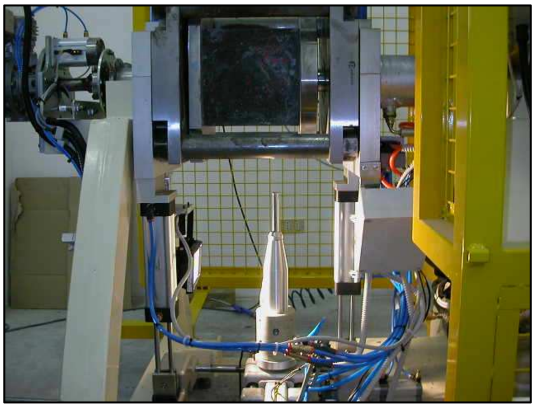


Photo no. 4

Photo no. 5

DRC srl
Via Montesicuro snc 60131 Ancona – Italy
Tel +39 071 8036077 FAX +39 178 2205318
C.F. e P.IVA 02478810423
info@drcitalia.it www.drcitalia.it

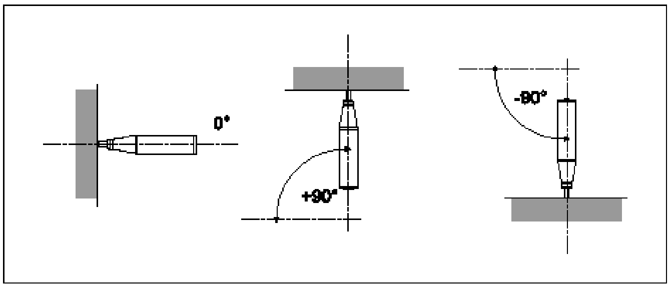
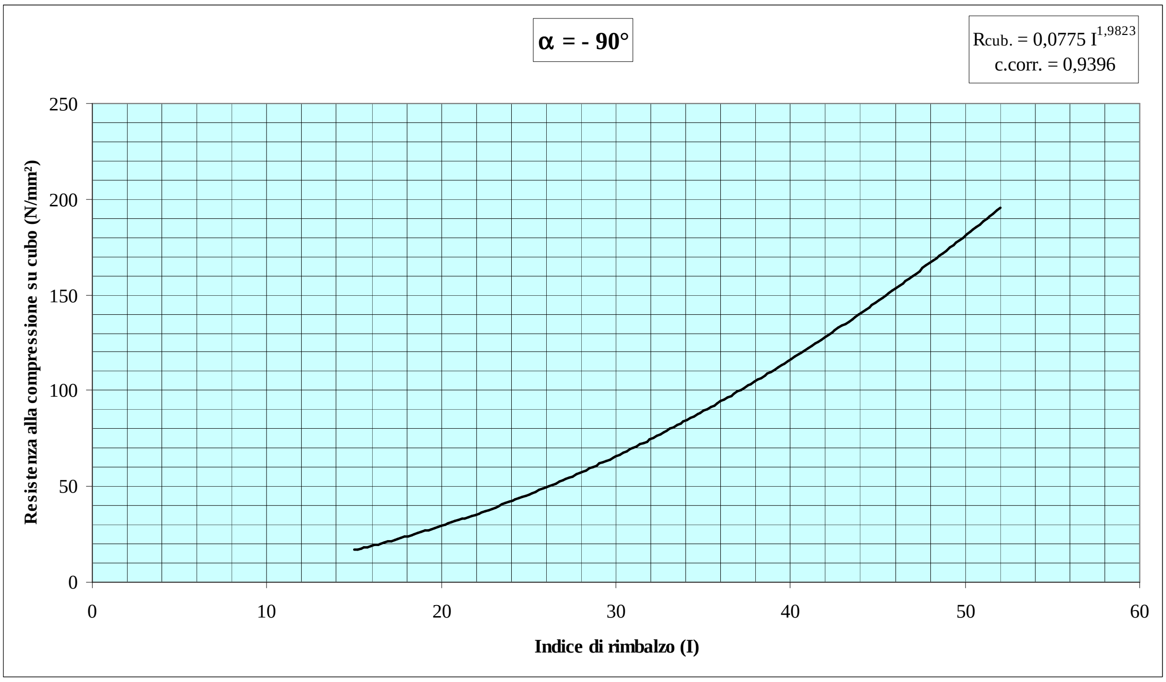


Figure no. 2



x axis: rebound number (I)
y axis: compressive strength on cube N/mm²

Figure no. 3

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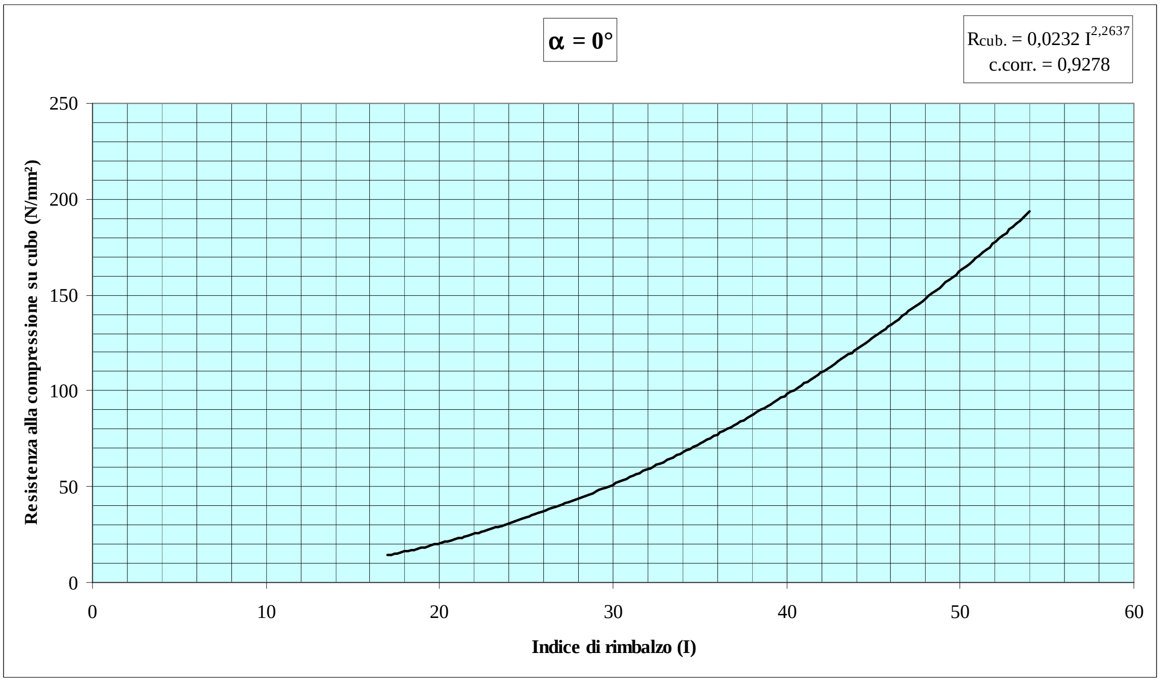
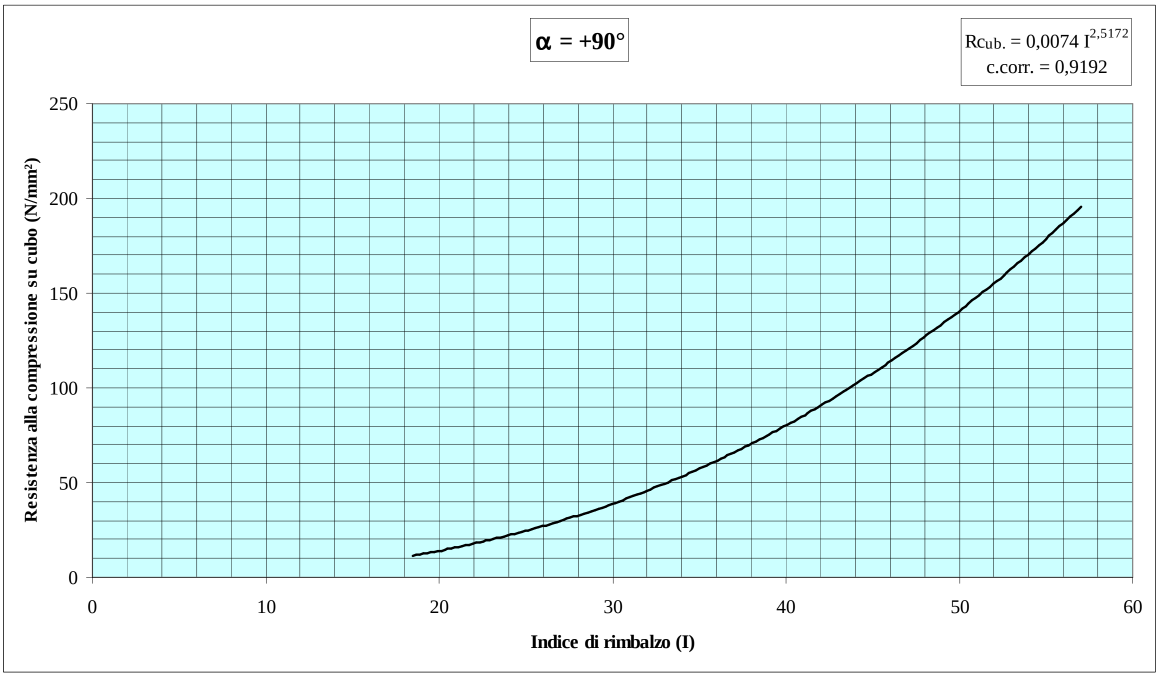
Via Montesicuro snc 60131 Ancona – Italy
Tel +39 071 8036077 FAX +39 178 2205318
C.F. e P.IVA 02478810423
info@drcitalia.it www.drcitalia.it



x axis: rebound number (I)
y axis: compressive strength on cube N/mm²

Figure no. 4



x axis: rebound number (I)
y axis: compressive strength on cube N/mm²

Figure no. 5

Acknowledgments

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[1] N.d.T.: *Technical Geology*
[2] N.d.T.: *Rocks*

DRC srl
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Tel +39 071 8036077 FAX +39 178 2205318
C.F. e P.IVA 02478810423
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