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RESEARCH ARTICLE

Tensile Strength Modeling of Limestone Rocks in Sulaymaniyah City, Iraq Using Simple Tests

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ABSTRACT

Tensile strength of rocks is one of the mechanical properties of intact rock that is a significant parameter for designing geotechnical structures includes dam foundations and tunnels. The tensile strength can be determined indirectly using Brazilian indirect test procedure that is mentioned in the International Society for Rock Mechanics suggested methods. The availability of rock samples is needed to perform the Brazilian indirect test so as to determine their tensile strength which is expensive, time-consuming, and cost-effective especially for weak quality rock formations. Therefore, non-destructive methods for predicting the tensile strength of the rock are crucially needed during the poor quality of rock samples. Non-destructive tests can be correlated with indirect tests to predict Brazilian tensile strength (BTS) of rocks such as ultrasonic pulse velocity and Schmidt hammer. These methods are simple and can be easily conducted in the field. This study is focused on the tensile strength of limestone rocks for three main formations of Sulaymaniyah city. The samples were obtained using a standard core barrel. Statistical analysis including minimum, maximum, mean, standard deviation, variance, and coefficient of variance for the results was conducted. Single and multiple correlations between BTS and each of ultrasonic pulse velocity and Schmidt hammer rebound number of limestone rocks were created. Reasonable empirical equations were developed to predict the tensile strength of limestone rocks. In addition, the point load strength index was correlated with BTS. The comparison between proposed equations from this study and equation from the literature was also investigated.

Keywords: Brazilian tensile strength; Limestone rocks; Point load test; Schmidt Hammer test; Ultrasonic pulse velocity

INTRODUCTION

The tensile strength of rocks is a mechanical property that is crucial in the construction of several engineering projects such as the foundation of dams and tunnels (Gokceoglu and Zorlu, 2004; Baykasoğlu et al., 2008; Gurocak et al., 2012). Brazilian tensile strength (BTS) test is an indirect method to determine the tensile strength of rocks (Garcia-Fernandez et al., 2018). The international society for rock mechanics (ISRM) suggested method can be used to find the BTS of rocks (Brown, 1981).

BTS needs the preparation of high-quality core samples and time but during the poor quality of the rocks, the samples may not be obtained; therefore, some other tests can be used to predict BTS of rocks including ultrasonic pulse velocity test (V_p), Schmidt hammer rebound number test (R_L), and point load test (PLT) (Gokceoglu and Zorlu, 2004; Kılıç and Teymen, 2008; Kallu and Roghanchi, 2015; Kurtuluş et al., 2016).

Ultrasonic pulse velocity and Schmidt hammer are non-destructive tests that used to compute BTS of rocks indirectly (Kılıç and Teymen, 2008; Kallu and Roghanchi, 2015). PLT is a simple and indirect test method to compute the point load strength index ($Is_{(50)}$) of rocks and that can be used to predict BTS of rocks (Heidari et al., 2012). These tests consist of portable instruments that can be used in the field.

Literature review reveals that the correlation of BTS with V_p, R_L, and $Is_{(50)}$ for various rock types in several countries was investigated but the relationships of BTS with each of V_p, R_L, and $Is_{(50)}$ for core samples of limestone rocks of Sulaymaniyah city in Iraq were not investigated yet; therefore, this study focused on the tensile strength modeling of limestone rocks for three main formations of Sulaymaniyah city. Statistical analysis including minimum, maximum, mean, standard deviation, variance, and coefficient of variance for the results was conducted. Single and multiple correlations between BTS with V_p, R_L, and $Is_{(50)}$ of limestone rocks were developed. The proposed equations from this study were compared with the equations from literature.

Previous Empirical Equations

Several researchers investigated the relationship between BTS and each of V_p, $Is_{(50)}$, and R_L. Some of these researchers including Kılıç and Teymen (2008); Kurtuluş et al. (2016); Khandelwal and Singh (2009); Alshkane et al. (2018); and Hama Salih and Alshkane (2018) found the correlation equation between BTS and V_p, as presented in Table 1.

Some of other researchers including Gurocak et al. (2012); Kılıç and Teymen (2008); Hama Saeed and Alshkane (2018); Kallu and Roghanchi (2015); Heidari et al. (2012); Khanlari et al. (2014); Alshkane et al. (2018); and Salehin (2017) created the correlation equation between BTS and $Is_{(50)}$, as presented in Table 2.

In addition, few researchers such as Kallu and Roghanchi (2015) carried out BTS and R_L tests for rhyolite and basalt rocks and they proposed the following power equation with the coefficient of correlation (R) of 0.91 using ASTM D3967-08 and ASTM D5873-05 for BTS and R_L tests, respectively:

$$BTS = 0.15*(R_L)^{1.33} \quad (1)$$

The aim of this study is to develop empirical equations to predict BTS from PLT, V_p, and R_L for limestone rocks of Sulaymaniyah Province using simple and multiple regression analysis.

Sampling Locations

Three main geological formations of Sulaymaniyah city [Figure 1] were selected so as to obtain the rock core samples. These formations with lithology, according to Numan et al., 1998; Al-Barzinjy, 2008; Khanaqa, 2011 are as follows:

1. Kometan Formation at Qlyasan region, lithology was white limestone
2. Pila Spy Formation at Qaradax region, lithology was dolomitic limestone
3. Sinjar Formation at Tasluja town, lithology was milky limestone.

A total of 33 limestone core samples were obtained using a standard core barrel. 10, 12, and 11 samples were obtained

Table 1: Empirical equations between BTS and V_p from literature

Eq. no.	References	Equations	R	Rock types	Remarks
2	Kılıç and Teymen (2008)	$BTS=0.4935*(V_p)^{1.8723}$	0.96	Various rock types	Used ISRM (1981) to perform BTS and Vp tests with 42 mm core size diameter
3	Khandelwal and Singh (2009)	$BTS=14.5* V_p-24.55$	0.97	Sedimentary	Used 54 mm core size diameter to perform BTS and V_p tests based on ISRM (1981 and 1978), respectively
4	Kurtuluş et al. (2016)	$BTS=8* V_p+3.84$	0.88	Sedimentary and igneous	Performed BTS test based on ISRM (1978) and V_p test based on ISRM (2007) and ASTM (2001) with core size diameter of NX (54 mm)
5	Alshkane et al. (2018)	$BTS=3.9419* e^{(0.1587*Vp)}$	0.71	Sedimentary	Performed splitting and V_p tests based on ISRM (1981)
6	Hama Salih and Alshkane (2018)	$BTS=3.138*e^{(0.3*Vp)}$	0.67	Igneous	Used data from literature

BTS: Brazilian tensile strength

Table 2: Empirical equations between BTS and $Is_{(50)}$ from literature

Eq. no.	References	Equations	R	Rock types	Remarks
7	Kılıç and Teymen (2008)	$BTS=7.5062*Ln(Is_{(50)})+2.2219$	0.96	Various rock types	Performed BTS test based on ISRM (1981) and diametrical PLT with core size of 50 mm diameter
8	Gurocak et al. (2012)	$BTS=1.81*Is_{(50)}+4.78*10^{-6}$	0.90	Various rock types	Performed BTS based on ISRM (1981) and PLT based on ISRM (1985) with core size of 50 mm
9	Heidari et al. (2012)	$BTS=2.8892*Is_{(50)}-0.0723$	0.94	Gypsum rocks	Performed BTS test based on ASTM (2001) and three types of PLT include axial, diametrical, and irregular lump using 56.7 mm core size diameter with ASTM D5731-01
10		$BTS=2.9028*Is_{(50)}+1.1038$	0.88		
11		$BTS=3.4798*Is_{(50)}-0.523$	0.93		
12		$BTS=1.36*Is_{(50)}+2.06$	0.96		
13		$BTS=1.77*Is_{(50)}+2.57$	0.93		
14		$BTS=0.88*Is_{(50)}+2.7$	0.97		
15	Khanlari et al. (2014)	$BTS=2.2*(Is_{(50)})^{0.79}$	0.86	Metamorphic	Performed BTS and PLT using core size of 54 mm that prepared the samples with ISRM (1985)
16	Kallu and Roghanchi (2015)	$BTS=11*Is_{(50)}$	0.90	Rhyolite and basalt	Performed BTS test based on ASTM D3967-08 and PLT based on ASTM D5731-08
17	Salehin (2017)	$BTS=0.617*Is_{(50)}+1.139$	0.77	Marlstone	-
18	Alshkane et al. (2018)	$BTS=0.485*Is_{(50)}+3.0755$	0.83	Sedimentary	Used ISRM (1981) and ASTM for splitting and diametrical PLT tests, respectively
19	Hama Saeed and Alshkane (2018)	$BTS=[Is_{(50)}/(0.968+0.076*Is_{(50)})]-0.023$	0.97	Sedimentary	Used data from literatures

PLT: Point load test, BTS: Brazilian tensile strength from Qlyasan, Qaradax, and Tasluja regions, respectively, so as to perform BTS, V_p, R_L, and PLT tests.

MATERIALS AND METHODS

In this study, the limestone samples were taken from three site locations using drilling core machine with single-core barrel with a diameter size of NX (54.7 mm) and length of 400 mm. The samples were drilled in both lateral and vertical directions, in each site location. Half of the samples were drilled laterally and other halves were drilled vertically. These core samples were prepared according to ISRM (Brown, 1981) and cut by rock trimmer instrument. From each core sample, four pieces were prepared to perform BTS, V_p, R_L, and PLT tests.

BTS test was performed based on ISRM (1981) with length to diameter ratio of 0.37 using the compressive testing machine and 40 mm thick of two steel loading jaws to grip the samples during the loading that was created according to ISRM (Brown, 1981), as shown in Figure 2. V_p tests were conducted with length to diameter ratio of 2:1 and the samples ends were grinded to the flat of 0.02 mm according to ISRM (Brown, 1981). R_L test was performed according to ISRM (Ulusay, 2015) with length of 100 mm.

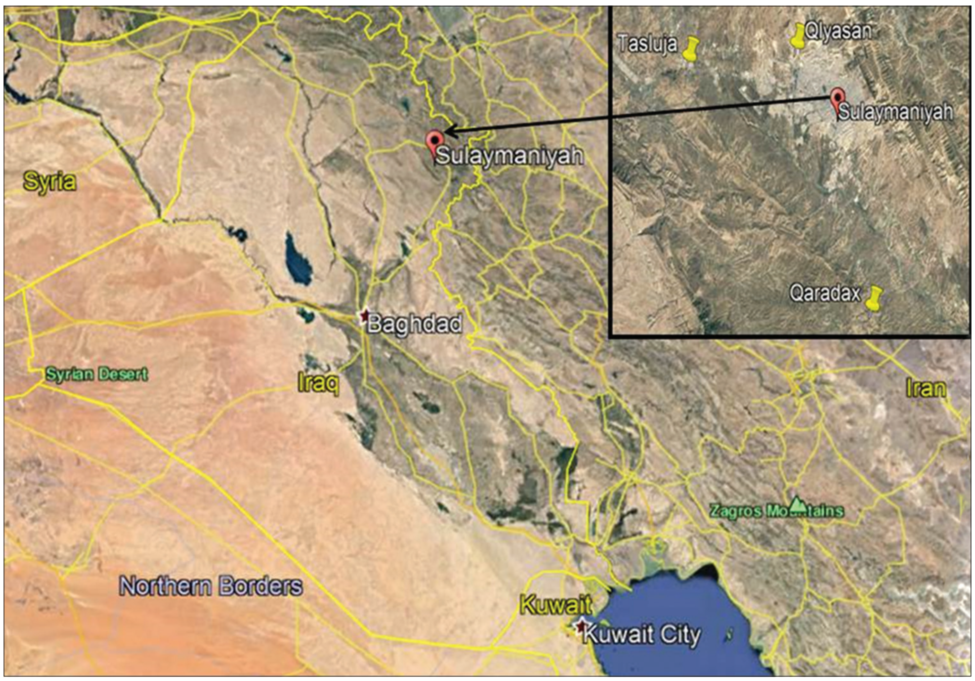

Figure 1: Sampling locations of limestone rocks

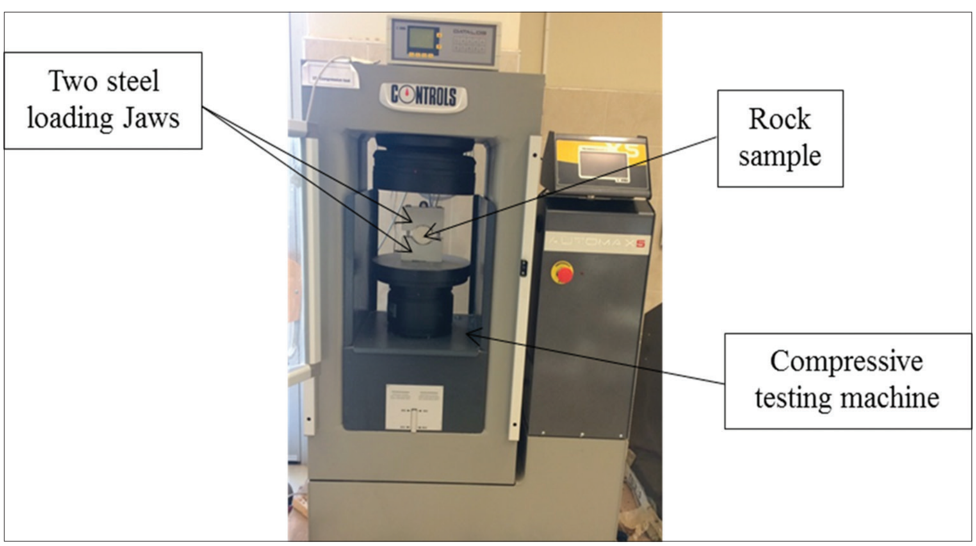

Figure 2: Compressive testing machine with two steel loading jaws to perform Brazilian tensile strength

Table 3: Statistical analysis of test results

Properties	No. of data	Minimum	Maximum	Mean	Stand. deviation	Variance	CoV.
BTS (MPa)	33	15.132	40.041	26.027	7.450	55.510	28.63
V_p (km/s)	33	3.224	5.832	4.674	0.636	0.405	13.61
R_L	33	26.714	43.347	33.537	3.915	15.326	11.67
$Is_{(50)}$ (MPa)	33	1.588	6.336	4.212	1.023	1.047	24.29
n%	33	1.512	13.600	7.590	3.056	9.340	40.27
γ_d (g/cm^3)	33	2.061	2.669	2.420	0.125	0.016	5.16

BTS: Brazilian tensile strength

Axial PLT was carried out according to ISRM (1985) with length to diameter ratio of 0.37.

RESULTS AND DISCUSSION

The results of mechanical properties for limestone rocks of Sulaymaniyah city showed that the range of BTS was from 15.132 MPa (milky limestone) to 40.041 MPa (white limestone), while the range of porosity (n) % was from 1.512% to 13.6% and γ_d was from 2.061 g/cm^3 to 2.669 g/cm^3. These results showed that the tensile strength of the white limestone of Qlyasan from Kometan formation is stronger than the other two locations. Furthermore, the statistical analyses for the results of other properties for all three site locations are presented in Table 3.

The results were used to develop a single regression model between BTS and each of V_p, R_L, and $Is_{(50)}$ as well as a multiple regression model was used to predict BTS from V_p, R_L, and $Is_{(50)}$. The coefficient of correlation (R) and root mean square error (RMSE) for single and multiple regression models were computed and analyzed. According to Harris and Taylor (2003), there are several ranges of coefficient of correlation (R) for considering the degree of correlation between two parameters, as shown in Table 4.

Table 4: Description of R ranges after Harris and Taylor (2003)

Ranges of R	Descriptions
0–0.2	Very low and probably meaningless
0.2–0.4	Low correlation
0.4–0.6	Reasonable correlation
0.6–0.8	High correlation
0.8–1	Very high correlation

Single Regression Models

The relationship between BTS and V_p was obtained for limestone rocks of Sulaymaniyah city that is presented in Figure 3a. It can be observed that BTS was increased by increasing V_p. The logarithmic model was developed to predict BTS from V_p. This is presented as Eq. (20) in Table 5. According to Harris and Taylor (2003), the correlation between BTS and V_p is a low correlation because the R of this correlation is 0.37 which is between 0.2 and 0.4. It should be noted that the low value of R can be increased using multiple-regression model that will be presented in the next subsection.

The relationship between BTS and R_L is presented in Figure 3b. It can be seen that as the value of R_L increases, the value of BTS increases. The empirical equation to predict BTS from R_L is presented as an exponential equation (Eq. (21)) in Table 5. According to Harris and Taylor (2003), there is a high correlation between BTS and R_L since the value of R is 0.66.

Figure 3c shows the relationship between BTS and $Is_{(50)}$; it can be observed that BTS was directly proportional to $Is_{(50)}$. The empirical equation to predict BTS from $Is_{(50)}$ is presented as a power equation (Eq. (22)) in Table 5. A reasonable correlation was observed for Eq. (22) based on the value of R because the value of the R lies between 0.4 and 0.6 and equals to 0.42.

It can be seen that in all single correlations, the data are scattered around the trend line and according to Harris and Taylor (2003), a very high correlation was not obtained. Therefore, the multiple regressions are used for obtaining a reliable equation to predict BTS using simple tests.

Multiple Regression Models

The multiple regression models were utilized to predict BTS from V_p and R_L. A power empirical equation was created. Eq. (23) shows this relationship, as presented in Table 5.

The multiple regression model was also developed to predict BTS from V_p and $Is_{(50)}$. As a result, a logarithmic equation was created, as shown in Eq. (24) in Table 5.

The prediction of BTS from R_L and $Is_{(50)}$ were created using power equation (Eq. (25)), as presented in Table 5.

In addition, three mechanical parameters of V_p, R_L, and $Is_{(50)}$ were correlated with BTS using linear equation (Eq. (26)), as presented in Table 5.

Based on the values of R and according to Harris and Taylor (2003), in all multiple equations, high correlation

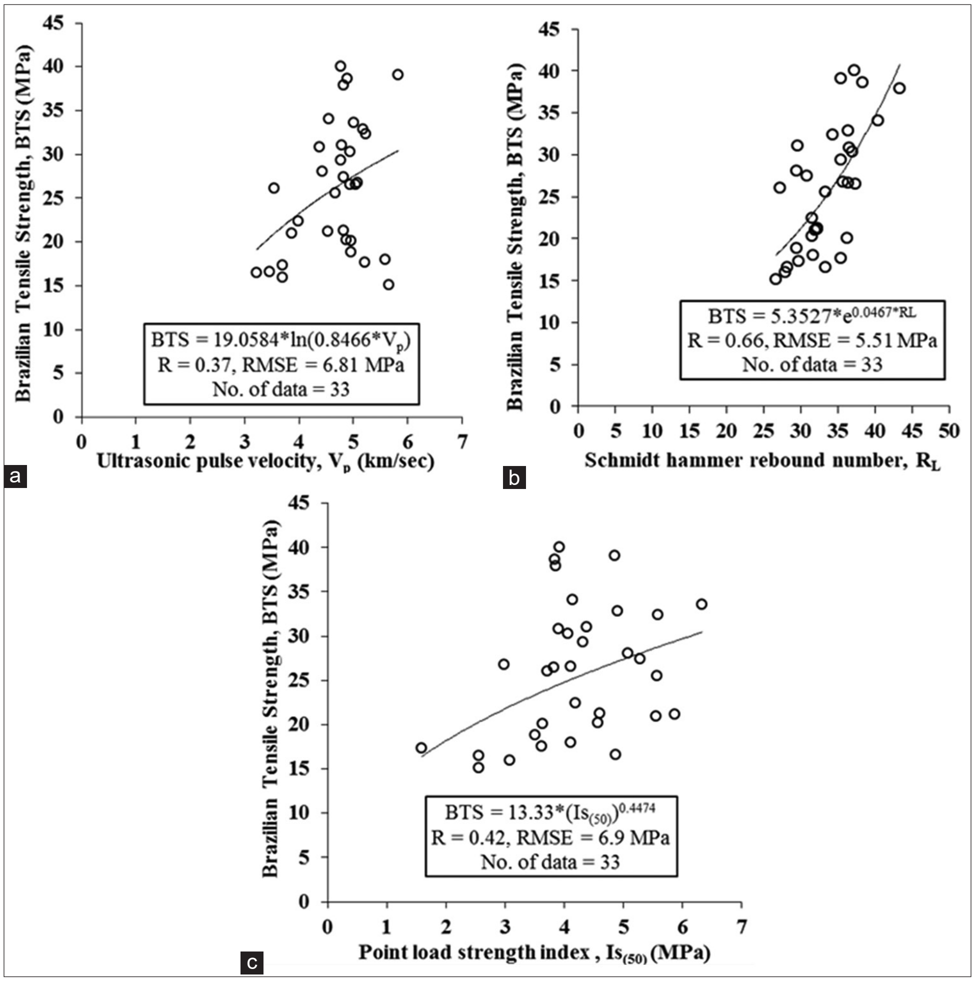

Figure 3: Correlation between: (a) Brazilian tensile strength (BTS) with V_p, (b) BTS with R_L, and (c) BTS with $Is_{(50)}$

Table 5: Single and multiple equations to predict BTS

Equations	RMSE (MPa)	R	Eq. no.	Remarks
$BTS=19.0584*\ln(0.8466*V_p)$	6.81	0.37	20	Low correlation
$BTS=5.3527*e^{(0.0467*RL)}$	5.51	0.66	21	High correlation
$BTS=13.33*(Is_{(50)})^{0.4474}$	6.9	0.42	22	Reasonable correlation
$BTS=4.9204*(V_p)^{0.6249}+0.0004*(R_L)^{2.9216}$	5.41	0.68	23	High correlation
$BTS=15.5981*\ln(2.9*V_p)+8.8781*\ln(0.048*Is_{(50)})$	6.49	0.47	24	Reasonable correlation
$BTS=0.001*(R_L)^{2.7170}+4.0359*(Is_{(50)})^{0.7253}$	5.13	0.71	25	High correlation
$BTS=1.1286*(V_p)+1.1209*(R_L)+1.6596*(Is_{(50)})-23.828$	5.2	0.98	26	Very high correlation

BTS in MPa, V_p in km/s, $Is_{(50)}$ in MPa. RMSE: Root mean square error, BTS: Brazilian tensile strength

was observed for Eq. (23) and Eq. (25), the reasonable correlation was observed for Eq. (24) and very high correlation was observed for Eq. (26).

In general, the developed models using multiple regression models were better than the produced models using single regression analysis because the multiple regression models have higher R and lower RMSE compared with equations were developed by single regression analysis and another reason is due to the fact that the BTS was the function for all three tests: V_p, R_L, and $Is_{(50)}$. However, from Table 5, it can be seen that the R_L has a greater effect on the increasing the value of R if compared with V_p and $Is_{(50)}$ because in single regression analysis the value of R for correlation between BTS and R_L is a maximum if compared with the other single equations. Furthermore, in multiple regression, the value of R for the equations that including R_L is greater than the other equations that include V_p and $Is_{(50)}$. Furthermore, it can be observed that the Eq. (26) is better than the other multiple equations because the value of R for this equation is a maximum and equals to 0.98.

The range of RMSE of all empirical equations was from 5.13 MPa to 6.9 MPa. There was a small difference between

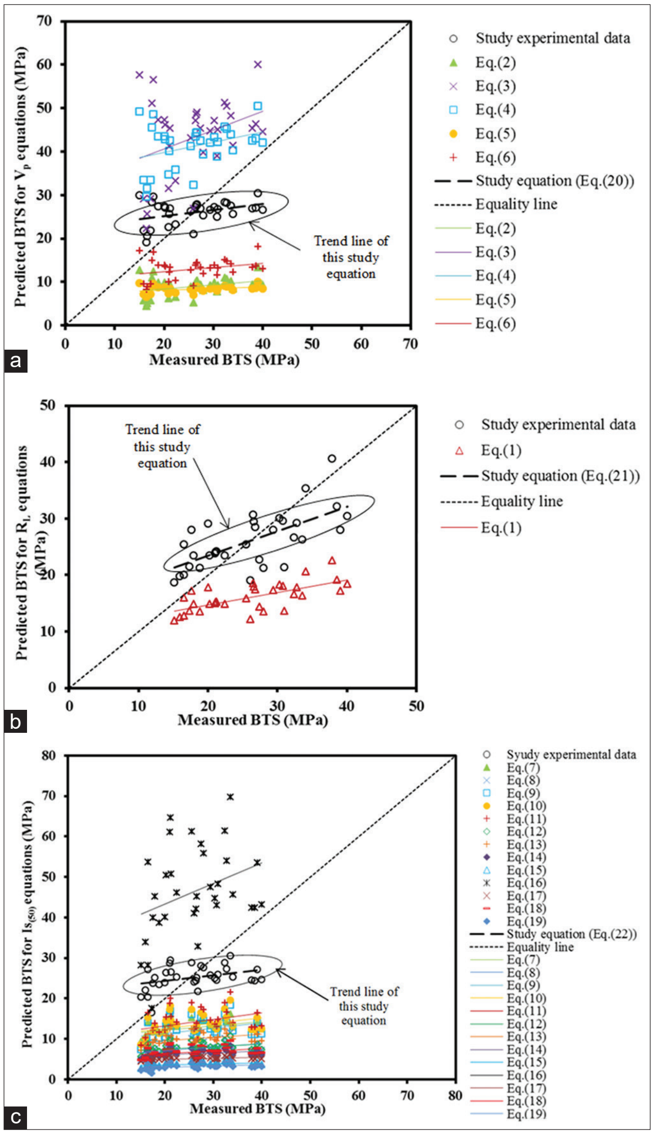

Figure 4: Correlation between measured and predicted Brazilian tensile strength for: (a) V_p, (b) R_L, and (c) $Is_{(50)}$

them but the RMSE of Eq. (25) and Eq. (26) was 5.13 MPa and 5.2 MPa, respectively, that were low values compared with RMSE of other regression models.

Comparison with Other Expressions from the Literature

Single regression models of this study were compared with literature equations for correlation of BTS with each of the V_p, R_L, and $Is_{(50)}$, as shown in Figure 4a-c, respectively. RMSE was computed, as summarized in Table 6.

From Figure 4a and Table 6, it can be observed that the regression model Eq. (20) based on pulse velocity (V_p) of this study is more applicable to the limestone rocks to predict BTS compared with literature equations. It is interesting to see that the data from Eq. (20) of this study are closer to the equality line than the other data in the literature equations. Furthermore, the RMSE of Eq. (20) is lower than that of literature equations. It should be noted that the literature equations were developed for various rock types but the current study equations were especially developed for limestone rocks.

Table 6: RMSE of the literature equations and study equations

Eq. no.	Equations	RMSE (MPa)	Remark
1	$BTS=0.15*(R_L)^{1.33}$	11.62	Literature equations
2	$BTS=0.4935*(V_p)^{1.8723}$	18.40	
3	$BTS=14.5*V_p-24.55$	19.64	
4	$BTS=8*V_p+3.84$	16.87	
5	$BTS=3.9419*e^{(0.1587*Vp)}$	19.09	
6	$BTS=3.138*e^{(0.3*Vp)}$	14.80	
7	$BTS=7.5062*Ln(Is_{(50)})+2.2219$	14.92	
8	$BTS=1.81*Is_{(50)}+4.78*10^{-6}$	19.67	
9	$BTS=2.8892*Is_{(50)}-0.0723$	15.55	
10	$BTS=2.9028*Is_{(50)}+1.1038$	14.46	
11	$BTS=3.4798*Is_{(50)}-0.523$	13.79	
12	$BTS=1.36*Is_{(50)}+2.06$	19.53	
13	$BTS=1.77*Is_{(50)}+2.57$	17.44	
14	$BTS=0.88*Is_{(50)}+2.7$	20.86	
15	$BTS=2.2*(Is_{(50)})^{0.79}$	23.41	
16	$BTS=11*Is_{(50)}$	23.11	
17	$BTS=0.617*Is_{(50)}+1.139$	22.11	
18	$BTS=0.485*Is_{(50)}+3.0755$	20.44	
19	$BTS=[Is_{(50)}/(0.968+0.076*Is_{(50)})]-0.023$	23.91	
20	$BTS=19.0584*ln(0.8466*V_p)$	6.81	Current study
21	$BTS=5.3527*e^{(0.0467*RL)}$	5.51	
22	$BTS=13.33*(Is_{(50)})^{0.4474}$	6.90	

RMSE: Root mean square error, BTS: Brazilian tensile strength

Concerning the Schmidt hammer rebound number, and point load strength index, it can be seen from Figure 4b and c that the Eq. (21) and Eq. (22) from this study are more reliable compared with literature equations. Based on this analysis, the equations that were developed in this study are more reliable to predict BTS using simple tests.

CONCLUSIONS

This study focused on the mechanical properties includes BTS, V_p, R_L, and PLT of intact limestone rocks for three formations of Sulaymaniyah city in Iraq. The statistical analysis of test results was conducted. The single and multiple correlations between BTS and each of V_p, R_L, and PLT were investigated using single and multiple regression models. The following conclusions are drawn:

- Based on the test of BTS on the three limestones, the tensile strength of white limestone was stronger than the tensile strength of dolomitic and milky limestone
- Based on the V_p test results, milky limestone has the highest V_p which is 5.832 km/s if compared with other limestone types

- Based on R_L results, white limestone is harder than milky, and dolomitic limestone rocks and R_L of dolomitic with milky limestone rocks were approximately similar
- Test results concluded that $Is_{(50)}$ of dolomitic limestone is stronger than $Is_{(50)}$ of milky limestone, and approximately $Is_{(50)}$ of white limestone was between the $Is_{(50)}$ of other two types of limestone
- Based on R and RMSE values, it can be said that the R_L has a significant effect on the increasing R and decreasing RMSE if compared with other parameters for single and multiple equations. Therefore, the correlation between BTS and R_L is better than the correlation between BTS and other parameters
- A very strong correlation (R) was observed to predict BTS using three simple tests (Pulse Velocity, Schmidt Hammer, and PLT) based on a multiple linear regression model.

REFERENCES

Al-Barzinjy, S. T. 2008. Origin of chert nodules in Kometan Formation from Dokan area, Northeast Iraq. Iraqi Bull. Geol. Min. 4(1): 95-104.

Alshkane, Y. M., H. S. Daoud and K. A. Rashed. 2018. Mechanical and petrological properties of Gercus formation in Dukan area, Kurdistan of Iraq. Sulaimani J. Eng. Sci. 5: 27-39.

Hama Saeed, S. B. and Y. M. Alshkane. 2018. Effect of freezing and thawing on physical and mechanical properties of sedimentary rock. J. Garmian Univ. 5(2): 126-140.

Baykasoğlu, A., H. Güllü, H. Çanakçı and L. Özbakır. 2008. Prediction of compressive and tensile strength of limestone via genetic programming. Expert Syst. Appl. 35(1-2): 111-123.

Brown, E. T. 1981. ISRM Suggested Methods. Rock Characterization Testing and Monitoring. Royal School of Mines, London.

Garcia-Fernandez, C. C., C. Gonzalez-Nicieza, M. I. Alvarez-Fernandez and R. A. Gutierrez-Moizant. 2018. Analytical and experimental study of failure onset during a Brazilian test. Int. J. Rock Mech. Min. Sci. 103: 254-265.

Gokceoglu, C. and K. Zorlu. 2004. A fuzzy model to predict the uniaxial compressive strength and the modulus of elasticity of a problematic rock. Eng. Appl. Artif. Intell. 17(1): 61-72.

Gurocak, Z., P. Solanki, S. Alemdag and M. M. Zaman. 2012. New considerations for empirical estimation of tensile strength of rocks. Eng. Geol. 145: 1-8.

Harris, M. and G. Taylor. 2003. Medical Statistics Made Easy. CRC Press, Boca Raton, Florida, United States.

Heidari, M., G. R. Khanlari, M. T. Kaveh and S. Kargarian. 2012. Predicting the uniaxial compressive and tensile strengths of gypsum rock by point load testing. Rock Mech. Rock Eng. 45(2): 265-273.

Franklin, J.A. 1985. Suggested method for determining point load strength. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. 22(2): 51-60.

Kallu, R. and P. Roghanchi. 2015. Correlations between direct and indirect strength test methods. Int. J. Min. Sci. Technol. 25(3): 355-360.

Khanaqa, P. A. 2011. Interpretation of new facies in the Pila Spi formation (middle-late eocene), in Sulaimaniyah, NE Iraq. Iraqi Bull. Geol. Min. 7(3): 33-45.

Khandelwal, M. and T. N. Singh. 2009. Correlating static properties of coal measures rocks with P-wave velocity. Int. J. Coal Geol. 79(1-2): 55-60.

Khanlari, G. R., M. Heidari, A. A. Sepahigero and D. Fereidooni. 2014. Quantification of strength anisotropy of metamorphic rocks of the Hamedan Province, Iran, as determined from cylindrical punch, point load and Brazilian tests. Eng. Geol. 169: 80-90.

Kılıç, A. and A. Teymen. 2008. Determination of mechanical properties of rocks using simple methods. Bull. Eng. Geol. Environ. 67(2): 237.

Kurtuluş, C., F. Sertçelik and I. Sertçelik. 2016. Correlating physico-mechanical properties of intact rocks with P-wave velocity. Acta Geodaetica Geophys. 51(3): 571-582.

Numan, N. M. S., R. A. Hammoudi and J. Chorowicz. 1998. Synsedimentary tectonics in the Eocene Pila Spi limestone formation in Iraq and its geodynamic implications. J. Afr. Earth Sci. 27(1): 141-148.

Salehin, S. 2017. Investigation into engineering parameters of marls from Seydoon dam in Iran. J. Rock Mech. Geotech. Eng. 9(5): 912-923.

Hama Salih, S. J. and Y. M. Alshkane. 2018. Statistical analysis of mechanical and physical properties of igneous rocks. J. Garmian Univ. 5(2): 174-189.

Ulusay, R. editor. 2015. The Complete ISRM Suggested Methods for Rock Characterization, Testing and Monitoring: 2007-2014. Springer. Cham. Switzerland. 143-155.