Australian Journal of Basic and Applied Sciences, 7(7): 216-229, 2013
ISSN 1991-8178

Correlation Between Point Load Index And Very Low Uniaxial Compressive Strength Of Some Iraqi Rocks

[1]Zuhair Kadhim JahanGer, M. Sc. Civil Engineering

[1]Lecturer, Water Resources Engineering Department, University of Baghdad, Iraq
[2]Dr. Azad Abbas Ahmed, Ph.D Civil Engineering
[2]General Director of Andrea Engineering Test Laboratory

Abstrac: The Point load testing is used to determine rock strength indexes in scientific researches and geotechnical practices. The apparatus of point load test and its procedure enables economical testing of cores or lump rock samples in either a field or laboratory set up. In order to estimate uniaxial compressive strength, index –to- strength conversion factors are used. These factors have been proposed by various researchers worldwide and are dependent upon rock type. This study involved extensive universal load machine and point load testing of sandstone, clay stone, siltstone, chalky stone, and limestone rocks from four Iraqi different sites: Erbil Site, Al-Sulaimaniya Site, Al-Samawa site, and Al-Najaf site, the former two sites in the northern of Iraq and the latter two in the Sothern west of Iraq. To enrich the library with new correlation factor (k) between uniaxial compression strength and point load test, more than (245) individual test results, from four distinct rock unit site investigations, were used in this study. Plots of the soil- rock log for intact rocks were classified into general categories and conversion factors were determined for each category. This allows for intact rock strength data to be made available through point load testing for numerical geotechnical analysis and empirical rock mass classification systems. A correlation factor (k) between uniaxial compression strength and point load test of about (6) has been proposed, for rock of very low strength of 27.5 MPa or less. This study confirms that the UCS estimation equations are rock dependent. But as the ratio of (mean UCS/mean PLT) increases the k factor increased linearly as the equation, $k = 0.871\left(\frac{mean\ UCS}{mean\ PLT}\right) - 0.293$, which is a new derived equation easily can be used and must be the $\left(\frac{mean\ UCS}{mean\ PLT}\right)$ greater than one. This paper presents the experimental results of laboratory point load testing program and uniaxial compressive strength carried out to estimate some Iraqi rock index-to-strength conversion factor. The correlation equations for predicting compressive strength using point load index for each groups are presented along with their confidence limits to show the variability of results produced from each equation.

Key words: Index tests, uniaxial compression tests, weak rock, engineering properties, mean UCS/mean PLT.

INTRODUCTION

The Point Load Test (PLT) was developed as an index test to predict the Uniaxial Compressive Strength (UCS) of core too broken for UCS testing. A correlation factor (K) between UCS and PLT strength of 24 has been proposed although this value is disputed. This paper investigates the value of K for some Iraqi rocks using published and unpublished data sets and concludes that K is not a unique value even for a single set of specimens but is strength dependent, generally being between 10 and 20 for weaker rock (>25 MPa). It is often less than 10 for rocks of (5 MPa) strength or less. Operator error is evaluated and considered to contribute too much of the reported scatter in Point Load Test results. The PLT is considered an appropriate and useful test for predicting the UCS of weak rocks provided that the ISRM methods are strictly observed and that samples with a range of strengths are tested to determine the variation in the correlation factor K with change in strength, (Bowden, *et al*, 1998).

In rock, except for very soft or partially decomposed sandstone or limestone, blow counts are at the refusal level *(N* > 100) The point load test (PLT) is an accepted rock mechanics testing procedure used for the calculation of rock strength index. This index can be used to estimate other rock strength parameters. The focus of this paper is to present the data analysis used to correlate the point load index (Is_{50}) with the uniaxial compressive strength (UCS), and to propose appropriate (Is_{50}) to (UCS) conversion factors for different Iraqi rocks. The rock strength determined by (PLT), like the load frame strengths that they are estimate, are an indication of intact rock strength and not necessarily of the rock mass. The recovery ratio term used earlier also has significance for core samples. A recovery ratio near 1.0 usually indicates good-quality rock. In badly fissured or soft rocks the recovery ratio may be 0.5 or less .Rock quality designation (RQD) is an index or measure of the quality of a rock mass [Bowels (1997)] used by many engineers. RQD is computed from

---

Corresponding Author: Zuhair Kadhim JahanGer, Lecturer, Water Resources Engineering Department, University of Baghdad, Iraq

recovered core samples as, Lengths of intact pieces of core greater than 100 mm divided by Length of core advance

For example, a core advance of 1500 mm produced a sample length of 1310 mm consisting of dust, gravel, and intact pieces of rock. The sum of lengths of pieces 100 mm or larger 9 (pieces vary from gravel to 280 mm) in length is 890 mm. The recovery ratio Lr = 1310/1500 =0.87 and RQD = 890/1500 = **0.59.** The rating of rock quality may be used to approximately establish the field reduction of modulus of elasticity and/or compressive strength and the following may be used as a guide, but for the case study of this research is not a satisfactory guide and indication of the rock quality and it is compressive strength. **Table 1** shows the rock quality designation (Bowles, 1997).

Properties Of Intact Rocks:

Physical Properties for Intact Rocks:

2.1.1Density, Specific Gravity, Unit Weight.
2.1.2Porosity, n.
2.1.3Void ratio, e.
2.1.4Permeability, k.
2.1.5Absorption, Abs.

Mechanical Properties for Intact Rocks:

2.1.1 Strength
2.1.1.1 Tensile Strength of Intact Rock.
2.2.1.1.1 Indirect Tests: (PLT & Brazilian Test) gives index value.
2.2.1.1.2 Direct Tests: (UCS) gives true and real value.
2.2.1.1.3 Tests :(PLT) and Schmidt Hammer Test (L-Type).
2.2.1.2 Shear Strength of Intact Rock.
2.2.1.2.1 Triaxial Compression Test.
2.2.1.2.2 Direct Shear test.
2.2.1.3. Deformation.
2.2.1.3.1 Modulus of Elasticity, E.
2.2.1.3.2 Poisson’s Ratio, *V*.

2.3 Factors Controlling the Engineering Properties of Intact Rocks:-

2.3.1 Geologic Factors:

2.3.1.1 Rock Type.
2.3.1.2 Grain Size.
2.3.1.3 Mineral Composition.
2.3.1.4 Degree of Weathering
2.3.1.5 Porosity and Intensity of fractures.
2.3.1.6. Anisotropy.

2.3.2 Engineering Factors:

2.3.2 1 Degree of Saturation,
2.3.2 2 (L/D) Ratio between (1.5 and 2.5).
2.3.2 3 Rate of Loading.
2.3.2 4 Machine Type.
2.3.2 5 End Condition of the samples.

4. The Uniaxial Compressive Strength Test (UCS):

The UCS covers the determination of the strength of intact rock core specimens in uniaxial unconfined compression state (Unconfined Compressive Strength of Intact Rock Core Specimens). The tests provide data in determining the strength of rock, namely: the uniaxial compression strength. Unconfined compressive strength of rock is used in many design formulas and is sometimes used as an index property to select the appropriate excavation technique.

The UCS is the undoubtedly the geotechnical property that is most often quoted in rock engineering practice. It is widely understood as a rough index which gives a first approximation of the range of issues that are likely to be encountered in a variety of engineering problems including roof support, pillar design, and excavating technique. For most geotechnical design problems deals with rock, a reasonable approximation of the UCS is could be sufficing .This is due in part to the high variability of UCS measurements .Moreover, the tests are expensive ,primarily because of the need to carefully prepare the specimens to ensure that their ends are perfectly parallel.

The deformation and strength properties of rock cores measured in the laboratory usually do not accurately reflect large-scale *in situ* properties because the latter are strongly Influenced by joints, faults, inhomogeneities, weakness planes, and other factors. Therefore, laboratory values for intact specimens must be employed with proper judgment in engineering applications.

Table 1: Rock quality designation (Bowls, 1997)

RQD	Rock description
<0.25	Very poor
0.25-0.50	Poor
0.50-0.75	Fair
0.75-0.90	Good
>0.90	**Excellent**

Table 2: Engineering classification of intact rock on basis of strength (Deer and Miller, 1966)

Class	Uniaxial Compressive Strength (MPa)	Description
A	>200	Very high strength
B	110 -220	High Strength
C	55-110	Medium Strength
D	27.5-55	Low strength
E	< 27.5	Very low strength

Point Load Test (Plt):

The PLT is an attractive to the UCS because it can provide similar data at a lower cost. The PLT has been used in geotechnical analysis for over thirty years (ISRM, 1985).The PLT involves the compression of a rock sample between conical steel platens until failure occurs. The apparatus for this test consists of a rigid frame, two point load platens, a hydraulically activated ram with pressure gauge and a device for measuring the distance between the loading points. The pressure gauge should be of the type in which the failure pressure can be recorded. A state of the art point load testing device with sophisticated pressure reading instrumentation is shown in **Fig.1**,**2, 3, and 4**.

Fig. 1: Photograph of rock core from borehole

(A) Before testing **(b) After testing**

Fig. 2: Core separated into specimens for PLT and UCS tests

(A) Before testing **(B) UCS Test Device** **(C) After testing**

Fig. 3: Core specimens for UCS tests.

Fig. 4: Pictorial overview of PLT stages.

The International Society of Rock Mechanics (ISRM, 1985) has established the basic procedure for testing and calculation of the point load strength index. There are three basic types of point load tests: axial, diametral, and block or lump. The axial and diametral tests are conducted on rock core samples. In the axial test, the core is loaded parallel to the longitudinal axis of the core, and the test is most comparable to a UCS test. The size and shape requirements for diametral, axial, block or irregular lump testing shall conform to the recommendations of (ISRM, 1985). The sides of the specimens shall be free from abrupt irregularities that can generate stress concentrations. No specimen preparation is required.

6. *Previous Investigations:*

The point load test has been reported as an indirect measure of the compressive or tensile strength of the rock.

Broch, E, Franklin J.A. (1972), reported that for 50 mm diameter cores the uniaxial compressive strength is approximately equal to 24 times the point load index. They also developed a size correction chart so that core of various diameters could be used for strength determination.

$$UCS = 24\, I_{s(50)} \tag{1}$$

Bieniawski, Z.T., (1974), suggested the following approximate relation between UCS, $I_{s(50)}$.

$$UCS = 24\, I_{s(50)} \tag{2}$$

According to ISRM commission on Standardization of Laboratory and Field Test report , the compressive strength is 20-25 times $I_{s(50)}$ However, it is also reported that in tests on many different rock types the range varied between 15 and 50, especially for anisotropic rocks. So errors up to 100 % should be expected if an arbitrary ratio value is chosen to predict compressive strength from point load tests.

Hassani, *et al.*(1980), Adopted from Akram, M. And Bakar, from performed the point load test on large specimens and revised the size correlation chart commonly used to reference point load values from cores with differing diameters to the standard size of 50 mm. With this new correction, they found the ratio of UCS to $I_{s(50)}$to be approximately 29.

Brook, N. (1985), emphasized the possible sources of error when using the point load test, and proposed an analytical method of “Size Correction” to a chosen standard size. The formula containing the “Size Correction Factor”, f, is:

$$I_{s(50)} = f.\ F/ D^2_e \tag{3}$$

Where:
$f = (De/50)^{0.45}$ and
F = Applied Load.
De = Equivalent Core Diameter.
f = Size Correction Factor.

Cargill, J.S., and Shakoor, A., (1990), the dependence of the UCS versus $I_{s(50)}$correlation on rock types was demonstrated by They found the following correlation equation:

$$q_u = 13 + 23\, I_{s(50)} \tag{4}$$

Singh, V.K., and Singh D.P., (1993), was examined the relationship of the point load test with uniaxial compressive strength using quartzite rocks to substantiate the existing correlations.

Chau, K.T., Wong, R. H. C., (1996) proposed a simple analytical formula for the calculation of the UCS based on corrected Is to a specimen diameter of 50 mm $I_{s(50)}$. The index-to-strength conversion factor (k) relating UCS to $I_{s(50)}$was reported to depend on the compressive to tensile strength ratio, the Poisson’s ratio, the length and the diameter of the rock specimen. Their theoretical prediction for k=14.9 was reasonably close to the experimental observation k = 12.5 for Hong Kong rocks.

Bowden, *et al*, (1998), reported that k is not a unique value even for a single set of specimens but is strength dependent, generally being between 10 and 20 for weaker rock (greater than 25 MPa). It is often less 10 for rocks of 5MPa strength or less.

Rusnak and Mark, 2000, reported the following relations for different rocks: For coal measure rocks:

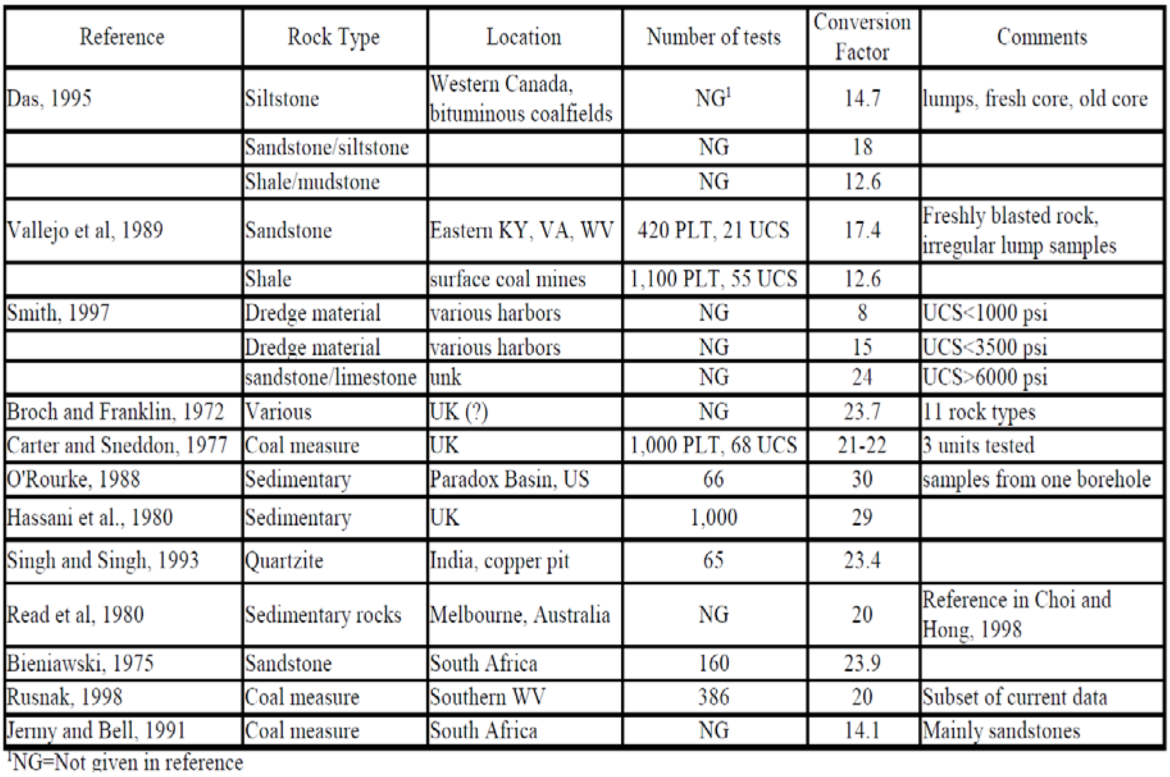
$$q_u = 23.62\, I_{s(50)} - 2.69 \tag{5}$$

For other rocks:

$$q_u= 8.41 I_{s(50)}+ 9.51 \qquad (6)$$

Akram, M. And Bakar, (2007), performed Two hundred rock cores were drilled and used for the uniaxial compressive strength and point load index tests. The UCS was found to be correlated with Is(50) through a linear relationship having slope of 22.792 and intercept of 13.295 for Group A rocks. The UCS versus Is (50) correlation for Group B rocks was also found to be linear but with a slope of 11.076 and zero intercept. This study confirms that the UCS estimation equations are rock dependent. **Table 3** Shows Published comparisons between the PLT and UCS for sedimentary rock (Rusnak, J. and Mark C., 2000).

Table 3: Published comparisons between the PLT and UCS for sedimentary rock (Rusnak, J. and Mark C., 2000)



Reference	Rock Type	Location	Number of tests	Conversion Factor	Comments
Das, 1995	Siltstone	Western Canada, bituminous coalfields	NG[1]	14.7	lumps, fresh core, old core
	Sandstone/siltstone		NG	18	
	Shale/mudstone		NG	12.6	
Vallejo et al, 1989	Sandstone	Eastern KY, VA, WV	420 PLT, 21 UCS	17.4	Freshly blasted rock, irregular lump samples
	Shale	surface coal mines	1,100 PLT, 55 UCS	12.6	
Smith, 1997	Dredge material	various harbors	NG	8	UCS<1000 psi
	Dredge material	various harbors	NG	15	UCS<3500 psi
	sandstone/limestone	unk	NG	24	UCS>6000 psi
Broch and Franklin, 1972	Various	UK (?)	NG	23.7	11 rock types
Carter and Sneddon, 1977	Coal measure	UK	1,000 PLT, 68 UCS	21-22	3 units tested
O'Rourke, 1988	Sedimentary	Paradox Basin, US	66	30	samples from one borehole
Hassani et al., 1980	Sedimentary	UK	1,000	29	
Singh and Singh, 1993	Quartzite	India, copper pit	65	23.4	
Read et al, 1980	Sedimentary rocks	Melbourne, Australia	NG	20	Reference in Choi and Hong, 1998
Bieniawski, 1975	Sandstone	South Africa	160	23.9	
Rusnak, 1998	Coal measure	Southern WV	386	20	Subset of current data
Jermy and Bell, 1991	Coal measure	South Africa	NG	14.1	Mainly sandstones

[1] NG=Not given in reference

Agustawijaya, D.S., (2007), The UCS values were then correlated with the point load strength index values, which show a good correlation. The conversion factor for soft rocks is found to be about 14, which is about 58% of the conversion factor for hard rocks.

Conclusion:

The PLT is a fabulous method to determine intact rock strength properties from drill core samples. It has become a famous test in geotechnical engineering. **Table 4, and 5** Shows test results of the UCS and PLT for the study.

The Iraqi rocks from four locations, Erbil, Al-Samawa, Al- Sulaimaniya, and AL-Najaf sites were used to find the conversion factor k between UCS and PLT. **Figs. between 8 and 12** show UCS values were correlated with the point Load strength index values, which show a good correlation using the regression equation of through origin equation which is showing the best coefficient of determination, R-squared.

The conversion factor for Iraqi rocks is found to be about (5.28) for CLAYSTONE ROCK, between (5.65 and 11.18) for LIMESTONE ROCK, and (1.52) for greenish gray SANDSTONE ROCK, which are about (8-40 %) of the conversion factor for hard rocks. The rock type is almost very low strength due to that the average UCS is below 27.5 MPa. This study confirms that the UCS estimation equations are rock dependent.

Table 4: Summary of results of the UCS and PLT test for rocked samples

Site Locations	Rock Type	No. of specimens	Uniaxial Compressive Strength,UCS			Point Load Strength Index, Is_{50}		
			Mean (MPa)	Standard Deviation		Mean (MPa)	Standard Deviation	
				(MPa)	Coefficient of Variation (%)		(MPa)	Coefficient of Variation (%)
Erbil Site	CLAYSTONE, Reddish Brown	40	20.35	1.485	7.23	2.405	0.253	10.54
Al-Samawa site	LIMESTONE, White	155	13.27	2.92	22.00	1.078	0.419	38.83
Al-Sulaimaniya Site	SANDSTONE, Greenish Gray to Gray	30	4.05	1.612	39.81	1.892	1.170	61.83
Al-Najaf Site	LIMESTONE, White and Milky	23	18.88	13.72	72.64	3.39	1.638	48.33

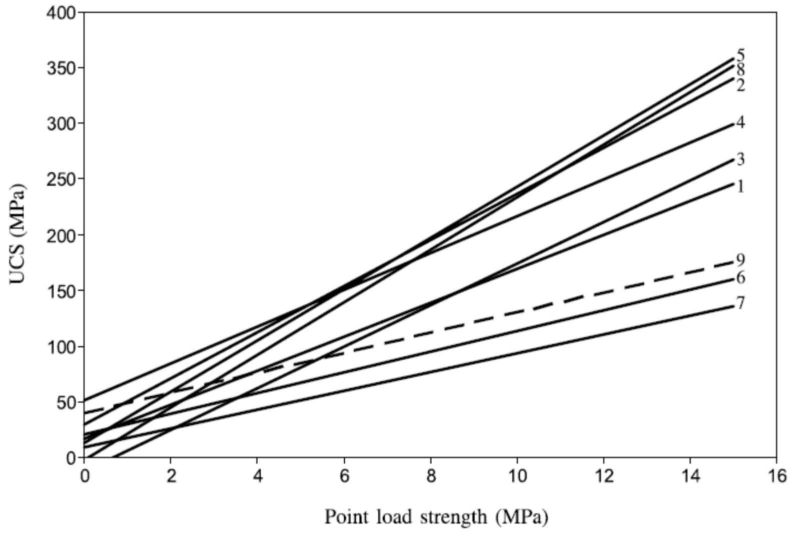
Table 5: Summary of fit equation results

Erbil Site			
Fit Equation	R^2	R	Regression Equation
Linear, Y=B*X+A	0.063	0.25	UCS = 0.714 * Is_{50} + 18.633
Log, Y=B*log(X)+A	0.014	0.11	UCS = 0.836 * log(Is_{50}) + 19.898
Exponential, Y=exp(B*X)+A	0.060	0.25	UCS = exp(0.032 * Is_{50}) * 18.142
Through origin, Y=B*X	0.613	0.79	UCS = 5.286* Is_{50}
Al- Samawa Site			
Fit Equation	R^2	R	Regression Equation
Linear, Y=B*X+A	0.28	0.53	UCS = 3.699 * Is_{50} + 9.288
Log, Y=B*log(X)+A	0.29	0.54	UCS = 4.210 * log(Is_{50}) + 13.252
Exponential, Y=exp(B*X)+A	0.26	0.51	UCS = exp(0.272* Is_{50}) * 9.660
Through origin, Y=B*X	0.90	0.95	UCS = 11.184* Is_{50}
Al- Sulaimaniya Site			
Fit Equation	R^2	R	Regression Equation
Linear, Y=B*X+A	0.009	0.09	UCS = -0.130 * Is_{50} + 4.296
Log, Y=B*log(X)+A	0.006	0.08	UCS = -0.151 * log(Is_{50} + 4.106
Exponential, Y=exp(B*X)+A	0.009	0.09	UCS = exp(-0.035 * Is_{50}) * 3.971
Through origin, Y=B*X	0.605	0.78	UCS=1.526 * Is_{50}
AL-Najaf Site			
Fit Equation	R^2	R	Regression Equation
Linear, Y=B*X+A	0.5182	0.719	UCS = 6.02831 * Is_{50} -1.54848
Log, Y=B*log(X)+A	0.292	0.540	UCS = 7.49096 * log(Is_{50}) + 11.796
Exponential, Y=exp(B*X)+A	0.4333	0.658	UCS = exp(0.477256 * Is_{50}) * 2.4165
Through origin, Y=B*X	0.8327	0.912	UCS = 5.65803 * Is_{50}
Scatter Plot			
Fit Equation	R^2	R	Regression Equation
Linear, Y=B*X+A	0.1734	0.4164	UCS = 2.212 * Is_{50} + 10.271
Log, Y=B*log(X)+A	0.1258	0.3546	UCS = 3.652 * log(Is_{50}) + 13.003
Exponential, Y=exp(B*X)+A	0.0380	0.1949	UCS = exp(0.093 * Is_{50}) * 10.188
Through origin, Y=B*X	0.6535	0.8083	UCS = 6.023 * Is_{50}

Continue table 5

Al Samawa Site	Erbil Site	Al-Sulaimaniya Site	Al-Najaf Site	Scatter plot
Fit 1: Linear, Y=B*X+A Equation: Y = 3.69903 * X + 9.2883 Number of data points used = 155 Average X = 1.07895 Average Y = 13.2794 Regression sum of squares = 370.627 Residual sum of squares = 951.187 Coef. of determination, R-squared = 0.280392 Residual mean square, sigma-hat-sq'd =	Fit 1: Linear, Y=B*X+A Equation: Y = 0.714451 * X + 18.6331 Number of data points used = 40 Average X = 2.40522 Average Y = 20.3515 Regression sum of squares = 82.0339 Residual sum of squares = 1215.78 Coef. of determination, R-squared = 0.0632092 Residual mean square, sigma-hat-sq'd =	Fit 1: Linear, Y=B*X+A Equation: Y = -0.130489 * X + 4.29673 Number of data points used = 30 Average X = 1.89207 Average Y = 4.04983 Regression sum of squares = 0.676962 Residual sum of squares = 74.7702 Coef. of determination, R-squared = 0.00897267 Residual mean square,	Fit 1: Linear, Y=B*X+A Equation: Y = 6.02831 * X + -1.54848 Number of data points used = 23 Average X = 3.39 Average Y = 18.8875 Regression sum of squares = 2244.05 Residual sum of squares = 2086.18 Coef of determination, R-squared = 0.518229 Residual mean square, sigma-hat-sq'd =	Fit 1: Linear, Y=B*X+A Equation: Y = 2.21218 * X + 10.2719 Number of data points used = 248 Average X = 1.60556 Average Y = 13.8237 Regression sum of squares = 2121.78 Residual sum of squares = 10109.6 Coef of determination, R-squared = 0.173471 Residual mean square, sigma-hat-sq'd =

6.21691	31.9943	sigma-hat-sq'd = 2.67036	99.3418	41.0958
Fit 2: Log, Y=B*log(X)+A Equation: Y = 4.21043 * log(X) + 13.2525 Number of data points used = 155 Average log(X) = 0.00637105 Average Y = 13.2794 Regression sum of squares = 382.241 Residual sum of squares = 939.573 Coef. of determination, R-squared = 0.289179 Residual mean square, sigma-hat-sq'd = 6.141	Fit 2: Log, Y=B*log(X)+A Equation: Y = 0.836195 * log(X) + 19.8982 Number of data points used = 40 Average log(X) = 0.542123 Average Y = 20.3515 Regression sum of squares = 18.9391 Residual sum of squares = 1278.88 Coef. of determination, R-squared = 0.0145931 Residual mean square, sigma-hat-sq'd = 33.6546	Fit 2: Log, Y=B*log(X)+A Equation: Y = -0.151456 * log(X) + 4.10647 Number of data points used = 30 Average log(X) = 0.373949 Average Y = 4.04983 Regression sum of squares = 0.459387 Residual sum of squares = 74.9878 Coef .of determination, R-squared = 0.00608886 Residual mean square, sigma-hat-sq'd = 2.67813	Fit 2: Log, Y=B*log(X)+A Equation: Y = 7.49096 * log(X) + 11.7969 Number of data points used = 23 Average log(X) = 0.946553 Average Y = 18.8875 Regression sum of squares = 1268.21 Residual sum of squares = 3062.02 Coef of determination, R-squared = 0.292874 Residual mean square, sigma-hat-sq'd = 145.81	Fit 2: Log, Y=B*log(X)+A Equation: Y = 3.6526 * log(X) + 13.0039 Number of data points used = 248 Average log(X) = 0.224442 Average Y = 13.8237 Regression sum of squares = 1538.89 Residual sum of squares = 10692.5 Coef of determination, R-squared = 0.125815 Residual mean square, sigma-hat-sq'd = 43.4653
Fit 3: Exponential, log(Y)=B*X+A Equation: log(Y) = 0.272233 * X + 2.26809 Alternate equation: Y = exp(0.272233 * X) * 9.6609 Number of data points used = 155 Average X = 1.07895 Average log(Y) = 2.56181 Regression sum of squares = 2.00743 Residual sum of squares = 5.67043 Coef. of determination, R-squared = 0.261458 Residual mean square, sigma-hat-sq'd = 0.0370616	Fit 3: Exponential, log(Y)=B*X+A Equation: log(Y) = 0.0325954 * X + 2.89826 Alternate equation: Y = exp(0.0325954 * X) * 18.1426 Number of data points used = 40 Average X = 2.40522 Average log(Y) = 2.97666 Regression sum of squares = 0.170751 Residual sum of squares = 2.66704 Coef .of determination, R-squared = 0.0601702 Residual mean square, sigma-hat-sq'd = 0.0701854	Fit 3: Exponential, log(Y)=B*X+A Equation: log(Y) = -0.0351647 * X + 1.37918 Alternate equation: Y = exp(-0.0351647 * X) * 3.97166 Number of data points used = 30 Average X = 1.89207 Average log(Y) = 1.31265 Regression sum of squares = 0.0491622 Residual sum of squares = 5.50308 Coef. of determination, R-squared = 0.00885447 Residual mean square, sigma-hat-sq'd = 0.196539	Fit 3: Exponential, log(Y)=B*X+A Equation: log(Y) = 0.477256 * X + 0.882319 Alternate equation: Y = exp(0.477256 * X) * 2.4165 Number of data points used = 23 Average X = 3.39 Average log(Y) = 2.50022 Regression sum of squares = 14.0651 Residual sum of squares = 18.3888 Coef of determination, R-squared = 0.433388 Residual mean square, sigma-hat-sq'd = 0.875657	Fit 3: Exponential, log(Y)=B*X+A Equation: log(Y) = 0.0938488 * X + 2.32122 Alternate equation: Y = exp(0.0938488 * X) * 10.1881 Number of data points used = 248 Average X = 1.60556 Average log(Y) = 2.4719 Regression sum of squares = 3.81871 Residual sum of squares = 96.4818 Coef of determination, R-squared = 0.0380727 Residual mean square, sigma-hat-sq'd = 0.392203
Fit 4: Y=B*X, through origin Equation: Y = 11.1841 * X Number of data points used = 155 Average X = 1.07895 Average Y = 13.2794 Residual sum of squares = 2696.57 Coef. of determination, R-squared = 0.905894 Residual mean square, sigma-hat-sq'd = 17.5102	Fit 4: Y=B*X, through origin Equation: Y = 5.28623 * X Number of data points used = 40 Average X = 2.40522 Average Y = 20.3515 Residual sum of squares = 6907.76 Coef. of determination, R-squared = 0.613339 Residual mean square, sigma-hat-sq'd = 177.122	Fit 4: Y=B*X, through origin Equation: Y = 1.52689 * X Number of data points used = 30 Average X = 1.89207 Average Y = 4.04983 Residual sum of squares = 224.408 Coef. of determination, R-squared = 0.604555 Residual mean square, sigma-hat-sq'd = 7.7382	Fit 4: Y=B*X, through origin Equation: Y = 5.65803 * X Number of data points used = 23 Average X = 3.39 Average Y = 18.8875 Residual sum of squares = 2096.62 Coef of determination, R-squared = 0.832741 Residual mean square, sigma-hat-sq'd = 95.301	Fit 4: Y=B*X, through origin Equation: Y = 6.02358 * X Number of data points used = 247 Average X = 1.61155 Average Y = 13.8471 Residual sum of squares = 20631.2 Coef of determination, R-squared = 0.653596 Residual mean square, sigma-hat-sq'd = 83.8665



The comparison of the derived equation with the previous equations used to predict UCS from point load strength. *1* D'Andrea et al. (1964), *2* Deere and Miller (1966), *3* Singh (1981), *4* Gunsallus and Kulhawy (1984), *5* Chargill and Shakoor (1990), *6* Grasso et al. (1992), *7* Kahraman (2001), *8* Kahraman (2001), *9* This study

Fig. 5: PLT VS UCS For previous study (Fener, *et al*, 2005)

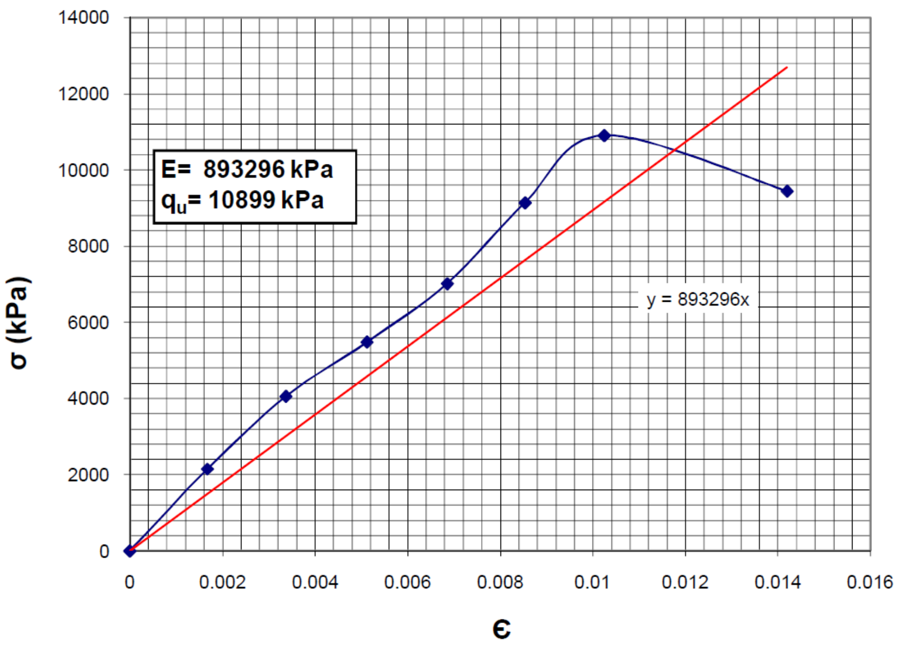
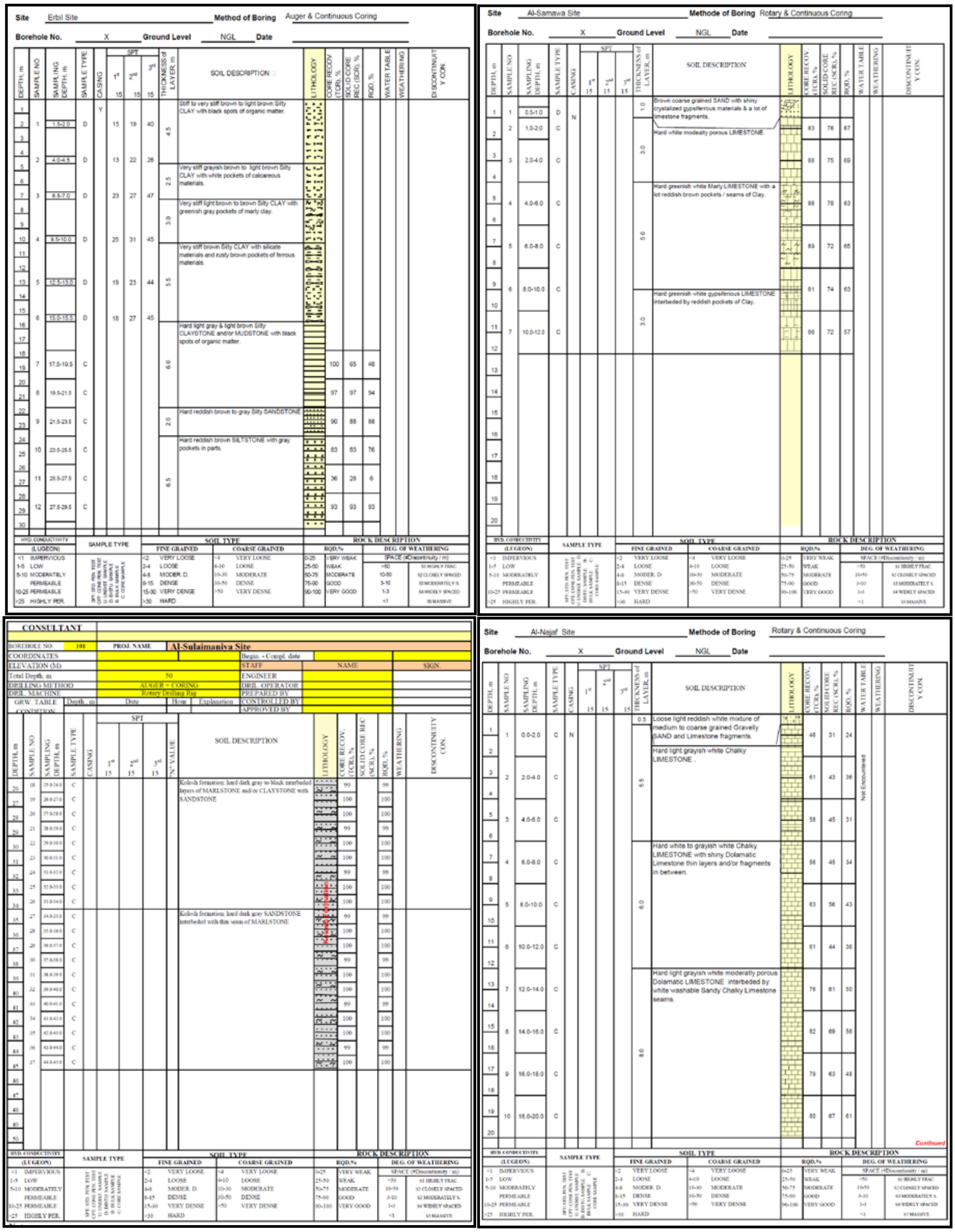


Fig. 6: UCS test curve



Site Erbil Site **Method of Boring** Auger & Continuous Coring
Borehole No. X **Ground Level** NGL **Date**

DEPTH, m	SAMPLE NO	SAMPLING DEPTH, m	SAMPLE TYPE	CASING	SPT 1st 15	SPT 2nd 15	SPT 3rd 15	THICKNESS of LAYER, m	SOIL DESCRIPTION	CORE RECOV. (TCR), %	SOLID CORE REC (SCR), %	RQD, %	WATER TABLE	WEATHERING	DISCONTINUITY CON.
1				Y				4.5	Stiff to very stiff brown to light brown Silty CLAY with black spots of organic matter.						
2	1	1.5-2.0	D		15	19	40								
5	2	4.0-4.5	D		13	22	26								
6								2.5	Very stiff grayish brown to light brown Silty CLAY with white pockets of calcareous materials.						
7	3	6.5-7.0	D		23	27	47								
8								3.0	Very stiff light brown to brown Silty CLAY with greenish gray pockets of marly clay.						
10	4	9.5-10.0	D		25	31	45								
11								5.5	Very stiff brown Silty CLAY with silicate materials and rusty brown pockets of ferrous materials.						
13	5	12.5-13.0	D		19	23	44								
16	6	15.0-15.5	D		18	27	45								
16								6.0	Hard light gray & light brown Silty CLAYSTONE and/or MUDSTONE with black spots of organic matter.						
19	7	17.5-19.5	C							100	65	48			
21	8	19.5-21.5	C							97	97	94			
23	9	21.5-23.5	C					2.0	Hard reddish brown to gray Silty SANDSTONE.	90	88	88			
25	10	23.5-25.5	C					6.5	Hard reddish brown SILTSTONE with gray pockets in parts.	83	83	76			
27	11	25.5-27.5	C							36	28	6			
29	12	27.5-29.5	C							93	93	93			
30															

HYD. CONDUCTIVITY (LUGEON)		SAMPLE TYPE	SOIL TYPE FINE GRAINED		SOIL TYPE COARSE GRAINED		ROCK DESCRIPTION RQD,%		DEG. OF WEATHERING SPACE (#Discontinuity / m)	
<1	IMPERVIOUS	SPT: STD. PEN. TEST	<2	VERY LOOSE	<4	VERY LOOSE	0-25	VERY WEAK	>50	S1 HIGHLY FRAC.
1-5	LOW	CPT: CONE PEN. TEST	2-4	LOOSE	4-10	LOOSE	25-50	WEAK	10-50	S2 CLOSELY SPACED
5-10	MODERATELY PERMEABLE	U: UNDIST. SAMPLE	4-8	MODER. D.	10-30	MODERATE	50-75	MODERATE	3-10	S3 MODERATELY S.
10-25	PERMEABLE	D: DISTU. SAMPLE	8-15	DENSE	30-50	DENSE	75-90	GOOD	1-3	S4 WIDELY SPACED
>25	HIGHLY PER.	B: BULK SAMPLE	15-30	VERY DENSE	>50	VERY DENSE	90-100	VERY GOOD	<1	S5 MASSIVE
		C: CORE SAMPLE	>30	HARD						

Site Al-Samawa Site **Methode of Boring** Rotary & Continuous Coring
Borehole No. X **Ground Level** NGL **Date**

DEPTH, m	SAMPLE NO	SAMPLING DEPTH, m	SAMPLE TYPE	CASING	SPT 1st 15	SPT 2nd 15	SPT 3rd 15	THICKNESS of LAYER, m	SOIL DESCRIPTION	CORE RECOV. (TCR), %	SOLID CORE REC (SCR), %	RQD, %	WATER TABLE	WEATHERING	DISCONTINUITY CON.
1	1	0.5-1.0	D	N				1.0	Brown coarse grained SAND with shiny crystalized gypsiferrous materials & a lot of limestone fragments.						
2	2	1.0-2.0	C					3.0	Hard white modealty porous LIMESTONE.	83	76	67			
3	3	2.0-4.0	C							88	75	69			
5	4	4.0-6.0	C					5.0	Hard greenish white Marly LIMESTONE with a lot reddish brown pockets / seams of Clay.	86	78	63			
7	5	6.0-8.0	C							89	72	65			
9	6	8.0-10.0	C							81	74	63			
10								3.0	Hard greenish white gypsiferious LIMESTONE interbeded by reddish pockets of Clay.						
11	7	10.0-12.0	C							86	72	57			
12–20															

CONSULTANT

BOREHOLE NO: 101	PROJ. NAME	Al-Sulaimaniya Site			
COORDINATES			Begin. - Compl. date		
ELEVATION (M)			STAFF	NAME	SIGN.
Total Depth, m	50		ENGINEER		
DRILLING METHOD	AUGER + CORING		DRIL. OPERATOR		
DRIL. MACHINE	Rotary Drilling Rig		PREPARED BY		
GRW. TABLE CONDITION	Depth, m	Date	Hour	Explanation	CONTROLLED BY
					APPROVED BY

DEPTH, m	SAMPLE NO	SAMPLING DEPTH, m	SAMPLE TYPE	CASING	SPT 1st 15	SPT 2nd 15	SPT 3rd 15	"N" VALUE	SOIL DESCRIPTION	CORE RECOV. (TCR), %	SOLID CORE REC (SCR), %	RQD, %	WEATHERING	DISCONTINUITY CON.
26	18	25.0-26.0	C						Kolosh formation: hard dark gray to black interbeded layers of MARLSTONE and/or CLAYSTONE with SANDSTONE	99		99		
27	19	26.0-27.0	C							100		100		
28	20	27.0-28.0	C							100		100		
29	21	28.0-29.0	C							99		99		
30	22	29.0-30.0	C							100		100		
31	23	30.0-31.0	C							100		100		
32	24	31.0-32.0	C							99		99		
33	25	32.0-33.0	C							100		100		
34	26	33.0-34.0	C							100		100		
35	27	34.0-35.0	C						Kolosh formation: hard dark gray SANDSTONE interbeded with thin seam of MARLSTONE	99		99		
36	28	35.0-36.0	C							100		100		
37	29	36.0-37.0	C							100		100		
38	30	37.0-38.0	C							99		99		
39	31	38.0-39.0	C							100		100		
40	32	39.0-40.0	C							100		100		
41	33	40.0-41.0	C							99		99		
42	34	41.0-42.0	C							100		100		
43	35	42.0-43.0	C							100		100		
44	36	43.0-44.0	C							99		99		
45	37	44.0-45.0	C							100		100		
46–50														

Site Al-Najaf Site **Methode of Boring** Rotary & Continuous Coring
Borehole No. X **Ground Level** NGL **Date**

DEPTH, m	SAMPLE NO	SAMPLING DEPTH, m	SAMPLE TYPE	CASING	SPT 1st 15	SPT 2nd 15	SPT 3rd 15	THICKNESS of LAYER, m	SOIL DESCRIPTION	CORE RECOV. (TCR), %	SOLID CORE REC (SCR), %	RQD, %	WATER TABLE	WEATHERING	DISCONTINUITY CON.
1	1	0.0-2.0	C	N				0.5	Loose light reddish white mixture of medium to coarse grained Gravelly SAND and Limestone fragments.	46	31	24	Not Encountered		
2								5.5	Hard light grayish white Chalky LIMESTONE .						
3	2	2.0-4.0	C							61	43	36			
5	3	4.0-6.0	C							58	45	31			
7	4	6.0-8.0	C					6.0	Hard white to grayish white Chalky LIMESTONE with shiny Dolamatic Limestone thin layers and/or fragments in between.	56	45	34			
9	5	8.0-10.0	C							63	56	43			
11	6	10.0-12.0	C							61	44	36			
13	7	12.0-14.0	C					8.0	Hard light grayish white moderatly porous Dolamatic LIMESTONE interbeded by white washable Sandy Chalky Limestone seams.	76	61	50			
15	8	14.0-16.0	C							82	69	56			
17	9	16.0-18.0	C							79	63	48			
19	10	18.0-20.0	C							80	67	61			

Continued

Fig. 7: Typical soil -rock borehole logs for the studied sites

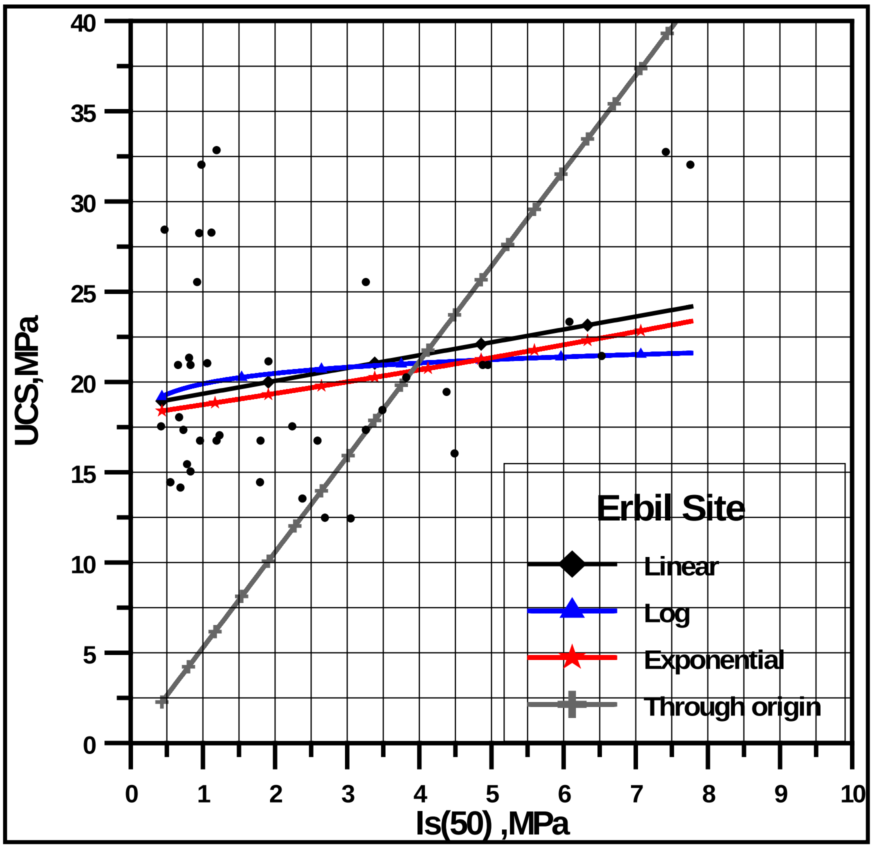


Fig. 8: Point load test vs. uniaxial compressive strength test.

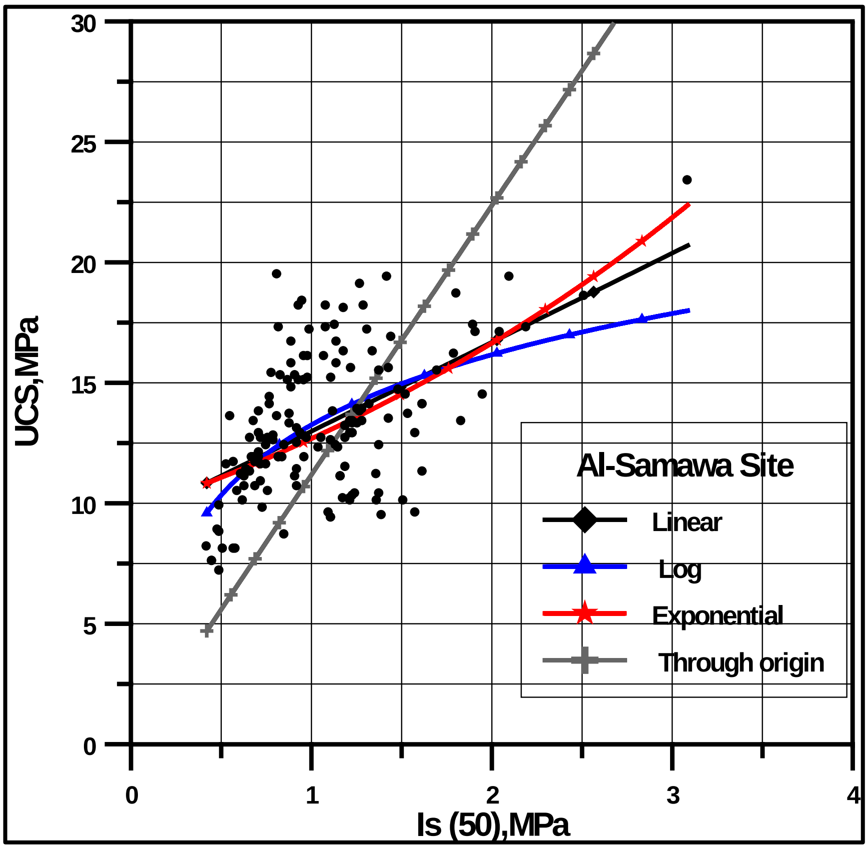


Fig. 9: Point load test vs. uniaxial compressive strength test.

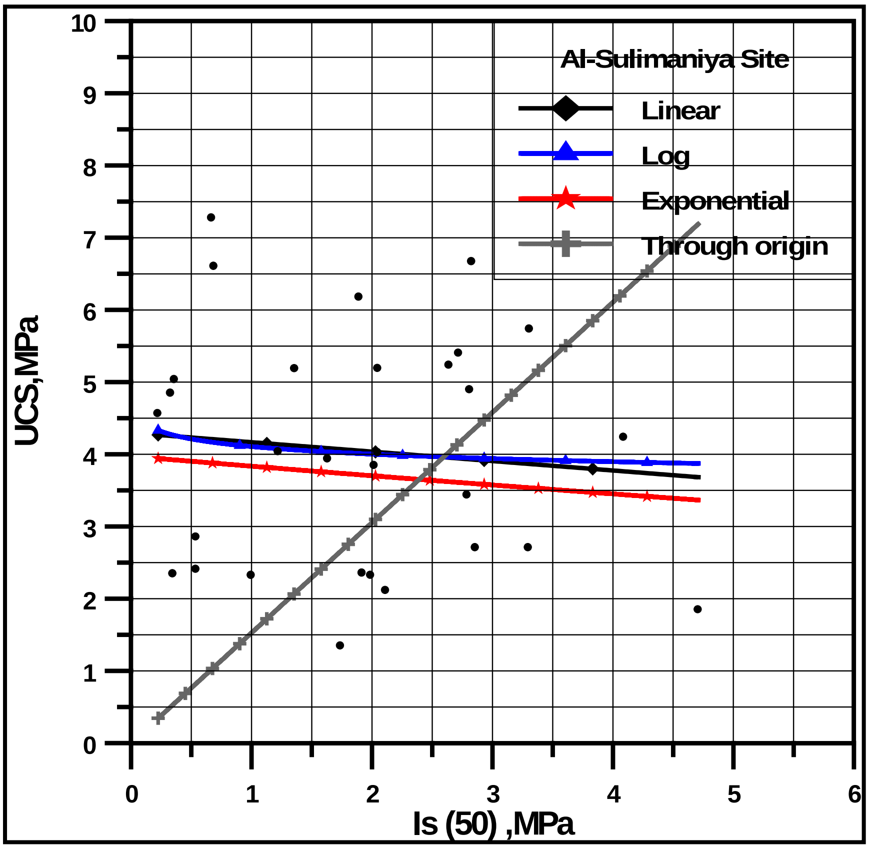


Fig. 10: Point load test vs. uniaxial compressive strength test.

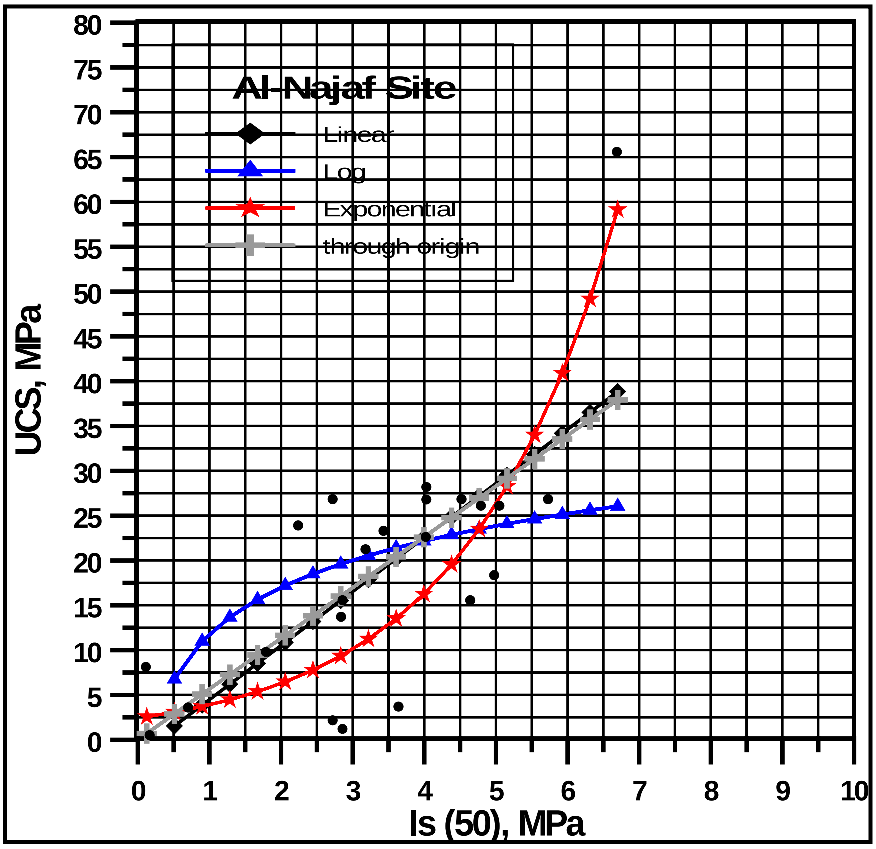


Fig. 11: Point load test vs. uniaxial compressive strength test.

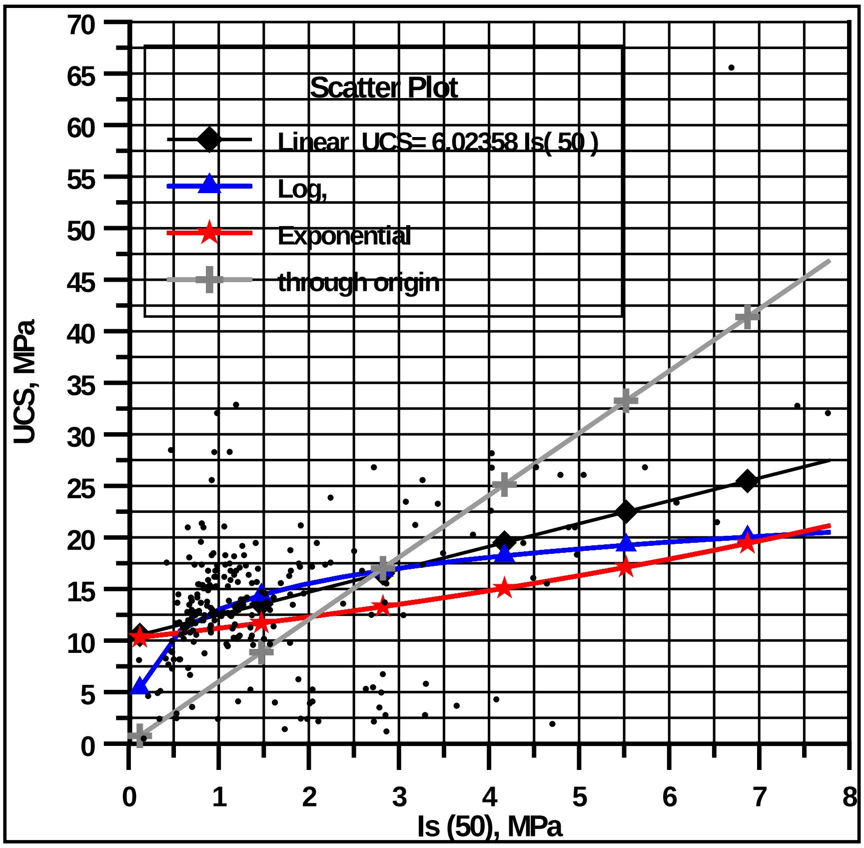


Fig. 12: Point load test vs. uniaxial compressive strength test.

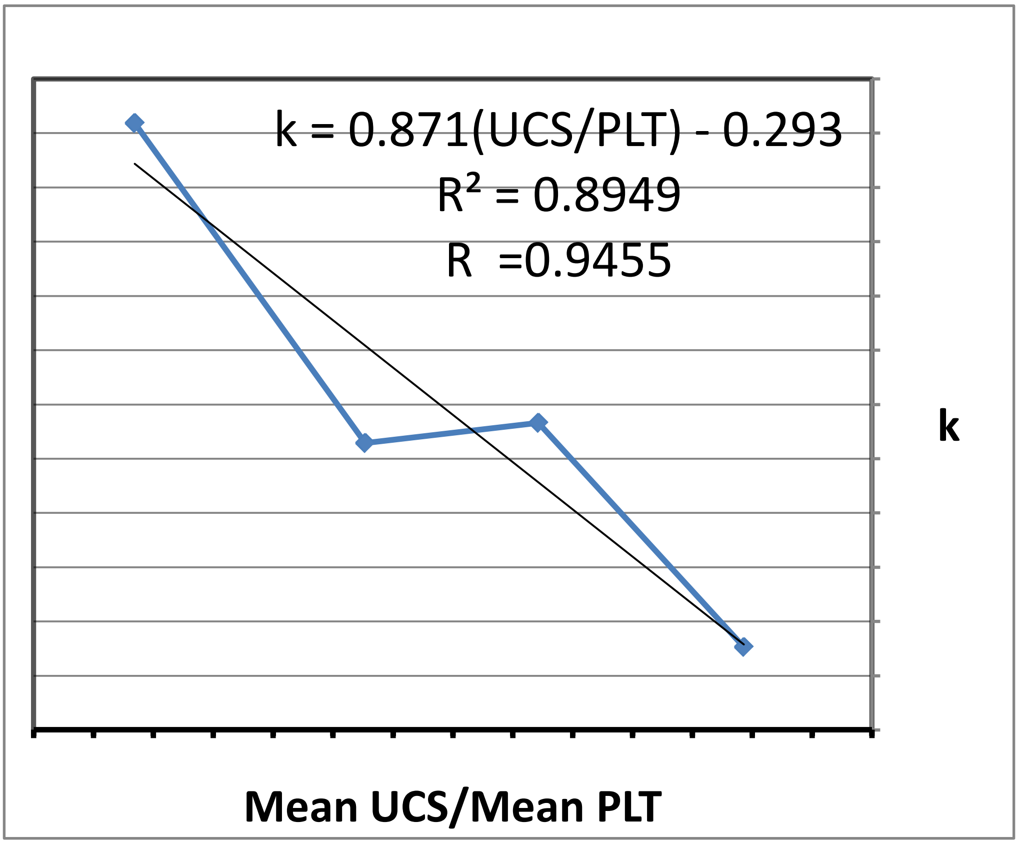


Fig. 13: Mean UCS/mean PLT vs. k for all sites.

As the ratio of (mean UCS/mean PLT) increases the k factor increased linearly too as shown in **Fig 13**.and the equation,

$$k = 0.871\left(\frac{mean\ UCS}{mean\ PLT}\right) - 0.293 \qquad (7)$$

Which is a new equation easily can be used and must be the $\left(\frac{mean\ UCS}{mean\ PLT}\right)$ greater than one.

Rock quality designation (RQD) is an in**d**ex or measure of the quality of a rock mass used by many engineers but, for the case study of this research is not a satisfactory guide and indication of the rock quality and it is compressive strength.

This study found that a conversion factor **k=6** worked well for very low strength rock of UCS below 27.5 MPa.

REFFERENCES

Agustawijaya, D.S., 2007. "The Uniaxial Compressive Strength of Soft Rock "Civil Engineering Dimension, 9(1): 9-14, March 2007, Mataram University, Mataram, Indonesia

Akram, M. And M.Z.A. Bakar, 2007." Correlation between Uniaxial Compressive Strength and Point Load Index for Salt-Range Rocks" Pakistan J. Engg. & Appl. Sci. Vol. 1.

Barton, T.M., S.K. Bhatt, G.M. Molinda and Mark, 2008. "Effect of Specimen Age on the Uniaxial Compressive Strength and Moisture Content of Weak Coal Measure Rocks"**.**

Bieniawski, Z.T., 1974. "Estimating the Strength of Rock Materials" Journal of the South Africa Institute of Mining and Metallurgy, pp: 312-320.

Bowden, A.J., J.L. Black and S. Ullyott, 1998. "Point Load Testing of Weak Rocks with Particular Reference to Chalk", Journal of engineering geology and hydrology.

Bowles, J.E., 1997."Foundation Analysis and Design", 5th edition, McGraw-Hill.

Broch, E., J.A. Franklin, 1972." The Point Load Strength Test". Int. Journal Rock Mech. Min. Sci, 9: 669-697.

Brook, N., 1985. "International Journal of Rock Mechanic and Mining Science & Geomechanic", 22: 61-70.

Chau, K.T., R.H.C. Wong, 1996. "Uniaxial Compressive Strength and Point Load Strength of Rocks", International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, 33(2): 183-188.

Cargill, J.S. and A. Shakoor, 1990. "Evaluation of Empirical Method for Measuring the Uniaxial Compressive Strength of Rock." Int. J. Rock Mech. Min. Sci & Geomech, Abstract., 27: 495-503.

Das, B.M., 2008. "Principles of Foundation Engineering", 6th edition, Thomason.

Fener, M., S. Kahraman, A. Bilgil and O. Gunaydin, 2005. " Comparative Evaluation of Indirect Methods to Estimate the Compressive Strength of Rocks", Rock Mech. Rock Engng, 38(4): 329-343.

ISRM. International Society of Rock Mechanics Commission on Testing Methods, 1985. "Suggested Method for Determining Point Load Strength", Int. J. Rock Mech. Min. Sci. and Geomechanic", Abstract., 22: 51-60.

Singh, V.K., and D.P. Singh, 1993. "Correlation between Point Load Index and Compressive Strength for Quartzite Rocks", Geotechnical and Geological Engineering, 11: 269-272.

Standard Test Method for Determination of the Point Load Strength Index of Rock, 2005. "ASTM D 5731 – 05", American Society for Testing and Material, Philadelphia, Pa.

Rusnak, J. and C. Mark, 2000. " Using The Point Load Test To Determination The Uniaxial Compressive Strength Of Coal Measure Rock", 19th Ground Control Conference in Mining, West Virginia University, pp: 362-371.