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Correlation between point load index and uniaxial compression strength for claystone from Caycuma formation Kocaeli, Turkey

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Abstract – Evaluation of rock engineering properties is a significant phenomenon for mining, civil and geotechnical engineering disciplines. Uniaxial compressive strength is one of the most important engineering parameters and it is used to characterize rocks from the strength point of view. The procedure to determine the uniaxial compression strength is standardized by International Society of Rock Mechanics Commission on Testing Methods (ISRM) and American Society for Testing and Materials (ASTM). The indirect method proposed by the societies are generally preferred to evaluate the uniaxial compressive strength utilizing the point load test because of simplicity and inexpensiveness of application. Numerous correlations are offered in the literature those are integrating uniaxial compression strength to the point load strength index. These equations' variability range is very large depending on the rock type and geological conditions. Because of these fundamental changes of equations it becomes important to select the proper index for the determination of rock strength. This paper involves point load tests of clay stones which are a member of Caycuma formation of Kocaeli province for evaluating the uniaxial compression strength. 208 point load tests and 30 uniaxial compression tests are used to identify Caycuma formations' characteristics throughout fifty meters depth. As a consequence, an appropriate particular index value for calculating Caycuma clay stones' uniaxial compression strength is achieved with the correlations subjected to the point load tests.

Keywords – *Rock, point load test, uniaxial compression strength, correlation.*

I. Introduction

Uniaxial compressive strength is an incontrovertibly important geotechnical property that is mostly preferred in rock engineering problems for classification. This value of strength represents the maximum limit of the actual rock masses and dependent on its size, cracks and fissures [1]. In a general point of view uniaxial compressive strength parameter is thought like a rough index that is given a first approximation for the range of subjects that probably encountered various engineering issues containing excavation, pillar design and roof support [2]. The procedure to determine the uniaxial compression strength is standardized by International Society of Rock Mechanics Commission on Testing Methods (ISRM) and American Society for Testing and Materials (ASTM). The details of the test is very simple but it is also expensive and time consuming in application. The specimens that are going to be used in the tests have to be prepared carefully and the assurance of obtaining parallel planes at the bottom and top of the sample have to be supplied. This procedure is very difficult to perform for all rock based problems so that index-to-strength conversion factors are mostly preferred to achieve uniaxial compressive strength values [3]. Uniaxial strength value is depended on the type of rock, strength of medium and geological conditions variability. Therefore it is the most important phenomenon to choose the appropriate testing method for evaluating strength index value according to the rock properties.

Point load test and the use of point load index value ($I_{s(50)}$) is one of the most preferred methods to predict strength of rocks [4]. The testing equipment is not complex and sample preparation process is less than other methods. It is easy to carry out the test in the field or laboratory conditions. Point load test consists of a procedure that is beginning with the compressing the rock sample between two conical steel platens till failure takes place. ISRM standardized types of point load tests which are limited axial, diametric and block or lump types. The axial and diametric types are carried out on rock core samples. Axial tests is conducted on the core that is parallel to the longitudinal axis and the result of the test gives the most appropriate value to correlate with the uniaxial strength value [3]. Lots of correlations are available in the literature to obtain a specific formulation for calculating this index value [5, 6]. But the need of variable index ranges or values is an apparent truth that is subjected to different behavior characteristics of rocks all around the universe.

The main objective of this study is to evaluate the most appropriate index-to-strength conversion factor value for determining uniaxial compressive strength of Caycuma formations clay stone based rock. For this purpose 208 point load tests and 30 uniaxial compression tests are used to make regression analysis with curve fitting option and to identify Caycuma formations' characteristics throughout fifty meters depth.

II. Materials and Method

The aim of this study is to calculate appropriate index-to-strength conversion factor value to determine uniaxial compression strength of clay stone which takes place in

Kocaeli province as being a member of Caycuma formation. It is a known fact that to possess an extensive knowledge about the application site is necessary. Therefore a brief description of Caycuma formation is given below. After, the point load and uniaxial compression tests application and equipment details are given and literature investigations and standardization limits are summarized. Consequently the process of determining uniaxial compression strength for a specific site with regression analysis is given with detailed description.

A. Characteristics of Caycuma Formation

Caycuma formations general geology consists of volcanic intercalated sandstone, siltstone, claystone and shale intercalations. The formation takes its general characteristics from the district of Caycuma in the province of Zonguldak and also the unit can be observed around Bartın province. The lower and middle parts of the formation involves grayish, green colored, thin to medium layered, shale with carbonate and rarely green and purple limestones. The tuffite intercalations are observed towards the upper parts of the unit. At the top of the formation there are abundant fossil intercalations with Nummulites. The Caycuma formation is transitional with the Akveren formation at the base. However, this transition can be determined as very difficult lithological. The upper contact is covered by young units and its thickness is about 350 meters. The age of the Caycuma formation is Lower-Middle Eocene [7].

B. Point Load Test Application Details and Literature Review

Point load test is the most preferred rock classification experiment in terms of simplicity compared to other tests and also known as the Franklin test [8]. It has been reported as an indirect measure of the uniaxial compressive strength of all types of rocks ([1-6], [8-13]) and it can provide similar data with a lower cost [3]. The method of application consists of compression of a selected rock sample between conical steel platens until collapse of the rock occurs. The testing apparatus has a rigid frame, two load platens, a ram with pressure gauge and a distance measuring equipment. Point load test has two main advantages. The first advantage is the portability of press mechanism that allows users to practice in the laboratory or in-situ conditions. The second conspicuous advantage is the requirement level on the samples that is going to be tested. The experiment only needs minimum geometric dimensions from rocks and the boundaries of the sizes are given in the literature [8]. The sample size used in the experiments carried out in this study for the clay stone from Caycuma formation was taken from the weathered rock in dimensions of smaller than 10 mm. The samples have irregular dimensional shapes. 208 point load tests are conducted to make regression analysis and to identify Caycuma clay stones strength characteristics.

Point load test is used for the determination of uniaxial shear strength and for that purpose the value of point load resistance index ($I_{s(50)}$) is normalized for cylindrical specimens with 50 mm in diameter. In addition to this index to strength conversion factors are required for the evaluation of uniaxial compression strength. Lots of studies are done to determine this conversion factors for different types and characteristics of rocks. But there are significant differences between the proposed values of correlations done between point load test and uniaxial compression strength. The correlations are usually in a linear form with a standard formulation as "$\sigma_c = k.I_{s(50)}$". σ_c represents the uniaxial compressive strength value of chosen rock (UCS) and *k* represents a linear correlation factor. Some of the correlations that are purposed in the literature are given in Table 1.

Table 1. Purposed correlation equations of different studies

Rock type	Reference	Correlation equation
All type of rocks	[15]	UCS=15.3 $I_{s(50)}$+16.3
All type of rocks	[16]	UCS=20.7 $I_{s(50)}$+29.6
Various rock types	[10]	UCS=23.7 $I_{s(50)}$
Sandstones	[9]	UCS=23.9 $I_{s(50)}$
Sedimentary rocks	[17]	UCS=29 $I_{s(50)}$
Sedimentary rocks	[18]	UCS=20 $I_{s(50)}$
All type of rocks	[19]	UCS=18.7 $I_{s(50)}$-13.2
All type of rocks	[12]	UCS=14 $I_{s(50)}$
All type of rocks	[5]	UCS=(20~25) $I_{s(50)}$
Limestone	[20]	UCS=26.5 $I_{s(50)}$
Sandstone		UCS=24.8 $I_{s(50)}$
Shale		UCS=12.6 $I_{s(50)}$
All type of rocks	[21]	UCS=23 $I_{s(50)}$+13
Granites	[22]	UCS=16 $I_{s(50)}$
Power Relation	[25]	UCS=25.67 $I_{s(50)}^{0.57}$
Linear Relation		UCS=9.30 $I_{s(50)}$+20.04
Quartzite	[25]	UCS=23.4 $I_{s(50)}$
Sandstone	[25]	UCS=19 $I_{s(50)}$+12.7
All type of rocks	[25]	UCS=12.5 $I_{s(50)}$
Sandstone/Limestone	[25]	UCS=24 $I_{s(50)}$
Shale		UCS=12.6 $I_{s(50)}$
Shale	[3]	UCS=21.8 $I_{s(50)}$
Siltstone		UCS=20.2 $I_{s(50)}$
Sandstone		UCS=20.6 $I_{s(50)}$
Limestone		UCS=21.9 $I_{s(50)}$
Other rock types	[23]	UCS=8.41 $I_{s(50)}$+9.51
Coal measure rocks		UCS=23.62 $I_{s(50)}$-2.69
Strong rocks	[25]	UCS=24.4 $I_{s(50)}$
Weak rocks		UCS=3.86 $I_{s(50)}^2$ + 5.65 $I_{s(50)}$
Power relation	[24]	UCS=7.3 $I_{s(50)}^{1.71}$
Linear relation		UCS=23 $I_{s(50)}$
Various rock types	[25]	UCS=9.08 $I_{s(50)}$+39.32
Various rock types	[25]	UCS=10.91 $I_{s(50)}$+27.41
Gypsum	[25]	UCS=5.575 $I_{s(50)}$+21.92

The factors that are used in the calculation of the uniaxial compression strength value are often associated with this type of rock in Table 1. Therefore, it is very important to determine the types of rocks and also to classify them according to their strength values. In the literature, there is a wide range of classification charts and systems that is proposed for the characterization of rock strength depending on the value of uniaxial compressive strength. The most favored example of the aforementioned classification systems is presented in Table 2.

Table 2. Classification of rocks according to the uniaxial compressive strength [5]

Classification	**UCS** (σ_c) (MPa)
Soil	$\sigma_c<0.25$
Extremely low strength	$\sigma_c=0.25\text{-}1.0$
Very low strength	$\sigma_c=1.0\text{-}5.0$
Low strength	$\sigma_c=5.0\text{-}25.0$
Medium strength	$\sigma_c=25.0\text{-}50.0$
High strength	$\sigma_c=50.0\text{-}100.0$
Very high strength	$\sigma_c=100.0\text{-}250.0$
Extremely high strength	$\sigma_c>250.0$

In addition to this, rock samples are classified in terms of their resistance to point load. These resistance to point loading is also the identification parameter for geomechanic characteristics of rock. Examples of this classification type is given in Table 3.

Table 3. Classification of rocks according to the point load resistance (Carol, 2008; Garnica et. Al, 1997, garrido et al, 2010)

$I_{s(50)}$ (MPa)	**Classification**	
	[ref, garnica]	[ref, carol]
<0.03	Extremely low	Very low
0.03-0.1	Very low	Very low
0.1-0.3	Low	Low
0.3-1.0	Moderate	Medium
1.0-3.0	High	High
3.0-10.0	Very high	Very high
>10.0	Extremely high	Extremely high

C. Uniaxial Compression Test and Literature Review

Uniaxial compression test is the direct way of achieving UCS value and used to investigate the mechanical properties of intact rocks. The method requires rock samples in the form of specimens of regular geometry. The test is expensive and required to prepare the specimens carefully that the top and the bottom have to be perfectly parallel and smooth. The rock specimens that are taken from drill cores have to be a certain length and diameter. The recommended height/diameter ratio of the specimens have to be between 2 or 3. A suitable machine should be used to apply and measure the axial load that is conducted to the specimen. Steel platens are used as a form of discs and placed at the top and bottom planes of the specimen. One of the platens should incorporate a spherical seat and the seat has to be placed on the top plane of the specimen. The specimen, platens and seat have to be accurately centred with respect to each other. Axial loading is applied up to the failure of the specimen or a prescribed level of deformation is sought and measured during loading. The number of the tests can be selected subjected to practical considerations but minimum five experiments are suggested. The uniaxial strength value of the specimen can be found by an easy equation that is the ratio of maximum load that is carried by the specimen during test sequence to cross sectional area of the specimen [5]. The difficulties of sample preparation and uniaxial compression test cost redundancy makes it indispensable to use a reasonable approximation to obtain strength value of rocks.

D. Evaluation of the Correlation between Point Load Index and Uniaxial Compression Strength for the Clay Stone of Caycuma Formation

208 point load and 30 uniaxial compression tests are experienced to apply regression analysis for obtaining a reasonable approximation between point load and uniaxial strength values. The specimens are taken from different depths between 0 to 50 meters from ground surface. The rocks that are processed to tests are characteristic clay stones of Caycuma formation of Kocaeli province.

The relationship between point load value and uniaxial compressive strength necessitates univariate analysis. Curve fitting method can be applied for this kind of analysis by two methods: i) using Matlab graphics, ii) using commands related to curve fitting. Usage of Matlab is not the concern of this study. Curve fitting commands with regard to Microsoft Excel is going to be used to run regression analysis. For performing regression analysis in Excel two options can be used. If the analysis is univariate chart method can be used but for evaluating general linear equation, regression analysis have to be called from data analysis package. The first option of analysis is chosen (chart method) and firstly all the data acquired from tests are drawn as a whole in Figure 1.

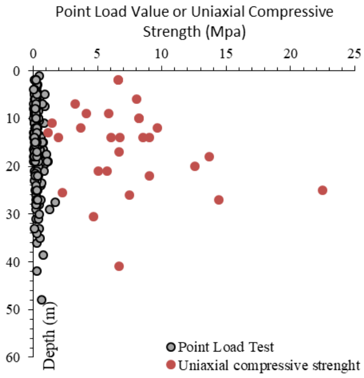

Figure 1. The change of point load value and uniaxial compressive strength depending on depth

It can be seen that the values of point load value and uniaxial compressive strength is not into a common trend. This situation requires the two experiments to be expressed in terms of each other. The individual representation of each test is given in Figure 2 and Figure 3 respectively.

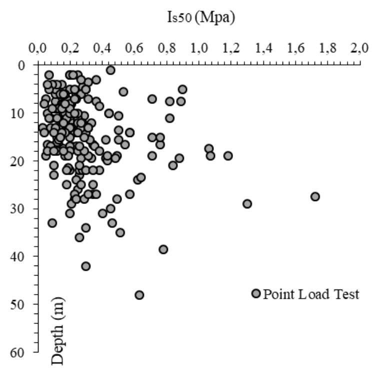

Figure 2. Point load test results depending on depth

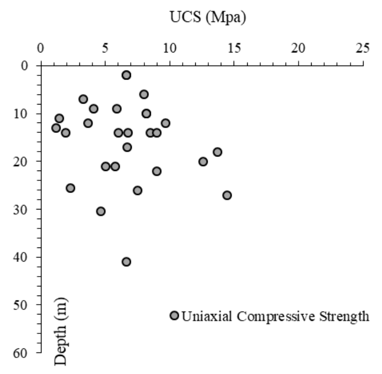

Figure 3. Uniaxial compression strength value depending on depth

As shown in Figure 2 and Figure 3, the test results vary within a wide range of values. Therefore, the strength values obtained from the experiments are named according to the classification systems given in Table 2 and Table 3. Figure 4 is achieved by the use of given index boundaries of point load test from Table 3. Figure 5 is achieved by the use of given boundaries of uniaxial compression strength values from Table 2. Point load test results are scanned between 0-3 MPa. When the results of the experiments were classified, it was seen that a wide range of values has medium and low strength. Due to this reason, the point load values that are used to perform regression analysis are constricted between 1-0 MPa values and the illustration is changed for this situation and given in Figure 6.

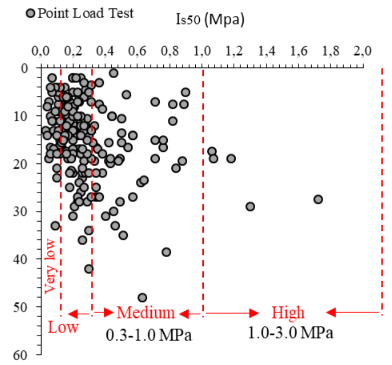

Figure 4. Classification of rocks with respect to point load test results

Uniaxial compression test results are constricted between 25-0 MPa values. Subjected to the Table 2, clay stone can be defined with medium and low strength ranges.

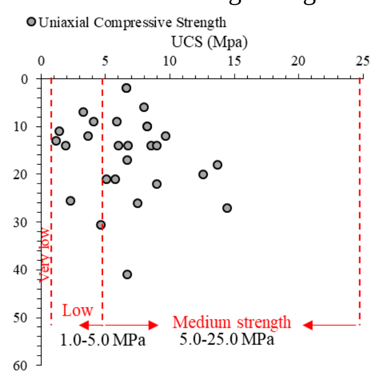

Figure 5. Classification of rocks with respect to uniaxial compression strength

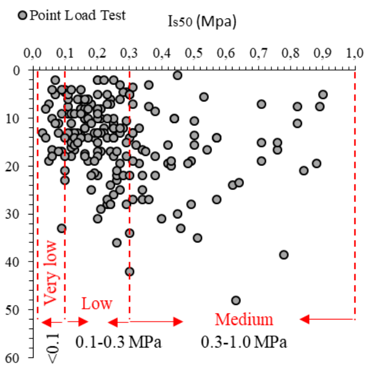

Figure 6. Classification of rocks with respect to point load test results

This study is focused on the investigation of characteristics of low and medium strengthen clay stone with the use of determined limits above.

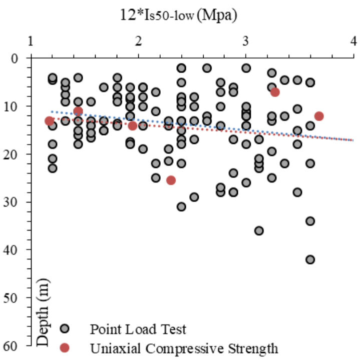

Figure 7. Regression analysis of low strengthen clay stones with curve fitting method

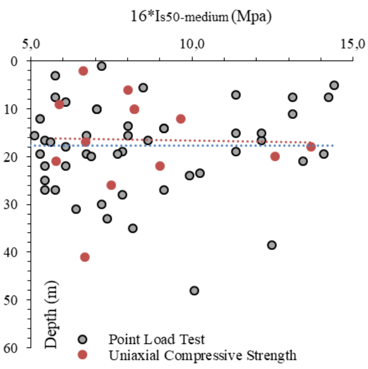

Figure 8. Regression analysis of medium strengthen clay stones with curve fitting method

With the aid of drawn point distribution curves, trend line adding option of Excel is applied to low and medium strengthen clay stones test values respectively. For low strengthen clay stones the multiplier of the point load index value is attempted between 10-25 values and selected as 12 for evaluating real-like approximation (Figure 7). For medium strengthen clay stones the multiplier of the point load index value is attempted between 10-25 values and selected as 16 for evaluating real-like approximation (Figure 8).

III. Results

In this study the point load conversion factor is selected 12 for low strengthen clay stones and 16 for medium strengthen clay stones of Caycuma formation. The variability of point load test was not bigger than that of uniaxial compression test.

The tendency of the point load conversion factor is decreasing from medium to low strengthen materials for this case.

IV. DISCUSSION

Evaluation of compression strength values of rock masses by indirect ways is always becomes the main problem of classification of intact rocks. In this study uniaxial compression strength value is acquired by point load index values with applying curve fitting option of Microsoft Excel. There are lots of studies in the literature which are searching for an appropriate linear formulation for obtaining uniaxial compression strength value. Various equations are given from the literature in Table 1 according to the type of rocks. It can be seen from the table that there are no formulations for clay stones. Because of this reason engineers can be used any of the formulation which is arranged for all types of rocks. In this part of study discussions are made for the evaluation formulas of clay stones with low strength. Some of the equations are selected from Table 1 and calculations are done for the clay stones of Caycuma formation. The equations taken from the sources [5], [10], [12], [15], [25] is used to make discussions and Figure 8 is obtained. Figure 8 represents the precipitous difference between the values of calculated strength values and shows the risks of designs which are envisaged by arbitrary chosen equations. There is a difference between strength values up to 10 times and it means that projects are designed with 10 times insecure with respect to strength of rock. Accordingly this situation generates a puzzling search subject and requires special attention.

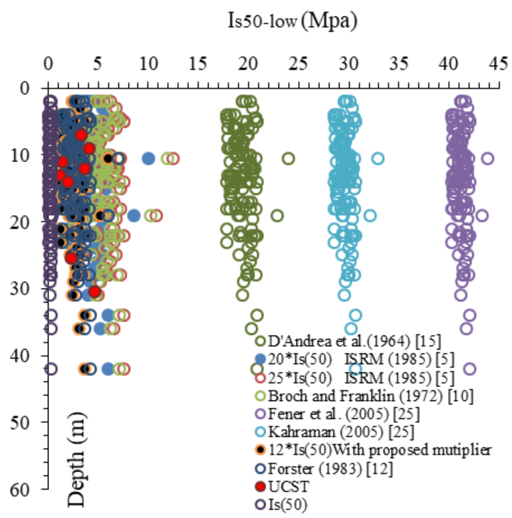

Figure 8. Comparison of the proposed equations

V. CONCLUSION

Consequently point load test is an effective indirect experience for determining strength characteristics of rocks and widely accepted in geotechnical parameter evaluations. But special attention have to be given for the use of proposed equations for converting point load index values to the strength value of rocks. Not only the type of rock effects the values of strength but also the location of the formation changes differentiate strength characteristics. Therefore all the tests have to be evaluated in defiance of the environmental conditions and the values should be checked with in-situ tests.

REFERENCES

[1] A. L. Fayed, *Correlation Between Uniaxial Compressive Strength and Point Load Index for Simsima Limestone of Qatar Peninsula*, International Conference on Advances in Structural and Geotechnical Engineering, Egypt, 6-9 April 2015.

[2] E. Hoek, *Rock Mechanics Laboratory Testing in the Context of a Consulting Engineering Organization*, International Journal of Rock Mechanics, Mining Science and Geomechanics, Abstract 14, pp. 93-101, 1977.

[3] J. Rusnak and C. Mark, *Using the Point Load Test to Determine the Uniaxial Compressive Strength of Coal Measure Rock*, 2004.

[4] M. Akram and M. Z. A. Bakar, *Correlation Between Uniaxial Compressive Strength and Point Load Index for Salt-Range Rocks*, Pakistan Journal of Engineering and Applied Sciences, Vol 1(1), pp. 1-7, 2007.

[5] ISRM, International Society of Rock Mechanics Commission on Testing Methods, *Suggested Method for Determining Point Load Strength, International Journal of Rock Mechanics*, Mining Science and Geomechanics, Abstract 22, pp. 51-60, 1985.

[6] Annual Book of ASTM Standards 4.08, *Standard Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens, Soil and Rock, Building Stones*, ASTM, Philadelphia, Pennsylvania, 1984.

[7] A. Ateş, E. Totiç, B. Yeşil, *Kutlubeyyazıcılar Kampüs Alanının (Bartın Üniversitesi) Yerleşime Uygunluk Açıdan Değerlenririlmesi*, Düzce Üniversitesi Bilim ve Teknoloji Dergisi, Vol. 3, pp. 373-397, 2015.

[8] M. Galvan, J. Preciado, J. Seron, *Correlation Between the Point Load Index, $I_{s(50)}$, and the Resistance to Unconfined Compression in Limestone from the Comunidad Valenciana, Spain*, Acta Geotechnica Slovenica, 2, 2014.

[9] Z. T. Bieniawski, *Point Load Test in Geotechnical Practice*, Engineering Geology, 9(1), 1-11, 1975.

[10] E. Broch and J. A. Franklin, *Point Load Strength Test*, International Journal of Rock Mechanics and Mining Sciences, 9(6), 669-697, 1972.

[11] N. Brook, *Size Correction for Point-Load Testing*, International Journal of Rock Mechanics and Mining Sciences and Geomechnanical Abstract, 11, 231-235, 1980.

[12] I. R. Forster, *The Influence of Core Sample Geometry on the Axial Point Load Test*, International Journal of Rock Mechanics and Mining Sciences and Geomechanical Abstract, 20(6), 291-295, 1983.

[13] D. K. Ghosh and M. Srivastava, *Point-Load Strength: An Index for Classification of Rock Material*, Bulletin of the International Association of Engineering Geology, 44, 27-33, 1991.

[14] G. Guidicini, C.M. Nieble, A.T. Cornides, *Analysis of Point Load Test as a Method for Preliminary Geotechnical Classification of Rocks*, Bulletin of the International Association of Engineering Geology, 1973.

[15] D. V. D'Andrea, R. L. Fisher and D. E. Fogelson, *Prediction of compression strength from other rock properties*, Colorado Sch. Mines Quart., 59, (4B), 623–640, 1964.

[16] D. Deer and R. D. Miller, *Engineering classification and index properties for intact rock*, Univ. of Illinois, Tech. Rept. No. AFWL-TR-65-116, 1966.

[17] F. P. Hassani, B. N. Whittaker and M. J. Scoble, *Application of the Point Load Index Test to Strength Determination of Rock*, Proposals for a New Size Correlation Chart. Proceeding of the 21st U.S. Symp. on Rock Mech., Rolla, MO., 1980.

[18] J. R. L. Read, P. N. Thornten and W. M. Regan, A rational approach to the point load test, *Proceedings of the 3rd Australian– New Zealand geomechanics conference* 2, 35–39, Wellington, Institution of Engineers., 1980.

[19] T. N. Singh, A. Kainthola and A. Venkatesh, *Correlation between point load index and uniaxial compressive strength for different rock types*, Rock Mechan. Rock Eng., 45, (2), 259–264., 2012.

[20] A. B. Hawkins, *Aspects of rock strength*, Bull. Eng. Geol. Environ., 57, (1), 17–30., 1998.

[21] J. S. Cargill and A. Shakoor, *Evaluation of empirical methods for measuring the uniaxial compressive strength*, Int. J. Rock Mech. Min. Sci., 27, (6), 495–503, 1990.

[22] D. K. Ghosh, D. K. and M. Srivastava, *Point – load strength: an index for classification of rock material*, Bull. Int. Assoc. Eng. Geol., 44, (1), 27–33, 1991.

[23] S. Kahraman, *Evaluation of simple methods for assessing the uniaxial compressive strength of rock*, Int. J. Rock Mech. Min. Sci., 38, (7), 981–994, 2001.

[24] G. Tsiambaos and N. Sabatakakis, *Considerations on strength of intact sedimentary rocks*, Eng. Geol., 72, (3–4), 261–273., 2004.

[25] M. E. Garrido, C. Hidalgo, J. I. Preciado, *Practicas de laboratorio geotechnia y cimientos*, I. Departmento de Ingenieria del Terreno, Universidad Politecnica de Valencia, 2010.