*IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*
*e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 3 Ver. V (May- Jun. 2016), PP 01-07*
*www.iosrjournals.org*

# Prediction of Uniaxial Compressive Strength Using Point Load Index for Jointed Rocks

N.Kabilan[1], M.Muttharam[2], A.Siva[3], Nowell Philips[4]
[1,2,3](Department of Civil Engineering, College of Engineering Guindy/ Anna University, India)
[4](Department of Civil Engineering, University of California/ Irvine, USA)

***Abstract:*** *Joint orientation, Joint roughness, number of joints and location of joint affects the strength of jointed rocks. Point load index test needs less sample preparation, easy to handle and quick test while comparing with uniaxial compressive test. Lot of researchers comes out with a lot of correlations between uniaxial compressive strength and point load index for intact rocks. But there is only few reported research work in jointed rocks. So here with present study to create a equation relating uniaxial compressive strength and point load index for for both single and double jointed rocks by varying different joint orientation(0̊, 30̊, 45̊, 60̊, 90̊) and joint roughness(Smooth, Rough & joint filled with clay). Plaster of Paris and optimum moisture content of 38% was used as model material to prepare jointed rocks. One hundred and eighty different samples with different joint conditions were casted and tested on both uniaxial compression test and point load index testing machine. And the new correlation was formed using multi linear regression technique using SPSS software. The proposed equation is compared with previous work. And proposed equation may be compared with actual rooks like weathered limestone.*

***Keywords:*** *Correlation, Joint Conditions, Joint Roughness, Point load index & Unaxial Compressive Strength*

## I. Introduction

In most cases foundation material will be rock for several civil and mining engineering projects. Rock discontinuities play a major role to determine strength nature of rocks. Usually discontinuity planes in rock offers low tensile strength compared to joint free rocks (Intact rocks). Rocks can get fail in multiple ways like tension, compression or shear and it is mainly depends on the presence of discontinuities, distribution and configuration of load. Engineers dealing with rock commonly use uniaxial compressive strength to design structures resting as foundation bed on rock. Both International Society of Rock Mechanics and American society of testing and materials given procedure for perform uniaxial compressive strength [1-2]. This above said standardized method to determine uniaxial compressive strength (UCS) takes more time & cost on comparing with point load index [I50]. Easy procedure makes many researchers to create different correlations to predict unixial compressive strength using point load index [3-8]. These correlations are mainly for intact rocks and less number work has been done for jointed rocks. Previously, N.Kabilan and M.Muttharam formed a correlation between UCS & $I_{50}$ for single jointed rocks by varying joint orientation and joint roughness [9]. So present work is to create an equation correlating uniaxial compressive strength and point load index for both single and double jointed rocks by varying different joint orientation (0̊, 30̊, 45̊, 60̊, 90̊) and joint roughness(Smooth, Rough & joint filled with clay). Modeling of rocks is done, by the mixture of plaster of paris and water. Vekinis et al. [10] says that Plaster of Paris has very good potential as model material for ceramics, rock and cement because of its brittle, porous solid and easy to shape nature. Special equipment was created to simulate different joint roughness conditions [11]. Finally the degree of correlation and variability test results was analyzed statistically.

## II. Research Significance

The Strength data to be made available through point load testing is used for numerical geotechnical analysis and empirical rock mass classification like coal mine roof rating (CMRR).

## III. Methodology

### 1. Mould and Sample Preparation:

Mould preparation is a important and difficult process in this study because of different joint orientation and joint roughness condition. To achieve this PVC Pipe of 50 mm diameter is purchased from local shop. To maintain length to diameter ratio as 2, the purchased 50 mm diameter pipe is cutted at a interval of 100 mm height. So by this length to diameter is maintained constant throughout the experiment. Initially measurements of required joint orientations (0̊, 30̊, 45̊, 60̊, & 90̊) and number of joints (single & double joints are marked in the moulds. Saw toothed blade is used to cut the marked portions in the moulds. Two Clamps were used in upper and lower part of each mould to hold it properly. Thus finally different moulds are prepared for various joint conditions. This separate mould makes the sample preparation job very easier. It is not possible to core the rock specimen for proposed different joint conditions. So combination of plaster of Paris and water was used as a model material to bring the different joint conditions. Optimum moisture content is determined by testing intact specimen with different water content and it was 38%. Samples are prepared by using maximum moisture content and air voids are removed using kneading compaction technique.

**2. Making Joints roughness in Specimens:**

After casting, joint roughness should be created immediately along the joint orientation of the mould. In some cases there is no enough time to make joints because of its quick hardening property. So joints should be made as fast as possible. Slight delay leads to the situation of wasting the model material. To make this process easier, equipment is used to make different joints roughness conditions (single joint, double joint and joint filled with clay) is shown in Figure 1. By cutting along pre-existing joints in the prepared mould using this equipment can get desired samples with different joint roughness condition like smooth, rough and joint filled with bentonite clay.

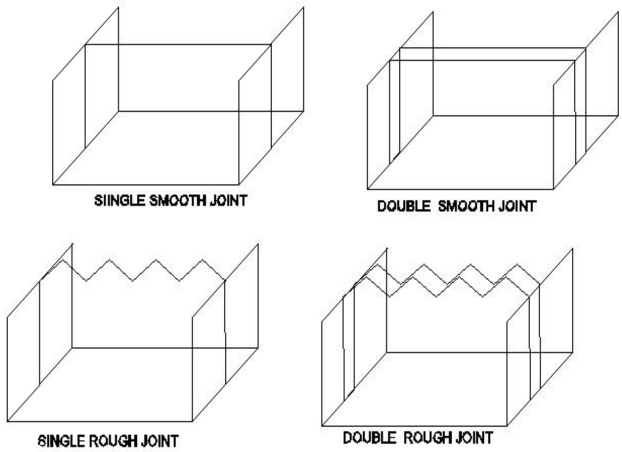


**Figure 1** Equipment Used To Make a Joint

**3. Test Procedures:**

Over 180 samples was prepared with different joint conditions like smooth joint, rough joint and joint filled with clay for both single and double joint. Thus prepared samples were tested in both uniaxial compressive strength and point load index as International society for rock mechanics. Flat and smooth samples are prepared with length to diameter ratio of 2 and met the tolerance limits of 2 to 2.5. Figure 2 shows the schematic diagram of uniaxial compressive testing machine. The point load index machine used for conducting the experiment is shown in Figure 3.

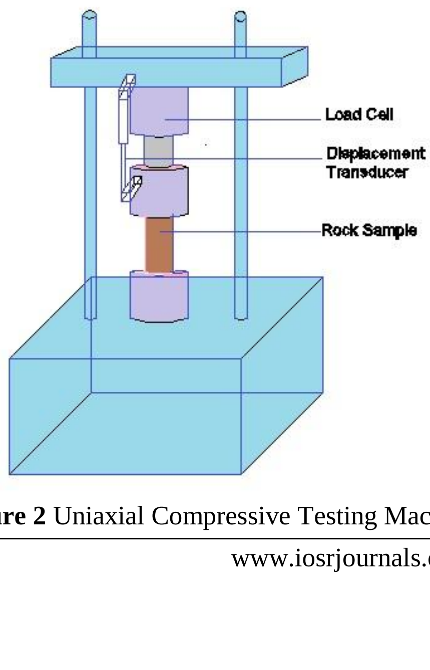


**Figure 2** Uniaxial Compressive Testing Machine

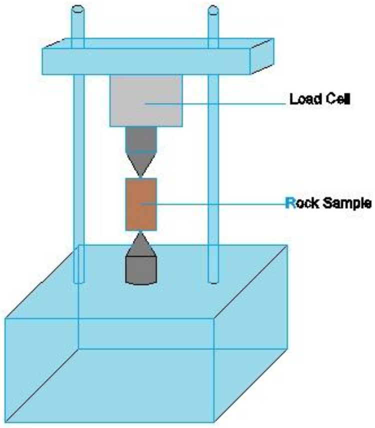


**Figure 3** Point Load Testing Machine

**4. Multiple Linear Regression Analysis:**

Multiple regression analysis is an advancement of simple linear regression. It gives better correlation compared to linear regression when we want to predict the value of a variable based on the value of two or more variables. Depended variable or criterion variable is the variable to find. When variable is used to find the value of the dependent variable is known as independent variable. Overall fit of the model is also achieved through multiple regression analysis. So, multi linear regression analysis by SPSS software was chosen for our prediction. By using multiple regressions analysis a correlation is created between uniaxial compressive strength and point load index for jointed rocks.

## IV. Test Results And Discussions

**1. Uniaxial Compressive Strength Test Results**

The uniaxial compressive strength tested readings was reported along with mean, standard deviation, coefficient of variation and 95% confidence interval in Table 1. These statistical parameters are determined to check the accuracy of tested results. Both Single and double jointed Specimens with different joint roughness conditions exhibit a lower value of uniaxial compressive during Joint orientation at $30^0$. This unfavorable orientation is the weakest plane because of it less resistance against loading. Double jointed specimen offer lesser strength value while comparing with Single joint specimen. Uniaxial compressive strength values for $90^0$ joint orientation shows a higher value while comparing with other orientation. This is mainly due to the loading direction is perpendicular to the plane of $90^0$ joint orientation. On comparing the UCS of smooth joint with that of joint filled with clay, the UCS values gets reduced about 83.8% for $30^0$ orientation, 86.22% for $45^0$ orientation, 49.9% for $60^0$ orientation and 36.22% for $90^0$ orientation .This may be due to the reduction in friction of joint because of the plastic nature of clay filled in joint.

**Table 1** Uniaxial Compressive Strength Results

| Different Joint Condition | | | Mean UCS (Mpa) | Standard Deviation | Coefficient of Variation | 95% Confidence Intervals(Mpa) |
|---|---|---|---|---|---|---|
| $0^0$ | Single Joint | Rough Joint | 2.61 | 0.055 | 2.10 | 2.55 to 2.67 |
| | | Smooth Joint | 2.28 | 0.191 | 8.40 | 2.06 to 2.49 |
| | | Joint Filled | 1.36 | 0.17 | 12.44 | 1.17 to 1.55 |
| | Double Joint | Rough Joint | 1.91 | 0.041 | 2.17 | 1.86 to 1.96 |
| | | Smooth Joint | 1.79 | 0.070 | 3.91 | 1.71 to 1.86 |
| | | Joint Filled | 0.96 | 0.045 | 4.77 | 0.9 to 1.01 |
| $30^0$ | Single Joint | Rough Joint | 1.46 | 0.035 | 2.39 | 1.42 to 1.5 |
| | | Smooth Joint | 1.04 | 0.092 | 8.90 | 0.93 to 1.14 |
| | | Joint Filled | 0.17 | 0.015 | 8.81 | 0.15 to 0.19 |
| | Double Joint | Rough Joint | 0.91 | 0.015 | 1.66 | 0.89 to 0.93 |
| | | Smooth Joint | 0.84 | 0.032 | 3.81 | 0.8 to 0.87 |
| | | Joint Filled | 0.16 | 0.020 | 10.82 | 0.14 to 0.18 |
| $45^0$ | Single Joint | Rough Joint | 1.72 | 0.052 | 3.07 | 1.66 to 1.77 |
| | | Smooth Joint | 1.54 | 0.176 | 11.38 | 1.34 to 1.74 |
| | | Joint Filled | 0.20 | 0.020 | 10.07 | 0.18 to 0.23 |
| | Double Joint | Rough Joint | 1.34 | 0.06 | 4.47 | 1.27 to 1.4 |
| | | Smooth Joint | 1.25 | 0.095 | 7.63 | 1.14 to 1.35 |
| | | Joint Filled | 0.17 | 0.010 | 5.88 | 0.15 to 0.18 |

| | | | | | | |
|---|---|---|---|---|---|---|
| $60^0$ | Single Joint | Rough Joint | 2.68 | 0.035 | 1.30 | 2.64 to 2.72 |
| | | Smooth Joint | 2.33 | 0.208 | 8.92 | 2.09 to 2.56 |
| | | Joint Filled | 1.23 | 0.112 | 9.11 | 1.10 to 1.36 |
| | Double Joint | Rough Joint | 2.09 | 0.123 | 5.88 | 1.95 to 2.23 |
| | | Smooth Joint | 1.93 | 0.085 | 4.39 | 1.83 to 2.02 |
| | | Joint Filled | 0.88 | 0.026 | 3.00 | 0.85 to 0.90 |
| $90^0$ | Single Joint | Rough Joint | 3.38 | 0.07 | 2.07 | 3.30 to 3.46 |
| | | Smooth Joint | 2.92 | 0.157 | 5.38 | 2.74 to 3.09 |
| | | Joint Filled | 1.85 | 0.068 | 3.66 | 1.77 to 1.93 |
| | Double Joint | Rough Joint | 2.52 | 0.040 | 1.58 | 2.47 to 2.56 |
| | | Smooth Joint | 2.31 | 0.075 | 3.23 | 2.23 to 2.4 |
| | | Joint Filled | 1.32 | 0.100 | 7.56 | 1.20 to 1.43 |

**2. Point Load Index Test Results**

For the joint oriented at $90^0$ shows a higher index value comparing with other orientation for all joint conditions. Plane offered by $90^0$ joint orientation is usually a strong plane. This plane act normal to the path of loading. So it offer higher resistance index with other planes. But in the case of $0^0$ joint orientations does not show any resistance against loading. This is mainly because of loading path exactly coincides with the plane of $0^0$ joint orientation. Because of the slippery nature for joint filled condition makes the specimen to offer resistance against only for $90^0$ joint orientations.

**Table 2** Point Load Index Test Results

| Different Joint Condition | | | Mean Point Load Index(Mpa) | Standard Deviation | Coefficient of Variation | 95% Confidence Intervals(Mpa) |
|---|---|---|---|---|---|---|
| $0^0$ | Single Joint | Rough Joint | - | - | - | - |
| | | Smooth Joint | - | - | - | - |
| | | Joint Filled | - | - | - | - |
| | Double Joint | Rough Joint | - | - | - | - |
| | | Smooth Joint | - | - | - | - |
| | | Joint Filled | - | - | - | - |
| $30^0$ | Single Joint | Rough Joint | 0.07 | 0.005 | 7.87 | 0.06 to 0.07 |
| | | Smooth Joint | 0.06 | 0.017 | 28.86 | 0.04 to 0.07 |
| | | Joint Filled | - | - | - | - |
| | Double Joint | Rough Joint | 0.04 | 0.005 | 13.32 | 0.03 to 0.04 |
| | | Smooth Joint | 0.03 | 0.011 | 31.49 | 0.02 to 0.04 |
| | | Joint Filled | - | - | - | - |
| $45^0$ | Single Joint | Rough Joint | 0.10 | 0.005 | 5.58 | 0.09 to 0.10 |
| | | Smooth Joint | 0.08 | 0.015 | 18.33 | 0.06 to 0.10 |
| | | Joint Filled | - | - | - | - |
| | Double Joint | Rough Joint | 0.06 | 0.005 | 8.66 | 0.06 to 0.07 |
| | | Smooth Joint | 0.05 | 0.005 | 10.82 | 0.04 to 0.05 |
| | | Joint Filled | - | - | - | - |
| $60^0$ | Single Joint | Rough Joint | 0.12 | 0.005 | 4.68 | 0.11 to 0.12 |
| | | Smooth Joint | 0.09 | 0.011 | 12.37 | 0.08 to 0.10 |
| | | Joint Filled | - | - | - | - |
| | Double Joint | Rough Joint | 0.11 | 0.005 | 5.09 | 0.10 to 0.11 |
| | | Smooth Joint | 0.08 | 0.011 | 13.32 | 0.07 to 0.09 |
| | | Joint Filled | - | - | - | - |
| $90^0$ | Single Joint | Rough Joint | 0.16 | 0.005 | 3.68 | 0.15 to 0.16 |
| | | Smooth Joint | 0.14 | 0.01` | 8.05 | 0.13 to 0.15 |
| | | Joint Filled | 0.09 | 0.015 | 15.8 | 0.07 to 0.11 |
| | Double Joint | Rough Joint | 0.13 | 0.005 | 4.22 | 0.13 to 0.14 |
| | | Smooth Joint | 0.11 | 0.01 | 9.09 | 0.09 to 0.12 |
| | | Joint Filled | 0.06 | 0.005 | 8.66 | 0.06 to 0.07 |

## V. Analysis Of Uniaxial Compressive Strength And Point Load Index

There are two major clusters showing different trend while plotting uniaxial compressive strength against point load index shown in figure 4. The formed two rock groups are listed in Table 3. The Predicted equations for Group a jointed rocks and Group B jointed rocks are given below as equations (1) and (2) respectively.

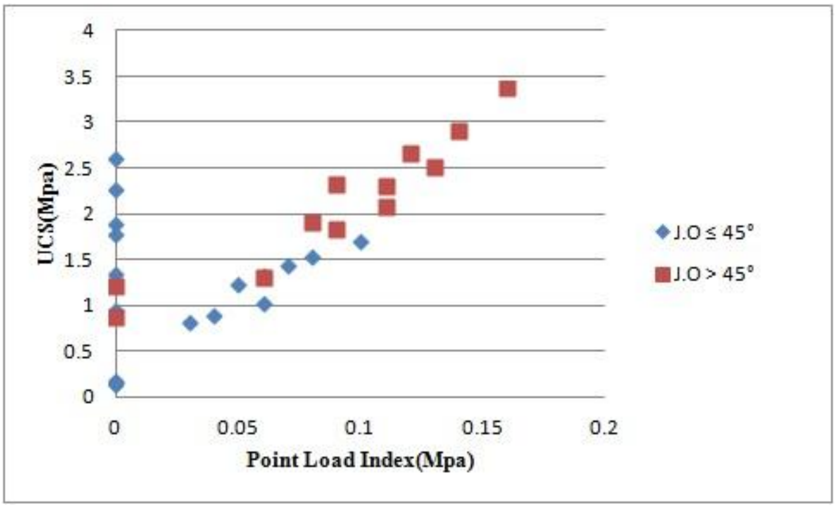


**Figure 4** Scatter Plot of Ucs Against Indirect Tension For All The Tested Joint Rocks

**Table 3** Jointed Rock Groups Identified by Scatter Plot of UCS and Point Load Index

| Jointed Rock Group A | Jointed Rock Group B |
|---|---|
| 0° , 30°and 45° Joint Orientation | 60°and 90° Joint Orientation |

: $UCS = -8.3I_{50} + 2.04\, J.C - 0.05$ $\quad J.O \leq 45°$ $\quad$ (1)

J.C – rough – 1, smooth – 0.88, filled -0.35

: $UCS = 12.11I_{50} + 0.4\, J.C + 0.7$ $\quad J.O > 45°$ $\quad$ (2)

J.C – rough – 1, smooth – 0.92, filled -0.35

Where,
UCS – Unconfined compressive strength
$I_{50}$ - Point Load Index
J.C – Joint Condition
J.O - Joint Orientation

In Figure 5 & 6 we can check the accuracy of created equation 1& 2.

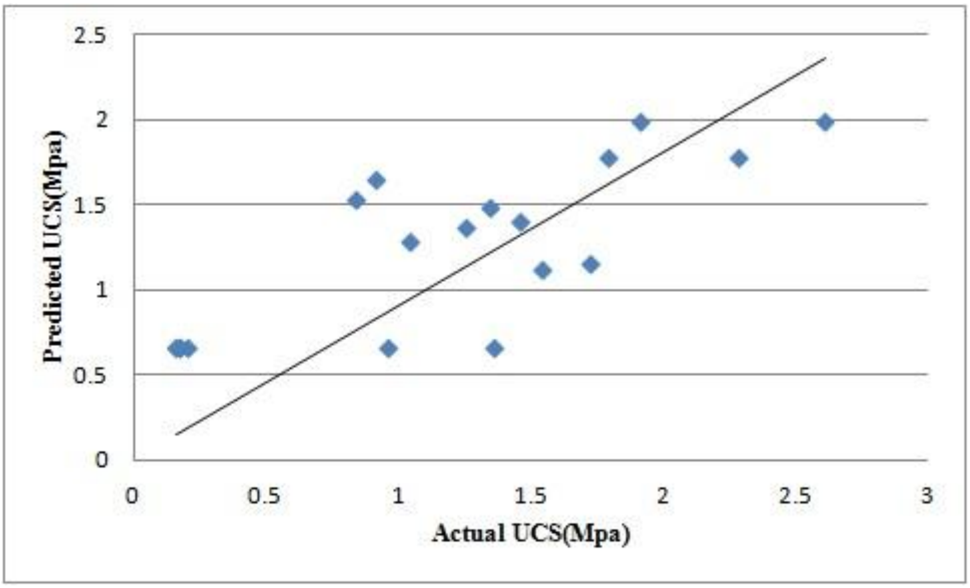


**Figure 5** Predicted Ucs Vs Actual Ucs For Jointed Rock Group A

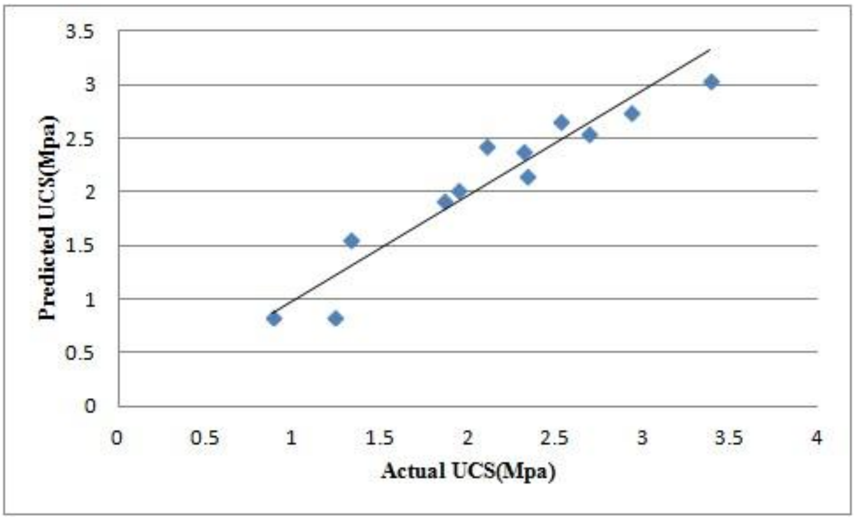


**Figure 6** predicted ucs vs actual ucs for jointed rock group b

From Figure 5 & 6, we can see the accuracy of predicted values to that of observed values. It is noticed that jointed rock group 2 shows higher closeness value to observed value. The deviation maximum for the joint filled with clay & oriented at 30° while predicting the values for jointed rock group 1.

## VI. Regreesion STATISTICS

Regression statistics of jointed rock group 2 shows higher strength value while comparing with jointed rock group 1. Regression statistics for group A rock and group B rock are given detailed in the Table 4. The strength of equation is mainly concluded with the R value closeness to 1.

**Table 4** Regression Statistics

| S.No | Name | J.O. ≤ 45° | J.O. > 45° |
|---|---|---|---|
| 1 | Multiple R | 0.84 | 0.94 |
| 2 | R square | 0.70 | 0.89 |
| 3 | Adjusted R square | 0.66 | 0.87 |
| 4 | Standard Error | 0.41 | 0.25 |

## VII. Results And Discussion

The observed reading of point load index is substituted in proposed formula & previous formula is listed in Table 5. It is noticed that proposed formula for joint orientation greater than 45˚ shows a close matching of predicted value with observed value irrespective of different joint conditions. But in the case of joint orientation lesser than 45˚ shows only a fair prediction of UCS. While increasing joint conditions like double joint makes the equation (1) as stronger than previous proposed equation but it is not much effective for equation (2). This is mainly because of missing values in point load index.

**Table 5** Comparison of Predicted UCS with Observed UCS

| No | *Sample type | Observed $I_{50}$(MPa) | Observed UCS(MPa) | Predicted UCS (MPa) N.Kabilan and Muttharam 2015 [9] | UCS(MPa) by Proposed Formula |
|---|---|---|---|---|---|
| 1 | S-0˚-R | 0 | 2.61 | 2.4 | 1.99 |
| 2 | S-30˚-R | 0.07 | 1.46 | 1.47 | 1.40 |
| 3 | S-45˚-R | 0.10 | 1.72 | 1.08 | 1.16 |
| 4 | S-60˚-R | 0.12 | 2.68 | 1.87 | 2.55 |
| 5 | S-90˚-R | 0.16 | 3.36 | 2.11 | 3.03 |
| 6 | S-0˚-S | 0 | 2.28 | 2.02 | 1.78 |
| 7 | S-30˚-S | 0.06 | 1.04 | 1.23 | 1.28 |
| 8 | S-45˚-S | 0.08 | 1.54 | 0.96 | 1.12 |
| 9 | S-60˚-S | 0.09 | 2.33 | 1.50 | 2.14 |
| 10 | S-90˚-S | 0.14 | 2.92 | 1.80 | 2.75 |
| 11 | S-0˚-JF | 0 | 1.36 | 0.76 | 0.66 |
| 12 | S-30˚-JF | 0 | 0.17 | 0.76 | 0.66 |
| 13 | S-45˚-JF | 0 | 0.20 | 0.76 | 0.66 |
| 14 | S-60˚-JF | 0 | 1.23 | 0.31 | 0.84 |
| 15 | S-90˚-JF | 0.09 | 1.85 | 0.86 | 1.92 |
| 16 | D-0˚-R | 0 | 1.91 | 2.4 | 1.99 |
| 17 | D-30˚-R | 0.04 | 0.91 | 1.87 | 1.65 |

| | | | | | |
|---|---|---|---|---|---|
| 18 | D-45˚-R | 0.06 | 1.34 | 1.61 | 1.49 |
| 19 | D-60˚-R | 0.11 | 2.09 | 1.81 | 2.43 |
| 20 | D-90˚-R | 0.13 | 2.52 | 1.93 | 2.67 |
| 21 | D-0˚-S | 0 | 1.79 | 2.02 | 1.78 |
| 22 | D-30˚-S | 0.03 | 0.84 | 1.62 | 1.53 |
| 23 | D-45˚-S | 0.05 | 1.25 | 1.36 | 1.37 |
| 24 | D-60˚-S | 0.08 | 1.93 | 1.44 | 2.02 |
| 25 | D-90˚-S | 0.11 | 2.31 | 1.62 | 2.39 |
| 26 | D-0˚-JF | 0 | 0.96 | 0.76 | 0.66 |
| 27 | D-30˚-JF | 0 | 0.16 | 0.76 | 0.66 |
| 28 | D-45˚-JF | 0 | 0.17 | 0.76 | 0.66 |
| 29 | D-60˚-JF | 0 | 0.88 | 0.31 | 0.84 |
| 30 | D-90˚-JF | 0.06 | 1.32 | 0.68 | 1.56 |

*

S – 0˚ - R = Single Joint – 0˚ Joint orientation – Rough joint condition
S – 45˚ - S = Single Joint– 45˚ Joint orientation – Smooth joint condition
S – 90˚ - JF = Single Joint– 90˚ Joint orientation – Joint filled condition
D – 60˚ - R = Double Joint – 60˚ Joint orientation – Rough joint condition
D – 30˚ - S = Double Joint– 30˚ Joint orientation – Smooth joint condition
D – 90˚ - JF= Double Joint– 90˚ Joint orientation – Joint filled condition

## VIII. Conclusion

The unconfined compressive strength tests and point load index were carried out on various joint orientations with different joint condition. And the following conclusions have been made.

1. From the Laboratory results, a new correlation was proposed for predicting UCS of jointed rocks specimens from point load index test.
2. Through a review on previous correlation for jointed rocks, it was observed that the proposed equation for joint orientation greater than 45˚ shows good prediction. But the equation is not effective for joint orientation less than 45˚.
3. The proposed correlation for "Simulate jointed rocks", study may be possible to compare actual rocks like weathered limestone.
4. In future we can create the correlation through Artificial Neural Network. By this we can predict the missing values in point load index for jointed rocks.

## References


[1]. E.T.Brown, Rock Characterization, Testing and Monitoring, ISRM Suggested Methods, Pergamon press, Oxford, 1985, 111-116
[2]. E. Broch, and J.Franklin, J. Rock Mech. Min.Sci, 9(6), 1972, 669-697.
[3]. M.Akram and M.Z.A Bakar, Correlation between Uniaxial Compressive Strengt And Point Load Index For Salt-Range Rocks, pak. J. Engg. &Appl.Sci, 1, 2007, 1-8.
[4]. R.Farah, Correlations Between Index Properties and Unconfined Compressive Strength of Weathered Ocala Limestone, UNF Theses and Dissertations, 2011, 142.
[5]. Zuhair Kadhim Jahanger and Azad Abbas Ahmed, Correlation Between Point Load Index and Very Low Uniaaill Compressive Strength of Some Iraqi Rocks, Australian Journal of Basic and Applied Sciences, 7, 2013, 216-229.
[6]. Ramli Nazir.,Ehsan Momeni, Danial Jahed Armaghani, and Mohd For Mohd Amin, Correlations Between Unconfined Compressive Strength and Indirect Tensile Strength of Limestone Rock Samples,EJGE, 18, 2013, 1737-1746.
[7]. Ehsan Momeni, Ramli nazir, denial Jahed Armaghani, Mohd for Mohd Amin, Edy Tonnizam Mohamad, Prediction of Unconfined Compressive Strength of Rocks:A Review Paper, Journal Technology, 2015, 43-50
[8]. R. Altindag and A.Guney, Predicting the relationship between brittleness and mechanical properties(UCS,TS and SH) of rocks, Scientific Research and Essay, 5(16), 2017-2118.
[9]. N.Kabilan and M.Muttharam, Correlation between Uniaxial Compression strength and point load index for jointed rocks, International Journal of Earth Sciences and Engineering, 8(2), 2015, 542-546.
[10]. Vekinis G, Ashby M.F and Beaumont W.R, Plaster of paris as a model material for brittle porous solids, Journal of material science, 28, 1993, 3321-3227.
[11]. Mahendra Singh and Bhawani Singh, Laboratory and Numerical Modelling of a Jointed Rock mass, The 12th International conference of international association for computer methods and advances in geomechanics, 6, 1373-1380.