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Point load strength index of granitic irregular lumps: Size correction and correlation with uniaxial compressive strength

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ABSTRACT

The Uniaxial Compressive Strength (UCS) of rock cores is a key parameter for design analysis of rock engineering projects such as rock tunnels and piles in rockets. Diametral and axial point load tests on cylinder cores have been used to obtain Point Load Strength Index (PLSI). This PLSI is correlated to UCS. Recently, point load tests on irregular lumps are also used to obtain PLSI which is then correlated to UCS. However, the data on this correlation are very limited, especially for Hong Kong rocks. This paper presents the methodology for specimen preparation, testing, and data analysis. Results from irregular lump point load tests, diametral and axial point load tests, and uniaxial compressive tests (a total of 754 specimens of granitic rocks were tested) are then presented, analyzed, and discussed. A correlation between PLSI from irregular lump tests and UCS is established with a suitable size correction function. It is found that the $I_{s(50)}$ of the slightly decomposed Granite is between 7.31 MPa and 8.5 MPa. The $I_{s(50)}$ of the altered rock is 2.35 MPa, where the rock containing weakness plane is 5.59 MPa. The moderately decomposed Granite varies from 2.28 MPa to 4.92 MPa. The weathering affected the PLIS a lot. It is found that the values of power index value m in the size correction function is 0.443–0.600 for slightly decomposed granite (fine to coarse grains) and 0.545–5.562 for moderately decomposed granite (fine to medium and medium grains). Based on our study, for slightly decomposed coarse grain and fine to medium grain Granite, the size correction factor $F = (D_e/50)^{0.44}$ (lower bound) is recommend; while for all other weathering conditions and grain sizes, the size correction factor $F = (D_e/50)^{0.55}$ (lower bound) is recommended. The correlation between the UCS and PLSI *Is*(50) of irregular lumps is found to be 22.27, which is very close to the values of 21.61 and 21.72 for diametral and axial PL tests using the size correction factor of $F = (De/50)^{0.45}$. This indicates that the correlation between UCS and PLSI from point load tests on irregular lumps established in this paper is reliable.

1. Introduction

In Hong Kong, a number of large rock tunneling projects are under construction or in near completion. The projects include a 26-km Express Rail Link (XRL) from West Kowloon og Hong Kong to Shen Zhen of Mainland China and a rock tunnel for South Island Line of MTR in Hong Kong. In XRL project, 90% of the tunnel is in granitic rocks and are being constructed by tunnel boring or drill and blast methods. In addition, most piles in Hong Kong are installed in rock sockets. The uniaxial compressive strength (UCS) is an important strength parameter not only for the analysis of the stability of these rock tunnels, but also for the design of the rock-socketed piles.

The point load compression test to irregular lumps was actually proposed before the point load test for rock cores. Protodyakonov (Protodyakonov, 1960) first suggested the idea of testing irregular rock lumps in Russia in 1960. Testing on irregular rock lumps need no sample preparation (such as cutting and grinding). Hiramatsu and Oka (1966) proposed to carry out a point test on a rock sample to obtain a point load index (PLI) I_s as:

$$I_s = \frac{P}{D^2} \tag{1}$$

where D is the distance between two platen contact points. They used conical point contacts instead of flat platens. This kind of tests is now called Point Load Strength Test (PLST). They also showed that the tensile stress concentration within a sphere is a good approximation for irregular lumps. Riechmuth (1963, 1968) in USA applied PLST to rock

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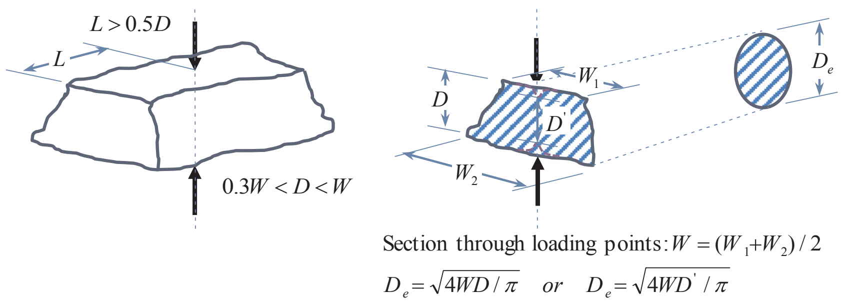

Fig. 1. Dimensions and equivalent diameter for an irregular lump.

cores, both axially and diametrally. D'Andrea et al. (1965) found that the point load index (PLI) I_s has a good correlation with uniaxial compressive strength (UCS). The scattering of point load index is less than that of uniaxial compressive strength (Broch and Franklin, 1972). Bieniawski (1975) presented general applications of PLST.

PLST was adopted by International Bureau for Rock Mechanics in 1964 (Broch and Franklin, 1972). The International Society for Rock Mechanics (ISRM) published a standard procedure for PLST which has been widely adopted nowadays (ISRM, 1985). ISRM (1985) recommends specimen requirements for axial, diametral and irregular lump PLST (see Fig. 1). For irregular lumps, ISRM (1985) suggests the point load index strength I_s below:

$$I_s = \frac{P}{D_e^2} \tag{2}$$

where P is the point in N and D_e in unit of mm is the equivalent diameter defined as

$$D_e = \sqrt{4WD/\pi} \quad or \quad D_e = \sqrt{4WD'/\pi} \tag{3}$$

where $W = (W_1 + W_2)/2$ and W_1,W_2,D,D' are defined in Fig. 1.

The measurement error for W and D should be within ± 5% and ± 2% respectively. The D_e from point load (PL) tests on samples of different sizes should be established with a correction factor to yield PLSI with reference to 50 mm diameter size (called PLI_{50} or $I_{s(50)}$). In case such data are not available, a size correction factor F can be applied to convert the PLSI (I_s) to $I_{s(50)}$ from a PL test on 50 mm diameter size as:

$$I_{s(50)} = FI_s = \left(\frac{D_e}{50}\right)^{0.45} I_s \approx \sqrt{\frac{D_e}{50}}\, I_s \tag{4}$$

where $F = \left(\frac{D_e}{50}\right)^{0.45} \approx \sqrt{\frac{D_e}{50}}$. The size of the lumps should be 50 ± 35 mm. At least 10 specimens should be tested. A point load should be applied along the smallest dimension of a lump. The point load is applied steadily and failure should occur within 10–60 s. Full details of the testing requirements are given in ISRM (1985). The American Society for Testing and Materials (ASTM) adopted and modified the ISRM (1985) standard first in 1995 (ASTM, 1995a) and was subsequently updated in 2008 (ASTM, 2008). The ASTM standard is similar to ISRM (1985). Except that, the irregular lumps should be from 30 mm to 85 mm, and at least 20 specimens should be tested.

Since the pioneering works of Protodyakonov (1960), Hiramatsu and Oka (1966), and others were published, more recent studies focused on irregular lump PLST have been done. Guidicini et al. (1973) conducted PLST on irregular lumps and UCS tests on cylinder specimens of six different rocks and concrete (including basalt, soft sandstone, gneissic granite and concrete). The relationship between PLSI ($I_{s(50)}$) and UCS (q_u) can be expressed as:

$$q_u = \kappa I_{s(50)} \tag{5}$$

The ratio κ in Eq. (5) was found significantly different from 24 suggested by Broch and Franklin (1972) as pointed out by Guidicini et al. (1973). Kohno and Maeda (2012) reported a total of 3828 PLI tests and 329 UCS tests for 44 different types of hydrothermally altered soft rocks from Hokkaido, Japan. For dry rocks, the axial PLI_{50} was about 1.4 times of PLI_{50} of irregular lumps, whereas for wet-rocks, this ratio dropped to 1.1. Therefore, moisture content seemed to be an important factor as well. The correlation coefficients for the relationship between the PLI_{50} and UCS of rocks in dry and wet states were 16.4 and 16.5 respectively. Bieniawski (1975) conducted about 30 specimens for each axial, diametral and irregular lump PLST for both sandstone and norite. Although the standard deviation for irregular lumps is the largest among three PLST, the PLI_{50} values for irregular lumps differs less than 20% from those of both axial and diametral PLST for the case of sandstone and less than 29% for the case of norite. Although there is larger scattering of data, the irregular lumps tests still can be used with confidence. Sarkar et al. (2010) reported estimation of strength parameters of rock using artificial neural networks. Sarkar et al. (2012) obtained an empirical correlation of index geomechanical parameters with the compressional wave velocity.

It was reported that 66 PLSTs were done on irregular lumps of dolerite from N.E. England, with size from 12.5 mm to 50 mm (Turk and Dearman, 1985). A hammering method was used to prepare irregular specimens. An exponential power function with a power index of 0.926 was found by Turk and Dearman (1985) for considering the size effects. This value of 0.926 agreed roughly with that of Panek and Fannon (1992). Panek and Fannon (1992) reported data from 500 PLSTs on irregular rock samples of ironformation, metadiabase, and ophitic basalt, with size from 25 mm to 270 mm. Basu and Aydin (2006) studied the significance of cone penetration on predicting uniaxial compressive strength by point load test. Basu and Kamran (2010) carried out point load test on schistose rocks and examined its applicability in predicting uniaxial compressive strength. The case of spherically isotropic spheres under PLST (*i.e.* anisotropic spheres with spherical isotropic surfaces normal to the radial directions) was considered by Chau and Wei (1999). These studies at The Hong Kong Polytechnic University provided the first theoretical basis for testing anisotropic irregular lumps. For Hong Kong rocks, axial point load strength tests on granite and tuff were carried out by Chau and Wong (1995, 1996). They proposed a microcrack-based theory in which the correlation factor κ between the uniaxial compressive strength and the point load index should be a function of rock types as well as the microstructures of the rocks, instead of the value of 24 suggested by Broch and Franklin (1972) for all rocks. Another series of theoretical stress analyses for PLST were considered by Chau (1998), and Chau and Wei (2001) for the case of diametral PLST, and by Wei and Chau (2002), and Wei et al. (1999) for the case of axial PLST. Note that the theoretical analysis of Wei and Chau (2002) is for anisotropic rock cores.

In Hong Kong, PLST was included in Geoguide 2 “Guide to Site Investigation” (GEO, 1987) as a standard field index test for rocks. The Geoguide 2 (GEO, 1987) includes the case of testing irregular lumps. A “Code of Practice for Foundations” was published by Buildings Department (BD) in 2004 (BD, 2004). Point Load Index strength corrected to sample size of 50 mm (called $I_{s(50)}$ or PLI_{50}) was included in the code (BD, 2004) as a way to measure strength of rock strata. This code allows the use of different presumed values of allowable bearing capacity, according to the tested value of PLI_{50}. Values of PLI_{50} of 3 MPa, 2 MPa