

## ELASTIC PROPERTIES OF ROCKS

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### Abstract

*The aim of this paper is to determine the elastic parameters of some rocks and especially limestones, schist, sandstones, conglomerates, peridotites and granites using a large number of laboratory tests performed on intact rock samples. The range of values for Young's modulus and uniaxial compressive strength is evaluated, while the relationship between elastic and strength parameters is defined. Regression analyses were applied to define relations among these parameters and the range of values of modulus ratio (MR) is estimated for each rock type.*

**Key words:** *Young's modulus, uniaxial compressive strength, modulus ratio, deformability, laboratory testing.*

### 1. Introduction

Deere and Miller (1966) proposed the classification of intact rock based on the ratio of tangent modulus of elasticity,  $E_t$ , to unconfined compressive strength ( $\sigma_c$ ) in five classes, from A (very high modulus ratio,  $E_t/\sigma_c > 500$ ) to E (very low modulus ratio,  $E_t/\sigma_c < 50$ ) respectively.

Hoek and Diederichs (2006) used this modulus ratio, calling this MR, along with the GSI value of the rock mass classification in order to estimate the rock mass deformation modulus,  $E_{tm}$ , giving general guidelines for the selection of MR values in the case of lack of experimental data.

In this paper the range of MR values for some representative Greek rocks is estimated and the obtained values are compared with those proposed by Hoek and Diederichs (2006) regarding GSI application.

### 2. Test procedure

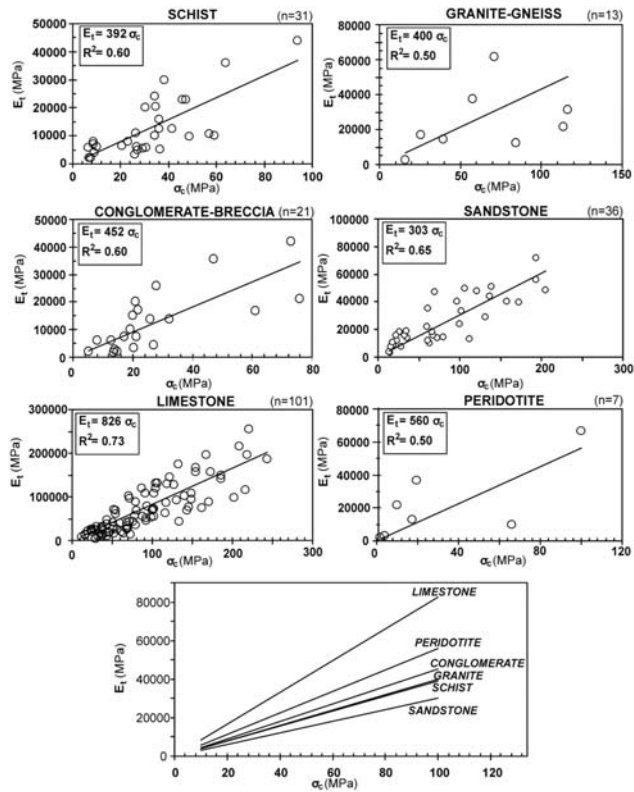
A number of block samples were obtained from different outcrops of rocks formations. The sampling locations were widely distributed around the Greek territory. Laboratory core drill and saw machines were used to cut the samples and end faces in order to provide cylindrical specimens in size, shape and ends geometries according to testing requirements. The specimen size was 54 mm (NX) to 80 mm in diameter with a length to diameter ratio of 2.0 to 2.5. The execution of laboratory tests on intact rock material was in accordance with I.S.R.M. suggested methods (1981) and A.S.T.M. standards (D 3148-93). More specifically, the parameters of rocks specimens determined by tests carried out in laboratory, in dry conditions for a better comparison of the results, were uniaxial compressive strength (UCS- $\sigma_c$ ), and  $E_t$  (elastic Young's modulus). Finally, laboratory tests were conducted in more than 200 intact rock specimens.

**Table 1.** Results of intact rock elastic parameters

<b>Results and statistical parameters</b>	$\sigma_c$ (MPa)	$E_t$ (MPa)	$MR = E_t / \sigma_c$
<b>schist</b>			
Minimum value (Min)	5.2	2000	134
Maximum value (Max)	94.0	44000	920
Mean value (Mean)	32.5	12690	445
Standard deviation (Std dev)	20.2	10286	230
Number of samples (n)	31	31	31
<b>peridotite</b>			
Minimum value (Min)	1.9	2050	152
Maximum value (Max)	100.0	66600	2235
Mean value (Mean)	31.2	21926	1082
Standard deviation (Std dev)	34.5	21361	676
Number of samples (n)	7	7	7
<b>conglomerate</b>			
Minimum value (Min)	5.2	1700	124
Maximum value (Max)	76.0	41800	962
Mean value (Mean)	25.5	13043	473
Standard deviation (Std dev)	13.9	11117	264
Number of samples (n)	21	21	21
<b>sandstone</b>			
Minimum value (Min)	13.5	3420	120
Maximum value (Max)	205.7	71750	727
Mean value (Mean)	80.9	26364	371
Standard deviation (Std dev)	56.4	17481	164
Number of samples (n)	36	36	36
<b>limestone</b>			
Minimum value (Min)	11.8	4700	160
Maximum value (Max)	243.9	254470	1445
Mean value (Mean)	89.7	71868	766
Standard deviation (Std dev)	56.8	59194	323
Number of samples (n)	101	101	101
<b>granite – gneiss</b>			
Minimum value (Min)	15.9	2590	147
Maximum value (Max)	116.6	88790	865
Mean value (Mean)	64.8	31874	455
Standard deviation (Std dev)	37.8	27410	285
Number of samples (n)	13	13	13

### 3. Test results – correlations between rock properties

The values of the determined elastic and strength rock material properties are summarized in Table 1. As it shown in Table 1, the MR values for tested rock specimens range as follows: 134 to 920 for



**Fig. 1:** Correlation between elastic Young's modulus  $E_t$  and uniaxial compressive strength  $\sigma_c$  for various rock material.

schist (loading perpendicular to weakness plane), 152 to 2235 for peridotites, 124 to 962 for conglomerate, 120 to 727 for sandstone, 160 to 1445 for limestones, and 147 to 865 for granite.

Regression analysis was applied to define the relation among elastic rock properties. The regression procedure was to fit a line through the points, which is computed so that the squared deviations of the measured points from that line are minimized. The line in a two-variable space was defined by the relevant equation, whereas the value of coefficient of determination or R-square value was also determined. The R-square value is an indicator of how well the model fits the data.

Comparing the determined MR values with those suggested by Hoek and Diederichs (2006), it is concluded that the MR values of the specimens tested and especially peridotite present a greater range.

Moreover, the relationships between  $E_t$  and UCS for rock specimens tested are expressed by the equations (Fig. 1):

$$E_t = 392 \cdot \sigma_c \text{ for schist } (E_t: \text{MPa}, \sigma_c: \text{MPa}), R^2 = 0.60 \quad (1)$$

$$E_t = 400 \cdot \sigma_c \text{ for granites - gneiss } (E_t: \text{MPa}, \sigma_c: \text{MPa}), R^2 = 0.50 \quad (2)$$

$$E_t = 452 \cdot \sigma_c \text{ for conglomerate - breccia } (E_t: \text{MPa}, \sigma_c: \text{MPa}), R^2 = 0.60 \quad (3)$$

$$E_t = 303 \cdot \sigma_c \text{ for sandstones } (E_t: \text{MPa}, \sigma_c: \text{MPa}), R^2 = 0.65 \quad (4)$$

$$E_t = 826 \cdot \sigma_c \text{ for limestones } (E_t: \text{MPa}, \sigma_c: \text{MPa}), R^2 = 0.73 \quad (5)$$

$$E_t = 560 \cdot \sigma_c \text{ for peridotites } (E_t: \text{MPa}, \sigma_c: \text{MPa}), R^2 = 0.50 \quad (6)$$

The above estimated relations for limestone and sandstone (eq. 4 and 5) are quite similar to those previously suggested by Sabatakakis et al (2009). It is noted that the eq. 5 in this study include a complementary number of about fifteen data pairs.

Tuğrul and Zarif (2000) suggested similar linear function for limestones, while power functions have been reported by Duncan and Dunne (1967), Dearman and Irfan (1978), Irfan and Powell (1985), Turk et al. (1994), Gupta and Rao (2000) for igneous, metamorphic and sedimentary rocks having different degree of weathering.

#### 4. Conclusions-Results

The evaluation of strength and deformability parameters of rocks obtained by laboratory test results led to the establishment of regression equations among elastic rock properties. A linear function exists between Young's modulus and unconfined compressive strength with RM values ranging a lot. The mean MR values for tested rock specimens are as follows: 392 for schist (loading perpendicular to weakness plane), 560 for peridotites, 452 for conglomerate, 303 for sandstone, 826 for limestones, and 400 for granite. The variability of deformability parameters is mainly related to the textural characteristics and composition changes of the rock material.

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