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# The determination of uniaxial compressive strength from point load strength for pyroclastic rocks

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ABSTRACT

The point load test has often been reported as an indirect measure of compressive strength. It has been used widely in practice due to easy testing, the simplicity of specimen preparation, and possible field applications. Many researchers have investigated the relation between uniaxial compressive strength (*UCS*) and point load index ($I_s$) for different rock types. However, there are limited studies in the literature for soft rocks such as pyroclastic rocks. In this study, the relation between *UCS* and $I_s$ was investigated for pyroclastic rocks having UCS values are less than 50 MPa. Very strong exponential relations were found for dry rocks, saturated rocks and both dry and saturated rocks. The results were also compared to the studies in the literature.



## 1. Introduction

The uniaxial compressive strength (*UCS*) of rock is widely used in various engineering projects performed in rock environment. Although the method is relatively simple, it is time consuming and expensive. It also requires well-prepared rock cores. For this reason, indirect tests are frequently used to predict the *UCS* for preliminary studies. Among the indirect tests, the point load test is commonly used in practice due to its testing ease, simplicity of specimen preparation, and possible field applications. Point load strength index ($I_{s50}$) has often been reported as an indirect measure of the compressive or tensile strength of rock (D'Andrea et al., 1964; Reichmuth, 1968; Broch and Franklin, 1972; Bieniawski, 1975; Hassani et al., 1980; Read et al., 1980; Gunsallus and Kulhawy, 1984). Although ISRM (1985) suggested that the ratio between the *UCS* and $I_s$ varies between 20 and 25, numerous researchers have investigated and showed that the ratio has a wide range.

Although, many researchers have investigated the relation between *UCS* and $I_s$ for different rock types, only few studies have been concentrated on soft rocks such as pyroclastic rocks. In this study, the correlations between the *UCS* and $I_s$ for pyroclastic rocks was investigated and obtained results were compared to the studies in the literature. The main purpose of this study is to develop some equations for the estimation of *UCS* from $I_s$ for pyroclastic rocks. Such equations will be practically used by engineers especially for preliminary studies since the determination of *UCS* is difficult and expensive compared to *Is*.

## 2. Previous studies

Because the point load apparatus is a valuable tool for the prediction of *UCS* in the field, many researchers have investigated the relation between the *UCS* and $I_s$ since 1960s. A brief summary of these studies are given as follows.

D'Andrea et al. (1964) used a linear regression model to obtain a correlation between uniaxial compression test and the point load test. Broch and Franklin (1972) showed that the compressive strength was approximately 24 times of the $I_s$ of a standard (50 mm) size core. They also presented a size correction chart so that cores of various diameters could be used for strength determination. Bieniawski (1975) indicated that the *UCS* was nearly 23 times of the $I_s$. Pells (1975) stated that the index to strength conversion factor of 24 could lead to a 20% error in the prediction of compressive strength for such rocks as dolerite, norite and pyroxenite. Al-Jassar and Hawkins (1979) carried out point load test on core samples with 30, 50, and 76 mm diameters and on block samples of thicknesses, 30, 50 and 70 mm. They showed that the point load strength decreased with an increase in the sample thickness. It was also shown that for core samples the index is lower than for block samples and the correlation between the point load index and the unconfined compressive strength is different for core and block specimens.

Read et al. (1980) investigated the ratio of UCS/$I_s$ for different rock types and different weathering grade. He showed that the ratio of *UCS*/$I_s$ varies with both rock type and weathering grade. Hassani et al. (1980) investigated the point load test using an expanded database with tests on large specimens. They also revised the size correlation chart commonly used to adjust the standard (50 mm) size for different diameter cores and found a generalized conversion factor of 29 to be the most appropriate. Singh (1981) tested weak coal measure rocks to

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derive some empirical equations for the estimation of *UCS* from $I_s$. He established a linear relation between *UCS* and $I_s$. Brook (1980) emphasized the possible sources of error when using point load tests, and suggested an analytical method of "size correction" to a chosen standard size. Greminger (1982) showed that the conversion factor of 24 could not be adequately applied to anisotropic rocks. Forster (1983) investigated the effect of core sample geometry on the axial point load test. He also studied the relations between the *UCS* and $I_s$ for greenstone plaster, dolerite and sandstone samples. He showed that the ratio of $UCS/I_s$ ranged from 11.8 to 17.6 (disregarding the greenstone plaster sample). Gunsallus and Kulhawy (1984) evaluated comparatively rock strength measures and presented a linear relation for the prediction of *UCS* from $I_s$ for sedimentary rocks. ISRM (1985) stated that on average, compressive strength was 20–25 times $I_s$, although it was pointed out that in tests of many different rock types the range varied between 15 and 50, especially for anisotropic rocks. Therefore, errors up to 100% should be expected if an arbitrary ratio value is chosen to predict compressive strength from point load tests. An easy method for determining standard point load strength $I_{s50}$ from the test results obtained from a number of irregular and regular prismatic specimens of different diameters using log–log plots of $I_s$ against diameter was proposed by Turk and Dearman (1985). O`Rourke (1988) correlated the *UCS* values to the $I_s$ values using the sedimentary rock data from the Paradox basin of Utah and found a linear correlation between the two parameters. He also discussed the applicability of the $I_s$ test for geo-engineering design in underground development. Vallejo et al. (1989) conducted the *UCS* and $I_s$ tests on the samples of shale and sandstone obtained from the surface coal mining sites in the Appalachian region and correlated the two parameters. They stated that the $UCS/I_s$ ratio was 12.5 for the shales and was 17.4 for the sandstones.

Cargill and Shakoor (1990) investigated the relation between the *UCS* and $I_s$ for different rock types and found a linear relation between the two parameters. Ghosh and Srivastava (1991) evaluated the test results of some granitic rocks from Western Himalaya and derived $UCS/I_s$ ratio of 16. Tsidzi (1991) examined the effect of anisotropic fabric on the $UCS/I_s$ ratio using the data of metamorphic rocks. He revealed that the $UCS/I_s$ ratio for metamorphic rocks varies very much with foliation. He stated that weakly foliated rocks could be assigned a $UCS/I_s$ ratio of 17 and those with more than moderate degree of foliation could have a value of 23. Grasso et al. (1992) correlated the *UCS* with $I_s$ using the data of a calcareous mudstone which is generally homogeneous. They established both power and linear correlations and indicated that the correlation coefficient of power relation was higher than that of linear relation. Ulusay et al. (1994) performed a study to develop some prediction models for engineering properties of a selected litharenite sandstone from its petrographic characteristics. They also correlated *UCS* with $I_s$ and found a good linear relation between the two parameters. A simple analytical formula was proposed by Chau and Wong (1996) for the calculation of the *UCS* based on the point load strength corrected to a specimen diameter of 50 mm. They showed that the $UCS/I_s$ ratio depends on the compressive to tensile strength ratio, the Poisson's ratio, the length and the diameter of the rock specimen. Their theoretical prediction for the $UCS/I_s$ ratio agrees with the experimental observations for Hong Kong rocks. Smith (1997) investigated the applicability of the $I_s$ test for the weak rock materials typical of many coastal deposits. He showed that the average $UCS/I_s$ ratio for the three lime rock sites was 14.3, which was low compared with an expected value of 24 based on hard rock testing experience. Hawkins (1998) indicated that the $UCS/I_s$ ratio varied from 7 to 68 for different lithologies and/or conditions. He suggested a table for the site specific ratio of the $UCS/I_s$ for sedimentary (in wet and dry conditions) and igneous rocks, and stated that the ratio for saturated rocks is often 50% lower than for dry rocks.

Rusnak and Mark (2000) evaluated the mechanical test results of sedimentary rocks (shale, siltstone, sandstone and limestone) from

**Table 1**
Equations correlating the UCS with the point load strength index.

| Reference | Equation |
|---|---|
| D'Andrea et al. (1964) | $UCS = 15.3I_{s50} + 16.3$ |
| Deere and Miller (1966) | $UCS = 20.7I_{s50} + 29.6$ |
| Broch and Franklin (1972) | $UCS = 24I_{s50}$ |
| Bieniawski (1975) | $UCS = 23I_{s50}$ |
| Al-Jassar and Hawkins (1979) | $UCS = 17....30I_{s50}$ |
| Hassani et al. (1980) | $UCS = 29I_{s50}$ |
| Read et al. (1980): | |
| 1) Sedimentary rocks | $UCS = 16I_{s50}$ |
| 2) Basalts | $UCS = 20I_{s50}$ |
| Singh (1981) | $UCS = 18.7I_{s50}$ -13.2 |
| Forster (1983) | $UCS = 11.8....17.6I_{s50}$ |
| Gunsallus and Kulhawy (1984) | $UCS = 16.5I_{s50} + 51.0$ |
| ISRM (1985) | $UCS = 20....25I_{s50}$ |
| O`Rourke (1988) | $UCS = 21.8I_{s50} + 43.2$ |
| Vallejo et al. (1989): | |
| 1) Shale | $UCS = 12.5I_{s50}$ |
| 2) Sandstone | $UCS = 17.4I_{s50}$ |
| Cargill and Shakoor (1990) | $UCS = 23I_{s54} + 13$ |
| Tsidzi (1991) | $UCS = 14....82I_{s50}$ |
| Ghosh and Srivastava (1991) | $UCS = 16I_{s50}$ |
| Grasso et al. (1992): | |
| 1) Power relation | $UCS = 25.67(I_{s50})^{0.57}$ |
| 2) Linear relation | $UCS = 9.30I_{s50} + 20.04$ |
| Ulusay et al. (1994) | $UCS = 19I_{s50} + 12.7$ |
| Chau and Wong (1996) | $UCS = 12.5I_{s50}$ |
| Smith (1997) | $UCS = 14.3I_{s50}$ |
| Hawkins (1998) | $UCS = 7....68I_{s50}$ |
| Rusnak and Mark (2000) | $UCS = 21.0I_{s50}$ |
| Kahraman (2001): | |
| 1) 22 different rock type | $UCS = 8.41I_{s50} + 9.51$ |
| 2) Coal measure rocks | $UCS = 23.62I_{s50} - 2.69$ |
| Quane and Russel (2003): | |
| 1) Strong rocks | $UCS = 24.4I_{s50}$ |
| 2) Weak rocks | $UCS = 3.86(I_{s50})^2 + 5.65I_{s50}$ |
| Tsiambaos and Sabatakakis (2004): | |
| 1) Power relation | $UCS = 7.3(I_{s50})^{1.71}$ |
| 2) Linear relation | $UCS = 23I_{s50}$ |
| Palchik and Hatzor (2004) | $UCS = 8....18I_{s50}$ |
| Kahraman et al. (2005): | |
| 1) Porosity < 1% | $UCS = 24.83I_{s50} - 39.64$ |
| 2) Porosity > 1% | $UCS = 10.22I_{s50} + 24.31$ |
| Fener et al. (2005) | $UCS = 9.08I_{s50} + 39.32$ |
| Santi (2006) (Derived from Smith, 1997) | $UCS = 12.25(I_{s50})^{1.59}$ |
| Kassim and Mohammad (2007) | |
| 1)$I_s < 1$ MPa | $UCS = 12.23I_{s50} + 1.75$ |
| 2)$I_s > 1$ MPa | $UCS = 14.45I_{s50} + 0.096$ |
| Sabatakakis et al. (2008): | |
| 1)$I_s < 2$ MPa | $UCS = 13I_{s50}$ |
| 2)$I_s = 2–5$ MPa | $UCS = 24I_{s50}$ |
| 3)$I_s > 5$ MPa | $UCS = 28I_{s50}$ |
| Cobanoglu and Celik (2008) | $\mathrm{UCS} = 8.66\ I_{s50} + 10.85$ |
| Kilic and Teymen (2008) | $\mathrm{UCS} = 100\ \mathrm{Ln}I_{s50} + 13.9$ |
| Diamantis et al. (2009): | |
| 1) Power relation | $UCS = 17.81(I_{s50})^{1.06}$ |
| 2) Exponential relation | $UCS = 16.45e^{0.39Is50}$ |
| 3) Linear relation | $UCS = 19.79I_{s50}$ |
| Tziallas et al. (2009) | |
| 1) Linear relation | $UCS = 14.49I_{s50}$ |
| 2) Power relation | $UCS = 10.58(I_{s50})^{1.14}$ |
| Basu and Kamran (2010) | $UCS = 11.103I_{s50} + 37.66$ |
| Basu (2012) | $UCS = 11.218I_{s50} + 4.008$ |
| Singh et al. (2012): | |
| 1) Harder rocks | $UCS = 21....24I_{s50}$ |
| 2) Softer rocks | $UCS = 14....16I_{s50}$ |
| Kohno and Maeda (2012) | $UCS = 16.4I_{s50}$ |
| Mishra and Basu (2013): | |
| 1) Granite | $UCS = 10.9I_{s50} + 49.03$ |
| 2) Schist | $UCS = 11.21I_{s50} + 40.01$ |
| 3) Sandstone | $UCS = 12.95I_{s50} - 5.19$ |
| 4) All tested rocks | $UCS = 14.63I_{s50}$ |
| Li and Wong (2013): | |
| 1) Meta-siltstone | $UCS = 19.83I_{s50}$ |
| 2) Metasandstone | $UCS = 21.27I_{s50}$ |