

Prediction of Uniaxial Compressive Strength and Modulus of Elasticity for Some Sedimentary Rocks in Kurdistan Region- Iraq using Schmidt Hammer.

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ABSTRACT

Uniaxial compressive strength (UCS) and Modulus of Elasticity or Young's Modulus (E) used in most of engineering projects in rock mechanics, are the most important mechanical parameters of rocks. The calculation of these parameters needs most cost, time and effort. There are indirect methods to estimate the (UCS) and (E) such as Schmidt Hammer, also known as a rebound number (RL), this indirect method is easily and quickly applicable in laboratory and in field and it is considered as a non-destructive method for evaluation of surface hardness. The aim of this paper is to establish a correlation between UCS, E and Schmidt Hammer rebound value and it has been carried out on forty-nine specimens of different sedimentary rock types that belong to three different formations in Kurdistan Region, Iraq (Pila Spi Formation, Fatha Formation "Lower Fars Formation" and Tanjero Formation) with ages (Middle-Late Eocene, Middle Miocene and Campaman-Maastrichtian) respectively. The samples were prepared as cuboids of size 5x5x10 cm. A new correlation with high accuracy level for prediction of (UCS) and (E) from Schmidt hammer of some sedimentary rocks is proposed for the first time in Kurdistan Region-Iraq.

Keywords: Uniaxial Compressive Strength, Modulus of Elasticity, Schmidt Hammer, Correlation, Sedimentary rocks

تقدير قوة الانضغاط أحادية المحور ومعامل المرونة لبعض الصخور الرسوبية في اقليم كردستان العراق باستخدام مطرقة شميدت.

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الملخص

قوة الانضغاط أحادية المحور ومعامل المرونة أو معامل يونك المستخدمة في ميكانيكا الصخور في معظم المشاريع الهندسية هما الأكثر أهمية من بين الخواص الميكانيكية للصخور. حساب هاتين الدالتين يتطلب الكثير من المال والوقت والجهد. هناك طرق غير مباشرة لتقدير وحساب (UCS) و (E) مثل مطرقة شميدت والمعروفة أيضا باسم عدد الارتداد (N)، هذه الطريقة غير مباشرة هي سهلة وسريعة التطبيق سواء في المختبر أو في الحقل وتعتبر من الطرق التي لا تؤدي إلى تخريب النماذج عند تقدير صلابة سطحها. الهدف من هذه الدراسة هو ايجاد وتثبيت علاقة بين قوة الانضغاط أحادية المحور ومعامل المرونة وقيمة ارتداد مطرقة شميدت. أجريت الدراسة على تسعة وأربعين نموذجا لثلاثة أنواع من الصخور الرسوبية والمنتمية لثلاثة تكوينات جيولوجية في اقليم كردستان وهي (تكوين بيلا سبي، تكوين الفتحة "الفارس الأسفل" تكوين تانجيرو) ذات الأعمار (الايوسين الأوسط المتأخر، الميوسين الأوسط وكامبانيان- مايس تريختيان) على التوالي. تم تحضير جميع العينات بقياس 10*5*5 سم. لأول مرة تم ايجاد علاقة جديدة مع دقة عالية لتقدير (UCS) و (E) بالاعتماد على قيمة ارتداد مطرقة شميدت لبعض الصخور الرسوبية في اقليم كردستان.

كلمات دالة: قوة الانضغاط أحادية المحور، معامل المرونة، مطرقة شميدت، ترابط.

1. Introduction

The Uniaxial Compressive Strength plays an important role in designing various geotechnical applications such as buildings, tunnels and dams [1]. Evaluation of this parameter and Modulus of Elasticity in laboratory by direct tests is expensive and needs time and effort. While quick determination of these mechanical properties of rocks with minimum cost, effort and time can be done by Schmidt hammer [2] which has been widely used to determine hardness and to predict the uniaxial compressive strength (UCS) of rocks. The Schmidt hammer test is easily and quickly applicable [3] in both laboratory and field and it is considered as a non-destructive method for evaluation of surface hardness [4]. Due to the non-destructive test, the same samples subjected to Schmidt hammer can be used to other tests and measurements. In present study, the same samples were used for both Schmidt hammer rebound value and compressive strength.

The Schmidt hammer test was developed in Switzerland in 1948 by Ernest Schmidt for determining the in situ hardness of concrete. Many research works have used the Schmidt Hammer test to evaluate the intact rock properties [5, 6 and 7]. Later it has been adapted for determination of Uniaxial Compressive Strength of rock [8].

This research presents a new correlation obtained through a set of experimental tests carried out on three types of rocks belonging to three formations of different ages (Pila Spi Formation, Lower Fars Formation and Tanjero Formation) with (Middle-Late Eocene, Middle Miocene and Campaman-Maastrichtian) respectively. These rocks are used in decoration (interior and exterior) of buildings such as limestones and most of the buildings of Sulaimani City are constructed on the sandstone of Tanjero Formation, that outcrops in many locations or at different depths ranging from 1-20 m.

The Pila Spi Formation was first described by Lees in 1930 from the Pila Spi area of the High Folded Zone [9]. This Formation is 100-200 m thick and the rocks are well bedded, bituminous, chalky, and crystalline limestones in the upper part with bands of white, chalky marl and chert nodules towards the top. The limestones are sometimes oolitic with rare layers of gastropod debris. The formation was deposited in a shallow lagoon [9 and 10]. However, conglomerates occur at the base of the formation in the Derbendikhan area [11].

The Fatha (Lower Fars) Formation was defined from the Fars Province in Iran and introduced to Iraq by Busk and Mayo in 1918 [9]. The type section has been located in the Al Fatha Gorge, 10 km north of Baiji town. The formation is an evaporitic sequence with thickness of 600 m and consists of repeated cycles of mudrock, marl, limestone and gypsum which is used for buildings decoration.

The Tanjero Formation mainly occurs in the Balambo-Tanjero Zone. It was defined by Dunnington, in 1952. The type section in the Sirwan valley (SE of Sulaimaniya) consists of two parts. The lower part consists of pelagic marl, and occasional beds of argillaceous limestone with siltstone beds in the upper part [9]. The upper part consists of silty marl, sandstone, conglomerates, and sandy or silty organic detrital limestones. The formation was deposited as flysch in a rapidly subsiding foredeep basin.

2. Previous studies

Due to the simplicity, speed, portability, minimum cost, effort and time the Schmidt hammer was used by many researchers who have studied the correlations between uniaxial compressive strength and Schmidt hammer rebound value. Table (1) presents a list of previous studies carried out for finding correlations between UCS and Schmidt hammer rebound value for different rock types. However, there are no researches and studies about prediction of UCS and Young's Modulus using Schmidt Hammer rebound value of sedimentary rocks in Kurdistan Region, Iraq.

The empirical correlation between UCS and Rebound number (RL) of Schmidt hammer, as shown in Table (1), are in the form of linear, exponential, and power functions. In the present study, the empirical correlation is in the form of exponential function. Miller (1965) [12] studied the relationship between unit weight, UCS and Schmidt hammer. Later, Deere and Miller (1966) [13] proposed a correlation between rock density, Young's modulus and Schmidt hammer rebound values. Haramy and DeMarco (1985) [14] have determined the utility of the Schmidt hammer in designing underground coal mine pillars by testing 10 types of U.S. coals. Ghose and Chakrabarti (1986) [15] have proposed an empirical correlation between Schmidt rebound values and UCS for Indian coals. Xu et al. (1990) [16] estimate the mechanical properties of weak rocks using Schmidt hammer rebound value. The relationship between UCS and Schmidt hammer rebound value for different rock types can be found in works presented by [17, 18, 2, 19, 20, 21 and 22].

Table (1): Correlation between UCS and Schmidt hammer rebound value [23]

References	Correlation	R	Rock Type
Kilic and Teymen (2008)	$\sigma_{UCS} = 0.0137 * R_L^{2.2721}$	0.93	Different rock types
Cobanoglu and Selik (2008)	$\sigma_{UCS} = 6.59 * R_L - 212.6$	64.7	Limestone, sandstone, cement mortar
Yasar and Erdogan (2004)	$\sigma_{UCS} = 0.000004 * R_L^{4.29}$	0.89	Carbonates, sandstone, basalt
Tugrul and Zarif (1999)	$\sigma_{UCS} = 8.36 * R_L - 416$	0.87	Granite
Sachpazis (1990)	$\sigma_{UCS} = 4.29 * R_L - 67.52$	0.96	33 different carbonates
Xu et al. (1990)	$\sigma_{UCS} = 2.98 * e^{(0.06 * R_L)}$	0.95	Mica-schist
Cargill and Shakoor (1990)	$\sigma_{UCS} = 18.17 * e^{(0.02 * \rho * R_L)}$	0.98	Carbonates
O' Rourke (1989)	$\sigma_{UCS} = 4.85 * R_L - 76.18$	0.77	Sandstone, siltstone, limestone, anhydride
Ghose and Chakraborti (1986)	$\sigma_{UCS} = 0.88 * R_L - 12.11$	0.87	Coal
Haramy and DeMarco (1985)	$\sigma_{UCS} = 0.99 * R_L - 0.38$	0.70	Coal
Singh et al.(1983)	$\sigma_{UCS} = 2 * R_L$	0.86	Sandstone, siltstone, mudstone, seatearth
Aufmuth (1973)	$\sigma_{UCS} = 0.33 * (R_L * \rho)^{1.35}$	0.80	25 different lithologies

3. Methodology

The samples of sandstone and limestone of three geological formations (Tanjero, Pila Spi and Fatha) were collected from three different locations in Sulaimani Governorate in Kurdistan Region, Iraq. The block samples of Pila Spi Formation were collected from quarry of limestone rocks near Blkan Village, about 10 km to the west of Zarayen town in Sulaimani Governorate. The samples of limestone of Fatha Formation were obtained from one of the decoration companies in Sulaimani City, while the block samples of sandstone were collected near check point on the Qaywan road. The samples were prepared as cuboids of size 5x5x10 cm Fig. (1). The samples represent intact rocks and there weren't any macro or micro-cracks. Forty-nine specimens were tested for this study for Schmidt hammer rebound value and compressive strength testing. The Schmidt hammer and compressive testing were performed on the same samples. The samples were put in water until they became saturated and the testing was performed in saturated condition. For Schmidt hammer test, the L type hammer was used with energy of 0.735 Nm and ten impact readings were recorded from each specimen Fig (2), the average of these readings was taken as a Schmidt rebound value.

Uniaxial compressive tests were performed on forty-nine cuboid samples, which had dimensions of 5x5x10 cm. Uniaxial compressive tests were performed with 0.5 MPa/s

constant stress rate. Uniaxial compressive strength values were calculated using the following formula:

$$\sigma_{UCS} = F/A$$

where σ_{UCS} is Uniaxial compressive strength (MPa), F is the Maximum failure load (N) and A is the section area of specimen (mm^2).

Modulus of elasticity values were calculated using the following formula:

$$E = \sigma_{UCS}/\epsilon$$

where E is the Modulus of elasticity, σ_{UCS} is the Uniaxial compressive strength and ϵ is the strain obtained from uniaxial compressive tests

4. Results and discussion

The results of tests for Schmidt hammer rebound value, Uniaxial Compressive Strength and Modulus of Elasticity are presented in Tables (2, 3 and 4). The range of Schmidt hammer rebound value was from 26.4 to 42.6 for limestone of Pila Spi Formation, 16.4 to 24.6 for limestone of Fatha Formation and 37.2 to 39.6 for sandstone of Tanjero Formation. The values of UCS were from 99.13 MPa to 193.62 MPa for limestone of Pila Spi Formation, 6.43 MPa to 11.29 MPa for limestone of Fatha Formation and 80.24 MPa to 173.92 MPa for sandstone of Tanjero Formation. While the values of E were from 44.0392 GPa to 78.4314 GPa for limestone of Pila Spi Formation, 1.0098 GPa to 13.4412 GPa for limestone of Fatha Formation and 32.1373 GPa to 68.9314 GPa for sandstone of Tanjero Formation. The lowest values of the mechanical properties found in the Lower Fars Formation limestone due to their high porosity and poor cementation.

In order to describe the relationships between Schmidt hammer rebound value with uniaxial compressive strength and modulus of elasticity of the tested rocks, regression analysis was performed Fig. (3, 4, 5 and 6). The plot of the Schmidt hammer rebound value as a function of UCS is shown in Fig. (3) while this plot between Schmidt hammer rebound value and modulus of elasticity is shown in Fig. (4, 5 and 6) show the measured UCS and E versus predicted UCS and E . Fig. (3) shows that there is a power relationship between Schmidt

hammer rebound value and UCS which has a coefficient of correlation ($R^2 = 0.879$). The following equation was obtained as a result of the correlation analyses between UCS and Schmidt hammer rebound value:

$$\sigma_{UCS} = 0.00004 \times R_L^{4.1643} \quad (1)$$

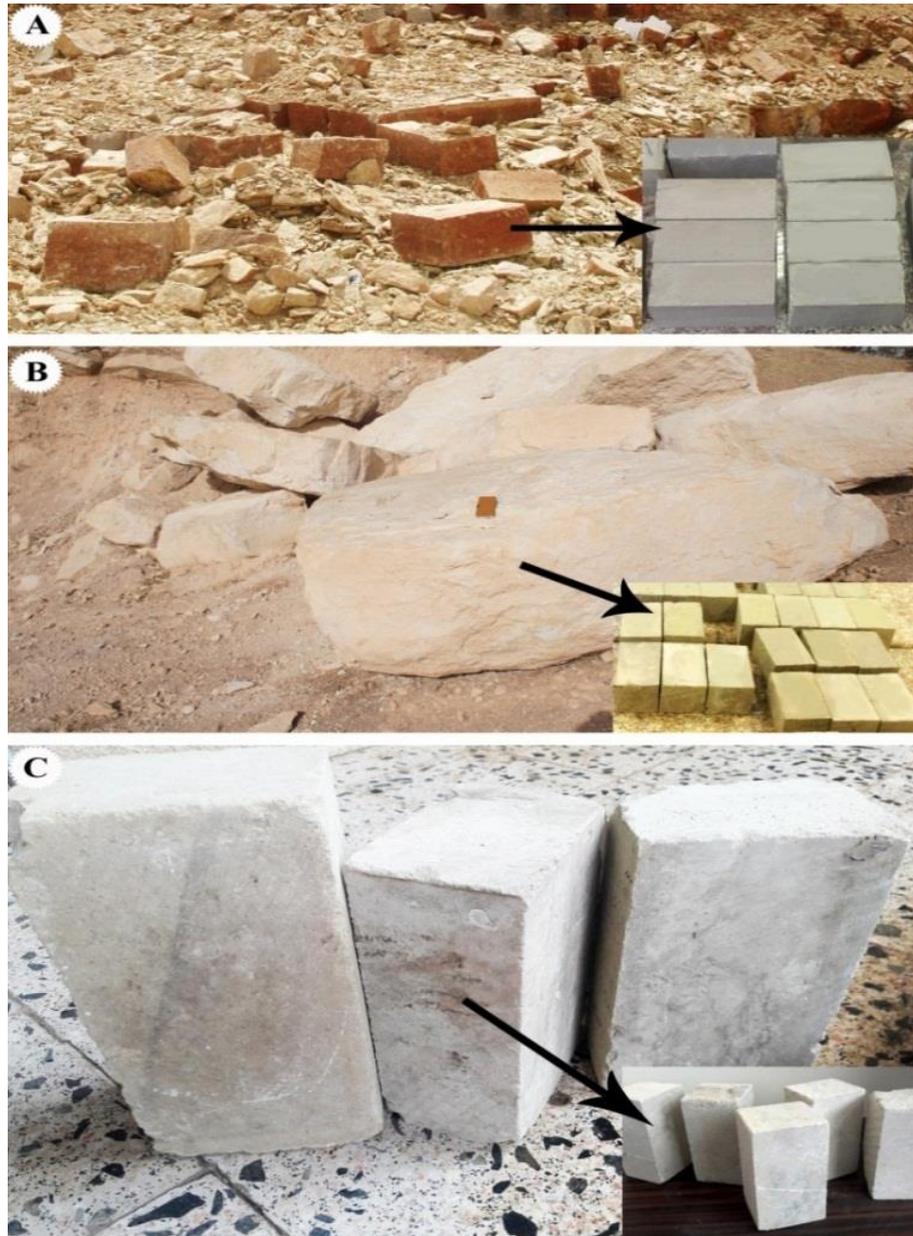


Fig. (1): A- Blocks of Sandstone of Tanjero Formation, B- Blocks of Limestone of Pila Spi Formation, C- Blocks of Limestone of Fatha Formation. The arrows indicate the prepared specimens from each type of rocks.

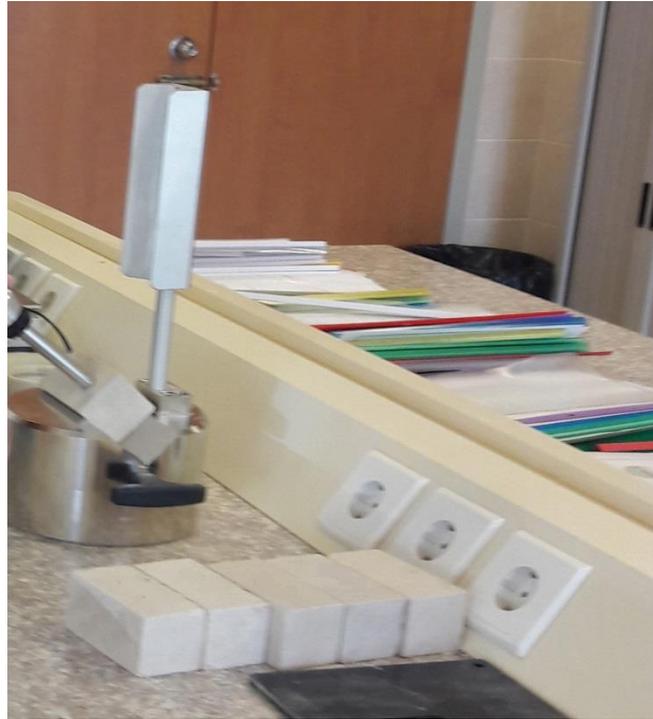


Fig. (2): Schmidt Hammer test

Similarly, a good power relationship has also been observed between Schmidt hammer rebound value and modulus of elasticity having a good coefficient of correlation ($R^2 = 0.685$) and the following equation was obtained as a result of the correlation analyses between Young's Modulus and Schmidt hammer rebound value:

$$E = 0.0004 \times R_L^{3.2825} \quad (2)$$

The correlation equation between measured and predicted UCS can be found from equation (3) with ($R^2=0.6724$)

$$\sigma_{UCS}(measured) = 1.0057 \times \sigma_{UCS}(predicted) \quad (3)$$

The correlation equation between measured and predicted Young' Modulus of Elasticity can be found from equation (4) with ($R^2=0.5999$)

$$E(measured) = 1.074 \times E(predicted) \quad (4)$$

As a result of this study, the UCS and E can be predicted using the Schmidt hammer rebound value.

Table (2): Limestone of Pila Spi Formation.

Sample No.	Schmidt hardness rebound value	Uniaxial Compressive Strength (MPa)	Modulus of Elasticity GPa
P1	30.40	125.82	54.9020
P2	37.60	166.34	72.7941
P3	42.60	166.34	73.9706
P4	34.40	136.36	62.0882
P5	37.20	117.74	54.9020
P6	33.60	127.13	62.0098
P7	32.60	155.76	62.8137
P8	32.20	169.94	66.7647
P9	32.80	155.60	71.0784
P10	26.40	128.28	54.9020
P11	36.20	157.43	60.3529
P12	40.40	193.62	78.4314
P13	32.40	119.29	76.7157
P14	36.60	177.15	70.8922
P15	29.60	123.76	71.5686
P16	32.40	125.15	53.9216
P17	32.80	122.42	74.7941
P18	29.60	99.13	44.0392
P19	33.40	117.35	68.6275
P20	41.00	180.12	73.0392

Table (3): Limestone of Fatha Formation.

Sample No.	Schmidt hardness rebound value	Uniaxial Compressive Strength (MPa)	Modulus of Elasticity GPa
L1	19.60	9.96	9.7059
L2	18.40	10.39	9.0000
L3	19.60	9.61	9.3137
L4	24.60	6.43	4.4118
L5	21.20	10.30	1.0098
L6	19.20	7.18	1.0196
L7	19.00	10.63	1.0490
L8	21.80	9.24	10.8725
L9	21.00	8.49	10.4902
L10	20.20	7.58	7.8922
L11	18.20	10.06	11.7059
L12	19.80	8.54	9.2745
L13	20.60	8.97	8.2255
L14	16.40	7.63	9.0196
L15	17.40	7.06	6.0686
L16	22.20	6.71	7.9608
L17	18.60	9.54	10.7549
L18	19.80	11.29	13.4412
L19	19.00	9.95	10.6373
L20	17.40	9.65	9.9510

Table (4): Sandstone of Tanjero Formation.

Sample No.	Schmidt hardness rebound value	Uniaxial Compressive Strength (MPa)	Modulus of Elasticity GPa
T1	38.40	128.55	52.7941
T2	39.60	172.94	68.9314
T3	38.20	156.86	58.1275
T4	37.60	91.14	32.1373
T5	37.20	137.88	46.4020
T6	39.20	80.24	33.1863
T7	38.80	156.98	66.1765
T8	38.80	173.92	60.6569
T9	36.80	100.16	39.2157

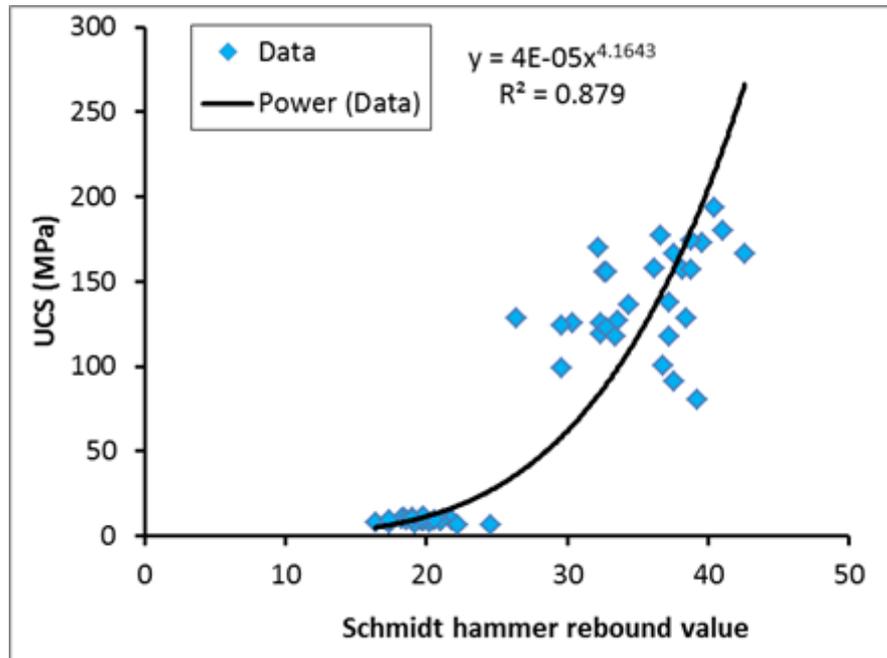


Fig. (3): Correlation between Uniaxial Compressive Strength and Schmidt hammer rebound value.

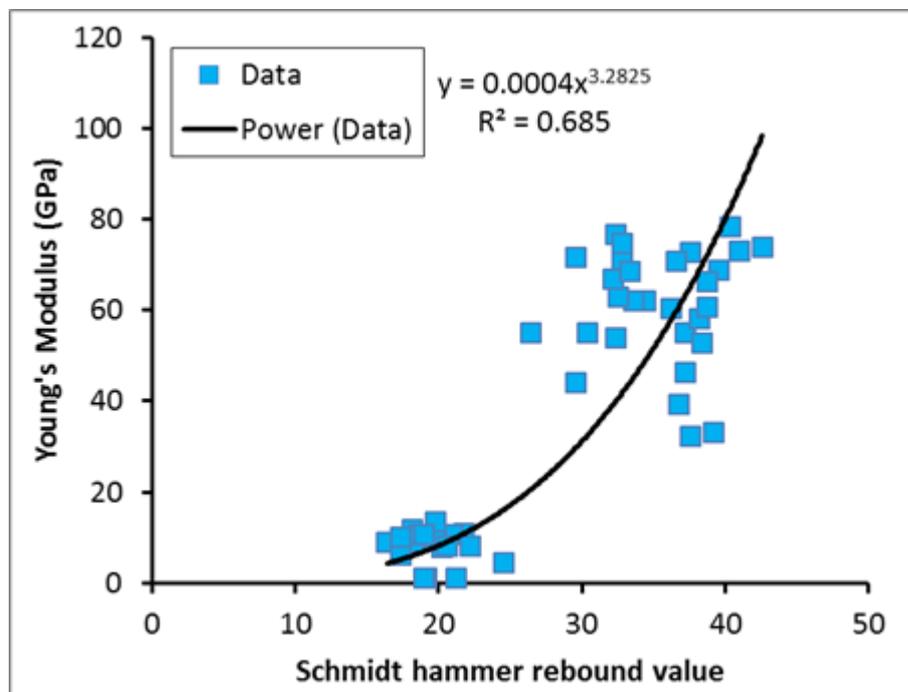


Fig. (4): Correlation between Young's Modulus and Schmidt hammer rebound value.

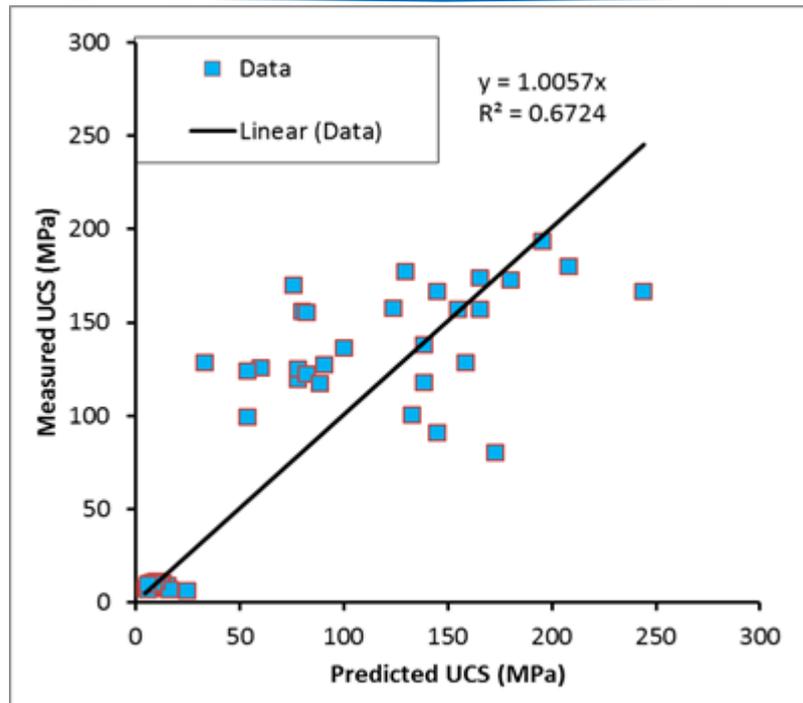


Fig. (5): Plot between predicted and measured values of Uniaxial Compressive Strength (MPa).

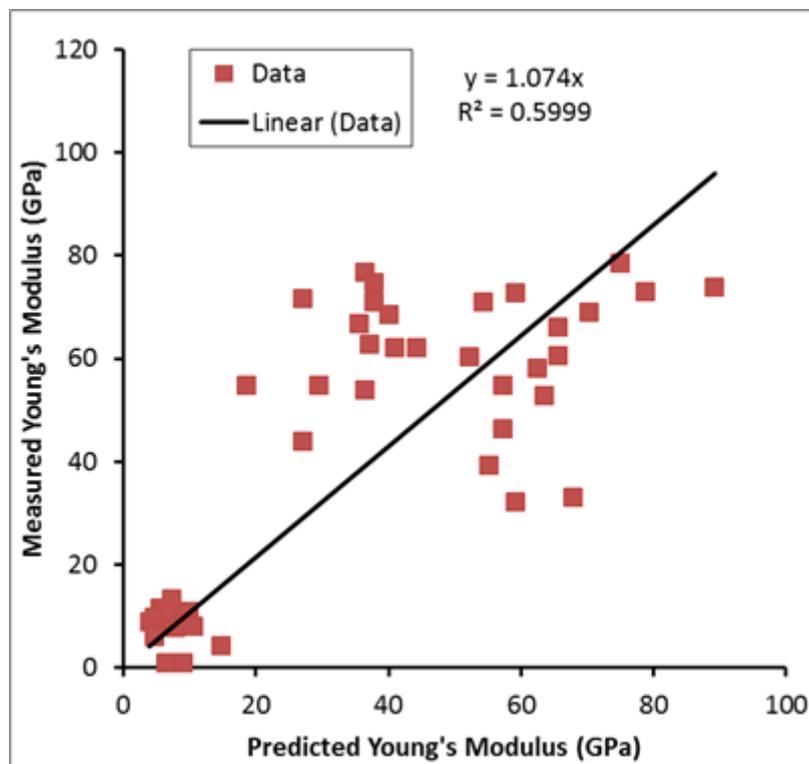


Fig. (6): Plot between predicted and measured values of Young's Modulus (GPa).

5. Conclusions

Uniaxial Compressive Strength (UCS) and Modulus of Elasticity (E) of rocks play an important role in many rock engineering projects. As a simple tool for quick prediction of these parameters is using Schmidt hammer rebound value which has been widely used for this purpose. In this study the acceptable correlations were developed to predict the UCS and E using Schmidt hammer rebound value for sedimentary rock in Kurdistan region, Iraq. The study indicated that the UCS and E can be estimated from the Schmidt hammer rebound value using the correlations:

1. $\sigma_{UCS} = 0.00004 \times R_L^{4.1643}$ correlation between (UCS) and Schmidt hammer rebound value;
2. $E = 0.0004 \times R_L^{3.2825}$ correlation between (E) and Schmidt hammer rebound value;
3. $\sigma_{UCS}(measured) = 1.0057 \times \sigma_{UCS}(predicted)$ correlation between measured and predicted (UCS);
4. $E(measured) = 1.074 \times E(predicted)$ correlation between measured and predicted (E).

Furthermore, a strong coefficient of correlation was found between UCS and Schmidt hammer rebound value ($R^2 = 0.879$).

Recommendations: To reach better results, we suggest further research on different types of sedimentary rocks that are predominant in Iraq as these types of rocks cover most of Iraq's surface.

References

- [1] Bieniawski. Z. T., “*Estimating the strength of rock materials*”, J. S. African Institute of Mining and Metallurgy, 74(8), 312, (1974).
- [2] Kahraman, S., “*A correlation between P-wave velocity, number of joints and Schmidt hammer rebound number*”, International Journal of Rock Mechanics and Mining Science, 38, 729, (2001).

- [3] Guney, A., Altindag, R., Yavuz, H. and Sarac, S., “*Evaluation of the Relationships Between the Schmidt Hardness Rebound Number and Other (Engineering) Properties of Rocks*”, The 19th International Mining Congress and Fair of Turkey, JMCET, 1, (2005).
- [4] Torabi, S. R., Ataei, M., and Javanshir, M., “*Application of Schmidt Rebound hammers Number for Estimating Rock Strength under Specific Geological Conditions*”, Journal of Mining and Environment, 1(2), 1, (2010).
- [5] Cargill J. S. and Shakoor A., “*Evaluation of empirical methods for measuring the uniaxial compressive strength of rock*”, Int J Rock Mech Min Sci & Geomech Abstr 27, 495, (1990).
- [6] Bilgin, N, Dincer, T. and Copur, H., “*The performance prediction of impact hammers from Schmidt hammer rebound values in Istanbul metro tunnel drivages*”, Tunnelling and Underground Space Technology 17, 237, (2002).
- [7] Aydin A. and Basu A., “*The Schmidt hammer in rock material characterization*”, Eng. Geol. 81, 1, (2005).
- [8] Schmidt, E., “*A non-destructive concrete tester*”, Concrete 59(8), 34, (1951).
- [9] Bellen, R. C. V., Dunnington, H. V., Wetzel, R. and Motron, D., “*Laxiqae stratigraphique International*”, Asie, Fasc 10 a, Iraq, Paris, (1959).
- [10] Jassim, S. Z. and Goff, J. C., “*Geology of Iraq*”, 341, Prague, Brno, (2006).
- [11] Jassim, S. Z., Al-Shaibani, S. K, and Ajina, T. M., “*Possible Middle Eocene block movements in the Derbendikhan area, Northeastern Iraq*”, J. Geol. Soc. Iraq, Special Issue, Baghdad, (1975).
- [12] Miller, RP., “*Engineering classification and index properties for intact rock*”, PhD thesis, University of Illinois, (1965).

- [13] Deere, DU. and Miller, RP, “*Engineering classification and index properties for intact rocks*”, Tech Rep Air Force Weapons Lab, New Mexico, no AFNL-TR, 65, (1966).
- [14] Haramy, K.Y. and DeMarco, M.J., “*Use of Schmidt hammer for rock and coal testing*”, In: 26th US Symp. On Rock Mechanics, 549, Rotterdam: Balkema, (1985).
- [15] Ghose, A.K. and Chakraborti, S., “*Empirical strength indices of Indian coals-an investigation*”, Proceedings of 27th US symposium on rock mechanics, Balkema, Rotherdam, 59, (1986).
- [16] Xu, S., Grasso, P. and Mahtab, A., “*Use of Schmidt hammer for estimating mechanical properties of weak rock*”, 6th Int IAEG Congress Balkema, Rotterdam, 511, (1990).
- [17] Kahraman, S., “*Basıncı direnci tahmininde Schmidt venokta yük indeksi kullanmanın güvenilirliği*”, In: Korkmazve S, Akcay M (eds) KTU” Jeoloji Muhendisligi Bolumu 30. Yıl Sempozyumu BildirilerKitabı, Trabzon, 362, (1996).
- [18] Katz, O., Reches, Z. and Roegiers, J.C., “*Evaluation of mechanical rock properties using a Schmidt hammer*”, Int. J. Rock Mech. Min. Sci., 37:723, (2000).
- [19] Kiliç, A. and Teymen, A., “*Determination of mechanical properties of rocks using simple methods.*” Bulletin of Engineering Geology and the Environment, 67(2), 237, (2008).
- [20] Gökçeoglu, C., “*Schmidt sertlik çekici kullanılarak tahmin edilen tek eksenli basınç dayanımı verilerinin güvenilirliği üzerine bir değerlendirme*”, Jeol. Mühendisligi. 48, 78 (In Turkish), (1996).
- [21] Yılmaz, I., and Sendir, H., “*Correlation of Schmidt hardness with unconfined compressive strength and Young's modulus in gypsum from Sivas (Turkey)*”, Eng. Geol. 66, 211, (2002).
- [22] Yasar, E., and Erdogan, Y., “*Estimation of rock physico-mechanical properties using hardness methods*”, Eng. Geol. 71, 281, (2004).

- [23] Ramli Nazir, Ehsan Momeni, Danial Jahed Armaghani and Mohd for Mohd Amin, “*Prediction of Unconfined Compressive Strength of Limestone Rock Samples Using L-Type Schmidt Hammer*”, EJGE, 18, Bund. I, 1767, (2013).

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