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STRENGTH AND DEFORMABILITY OF SPECIFIC SEDIMENTARY AND OPHIOLITHIC ROCKS

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Abstract

The paper deals with the evaluation of strength and deformability of sedimentary rocks and ophiolites based on the processing of laboratory testing results. Characteristic values and their typical range for the parameters σ_{ci}, E_i, as well as the Modulus Ratio (MR) are presented. These parameters are significant for the estimation of the strength and deformability of the rock mass since σ_{ci} is basic component for the solution of Hoek-Brown failure criterion and Ei and MR are important components of the latest rock mass deformability expression (Hoek-Diedrichs, 2006). The recent site investigation and laboratory work undergone for the design of numerous tunnels in the Greek territory provided very good and sufficient data, derived from a specifically established database, for the estimation of strength and deformability of specific rocks. These rocks are sandstones and siltstones of flysch and molassic formations, as well as limestones and ophiolites.

Key words: *rock strength, deformability, Modulus Ratio (MR), sedimentary rocks,ophiolite*

1. Introduction

Geotechnical engineering works such as surface and underground excavations requires strength and deformability rock parameters for a detailed design analysis. Most of the cases these parameters concerns the rock mass properties. However, the estimation of the rock mass properties, through certain relations, requires the intact rock strength and deformability values. Indeed the uniaxial compressive strength (UCS) of the intact rock is a basic component on the Hoek and Brown failure criterion (Hoek et al., 2002), which is used for the rock mass strength estimation. In addition, the deformation modulus of the intact rock (E_i) or the Modulus Ratio (MR) is often comprehended in several empirical relations for the calculation of the rock mass deformation modulus (E_{rm}). Such relations are suggested by Hoek and Diederichs (2006), Ramamurthy (2004), Sonmez et al. (2004) and Zhang and Einstein (2004). Some other important application of uniaxial compressive strength includes rock mass characterization and excavation method selection. Nevertheless, estimation or selection of an appropriate value of UCS or E_i can be difficult, since it can vary for the same rock.

A tool of this research was a database named "Tunnel Information and Analysis System" (TIAS) established in the frame of the PhD research of the author (Marinos, 2007). Through this database, a great number of geological, engineering geological and geotechnical data from the design and the construction of 62 tunnels of Egnatia Highway in Northern Greece were processed. A significant part of the input information in the database is the laboratory test results of several rocks. These data were evaluated and a result of this research is the definition of characteristic values for the Uniaxial Compressive Strength (UCS), intact rock deformation modulus (E_i) and Modulus Ratio (MR) for several rocks. The rocks that are examined in this paper are those of sandstone, siltstone, conglomerate, marly limestones and peridotites. It is noted that the properties of the clastic rocks (sandstone, siltstone and conglomerate) are examined for both flysch and molassic environments, since they present particular differences in their nature.

2. Strength and deformability parameters

2.1 Characteristic values of sedimentary rocks

The study for the uniaxial compressive strength (UCS) and the deformation modulus (E_i) of the sandstone, siltstone and the conglomerate intact rocks was done, based on numerous lab test results from the TIAS database. The great number of lab testing in these rocks enabled this process, reducing the possibility of error or confused values. These data were derived from the design of 13 tunnels in a flysch and 12 tunnels in molassic environment and are examined separately due to their different nature.

Both formations are characterized mainly by rhythmic alternations of sandstone and pelitic rocks (siltstones, silty or clayey shales). Conglomerate beds may also be included. Flysch is associated with orogenesis, since it ends the cycle of sedimentation of a basin before the paroxysm folding process. Molassic deposits were deposited during a quiescent period after the main orogenesis and have not suffered from compression. Naturally, flysch and molassic rock strength and deformability vary from place to place but their diverse sedimentation environment and compression history creates notable differences in their values.

The mean, minimum and maximum value of the uniaxial compressive strength (UCS) and deformation modulus (E_i) of these intact rock materials for flysch and molassic formations are presented in Table 1. The higher UCS values are presented in flysch sandstone with a mean value of 43MPa, a minimum of 10 MPa and a maximum of 120 MPa. Similar range is noted in molassic sandstone but with a mean value of 35 MPa. As far as the E_i is concerned, a mean value of around 13000MPa is observed for a flysch sandstone and 8700MPa for a molassic one. In siltstones a mean UCS value of around 16-17MPa is evaluated for both flysch and molassic formations, while Ei is estimated 4600MPa in a flysch environment and 3000MPa in molassic series. Conglomerates present UCS values between 16MPa (flysch) and 23MPa (molasse) and E_i values between 4600MPa (flysch) and 7400MPa (molasse).

It should be highlighted here, that siltstones and silty sandstones are susceptible to slaking, thus the rock after its atmospheric exposure can be rapidly altered, schistosed or even disintegrated. Thus, it is very important to test the specimen immediately in site if possible after their recovery, in order not to obtain very low results. In addition, point load may not be adequate to measure the strength, since the pressure point may "invade" within the weak rock. Anyhow, testing must be applied vertical to the direction of the rock fissility.

Accordingly, the mean, minimum and maximum UCS and E_i values for marly limestones are presented in Table 1. These values are generally low, because of their marly nature, with a mean UCS value of 21MPa and a maximum close to 50MPa.

2.2 Characteristic values of ophiolithic rocks

Measuring the strength of the intact rock, from such rock masses is always a problem because of the

Table 1. Characteristic UCS and Ei values, their typical range and standard deviation (STD) for sedimentary rocks and peridotites

Rock material	Rock material properties	Number of tests	Min	Max	Mean	STD
Sandstone (flysch)	UCS (MPa)	238	10.00	119.60	46.07	28.85
	Ei (MPa)	130	2019	56000	13354	12892
Sandstone (molasse)	UCS (MPa)	258	10.76	116.73	35.06	21.05
	Ei (MPa)	132	2000	31300	8763	7373
Siltstone (flysch)	UCS (MPa)	107	2.43	62.00	17.36	12.68
	Ei (MPa)	76	698	17000	4628	4116
Siltstone (molasse)	UCS (MPa)	152	1.92	51.11	16.91	10.77
	Ei (MPa)	58	650	9070	2984	1845
Conglomerate (flysch)	UCS (MPa)	61	5.18	54.00	16.16	2.37
	Ei (MPa)	48	669	14400	4588	3321
Conglomerate (molasse)	UCS (MPa)	165	5.00	68.19	23.05	13.86
	Ei (MPa)	82	1140	19400	7432	5096
Marly Limestone	UCS (MPa)	35	5.71	49.00	20.64	10.93
	Ei (MPa)	30	725.93	15980	3844	2072
Peridotite	UCS (MPa)	118	12.20	131.60	43.34	24.62
	Ei (MPa)	33	5000	44554	19924	11874

influence of ‘‘schistosity’’ which reduces the strength. A number of lab test results of the uniaxial strength (UCS) and deformation modulus (Ei) of peridotites were processed and the values are presented in Table 1.

A great range in both UCS and Ei values is presented. The mean value of the uniaxial compressive strength is 43MPa ranging from 12MPa to 130MPa. When peridotites are not serpentised they have a range of UCS from 50 MPa to more than 100 MPa. On the other hand, UCS is considered 40 MPa for the serpentinite and 30 MPa for the schisto-serpentinite (Marinos et. al., 2005).

3. Modulus Ratio (MR)

3.1 General

Hoek and Diedrichs (2006) proposed a new equation for the estimation of the rock mass deformation modulus E_{rm} (1).

$$E_{rm} = Ei\left[0.02 + \frac{1 - D/2}{1 + e^{((60+15D-GSI)/11)}}\right] \tag{1}$$

, where, E_i the intact rock deformation modulus, GSI is the Geological Strength Index and D the Disturbance factor due to the excavation method.

Table 2. Suggestions of MR values by Deere (1968) and Palmstrom and Singh (2001).

Rock material	MR value range
Sandstone	200-350
Siltstone	350-400
Conglomerate	300-400
Crystalline Limestone	400-600
Sparitic Limestone	600-800
Micritic Limestone	800-1000
Peridotite	250-300

This relation resulted after the evaluation of insitu tests on the deformability of the rock mass, together with information on the uniaxial compressive strength (UCS) and geological description of the rock mass. These information, allowed an analysis where the ration E_{rm}/E_i could be used. For this approach the Modulus Ratio (MR) after Deere (1968) is used for several rock types. The Modulus Ratio (MR) for the intact rocks is calculated from the equation (2):

$$E_i = MR\sigma_{ci} \tag{2}$$

, where, σ_{ci} is the uniaxial compressive strength (UCS) of the intact rock.

Hoek and Diedrichs (2006) note that the MR values are difficult to be calculated in precise, since a slight disturbance in rock state and structure (especially for weak rocks) can be crucial to the σci measure. A certain range of MR values are suggested by Deere (1968) and Palmstrom and Singh (2001) (Table 2.)

Previous research on sedimentary rocks in Greece provided MR value ranges for sandstone specimens from 120 to 727, with a mean value of 303 and for limestone specimens from 160 to 1380, with a mean value of 810 (Sabatakakis et al., 2008). Moreover, Tziallas et al. (2009) proposed a typical range of MR values for sandstones between 200 and 400 and for limestones between 300 and 500.

MR values for several sedimentary rocks and ophiolites are proposed in this paper after the evaluation of numerous lab tests processed from TIAS database.

3.2 Modulus Ratio (MR) characteristic values

Modulus Ratio (MR) is calculated from the correlation of the uniaxial compressive strength (UCS) and deformation modulus of the intact rock (Ei). The MR (Ei/UCS) correlation diagrams of sandstone, siltstone and conglomerate are separately presented for flysch (first column) and molassic (second column) formations in Fig. 1. MR value is estimated by a best fitted curve (confident limits 95%), where a range of possible values is also noted (grey area). Similarly, the UCS-Ei correlation diagram that provides the MR value for the limestone and peridotitic rocks is shown in Fig. 2.

The mean MR values (best fitted curve) and their typical range were calculated from the correlation of UCS and Ei lab tests and the results are presented in Table 2.

Table 3. Characteristic MR values and their typical range for sedimentary and ophiolithic rocks

Rock material	Number of tests	MR value	
		Range	Mean*
Sandstone (flysch)	72	80-300	140
Sandstone (molasse)	123	100-260	170
Siltstone (flysch)	65	100-400	245
Siltstone (molasse)	58	120-220	160
Conglomerate (flysch)	45	110-400	230
Conglomerate (molasse)	79	180-670	375
Marly Limestone	25	100-300	170
Peridotite	34	230-760	420

*Mean value is estimated by best fitted curve (confident limits 95%)

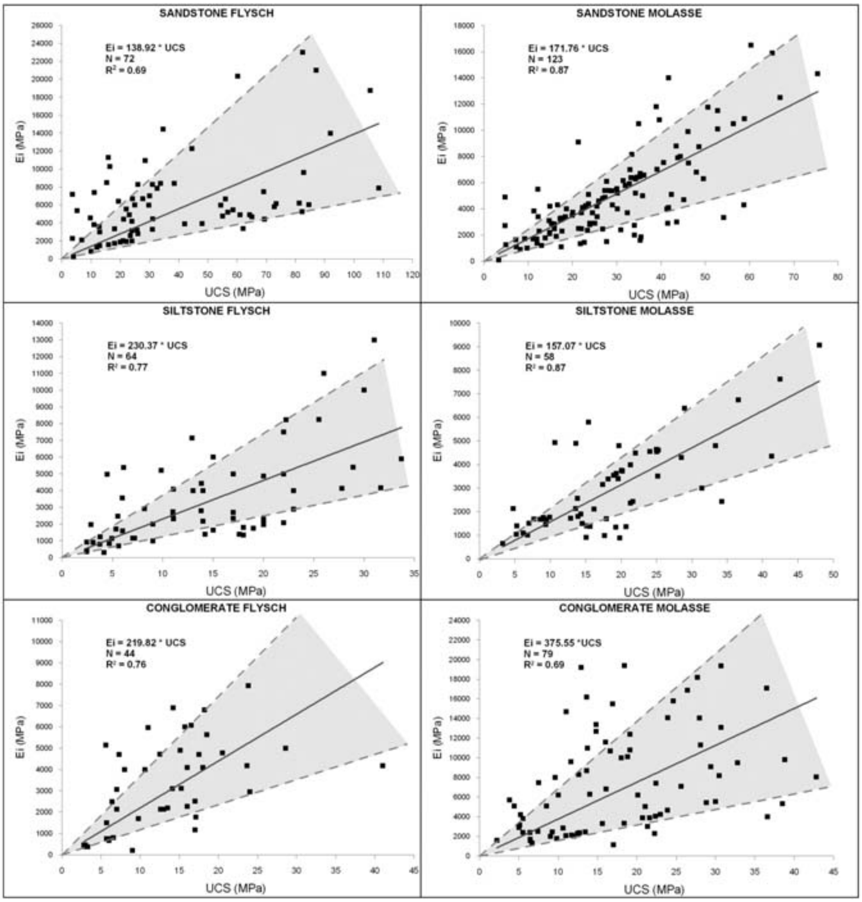

Fig. 1: UCS-Ei correlation diagram that provides the MR value of sandstone, siltstone and conglomerate for flysch (left column) and molassic (right column) formations

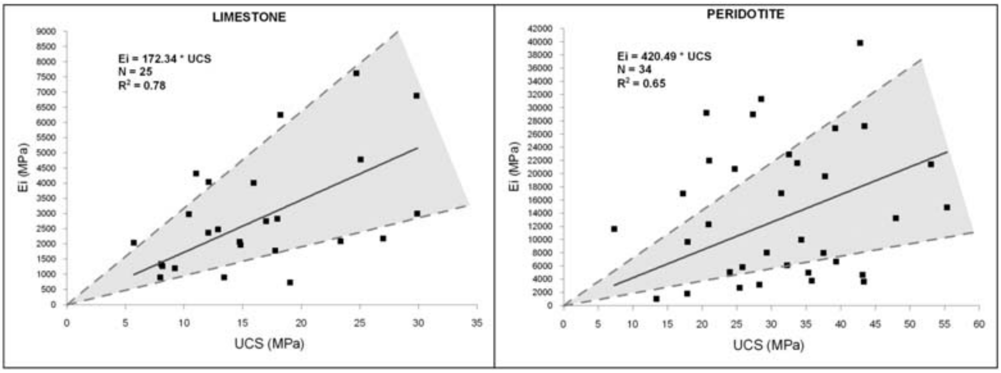

Fig. 2: UUCS-Ei correlation diagram that provides the MR value for the marly limestones and peridotites.

4. Discussion

4.1 Discussion on strength and deformability results

The uniaxial compressive strength of a sandstone in flysch formations is around 40-45MPa which is higher than the molassic one. Sandstone composite in molasses are often silty or marly and present lower strength values. The uniaxial compression strength may be around 10MPa when it is silty or marly and it can be over 50MPa in its typical granular form. A typical value that best describes the sandstone intact rock strength in molassic formations, in Northern Greece is 30-35MPa. On the other hand, typical intact rock strength of siltstones in flysch and molasses is around 15MPa. Nevertheless, when siltstones have high presence of clayey minerals the uniaxial compressive strength ranges between 5MPa to 10MPa. In conglomerates, the uniaxial compressive strength of the molassic formations is around 20-25MPa, while lower values (~15-17MPa) are met in flysch formations due to the poorer cement.

Similar differences are also met in the Ei values, as far as the sandstone is concerned. The deformation modulus (Ei) of the sandstone in a flysch environment is much higher than the molassic one. This is caused mainly due to the low compression during the sedimentation of the molassic formations. Smaller difference is also observed in the siltstone rocks. On the other hand, the Ei value of a conglomerate in molassic sediments is much higher than the flysch one. Here, the compression and sedimentation history does not define so the deformability of the material as much as the cementation does. The cementation in molassic conglomerates is calcarenitic, while in flysch formations is mainly clayey.

As far as the strength and deformability of the limestone is concerned, the observed low values are in agreement with the marly nature of the rock.

The UCS and Ei values of peridotitic rocks present a significant range. The evaluation of the results in peridotites shows that this great range of values corresponds to the variable peridotitic nature, namely of a fresh and a serpentinised peridotite. Serpentinisation (transformation of ferromagnesian minerals, olivine in particular, to serpentine - a lattice mineral of either fibrous or laminar form) changes the strength and deformation characteristics of peridotitic rocks, since the laminar-schistosed new minerals alter the rock texture.

4.2 Discussion on Modulus Ratio (MR) results

The suggested MR values from Deere (1968) and Palmstom and Singh (2001) are 275±75 for sandstone, 375±25 for siltstone and 350±50 for conglomerate. These values present notable differences with the ones of this study (Table 2), since the mean values are generally lower. Similar values are only presented in molassic conglomerates. Significant differences are also noted in limestones given that the same references propose MR values from 400 to 1000 according to the texture and in this research a value from 100 to 300 is suggested for the marly limestones.

As far as the peridotites are concerned, the proposed MR values from Deere (1968) and Palmstom and Singh (2001) are 250-300. Comparing these with the ones presented in this research it is evident that there is a significant difference in values. On the other hand, the same authors suggest an MR value for a gabbro around 450 (±50), which is approximate with the one resulted here (Table 3). This difference between these references and the ones processed here, highlight again the problematic nature of ophiolithic rocks because of the serpentinisation, in order to obtain representative Ei or MR values.

5. Conclusions

The unconfined compressive strength (UCS), deformation modulus (Ei) and the Modulus Ratio (MR) of the intact rock are basic components in certain relations, used to estimate the rock mass properties in whole. The evaluation of strength and deformability of sedimentary rocks and ophiolites based on the processing of laboratory testing results was done in this paper and the characteristic values and their typical range for the parameters σci, Ei, as well as the Modulus Ratio (MR) are presented. The rocks that were examined are those of sandstone, siltstone, conglomerate, marly limestones and peridotites. The properties of the clastic rocks were examined for both flysch and molassic environments and their differences were highlighted. The processed and evaluated data derived from a specifically established database from the design of 62 tunnels of Egnatia Highway in Northern Greece.

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