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Pull Experiment to Validate Photogrammetrically Predicted Friction Angle of Rock Discontinuities

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Abstract

The estimation of the mechanical properties of rock joints is crucial in terms of safety when it comes to design of slopes in open pit mines or caverns used for the storage of hazardous materials, for instance – nuclear waste. Photogrammetry provides a simple, objective method for joints roughness assessment, without the need for expensive and time consuming laboratory tests or subjective empirical methods. In this study, a new photogrammetric method was used to estimate the roughness, shear strength and friction angle of a discontinuity of 2 m by 1 m fresh rock joint. The estimation was done by analyzing the profiles of digital models of joint surface. Surface Length and Slope Measurement methods were used to calculate the values of Joint Roughness Coefficient (JRC) of analyzed surfaces. Next, the shear strength and friction angle of the rock discontinuity were obtained experimentally with multistage pull testing. The results obtained with both methods were analyzed and compared. JRC values from photogrammetrically created digital models of the joint surface were overestimated due to the low density of the models, which resulted in high noise to signal ratio. Shear strength obtained with photogrammetrically created models were overestimates in relation to the results of the pull test by approximately 45 %. The errors made during this research are analyzed in the article and recommendations on how to improve reliability of the results are made. Main error in photogrammetric prediction was low density of the point clouds and in laboratory test too low stiffness of the test arrangement. The alternative methodology for photogrammetric studies used in previous stage of the research project was tested during this study and was proven to give significantly higher accuracy of generated digital models. The stiffness of the testing machine and proper positioning of the sample halves on top of each other were identified as the most sensitive aspects of methodology of big scale pull test when it comes to the reliability of results.

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Keywords: Photogrammetry; pull test; friction angle; rock joints; shear strength; JRC prediction

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1. Introduction

The determination of shear strength of rock discontinuities is an object of research since the middle of the last century, yet the developed models and failure criterions are based on simplifications which are the topic of ongoing discussion in the field of rock mechanics [1]. The reason for that is the multiplicity and complexity of the parameters affecting the value of the shear strength of a joint. Those parameters include joint surface condition (dry, wet, submerged, weathered, unweathered), roughness of the joint surface, matedness (matching) of the opposites of a joint, compressive strength of a joint, normal load which the joint is subjected to and the mineral composition of the jointed rock, which determines its basic friction angle [2]. The parameter which is the most challenging to quantify is the roughness of a joint surface. That is mainly due to the anisotropic character of natural joints. Directional variation in the joint roughness results in the different shear strength of the same joint depending on the direction of shearing [3]. Therefore, most commonly used method of determining the roughness – Joint Roughness Coefficient (JRC) profiling [4], ISRM suggested method [5] is considered subjective by significant amount of investigators, since it only quantifies the roughness in one direction and involves a human decision on where to measure the shape of the profile, and then to match the obtained profile with a reference [3, 6, 7].

Significant contribution to the improvement of the peak shear strength criteria were made in recent decades, incorporating alternative methods of quantifying the roughness of a rock joint. Fractals are used very frequently as a measure of rock fracture roughness [7-13]. Conventional statistical parameters have been used by some researchers to quantify the joint roughness [6]. Although, those approaches only consider 2D profiles and therefore cannot represent the anisotropy which is present in natural rock joints. The limits of said methods were overcame by taking into account the three - dimensional surface geometry of a joint [3, 14]. The main principle of the criterion proposed by Tatone and Grasselli is to create a high density point cloud model of the joint surface collected by optical instruments – for instance, close range photogrammetry or laser scanning [14, 15]. However, there is a significant economic advantage of photogrammetry in relation to the laser scanning since it can produce good results using off-the-shelf equipment [16]. Photogrammetry has been successfully used for the surface roughness evaluation by many researchers [16-20]. Many publications report that results obtained by photogrammetry are more accurate compering to other methods such as dial gauges measurement, profilometry or drag measurement system [18]. In practice, the photogrammetry is commonly used to obtain the data for kinematic and numerical analyses inthe slope stability assessment [19].

The accurate estimation of the mechanical properties of rock joints is crucial in terms of safety when it comes to design of slopes in open pit mines or caverns used for the storage of hazardous materials *e.g.* nuclear waste. The goal of presented study was to validate the mechanical properties of a rock joint predicted using thephotogrammetry procedure described in [21]. The chosen research method is to compare the values of friction angles obtained using pull and tilt tests with results obtained using digital sampling of photogrammetrically created digital surface models. The main objectives of this research can be formulated as steps in the process of validation: first obtain peak friction angle using experiments and photogrammetry, then compare the results and identify any discrepancies, finally propose improvements to the experimental procedure and/or to the photogrammetric approach.

2. Methods

2.1. Sample description

This paper presents the comparative analysis of two methods of obtaining the shear strength of a rock joint: photogrammetric prediction and direct shear testing. The sample used in this study was a block of Grey Kuru granite with artificial tensile fracture. The length of the block was 200 cm, its width 95 cm and the total thickness 26 cm. The mass of the block was approximately 1300 kg and its density about 2630 kg/m^3. Uniaxial compressive strength of the material was 218 MPa [22]. Photogrammetric prediction of joints shear strength and friction angle was done by using the methodology presented in [21]. To determine the level of damage done to the sample by shear test, the joint surface was photographed twice, before and after the test. Additionally, the visual damage locations were mapped manually between the intermediate loading stages. Digital and hand measured roughness analysis was conducted at both stages, intact and damaged. Direct shear test was executed by means of a multistage pull test,