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NON-DESTRUCTIVE METHOD FOR RAPID "IN SITU" CHARACTERIZATION OF ROCKS

Ciornei N., Facaoaru I., Cetean V.

Raw Materials Laboratory, PROCEMA GEOLOGI, 136 Calea Grivitei, S1, 010707 Bucharest
georock@rdslink.ro

ABSTRACT

The effective determination of the field and place of application of the products resulting from stone working is a compulsory requirement in the building activity and is solved by laboratory analyses. This article presents details on the determination, by non-destructive method, of the compression strength of the rocks, both "in situ" (in the deposit) and in a laboratory. The originality of the method consists in simplifying the determination process of this parameter, a method that is in agreement with the systems proposed to be applied in the European Community. The method has the advantage of being applicable in quarries, where knowledge of this parameter leads to a rationalizing of the working and more especially to a selection of the blocks by quality criteria. The method is applicable to all categories of natural consolidated hard rocks, being a viable alternative for deposits with an inhomogeneous composition as to quality and structure.

1 INTRODUCTION

The qualitative characterization of the building rocks represents a requirement that is generally fulfilled by multiple and complicated operations. Each operation may bring about error elements in determining the actual value of the measured parameter. One of the considered parameters is the *compression strength*. Alone or associated with other parameters, the *compression strength* determines the field of application of the material or of the product resulting from stone working.

The starting point was constituted by the similitude between the process of determining the "in situ" compression strength of the concretes and the method specified by the European Community by which the rocks are characterized as to quality. The first tests, using non-destructive methods, were carried out in a laboratory and made possible the establishing of the working conditions, the application limits and chiefly the experimental determination of the correlations between the measured physical value and the quality of the rock.

Taking into consideration the results obtained with the equipments (Fig.1), the ultrasonic impulse method was chosen that is based on inducing impulses of ultrasonic frequency (40-60 kHz) in the tested body. The way the propagation takes place in the rock is examined and the propagation time between the emitter and a receiver is measured, by means of signal converters, a component part of equipment for concrete mark measuring.

The techniques for determining the longitudinal propagation velocity of the ultrasonic are follow (Fig.2):

- the direct transmission technique);
- the diagonal transmission technique, applicable when there are two accessible, perpendicular surfaces;
- the surface transmission technique, applicable only one testing surface is accessible.

In this technique, the energy of the received signal is minim; this is the most frequent case with the measurements carried out in quarries.

All auxiliary measures that make possible the increase of the amplitude of the received signal become extremely important.

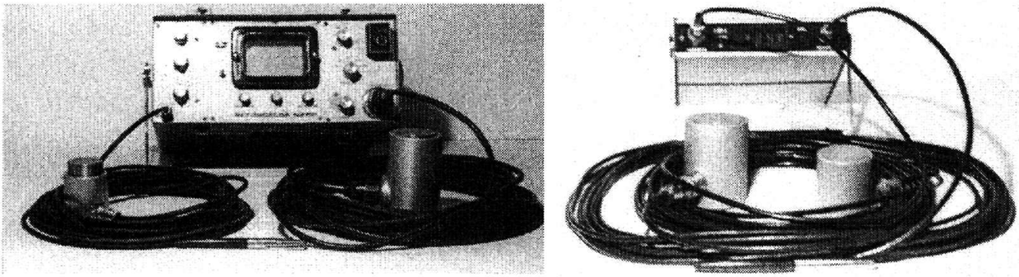

Figure 2. Sclerometer Schmidt type N, for acoustic (ultrasonic) measurements in the rocks

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Determining of the calculation relation of the Identification number was made starting from the general form (eq.1), determined experimentally:

$$I = \frac{V_L}{5435} + 2.91 \cdot \gamma_a + \frac{5.14}{D} - 4.59 \qquad (1)$$

and the values of coefficients A, B, C and D were experimentally determined by the relation (eq2):

$$I = \frac{V_L}{A} + \frac{N}{B} + \frac{\gamma_a}{C} - D \qquad (2)$$

where V_L: is the ultrasonic propagation velocity expressed in m/s, γ_a: is the volume weight expressed in t/m^3 and D: is the surface hardness of the obtained rock.

The original Romanian method proposes the uses of two physical parameters directly determined with attested equipment and are experimentally and analytically verified method. That it becomes applicable in laboratories, "in situ" in quarries or to all categories of consolidated rock blocks that are to be industrially processed. The new measuring method of the surface hardness has the advantage of making possible rock testing in the quarry on surface of every orientation. Besides requiring reduced processing of the tested surface, it offers a reduced working time and an increased sensitivity.

The results obtained under laboratory conditions for most of the ornamental and building rocks currently worked off in Romania (Fig.3).

The synthesis of the conducted tests, the processing of the data and the graphic representation of the results indicate a perfect similitude of the terms where the only differing intervening element is the correlation constant.

This conclusion is the result of the mathematical calculus and can be accepted as the ideal value for the Romanian method. It demonstrates the possibility of simplifying the correlation formulae and the qualitative characterization of the rocks elaborated at a European level, where the proposed characterization element is the *Reduced identification number.*

The reduced identification number included only the longitudinal propagation velocity and the recorded index, practically offering "in situ" possibilities of determination of the compression strength of the rocks in contrast with the Identification number (AFNOR) that is based on the measuring of three physical properties (ultrasonic wave velocity, apparent density and the surface hardness of the rock).

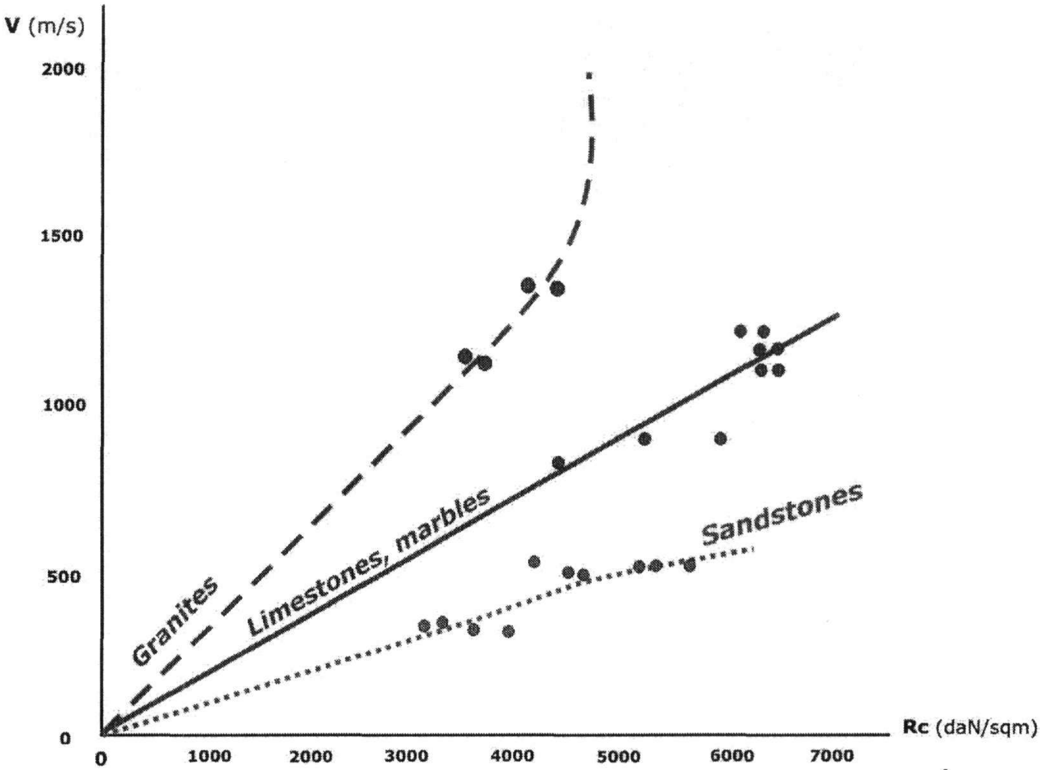

Figure 3 - Correlation graphs - longitudinal propagation velocity (m/s) / compression strength (daN/cm^2) for various categories of rocks quarried in Romania.

The proposed calculation formula has the following structure (eq.3):

$$I_R = V_L + \frac{N}{10} - 2, \qquad (3)$$

where V_L: is expressed in km/s and N: is expressed in divisions of the scale of the sclerometer Schmidt type N.

2 USE OF THE METHOD UNDER "IN SITU" QUARRY CONDITIONS

After the correlation formulae had been established the following working stage consisted in applying the working method in the most difficult working conditions, namely in quarries. The tests carried out in areas (fig.4, 5) and or rocks where the qualitative characteristics of the worked rock were not known in detail gave more than satisfactory results. The starting point was the similitude between the rock under research and some rocks for which the elastodynamic parameters had been determined in detail by tests conducted under laboratory conditions and on rock blocks.

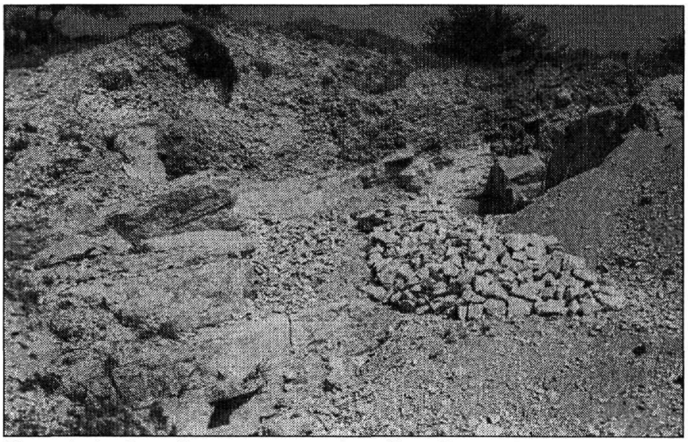 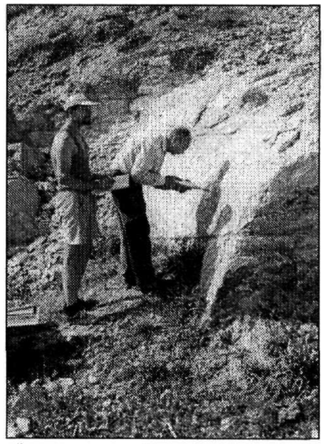

Figure 3, 4. Open limestone quarry from Slava Rusa, when carried out "in situ" tests

By comparing the results obtained for the compression strength with those subsequently determined by direct tests, the validity of the calculus relation was proved, the obtained mechanical resistances registering differences that can be included in the error tolerance limit. The correctness of the values of the longitudinal propagation velocity determined by the surface technique is verified, by comparing these values with the values of the propagation velocity measured with the direct transmission technique, insignificant differences existing between the two values

The possibility of orienting the works in the quarry depending on the required quality of the resulting quarried material should also be mentioned.

3 ESTIMATION OF THE COMPRESSION STRENGTH

3.1 General considerations

Based on the physical elements determined by non-destructive methods in the quarries, the compression mechanical strengths were calculated, equivalent to the reduced quality indices. Some examples are showed in the Table 1:

Testing direction/ perimeter	Compression strength (daN/scm)		
	1	2	3
Perpendicular to the stratification	450 – 500	550 – 600	250 – 260
Parallel to the stratification	350 – 400	500 – 550	160 – 180

The more accurate determination of the probable compression strength of the rock, based on "in situ" non-destructive tests, can be performed by means of some linear relations connecting the classic or reduced *Identification number* to the compression strength. These relations are not unique; therefore they have to be differentiated depending on the type of rock.

The research works carried out in a laboratory and on the site, followed by the processing of the data, confirmed the possibility of advancing an original Romanian methodology, as a counter - proposal to the method prepared by the European Community, consisting in reducing the number of parameters necessary for the calculation of the Identification number, from 3 to 2, by eliminating the apparent specific weight, made explicit in eq.2.

There are at least three reasons for taking such an initiative:

- as compared to the other factors depending on the propagation velocity and the recoil index, one can notice that the contribution of the term referring to the apparent specific weight in defining the Identification number, for a large number of rocks, is an almost constant quantity (frequently 2.2-2.9 g/cm^3), and for the others it represents a minor contribution ;

• the "in situ" determination of the apparent specific weight requires an equipment based in the use of gamma-radiations, either in the surface technique, by the retrodisperal method, or in the direct transmission technique, by the damping method.

The differences recorded between the compression strengths determined by a non-destructive method and those determined by classic methods on the same specimens, in a laboratory, were not higher than 10-12%, in average 8%, a tolerance considered as acceptable for the absolute values that characterize the quality of the building stone.

3.2 Determination of Identification number (inferred from 3 parameters) - compression strength correlation functions

The experimental results presented for 10 types of analyzed rocks prove that there is not an only relation between the Identification number and the compressive strength, irrespective of the type of rock. For the differentiation of the three categories of rocks, an important part was played by anisotropy degree of the rock, hence the intensity of the stratification phenomena in the rock.

The analyses made possible the inclusion of the rocks under research in 3 categories (Table 2), depending on the values obtained for the compression strength:

$Rc=f(I_R)$,under a numeric form included.

Category	I	II	III
Compression strength R_C (MP	$12.3\ I_R - 38.7$	$12.58\ I_R - 52.2$	$14.86\ I_R - 96.6$
Type of stone			
Limestone	Podeni, Baschioi, Vratza, Gura Vaii	Vistea	Caprioara
Marble	Ruschita	Moneasa	
Travertine			Geoagiu

3.3 Determination of Identification number (2 parameters) - compression strength correlation functions

To analyze the correlation functions between the Reduced identification number (I_R) and the compression strength, they were correlated with the Identification numbers. The correlations between the Reduced identification number and the compression strength can be approximated by a linear relation, obviously with other coefficients (Table 3):

Category	I	II	III
Compression strength R_C (MP	$12.3\ I_R - 29.2$	$13.02\ I_R - 41.0$	$15.65\ I_R - 84.5$

The synthesis of obtained results leads to the following conclusions:

A) The Reduced identification number consisting only in the longitudinal propagation velocity and the recoil index offers possibilities of "in situ" determination of the compression strength of the rocks and of the classic Identification number (AFNOR) based on the measuring of three physical properties, namely: the longitudinal propagation velocity, the apparent density and the apparent specific weight.

The rock qualitative classification scale, using the Reduced identification number, was given by the equation 3. Depending on this relation, the following values were obtained:

Category	Definition	Condition for I_R (Reduced identification number)
Soft rock	$R_C \leq 10$ MPa	$I_R < 3$
Semisoft rock	$10 \leq R_C \leq 40$ MPa	$3 \leq I_R < 5,2$
Semihard rock	$40 < R_C < 65$ MPa	$5.2 \leq I_R < 7.2$
Hard rock	$65 \leq R_C < 85$ MPa	$7.2 \leq I_R < 8.2$
Very hard rock	$R_C > 85$ MPa	$I_R > 8.2$

B) The more accurate calculation of the strength (the probable one of the rock to compression), based on the non-destructive tests carried out “in situ”, can be made by means of some linear relation, connecting the classic or reduced Identification number to the compression strength. These relations are not unique, and they should be differentiated depending on the type of rock.

4 CONCLUSIONS

The Romanian research works simplify this method, so that it becomes applicable in laboratories, “in situ” in quarries or to rock blocks that are to be industrially processed. The proposed method has a universal character, being applicable to all categories of consolidated rocks. The originality of the testing method consists in maintaining only two of the mentioned properties, namely the ultrasonic wave transfer velocity (V_L) and the surface hardness of the rocks (N) and the replacement of the static penetration and determination method by dynamic means, of the surface hardness parameter, with an equipment called sclerometer Schmidt type N.

Once practically verified, the working method requires certification by adopting some republican norms. The determination of the compression strength by non-destructive acoustic methods, of the Reduced normality index (I_R), should be included in the category of some qualitative parameter determination norms (standards).

REFERENCES

Jones R., Facaoaru I. 1972. The non destructive methods of concrete testing – Technical Ed., Bucharest (in Romanian)

*** 1987. Standards for concrete testing by non - destructive methods. INCERC Bucharest, C 26 – 85 (in Romanian)

Facaoaru I., Lungnani C., 1993. Contributions to the Diagnosis of Stone and Concrete by Structures by Using Non - Destructive Techniques” – Conservation of Stone and Other Materials , Vol. II , p. 238 / 251, Ed. Chapman & Hall London (in English)

Ciornei N., 1992. The use of ultrasonic non-destructive methods for establishing the massively degree of rocks, Romanian Journal of Building Materials (in Romanian)

Ciornei N., Facaoaru, I., 2001. Simplified formula for characterization and rapid testing of rocks quality by conformity with procedures of European Community, Geological Archive of PROCEMA (in Romanian)

Ciornei N., Facaoaru, I., Cetean, V., 2002. Acoustic methods for qualitative characterization of stones, Proceedings of Scientific Seminar Al. Steopoe, Technical University of Constructions, Bucharest (in Romanian and English)

Ciornei N., Cetean, V., 2003. The use of non-destructive methods for qualitative characterization of building stone, Romanian Journal of Building Materials, Bucharest (in Romanian and English)

***. AFNOR norms