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Joint spacing distribution of granites in Hong Kong

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ABSTRACT

The structural stability of rock masses is dictated by the inherent geological structures present, most notably joints. Joint spacings are one of crucial parameters to control the block volume, permeability, deformability as well as strength of rock masses. While extensive rock engineering projects have been carried out in Hong Kong in the last century, the distribution models of joint spacings in Hong Kong rocks have still rarely been studied systematically and published. This research examines true joint spacings of granites in fourteen different slope outcrops at various localities of Hong Kong. A total number of 1323 joint spacing measurements, belonging to 44 joint sets spanning from 0.005 m to 4.5 m, are obtained. The mean joint spacings among 44 joint sets studied are computed in a range of 0.11 m to 1.33 m. Lognormal Distribution is found to be the dominant joint spacing distribution of granites in Hong Kong. A further in-depth understanding of joint spacing distributions of Hong Kong granitic rocks, which covers about 35% of the total land area, is of profound practical value to the assessment of rock mass excavatability and numerical modelling of rock fracture network development.

1. Introduction

Joint spacing is one of the indispensable parameters to determine the block sizes of rocks (Rives et al., 1992), hydrogeological permeability (Zhang et al., 2004), deformability (Bahaaddini et al., 2013) and strength (Hoek and Brown, 1997; Bahaaddini et al., 2013) of rock masses. It also constitutes one of key parameters to rock mass quality assessments including Rock Mass Rating (Bieniawski, 1989). The engineering feasibility and budgeting aspects of excavation and quarrying of rock masses are critically determined by joint spacings (Abdullatif and Cruden, 1983).

The joint spacings in sedimentary rocks have long been well studied, which are formed to follow the Lognormal Distribution (Sen and Kazi, 1984; Bouroz, 1990; Narr and Suppe, 1991; Rives et al., 1992; Becker and Gross, 1996; Pascal et al., 1997), the Adjusted Lognormal Distribution (Annavarapu et al., 2012), the Gamma Distributions (Huang and Angelier, 1989; Gross, 1993; Castaing et al., 1996), the Negative Exponential Distribution (Priest and Hudson, 1976; Villaescusa and Brown, 1990) and the Normal Distribution (Ji and Saruwatari, 1998; Huang and Angelier, 1989). Nonetheless, the reason for such a wide variety of statistical distribution models in joint spacings has not yet come to a generally-accepted consensus and hence is grossly unsolved (Dershowitz & Einstein, 1988). One plausible explanation is that such assorted types of joint spacing distribution models result from a series of evolution stages during fracture development (Rives et al., 1992). Studies in sedimentary rock show that discontinuity spacing is dictated by the mechanical properties viz. Young's modulus and Poisson's ratio of the sedimentary layers and the loading conditions (Bogdonov, 1947; Bai and Pollard, 2000; Yin, 2010). Pragmatically speaking, joint spacing is of paramount importance to understand joint systems (Dershowitz & Einstein, 1988). A spatial and three-dimensional presentation of rock masses in Discrete Fracture Network Engineering can be achieved by taking joint spacing distribution, number of joint sets and joint orientations into consideration (Alghalandis, 2017). Besides, several computer software including (Finite Element Model) Phase^2, (Discrete Element Model) UDEC and (Indirect Boundary Element Model) TFSDDM have embedded effect of joint spacings towards the engineering properties for the sake of modelling geological rock masses, and calculating the deformability and stability of rock masses during excavation.

Digital photogrammetry (Roncella et al., 2005) and 3D documentation of outcrop by laser scanning (Slob et al., 2005) in mapping individual joints at rock outcrops have been studied with some proven efficiencies (Baratin, 1990). However, the introduction of these

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deterministic approaches studying joint spacings to geotechnical industries is slow (Wong and Ponti, 2013) and economically undesirable to invest. Practically, manual rock joint mapping by experienced engineering geologists is acclaimed to be non-replaceable owing to the nature of three-dimensional geometry of joint plane (Priest, 1993) and a cost-effective approach.

In this research, true (normal) joint spacing values are collected and analysed. It is a unique geometry relation as an orthogonal distance between two adjacent natural joints in the same joint set (Wong and Ponti, 2013). Window rock joint survey is carried out, followed by statistical approaches to reveal patterns of joint spacings of granites in Hong Kong which occupies about 35% of Hong Kong land area (Sewell, 2000). Hong Kong granitic rocks are mainly categorised as four major magmatic episodes, namely 164–161 Ma Lamma Suite, 148–146 Ma Kwai Chung Suite, 144–142 Ma Cheung Chau Suite and 140 Ma Lion Rock Suite, based upon petrology, rock geochemistry and ages (Sewell, 2000). A couple of vertical to sub-vertical joint sets striking NE-SW and NNW-SSE are ubiquitously present in Hong Kong granitic rocks and parallel to Hong Kong major fault systems (Choy et al., 1987; Sewell, 2000), and their origins are due plausibly to a resultant effect coupled by thermal and tectonic stresses (Basu, 2002). Low angle, horizontal to sub-horizontal sheeting joints parallel to topography and surfaces are observed in Hong Kong granites including Anderson Road Quarry and Shek O Quarry and the spacings of them in general increase with depth (Basu, 2002).

Fourteen outcrops are selected to visit based primarily on the accessibility and representativeness to the lithological variety for surveying joint spacings (Fig. 1 & Table 1). The collected joint spacing data, grouped according to joint sets, will be proceeded to Minitab17, a statistical software. The best-fit joint spacing distribution of joint spacings surveyed is analysed and correlated. The research findings provide a reference frame and database for engineering feasibility of excavation in geotechnical projects viz. site formation, rock tunnel, quarrying and foundation works of granites in Hong Kong. Meanwhile, applying such characterised statistical distribution models of joint spacings is relevant and pragmatic in stages of project budgeting, especially tender assessment.

2. Methodology

Window survey technique is adopted to gather true joint spacings that are defined as an orthogonal distance between two natural joint planes within the same joint set, which joint planes exhibit a similar orientation and confirmed by readings from a Clar compass (Fig. 2). True joint spacings are measured by mapped major joint sets accordingly (Fig. 3). The minimum joint spacing measured in this study is set to be 0.005 m. Those joint spacing values smaller than this value are not surveyed. With a scope to understand the joint spacing distributions in major joint sets, those minor or random fractures are neglected during the survey (Fig. 3) and a survey window is defined by the height of surveyor (i.e. 1.8 m in this survey) and the width of the outcrops (Fig. 3). The latter is constrained by the site conditions including accessibility, vegetation cover, etc. The number of joint spacings surveyed depends highly on sizes of survey window. The collected joint spacings in groups of joint sets are subsequently fed to a statistical software - Minitab 17. The built-in function, Individual Distribution Identification, assesses the correlation between joint spacings and a list of fourteen statistical distributions shown in Appendix A including types of distribution models and the associated probability density functions. Anderson-Darling (AD) statistic, *P*-value and Likelihood Ratio Test (LRT) p–value are the parameters computed to evaluate how well the sampling data can fit the respective types of distribution models. The definitions of these three parameters and supplementary criteria which help opt for the most representative distribution models are shown below (Minitab 17 Support, 2017):

- Anderson-Darling (AD) statistic is to evaluate the deviation between the measured field data and the distribution models. The smaller the AD value, the better the distribution fits the data set.
- P–value is an indicator of hypothesis testing. When the *p*-value of

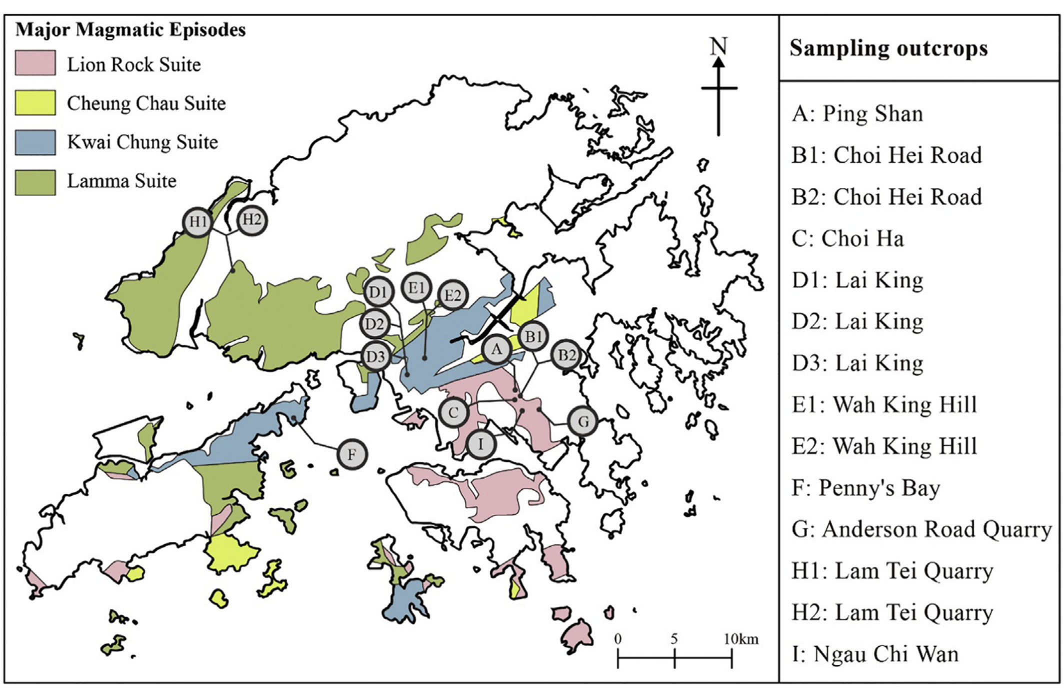

Fig. 1. Locations of granitic rocks in Hong Kong (modified from Sewell, 2000) and rock joint survey locations denoted as sampling outcrops. In term of whole rock geochemistry and formation age, granites in Hong Kong are generally formed by four major magmatic episodes: 164–161 Ma Lamma Suite, 148–146 Ma Kwai Chung Suite, 144–142 Ma Cheung Chau Suite, and 140 Ma Lion Rock Suite (Sewell, 2000). (Colour Figure Online).