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Determining Uniaxial Compressive Strength and Elastic Modulus of Rock Using Schmidt Hammer (Case Study of Iran and Turkey)

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ABSTRACT

Uniaxial compressive strength and elastic modulus are the most important engineering properties of rocks that are widely used in the design of surface and underground projects in rock masses. Using the Schmidt hammer and scleroscope is one of the indirect and non-destructive methods that can be used both in the laboratory and in a field. The Schmidt hammer can be used to determine the compressive strength of rocks. The use of these instruments provides the possibility to achieve uniaxial compressive strength and elastic modulus of the rocks in addition to measuring the recursive hardness of rocks. In this study, the experimental relationships for calculating the compressive strength and elastic modulus of rocks are stated and then a comparison is performed in the results of the Schmidt hammer test which includes the uniaxial compressive strength and elastic modulus with other relationships present in the literature on rocks of Shahrestaneh city in Iran as well as Denizli and Antalya city in Turkey.

1. INTRODUCTION

The Schmidt hammer was used in the late 1940s as a non-destructive method for determining concrete strength for the first time (Aydin A, and Basu A, 2005). For the first time in 1948, a Swiss engineer named Schmidt E proposed the use of the Schmidt hammer and for this reason, now it is known as the Schmidt hammer test. This instrument was used in rock mechanics to determine the uniaxial compressive strength and elastic modulus of stone materials in the early 1960s (Buyuksagis I. S., Goktan R. M, 2007). The Schmidt hammer is also widely used to determine the compressive strength of natural joint surfaces (JCS). The action mechanism of the Schmidt hammer is based on hitting the steel rod on the joint surface and returning it and reading the corresponding number from the hammer index. The value of the number read in this test is proportional to the surface hardness that the hammer steel rod contacts with it. The return number can be related to the calibration curve on the hammer to the compressive strength of the rock. The calibration curve for compressive strength is very sensitive in this method and it is influenced by various factors such as type of rock, weight of volume unit, porosity, moisture content, weathering degree and placing hammer to the rock surface during testing and using Schmidt hammer (Khanlari, Gholamreza 2009). In this study, the experimental relationships for calculating the compressive strength and elastic modulus of rock in the literature are fully stated. Then, the rocks on the margin of Ganjnameh-Shahrastaneh road located in southwest of Hamedan city as well as the rocks in Denizli and Antalya cities in Turkey have been tested and examined by the Schmidt hammer.

2. Geological property from the perspective of rock studies in Turkey

9 sites have been used for sampling rocks in the cities of Antalya and Denizli in Turkey that shown in Figure (1). The sample obtained from these sites is the rock of travertine, limestone and schist as shown in Figure (2). Travertine is generally the most rock type in the Denizli River Basin, the dolomite limestone and schist are two types of rocks in the Denizli River Basin as shown in Figure 1 that obtained near Antalya (Yagiz 2009). At least ten samples of each type of rock are prepared for the Schmidt hammer test. In Table (1), the properties of the ground layers of this range are fully expressed.

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Figure 1. Sampling sites of rock in the Denizli and Antalya river basin

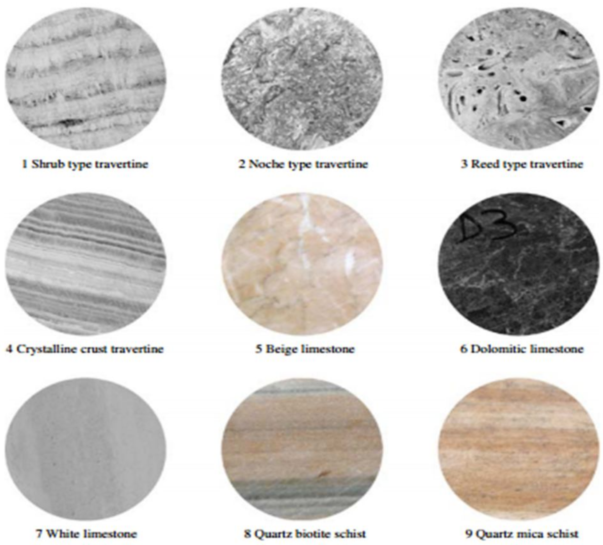

Figure 2. Large images related to the rocks studied

Table 1. Statistical summary of characteristics of the studied rocks in Turkey

Rock code	Hr (–)				UCS (MPa)				V_p (km/s)				*E* (GPa)			
	Max	Average	Min	St Dev	Max	Average	Min	St Dev	Max	Average	Min	St Dev	Max	Average	Min	St Dev
1	51	45	36	4.5	82	61	31	20.6	4.96	4.83	4.61	0.12	51	43	32	6.9
2	53	47	40	3.1	85	64	48	10.9	5.07	4.97	4.84	0.08	48	44	37	3.3
3	47	39	31	4.7	64	41	20	16.6	4.67	4.49	4.35	0.11	43	35	24	5.8
4	55	51	45	3.3	79	58	42	15.0	4.84	4.65	4.40	0.19	48	44	33	5.2
5	57	54	51	1.9	126	82	34	28.3	5.22	5.03	4.79	0.17	53	46	39	4.0
6	56	53	49	2.4	137	92	43	33.3	5.30	4.90	4.57	0.29	64	52	29	11.8
7	48	41	36	3.6	40	32	27	3.7	4.55	3.80	3.24	0.41	31	22	16	4.7
8	61	58	52	4.4	104	98	88	7.1	5.68	5.09	4.47	0.44	64	51	39	7.9
9	60	59	58	1.1	127	114	87	13.4	6.10	5.61	5.18	0.32	65	57	43	6.8

3. Experimental relationships to calculate the compressive strength and elastic modulus of rock

In rock mechanics, the main application of the Schmidt hammer is to calculate the values of compressive strength and elastic modulus of rock which can be calculated through graphs and experimental relationships. The researchers used a variety of states of equations such as linear and non-linear, regression analysis and exponential function as well as logarithmic to obtain the parameters that provided below by the relationships, tables, and graphs.

3.1 Deere equation (Hudson J. A., Harrison J. P. 2000)

Deere presented these equations to calculate the compressive strength and elastic modulus of rock.

$$\sigma_a = 6.9 \times 10^{[0.16+0.0078\,(H_r \times \gamma_a)]} \quad \textbf{(1)}$$

$$E_t = 600.5 \times (H_s.\gamma_a) - 20.276 \quad \textbf{(2)}$$

$$\sigma_a = 9.97 e^{[0.002\,(H_r \times \rho)]} \quad \textbf{(3)}$$

$$E_t = 0.19 \rho^2 H_r - 7.87 \quad \textbf{(4)}$$

$$jcs = 0.33 \times (\gamma \times R)^{1.35} \quad \textbf{(5)}$$

$$Logjcs = 0.00088 \gamma_d .R + 1.01 \quad \textbf{(6)}$$

$$UCS = 12.74 e^{0.02 H_r \rho} \quad \textbf{(7)}$$

$$E_t = 0.19 (H_r.\rho^2) - 7.87 \quad \textbf{(8)}$$

$$\sigma_a = 0.52 e^{[0.05 H_s + \gamma_a)]} \quad \textbf{(9)}$$

$$Log \sigma_c = 0.00014 \gamma_a .H_s + 3.16 \quad \textbf{(10)}$$

$$UCS = 2 H_r \quad \textbf{(11)}$$

$$UCS = 0.4 H_r - 3.6 \quad \textbf{(12)}$$

$$UCS = 0.0001 H_r^{\ 3.2658} \quad \textbf{(13)}$$

11-3 Katz equation (Katz et al. 2000)

$$UCS = 2.21 e^{0.07 H_r} \quad \textbf{(14)}$$

$$UCS = e^{0.818 + 0.059 H_r} \quad \textbf{(15)}$$

$$E_t = e^{1.146 + 0.054 H_r} \quad \textbf{(16)}$$

$$UCS = 1.45 e^{0.07 H_r} \quad \textbf{(16)}$$

$$E_t = 1.04 e^{0.06 H_r} \quad \textbf{(17)}$$

$$UCS = 0.0028 H_r^{\ 2.584} \quad \textbf{(18)}$$

$$E_t = 1.233 H_r - 17.8 \quad \textbf{(19)}$$

$$JCS = 10.070 \times e^{(0.020 H_s \times \gamma a)} \quad \textbf{(20)}$$

$$E = 34.912 \times e^{(0.0063 H_s \times \gamma a)} \quad \textbf{(21)}$$

JCS: joint compressive strength (MPa), e: neprine logarithm base, Hs: mean Schmidt hardness index,: γ_a rock volume unit weight($\frac{\text{gr}}{\text{cm}^3}$),: Et elastric modulus of rock (GPa),: Hs Mean Schmidt hardness index,: σ_c uniaxial compressive strength (Psi),: Hs Schmidt hardness recursive number, (MPa), R: Schmidt hardness recursive number, UCS: Uniaxial compressive strength of rock (MPa)

4. Results for elastic modulus and compressive strength of rocks in Hamedan city

In this section, the results of the elastic modulus and uniaxial compressive strength of the rocks of Hamedan are compared using Schmidt hammer and experimental relationships in the literature (Khanleri & Fereidouni, 2011). The results of lithological studies in this area have specified that most of the Alvand plutonic mass has been composed by granitoids and metamorphic rocks in most areas are quartz-feldspar Hornfels (Khanleri & Fereidouni, 2011). The Schmidt hammer recursive number has been using the Schmidt hammer on the rocks in the desert region, and then elastic modulus and uniaxial compressive strength of the rocks has been calculated using the experimental equations (Table 2).

Table 2. Elastic modulus and joint compressive strength for rocks in Hamedan city

Line	Lithology	Number of pulsations	Mean Schmidt return hardness	Weight of dry volume unit Gr/cm3	Joint compressive strength (JCS)(MPa)			Elastic modulus (E) (GPa)	
					Khanlari and Fereidouni (2011)	Barton and Kobi (1977)	Deere (1960)	Khanlari and Fereidouni (2011)	Deere (1960)
1	Diorite	146	60	2.93	329.95	329.68	330.12	104.73	104.83
2	Granite	88	64	2.66	304.11	304.02	302.24	102.52	102.44
3	Hornfels	90	58	2.80	264.29	264.87	264.78	98.20	98.27
4	Granite	88	63	2.66	281.25	281.83	281.87	100.11	100.15
5	Hornfels	132	60	2.76	270.56	270.60	270.56	98.88	98.92
6	Hornfels	188	59	2.70	239.86	240.13	239.86	95.28	95.31
7	Hornfels	97	54	2.68	178.25	178.62	178.01	86.25	86.37

5. Results obtained from uniaxial compressive strength and elastic modulus of rocks in Turkey

The samples of rock from the western region of Turkey are consisted of different types of travertine, limestone and schist. And Travertine is the most common type of rock in the Denizli River. Figure (3) shows the results of uniaxial compressive strength (UCS) against Schmidt hardness and Figure (4) shows the elastic modulus (E) against Schmidt hardness. Yagiz diagram is related to the Schmidt hammer test on the rocks of Denizli and Antalya in Turkey. In Fig. 3, Yagiz's laboratory and numerical diagram has been compared with other experimental relationships in the calculation of uniaxial compressive strength (UCS). Some models are linear, some are exponential and some are parabolic. Also in Fig. 4, which shows the diagram of elastic modulus against Schmidt hardness, the Yagiz model has been compared to other models for the rocks related to the cities of Denizli and Antalya. As shown in Figures (3) and (4), as the Schmidt hardness increases, the uniaxial compressive strength and elastic modulus increase for all models. But the difference between the models are high and the reason for this difference is that any model of laboratory data fit is obtained for a particular rock type and it cannot be used for other rocks of different materials, because rocks have different types, materials and hardness.

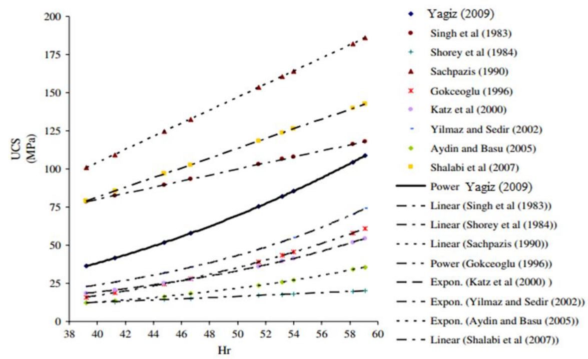

Figure 3. Diagram of uniaxial compressive strength against Schmidt hardness (comparing Yagiz equation with other equations)

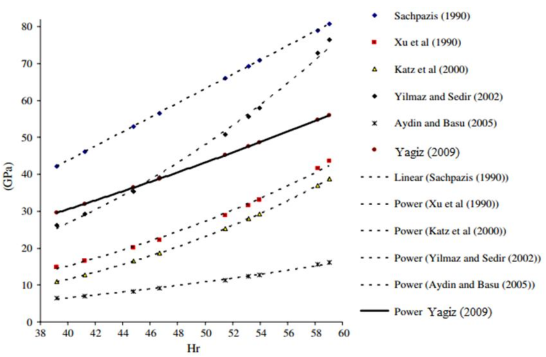

Figure 4. Diagram of elastic modulus against Schmidt hardness (comparing Yagiz equation with other equations)

5. CONCLUSION

The use of Schmidt hammer in determining the compressive strength and elastic modulus of rocks is one of the fast and non-destructive methods which is cost effective according to low cost. The value of uniaxial compressive strength, elastic modulus, P-wave velocity, dry and saturated volume unit weight, hollow and rock water uptake can be obtained by the Schmidt hammer return value. In this study, rocks in the margin of Ganjnameh-Shahrastaneh road located in the southwest of Hamedan city as well as rocks in Denizli and Antalya in Turkey were tested by a Schmidt hammer and uniaxial compressive strength and elastic modulus was obtained by fitting the numerical data and compared with other relationships in the literature. The results of the research show that the existing relationships for calculating the compressive strength and elastic modulus of the rocks are very different with each other, and because the material and the characteristics of the rocks in each area is different with each other, the existing relationships should be used cautiously because these relationships are obtained from the experimental data fitting of the rocks of a particular area. Finally, an applicable relationship cannot be used for all types of rocks.

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