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CORRELATING SCHMIDT HARDNESS WITH COMPRESSIVE STRENGTH AND YOUNG'S MODULUS OF CARBONATE ROCKS

CORRÉLATIONS ENTRE LA DURETÉ AU MARTEAU SCHMIDT ET LA RÉSISTANCE À LA COMPRESSION SIMPLE ET À LA DÉFORMATION (MODULE YOUNG) DE ROCHES CARBONATÉES

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Abstract

Schmidt hammer has increasingly been used world-wide as an index test for a quick rock strength and deformability characterization. The reason is mainly due to its rapidity and easyness in execution, non destructiveness, simplicity, portability and low cost.
Twentynine different types of Carbonate rocks from Greek territory and four ones from England have been collected and tested. The tests include the determination of Schmidt hammer rebound hardness, (N) number, Tangent Young's modulus, (Et), and Uniaxial compressive strength (U.C.S.).
Finally, these parameters were correlated and regression equations, of high practical value, were estanlished among N, Et and U.C.S., all presenting high coefficients of determination (R^2).

Résumé

Le marteau Schmidt s'utilise de plus en plus dans le monde comme un essai indicateur de qualification rapide de la résistance à la compression simple et de la déformation des roches.
Les raisons en sont surtout la rapidité et la facilité d'exécution qui ne provoquent pas de destruction, la simplicité, la portabilité et le faible coût.
Vingt neuf types différents de roches carbonatées de Grèce, et quatre types d'Angleterre ont été réunis et examinés.
Les essais comprennent la désignation de la dureté du marteau SCHMIDT, le numéro (N) du module d'élasticité de Young (Et) et la résistance à la compression simple (U.C.S.).
Ces paramètres ont été corrélés et on a déterminé les relations entre N, Et et U.C.S., qui présentent toutes des coefficients de corrélation élevés (R^2) d'une grande valeur pratique.

Introduction

Both strength and deformability characteristics of rocks, are considered to be very important parameters, necessary for the design of structures either upon or inside rocks. In addition, these properties are essential for classification of rock materials and judgement about their suitability for various construction purposes.

Determination of either compressive strength or deformability of a rock material, is time consuming, relatively expensive – if we consider that in order to produce a representative value for a large rock exposure, a great number of specimens have to be tested –, and involves destructive tests. For these reasons, substitution of these tests with a quick, non destructive, and of acceptable reliability test, as Schmidt hardness test is, would be very valuable for at least, the preliminary stage of designing a structure or for rock exposure zoning.

The International Society for Rock Mechanics, I.S.R.M. (1981), p. 30, suggests the use of the Schmidt hammer as a routine test apparatus, for determining the discontinuity wall strength in rock masses.

The Belgian unpublished recommendations for exposure mapping (p. A. 11-64) pointout the "necessity of developing various reliable correlations between Schmidt hammer rebound number obtained from outcrops, with both strength and deformation modulus of the rock" which would be applied especially to different petrological rock types.

Miller R.P. (1965) produced a general and crude correlation chart for Schmidt (L) hammer, relating rock density, compressive strength and rebound number (N), applicable to all rock types.

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Deere D.U. and Miller R.P. (1966) suggested another correlation chart for Schmidt (L) hammer, relating rock density, tangent modulus of elasticity and rebound number (N).

Ege *et al.* (1970) applied the rock test hammer technique to engineering geology field investigations in volcanic rocks.

In this paper the results of an investigation on the correlation between Schmidt rebound number (N) and compressive strength U.C.S., as well as tangent Young's Modulus, based on laboratory tests carried out on various carbonate rocks are reported.

The reason of selection of this rock type is due to the fact that carbonate rocks outcrop, covering a large percentage of Greek territory and as a result much construction activity is performed into, upon or from this rock type.

The study areas and rocks

Thirty three different carbonate rocks were sampled and tested for the execution of this study. Twenty nine rocks, out of them, were collected from various sites in Greece either from working and disused quarries or from natural rock outcrops (fig. 1). The rest four rocks were obtained from working and disused quarries in Northumberland, England (longhoughton and Mootlaw). The sampling procedure was strictly carried out according to A.S.T.M. : Spec. Tech pub. : 483, specification.

Fig. 1 : Sample localities.

Details of the study rocks and sampling locations are given in Table 1.

Specimen preparation

From each study location, block rock samples of dimensions approximately 25 × 25 × 20 cm were collected and carried to the laboratory.

After the execution of the Schmidt hammer test, (according to the I.S.R.M., Suggested Method), the blocks were cored – using a diamond impregnated drilling bit of NX core size, of approximate diameter 52 mm (only the English samples were cored using a 38 mm drilling bit.) – at a high range speed, according to the I.S.R.M. Suggested Method. The ends of the specimens were made flat and perpendicular to the axis of the specimen. Their sides were smooth and polished, and the specimens were inspected to be free of cracks, fissures, veins and other flaws which would act as selective planes of weakness and cause an undesireable change of the real properties of the rocks.

Six cores from each study rock type were prepared; four for the measurement of the uniaxial compressive strength and two for determining the deformability (tangent Young's Modulus) of Rock Materials. The Young's Modulus have been obtained by using bonded linear electrical resistance strain gauges, to the smooth parts on the sample surface (two vertical and two horizontal stain gauges on each core). The strain gauges were attached at mid – height of the specimen to minimize the end effects. Both tests were conducted in accordance with the I.S.R.M. Suggested Methods.

Review-Analysis

An extensive literature review, as mentioned in W.R. Dearman (1981) paper, has provided information and data on compressive strength and elastic modulus for various carbonate rocks (Lo, K.Y., Hori, M, 1979), including varieties of English chacks (Hobbs 1975), Jurassic limestones (Bell, 1981a,b) and Carboniferous limestones (Al – Jassar and Howkins, 1979). The results are plotted on Fig. 2. These experimentally determined results gave a relationship between average values of compressive strength and tangent modulus for the rocks tested. The relationship showed an average modulus ratio, which is defined as the specified modulus of elasticity divided by the uniaxial copressive strength, of about 300.

Deere D.U. and Miller R.P. (1966) experimenting with a great number of various petrological rock types resulted in a relationship correlating rock material density, uniaxial compressive strength and

Table 1 : Rock types tested and their locations.

Rock code Number	Petrological name	Location
1	Limestone	Longhoughton, England.
2	Limestone slightly metamorphosed	Longhoughton, England.
3	Limestone highly metamorphosed	Longhoughton, England.
4	Marble	Mootlaw, England.
5	Limestone	Laeika, Kalamata, Greece.
6	Limestone	Laeika, Kalamata, Greece.
7	Limestone	"Mpakas" Quarry, Kalamata, Greece.
8	Limestone	Katsaros, Kalamata, Greece.
9	Marble	Grammatiko, Ag. Marina, Attica, Greece.
10	Marble	Grammatiko, Ag. Marina, Attica, Greece.
11	Marble	Droutsoula, Ikaria, Greece.
12	Marble	Kampos, Ikaria, Greece.
13	Marble	Ag. Stathis, Ikaria, Greece.
14	Dolomite	Stefani, Madra, Attica, Greece.
15	Arenaceous Limestone	Vravrona, Attica, Greece.
16	Limestone	Hymmetus, Athens, Greece.
17	Oolitic Limestone	Sounio, Attica, Greece.
18	Limestone	Eleutheres, Attica, Greece.
19	Limestone	Eleusis, Attica, Greece.
20	Arenaceous Limestone	Sounio, Attica, Greece.
21	Marble	Penteli, Athens, Greece.
22	Marly Limestone	Eleusis, Attica, Greece.
23	Porous Limestone	Eleusis, Attica, Greece.
24	Marble	Merenta, Attica, Greece.
25	Dolomite	Thassos, Greece.
26	Limestone	Magnessia, Greece.
27	Marble	Kavala, Greece.
28	Limestone	Argolida, Greece.
29	Grey Marble	Ioannina, Greece.
30	Marble	Dionysos, Attica, Greece.
31	Limestone	Eretria, Evia, Greece.
32	Marble	Veria, Imathia, Greece.
33	Marble	Falakro, Drama, Greece.

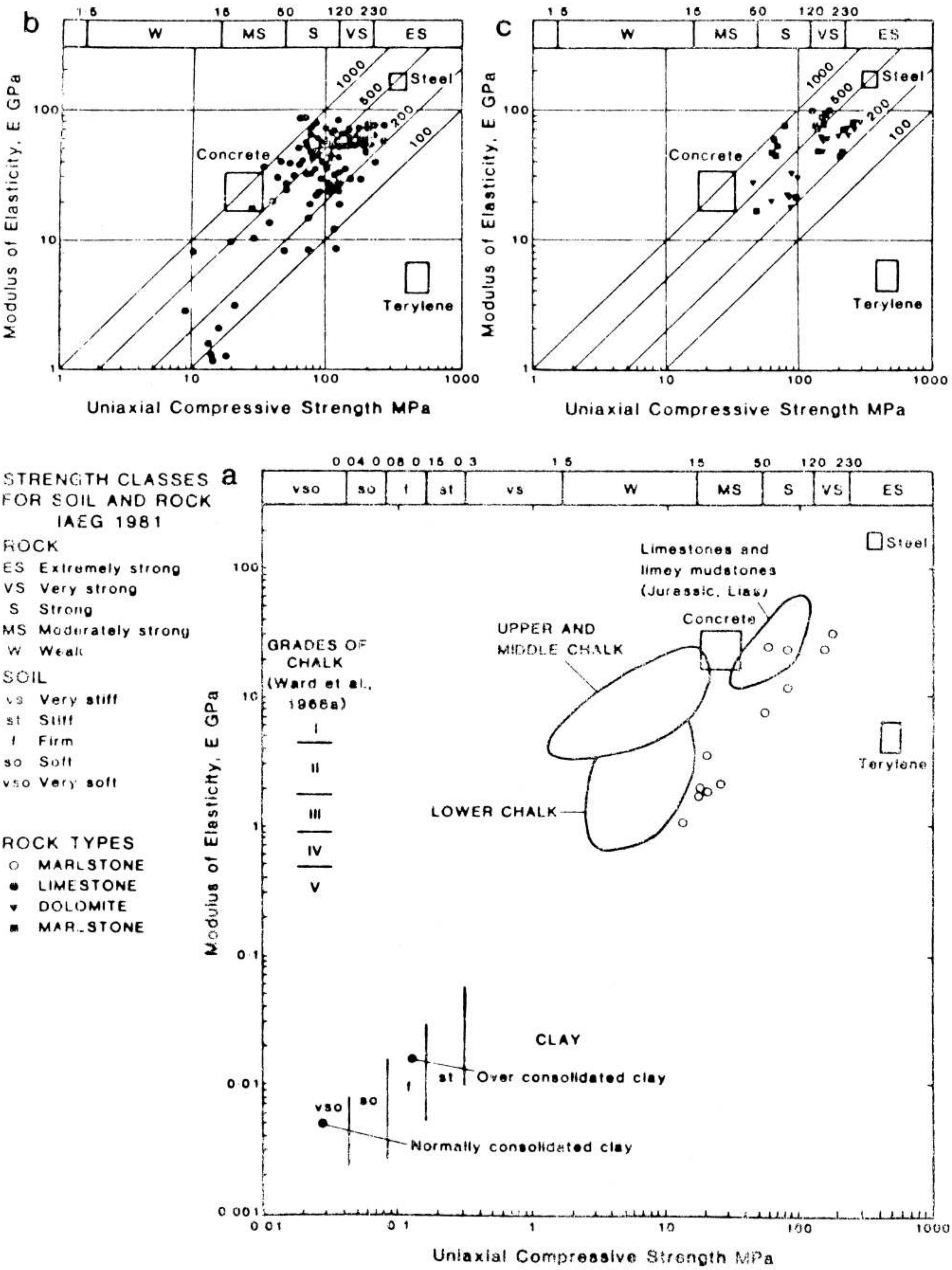

Fig. 2 : Engineering classification of limestones.
(a) the piot by Hobbs (1975) including the English Chalk and elastic modulus for chalk grades from Ward et al., 1968.
(b) additional data on limestones;
(c) additional data on dolomite, marble and marlstones.
The unconfined compressive strength scale is that adopted by IAEG in Anon., 1981.

schmidt hammer rebound number. The results are illustrated in a correlation chart as shown in fig. 3.

As it can be seen from the noted average dispersion of strength, the coefficient of determination is relatively low. Subsequently, the chart gives, in this case, only a rough means of estimating the strength of rock materials, and not a very much reliable and precise correlation method. This is mainly due to the fact that there are many factors which affect both the compressive strength and the rebound number of a rock material, such as mineralogical constituents, mineral grain size and shape, degree of grain interlocking, structure, texture and mainly porosity. These parameters differ greatly especially when a great number of rock types are involved and correlated, as in the case of Miller – Deere correlations.

Additionally, the results of S.H.R.N. and U.C.S., are not directly and precisely compared; the reason being that during compressive loading of a specimen, it is caused work which leads to a build up of potential energy within the specimen and then is released on failure, while Schmidt hammer test reflects the absolute hardness without an energy buildup. Therefore these two tests can not be strictly correlated. This different attitude and behaviour in the two tests, is even much more pronounced when a greater variety of rock materials are involved and their correlation becomes progressively weaker.

Furthermore, the same criteria are valid and applied in the case of correlating rock material compressive strength and modulus of elasticity.

However, when correlating the above mentioned properties within a certain rock group type, as carbonate rocks are, the correlation should be stronger and more reliable with higher coefficient of determination, as proved in this study.

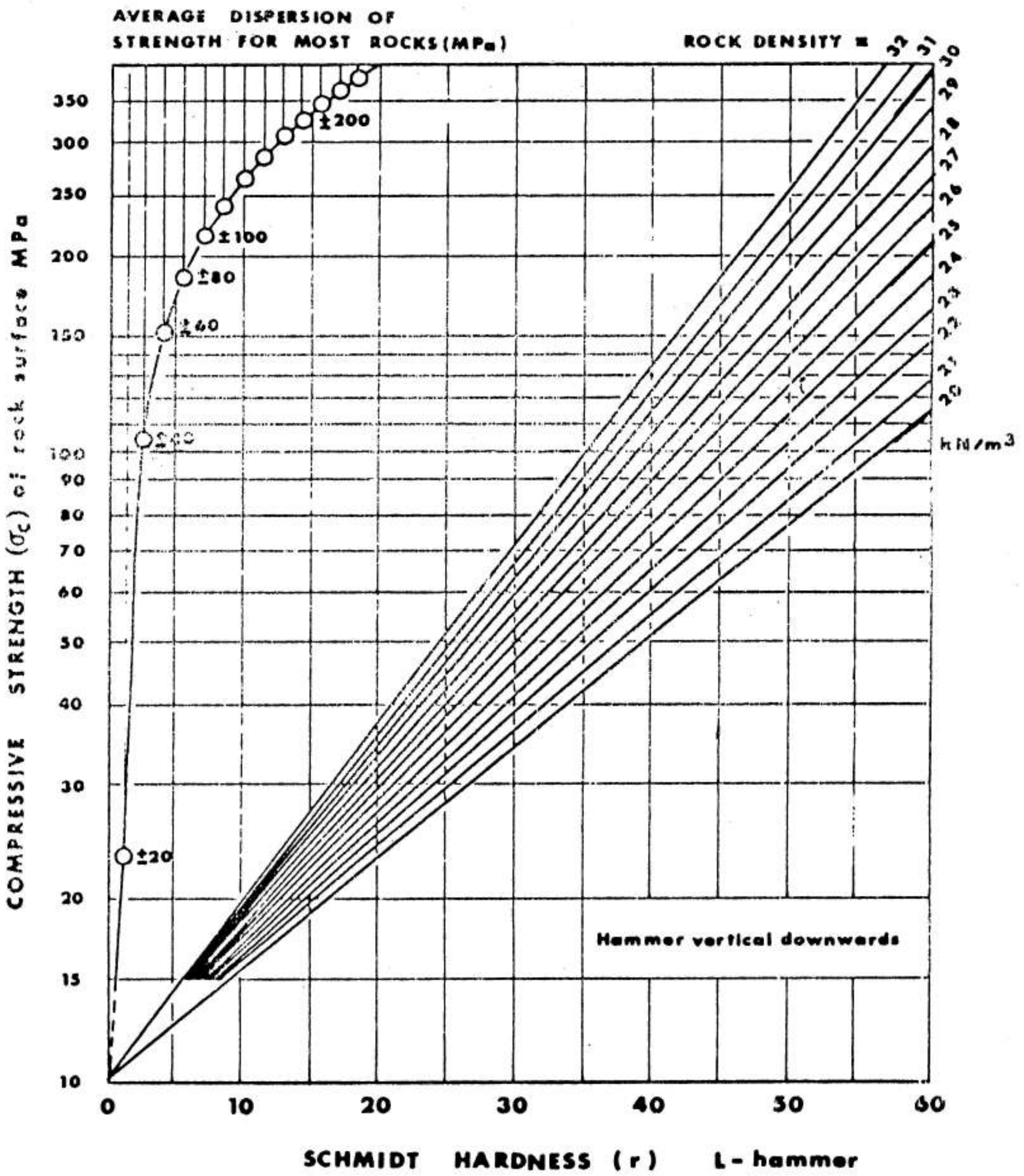

Fig. 3 : Correlation chart for Schmidt (L) hammer, relating rock density, compressive strength and rebound number after Miller et al.

Test results

Table 2 shows the rock types which have been tested with their test results. The basic test statistics are also included.

Out of the thirty three rock types tested, eighteen different rocks are generally described as limestones, thirteen as marbles and two as dolomites.

Figure 4 shows the percentage participation of the three main different petrological rock types of the carbonate rocls which were included in the study.

The U.C.S. average values range between 22 and 211, 78 and 121 and, 105 and 188 MN/m^2, in the case of limestones, marbles and dolomites, respectively. The Et average values range between 8 and 71, 29 and 48, and, 49 and 71 GPa, respectively as above. The N average values range between 16 and 59, 33 and 47, and, 40 and 60, respectively as above.

Fig. 5 shows a graphic demonstration of all test results for each rock tested.

The diagrams present a fairly consistent variation in the three properties values.

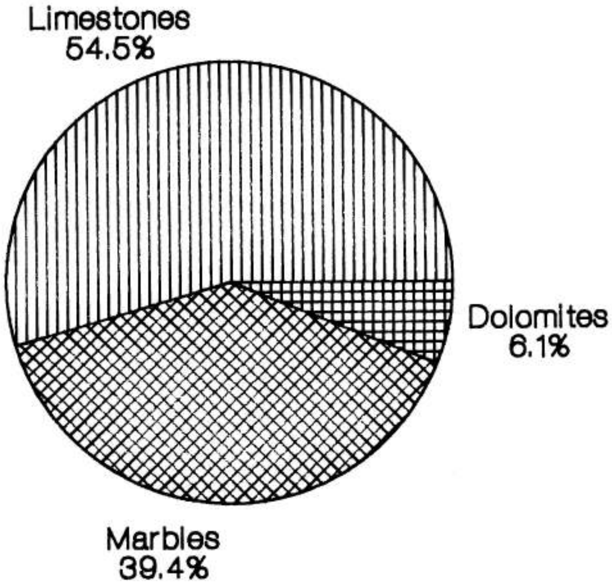

Fig. 4 : Percentage participation of rock types tested.

Table 2. Test results.

Rock Code Number	Rocktype	Tangent Young's Modulus (Et) [GPa	Uniaxial compresive Strength [MPa] (U.C.S.)		Schmidt Hammer Rebound number (N
		Average	Average	STD(1)	Average
1	L	71	311	23.1	59
2	L	47	106	8.7	38
3	L	34	81	3.2	32
4	M	57	88	5.4	33
5	L	67	157	11.1	51
6	L	59	147	18.7	50
7	L	51	133	10.0	44
8	L	64	153	8.3	48
9	M	29	91	7.6	39
10	M	32	95	19.8	38
11	M	47	101	21.3	42
12	M	31	94	11.2	40
13	M	26	83	3.7	35
14	D	71	188	5.9	60
15	L	11	29	0.8	17
16	L	38	95	1.9	39
17	L	36	82	9.7	33
18	L	51	108	11.3	42
19	L	53	103	7.4	42
20	L	8	22	0.3	16
21	M	41	85	1.7	41
22	L	29	62	3.5	31
23	L	14	38	2.1	23
24	M	48	121	11.9	47
25	D	49	105	7.3	40
26	L	52	119	6.4	47
27	M	29	78	3.9	35
28	L	29	93	7.1	40
29	M	41	89	8.2	37
30	M	61	119	7.9	45
31	L	54	109	15.6	41
32	M	46	102	31.4	43
33	M	38	92	17.3	38

M = Limestone, M = Marble, D = Dolomite, (1) STD = STANDARD DEVIATION
Notice : Four specimens were tested for the U.C.S. determination, and two ones for the Et

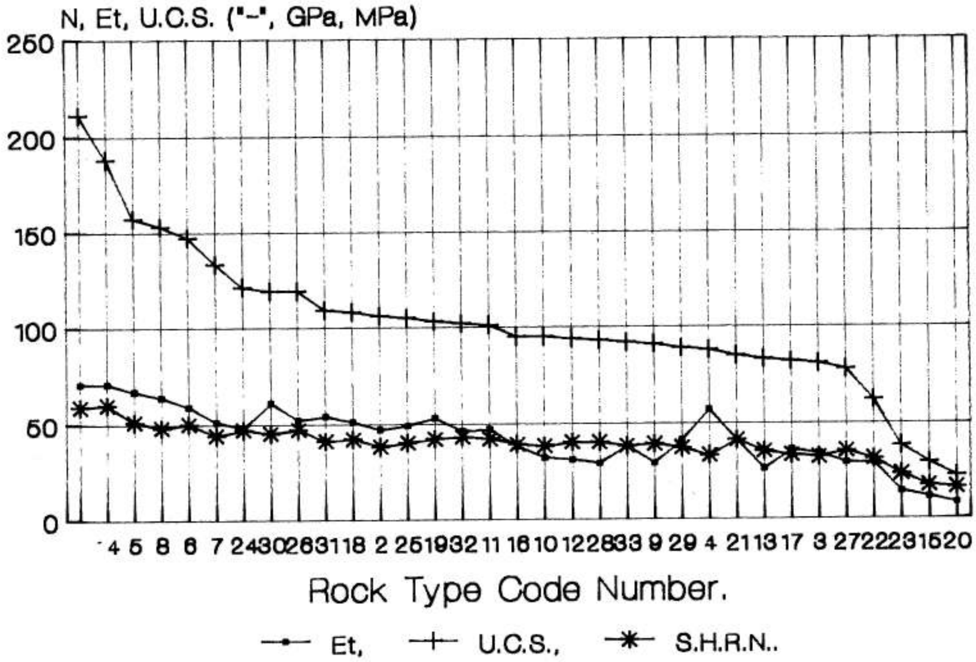

Fig. 5 : Graphical representation of average test results.

Data processing and regression analysis

Regression analysis is made to obtain the relationships amongst Schmidt Hammer Rebound Number (N), Uniaxial Compressive Strength (U.C.S.) and Tangent Young's Modulus (Et).

Thus, three regression analysis were performed, namely, between U.C.S. – N, Et – N and U.C.S. – Et, each one employing 33 imput data (No of observations).

In all these three cases, the best fitted relations were found to be straight lines.

The results of regression analysis and their related statistics, are given in Table 3.

It can be seen from Table 3 that the coeffricients of determination (R^2) can be considered as high, indicating a very good degree of accuracy in using these equations.

Figure 6 shows the plot of the Uniaxial Compressive Strength (U.C.S.) against the Schmidt N value for thirtythree carbonate rock samples tested. The test results have, on the whole, shown a very good fit to the regression straight line.

Figure 7 shows the plot of Tangent Young's Modulus, (Et) against Schmidt N value for the same rock samples. In this case, there exist a good fit to the regression straight line, although with a lower degree of accuracy as indicated by its lower coefficient of determination (R^2).

Finally, figure 8 shows the plot of U.C.S. against Et. Again, the regression straight line represents a good correlation between the two tested properties, indicating a relatively high degree of accuracy in using it.

Discussion

The correlations performed amongst U.C.S. – Et – N values suggest that there exist acceptably accurate mathematical equations relating these properties in the group of Carbonate Rocks. As indicated by the computed coefficients of determination (R^2), the correlation of U.C.S. and N values gave the higher degree of accuracy, whilest in the case of U.S.C. – Et and Et – N correlations, this degree was found to be somewhat lower, but nevertheless statistically acceptible.

However, the population of the analyzed and correlated data is relatively limited in this study, in order to establish the final and most precise equations which could be applied with absolute confidence.

Table 3 : Regression Analysis results

	Parameters related	Regression equation Y = X.A + B	No of Observations	Std Err of Y Est	Std Err of Coef.	R^2
1	U.C.S. – N	N = (U.C.S.) × 0.2329 + 15.7244	33	2.7793	0.0125	0.9178
2	Et – N	N = (Et) × 0.5155 + 17.4880	33	4.5833	0.0497	0.7764
3	U.C.S. – Et	Et = (U.C.S.) × 0.3752 + 4.479	33	7.1242	0.0321	0.8151

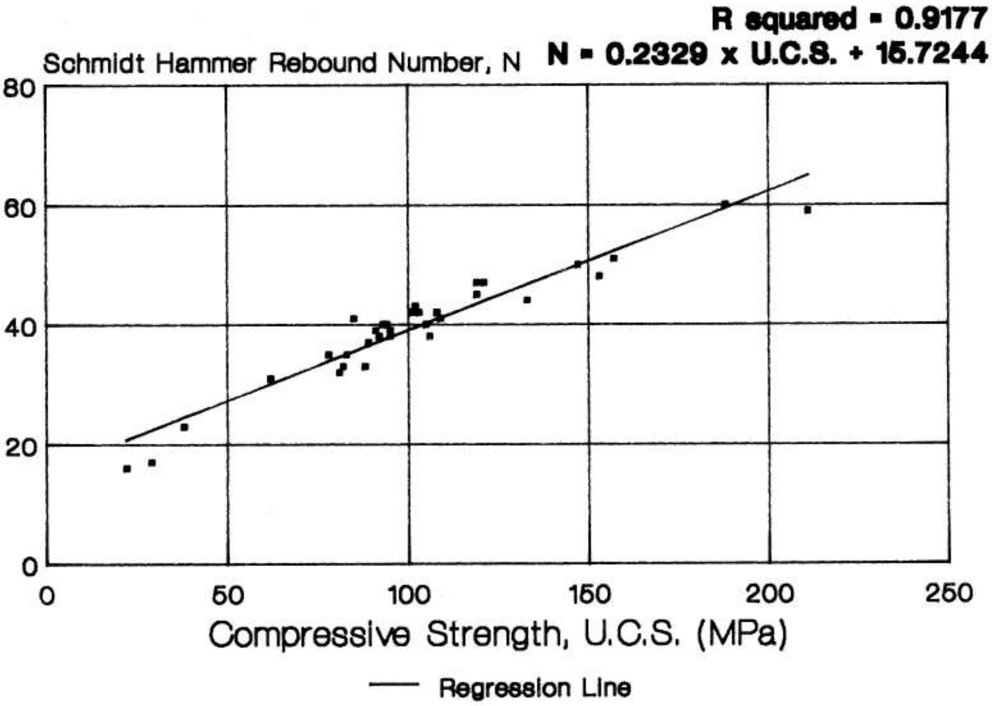

Fig. 6 : U.C.S. vs N correlation for carbonate rocks.

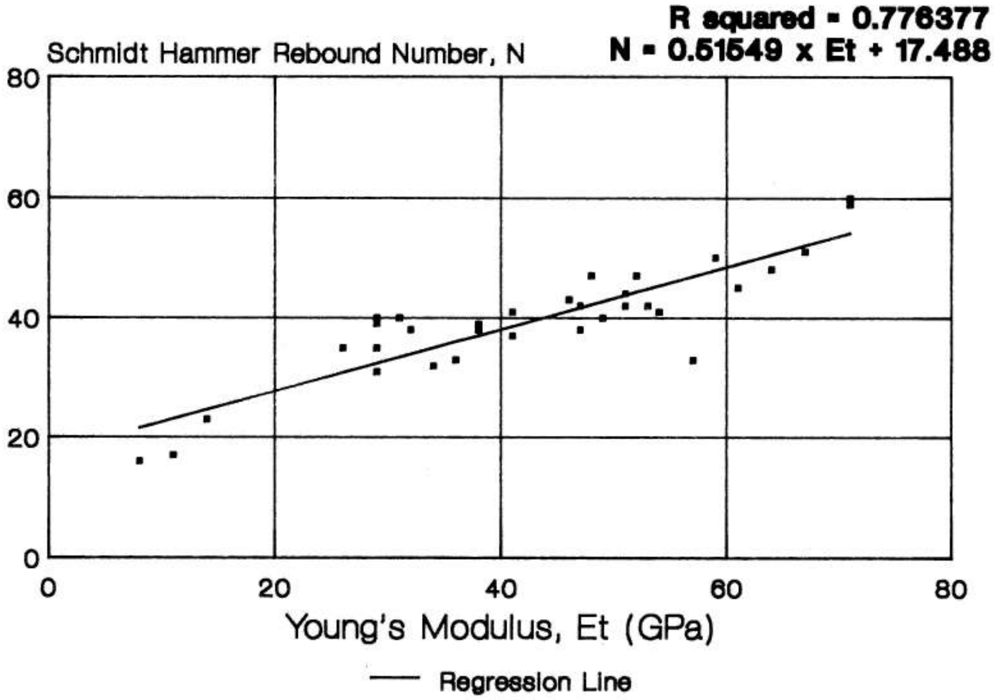

Fig. 7 : Et vs N correlation for carbonate rocks.

Thus, it is suggested that further research should be carried out in this field both in the carbonate rock group and in other rock groups such as volcanic, igneous, schistose, and other rock types. But, nevertheless, the equations determined by this research could be considered as a good introduction and initialization for further work into this direction.

In addition, the proposed equations give a means of estimating both the U.C.S. and Et of a carbonate rock from its Schmidt Hammer Rebound Number (N). The computed relations are very useful especially when there is not enough rock material available to carry out both tests, which, as it is known, are time – consuming, relatively expensive, destructive and require special testing apparatus.

Therefore, the practical outcome of the proposed equations is that these equations can be used, with acceptible accuracy, at the preliminary stage of designing a structure upon or inside a carbonate rock formation, as well as for the assessment of the men-

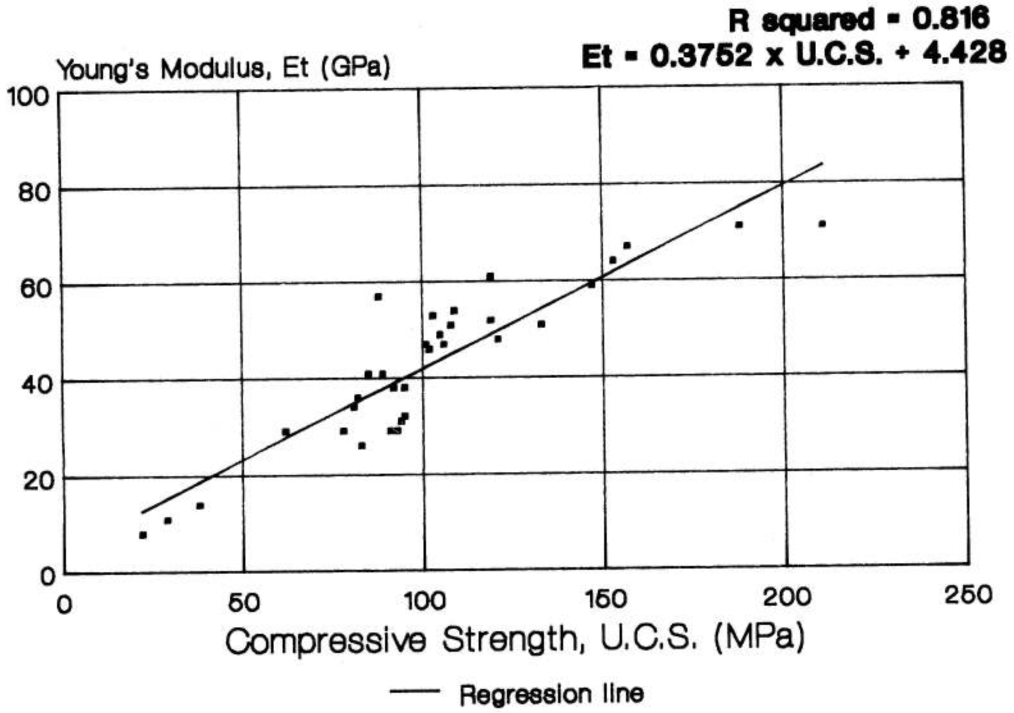

Fig. 8 : U.C.S. vs Et correlation for carbonate rocks.

tioned rock material properties of various carbonate building stones.

Conclusions

From this research, it appears that there is a possibility of estimating both Uniaxial Compressive Strength (U.C.S.) and Tangent Young's Modulus (Et) of various Carbonate rocks, from their Schmidt Hammer Rebound Number (N), by using simple mathematical relations at relatively good approximation.

Both U.C.S. versus N and Et versus N plots show linear relationships. The correlating equations are as follows :

1) **N = U.C.S. × 0.2329 + 15.7244 with R^2 = 0.92,**

2) **N = Et × 0.5155 + 17.488 with R^2 = 0.78, and**

3) **ET = U.C.S. × 0.3752 + 4.4279 with R^2 = 0.82.**

These equations can be used only in Carbonate rocks with acceptable accuracy, especially at the preliminary stage of designing a structure upon or inside a rock formation, or for assessing the properties of a building stone. In addition, there is a need to carry out further work in this area, in order to establish similar equations for the rest rock groups as well.

Finally, these equations are practical, simple and accurate enough to apply and are strongly recommended to be used in practice.

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