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Effect of grouting on shear behavior of rock joint

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ABSTRACT

Improper ground conditions should be improved to gain higher strength suitable for construction and the grouting with cement injection is the best option. Understanding the mechanical behavior of grouted fractured rock mass is based on characterization of grouted rock fractures. A systematic comprehensive study on the effect of consolidated grouting on mechanical behavior of fractures has yet to be conducted. The present research work incorporated identical artificial fractures produced through silicon casting and dental plaster as analogs to the ones found in Chamshir dam area in Gachsaran of Iran. By using dental silicone, samples with three different surface roughnesses were molded and finally by using dental plaster that had more strength than gypseous and more faster built up than concrete, several replicates of each samples were casted. Grouts with the water-cement ratios of 1:1 and 2:1 were generated and placed into the fractures. The grouted fractures were subjected to direct shear test and cohesion of the joint and friction angle in both residual and maximum shear strength were determined for different characteristics of rock joints like roughnesses and apertures. The results show that grouting is of positive effect on shear strength. With decreasing the water-cement ratio, grout compressive strength is increased but not necessarily an increase in its shear strength. Maximum friction angle of fractures experienced a decrease by 36–48% by means of 2:1 ratio grout and fluctuated between 5% and 15% through 1:1 ratio grout which approximately equals that of a natural joint. While maximum cohesion rose by 145–282% with 2:1 ratio grout and by 59–96% with 1:1 ratio grout.

1. Introduction

Due to the increasing use of grouting as an important operation in stabilization and reinforcement of rock mass, investigation of the behavior of grouted joints to evaluate their effect on rock mass behavior is imperative. Grouting is a method where a grout is injected into the fractures, pores, or fissures of a rock or soil body and enhances its properties. As a result, the permeability will reduce, the strength of layers will increase, and the overall deformability will decrease.[1] Grouts may be generally divided into three categories of organic, cement, and chemical, with the second finding the widest spectrum of industrial applications.[1] Grouting may be conducted for a variety of purposes including grout curtain or rock mass improvement to which the present research work is dedicated. In grouting operation, grout fills crack openings to improve mechanical properties of the rock mass. This idea contradicts the studies upon grouting effect on mechanical properties of fractures.[2] Shape of fractures (saw cut joint, saw tooth joint and natural rock joint) and their displacement direction in shear test are of importance and effects in shear strength as fractures have various shear strengths at different directions.[3] Moreover, samples subjected to previous studies were generally natural which yields to errors in them[4] since a natural fracture sampled at different points have diverse mechanical properties, based upon which numerous studies have involved gypseous or concrete fractures as they allow for multiple identical samples.[5,6] Artificial fractures made of natural talk can only be used for replicating soft fractures due to their low strength and production of concrete is quite difficult and time consuming. Therefore, new studies adopt materials with high strength and smaller duration of production.[7] Some reports have used Dental plaster which has higher strength and allows for time effective production of samples. Strength of grouted material in fracture considerably affects its behavior. Cement grouts with lower water-to-cement (W/C) ratios have higher compressive strength and this modification in properties has an impact on mechanical properties of fractures.[3] Due to the existent limitations and deficiencies, this study employed natural rocks sourced from Dental plaster, replicated, and then grouted. Using Dental plaster, a number of rock fractures were fabricated and grouted with two types of cement grouts and their shear behavior was eventually investigated in

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shear test to assess the effect of grouting on the mechanical behavior of the fractures. This paper initially presents the methods in sample fabrication and cement grouting, procedure of shear test, and finally draws the results and discussions.

2. Tests procedures

The objective of this research work is to investigate grouting effect on the mechanical behavior of a rock joint. As a result of varying joint mechanical properties at different points and impossibility of providing sufficient number of samples with similar characteristics, comparison of grouting results without involving other factors is unachievable. It was attempted to replicate natural jointed rocks to maintain their mechanical properties in every test and also to generate joints at desired quantities. Once joints bearing properly similar physical and mechanical properties were fabricated, the strength parameters of the rock were measured before and after the grouting. The resulted grout resembled those used in industry in terms of compound.

2.1. Fabrication of artificial joints

The natural rock joints were sourced from Chamshir dam located at 25 km distance from Gachsaran City, Kohgiluyeh and Boyer-Ahmad Province, Iran. By inspection of drilled cores from the Chamshir dam formation and according to the effect of geometrical characteristics of joint surface on the mechanical and hydraulic behaviors of jointed rocks, three joint types with three roughness values were selected and cast with dental silicons (putty). Following casting, a sufficiently large number of rock joints were fabricated using Dental plaster (Fig. 1-a, b)). Various materials have been employed to produce artificial samples including concrete and gypseous in previous studies. Concrete samples were inappropriate due to production duration (minimum time of 24 h for cast removal and 28 days for final strength attainment[8]). Indraratna and Haque used gypseous to construct rock joint samples and reported that gypseous is a better candidate to generate soft rock joint samples.[3] However, gypseous samples-despite their fast production- were not appropriate due to their low strength and hardness. After inquiries upon other materials, dental plaster (in this research work, MOLDANO TARA material) with the uniaxial compressive strength of 49 MPa, minimum time for cast removing 15 min, minimum time for maximum strength attainment 7 days and Specific Weight of 1.7 (g/cm^3), was selected for this study.[7,9] Approximately this type of gypseous enjoys strength as same as of lime stones and has yielded acceptable results in similar studies joints.[7] The cure time of this material is approximately 15 min which expedites the sample production and also attains its final strength in 7 days.[7] Fig. 1-c show the fabricated joints using this gypseous. The roughness coefficient was characterized by 3D scanning technique as presented in Figs. 1-d to 1-f and also 1D profilometer before grouting and shear test.

2.2. Joint aperture measurement

Joint aperture is defined as the vertical distance between two joint surfaces which filled with water or air.[10] Its types include hydraulic aperture, physical aperture, and mechanical aperture, with the latter being subjected to this study. In order to measure joint hydraulic aperture, a dental silicon namely Alginate was used in the tests. The silicon was mixed with water and injected into the joint from the top to determine the aperture. Once the layer cured, the silicon was removed from the joint surfaces and its surface was measured. Afterwards, the volume of the silicon layer was calculated using Archimedes approach. The average aperture was established by dividing the volume of the silicon layer to its surface.

2.3. Grouting operation

In order to evaluate the effect of grouting fluid on the mechanical behavior of the joint, the grout with different cement mixtures (expressed as kilograms per cubic meter of grout), filling materials, various additives, and different water-to-cement ratios may be used.[11,12] Cement is the main and important constituent of a grout. Cements are categorized using several of its assets including their strength and the heat released when they react with water.[8] One of the most important properties of cement is the dimensions of its grains. The grains should be small enough to allow the flow and propagation of the grout in soils and rocks with narrow joints. Commercial cements serve well as they are often course-grained. The present work employed Portland cement type B made by Sepahan Cement Co (Code: EN 197-1 CEM II /B-S-32.5N) bearing the blain of 3200 cm^2/g. Filling materials are generally not used in common grouts since they yield to closure of joints with low apertures and decrease the effective radius of penetration. Hence, they are only used in joints with high apertures.[13,14] Most of additives in grout affect the water-to-cement ratio and consequently the flow and the strength of the grout. In industry, for instance, more water is added for lubrication, which reduces the grout strength. Thus, Plasticizers or Super-plasticizer are added to the grout and water addition is avoided such that the grout is strengthened.[8] Due to the small area of the joints, the radius of dissemination of the grout was not concerned and lubricants and other additives were not involved.[13] Considering the effect of water-to-cement ratio on the mechanical properties of the grouting medium and the parameters taken into account in this operation, two water-to-cement ratios of 2:1 and 1:1 were adopted. Table 1 contains the characteristics of the grouts utilized in this paper.

2.4. Grouting into samples

Using the 8 mm-diameter (pneumatic pipe no 8) pipe placed on top of the joint, grout was injected in to the joint surface at 1 bar pressure. This amount of pressure was set due to small width of the joint and is a factor which governs the grout spread with no considerable effect on the mechanical properties of the joint. In order to avoid opening of the joint and mechanical deformation during the grouting process, the top and bottom parts of the joint were tied together using a metal wire and the joint aperture was continuously measured. Following grouting, the samples were stored at 100% moisture in order for the grout to cure and then were tested after the elapsed time of 28 days intended to acquire the highest strength of the grout.

2.5. Direct shear test on joints

The type of the direct shear tests performed in this test was Constant Normal Loading (CNL).[15] The instrument utilized in this study was a direct shear test at the rock mechanic laboratory of the Isfahan University of Technology which was manufactured in England. The device is capable of applying normal stress and its hydraulic pumps can provide loading up to 50 kN. Since the specimens were replicated from field cores, they were circular in shape. The displacement direction of the joints was marked on the molds in the molding stage and was maintained throughout the fabrication of the samples and ultimately the shear test was performed in this direction. Once prepared, cast in concrete molds, and with the passage of 28 days for grout cure, the specimens were subjected to direct shear test. The purpose of this test is to determine the maximum and residual shear strengths as functions of the normal stress acting on the shear failure plane. Variations in the shear force and shear displacement are logged at each normal stress during the test.[15] The results from the direct shear test on the samples were initially plotted in shear stress-displacement curves (Fig. 2). As observed, the shear stress is initially ascending, then descending, and finally amounts to a constant value,