



Research article

Experimental and numerical study of shear behavior of concrete-soft rock joint: with the approach of concrete penetration in rock pores

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Keywords	English Extended Abstract
Shear behavior Concrete-rock joint Roughness Concrete injection channel Tensile crack	Summary In this study, the shear behavior of the concrete-soft rock joint was simulated using PFC2D software (particle flow code), and the results were compared with physical tests. The concrete-rock joint has different geometries, and concrete was also infiltrated into the

gypsum pores. Specimens with dimensions of 15 cm × 15 cm × 5 cm were made containing gypsum and concrete layers. The concrete was placed in the middle of the specimen and surrounded by gypsum on both sides so that the concrete could penetrate the gypsum.

Nine different geometries were selected for the concrete-stone joint, namely, symmetrical zigzag joint, asymmetrical zigzag joint, and flat joint. The height of the concrete teeth, the base of the concrete teeth, and the angles of the teeth were also varied. In the fixed joint, the concrete penetrates the plaster from one, two, and three channels on each side. 27 different models were prepared. The samples were placed in the UCS (Uniaxial Compressive Strength) machine using special molds and tested under punch shear loading. Simultaneously with the tests, numerical simulation was also performed. In this way, the model was calibrated in the PFC software, and then numerical modeling of the shear behavior of the concrete-stone joint was performed.

Introduction

Large-scale tunnel construction is developing rapidly, and tunnel excavation usually exposes unfavorable geology, such as weak rock masses that are easily subject to mudflow, resulting in irreparable damage to the environment [1-3]. To cope with this, the injection method, in terms of fracturing injection, infiltration injection, filling injection, and compaction injection, has been widely used to enhance the mechanical properties of weak rock masses in tunnel engineering [4-5]. Among them, grout injection to create fractures will be the dominant process [6] when grout injection is performed in ground with low permeability, such as soil. High-pressure grouts are injected into the ground to create fractures [7] and then compacted and combined with the ground. In this way, the strength of the ground can be improved; therefore, one of the main issues in grouting applications is the selection of a suitable grouting material [8]. Due to its high strength, good injection ability, excellent durability, and low cost, cement-based grout has become the most commonly used grouting material in the past decades [9]. In previous studies, the effect of the geometry of the rock-concrete interface on the shear failure mechanism of the rock-concrete interface has not been investigated. Also, the effect of the concrete infiltrated into the rock on the shear properties of the rock-

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concrete interface has not been studied. In this study, the shear failure mechanism of 27 different geometries of the concrete-rock interface, including one, two, and three channels of concrete injected into the rock, was investigated using the physical punch shear test and the particle flow code PFC2D in two dimensions. To investigate the failure behavior of the rock-concrete interface, specimens with dimensions of $15 \times 15 \times 5$ cm containing layers of gypsum and concrete were fabricated. The concrete is located in the middle of the specimen and is surrounded by gypsum on both sides. The interface, concrete, and gypsum have different roughness. The specimen is fabricated in such a way that the concrete can penetrate into the rock in one, two, and three channels from each side.

Methodology and Approaches

The following materials and tools were used to prepare the sample: 9 hard plastic cube molds with dimensions of $15 \times 15 \times 15$ cm, foam with different angles, wooden logs with dimensions of $1 \times 2 \times 15$ cm, cement, plaster, sand, water, and grease. Figure 1 shows the method of preparing the sample. To reduce the dimensions of the sample to $5 \times 10 \times 10$ cm and save on material consumption, first a foam with dimensions of $15 \times 15 \times 9$ cm was placed in the bottom of the plastic molds (Figure 1-a), then angular foams with a height of 15 cm, a thickness of 5 and with different widths were prepared, so that 9 different arrangements for the foam were created (Figure 1-b). Inside these foams, one, two and three cavities are created (Figure 1-c). The distance between the holes in the two-hole foams is 6 cm and the three-hole foams are 2 cm. These holes are created to place the wooden timber (Figure 1-c). The timbers were prepared, and after greasing, they were placed in the holes (Figure 1-c). The foams were greased and placed in the middle of the mold (Figures 1-c and d). It should be noted that before placing the timber in the hole, the bottom and sides of the foams were greased to make it easier to remove the sample from the mold. After installing the timber, gypsum and water were poured in a ratio of 1.2 to 1 (Figure 1-e). After 20 minutes, the plastic molds were opened, and the plaster samples were removed from the central foam (Figure 1-f). The presence of wood in the plaster creates voids (Figure 1-g). The plaster samples are placed back in the plastic mold (Figure 1-h). The space between the two plaster samples is filled with concrete (Figure 1-h). In addition to filling the space between the two plaster samples, the concrete enters the plaster voids and penetrates the plaster. In this way, samples containing one, two, and three concrete injection channels on each side of the plaster sample were created.

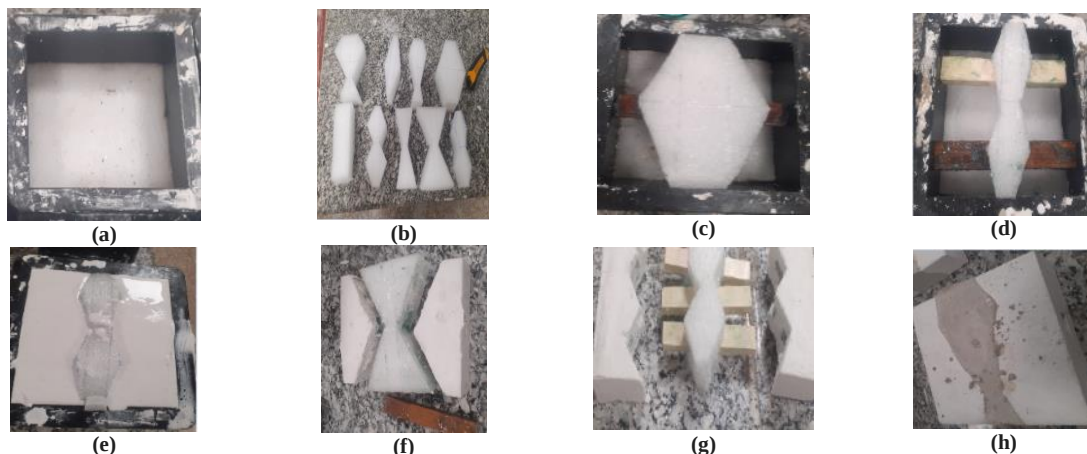


Fig. 1. How to prepare the sample.

Results and Conclusions

The results showed that the failure pattern of the rock-concrete joint is affected by the geometry of the concrete teeth. In specimens without concrete teeth, tensile failure occurs at the joint; however, with increasing roughness angle, in addition to tensile failure, tensile cracks are formed at the tip of the roughness in the specimen. With increasing angle from 0 to 30, the number of tensile cracks in the specimen increases.



With increasing concrete injection channels in the rock, the final failure pattern does not change, but the crack initiation stress, shear stiffness, and failure stress increase. There is good agreement between the experimental and numerical results.

Figures and Tables

Figure 2 shows the results of the experimental failure pattern of a rock-concrete joint including a concrete injection channel in the rock. In Model 4, a model with a concrete indentation at a 30-degree angle, a tensile crack initiated at the rock-concrete joint and propagated parallel to the shear loading direction through the concrete base until it merged with the model boundary. This tensile crack passed through the concrete and caused the rock-concrete joint to fail (Figure 2-a). In Model 6, a model with a concrete indentation at a -30-degree angle, a tensile crack initiated at the rock-concrete joint and propagated parallel to the shear loading direction at the rock-concrete contact until it merged with the model boundary. This tensile crack passed through the concrete and caused the rock-concrete joint to fail. Another tensile crack occurred diagonally in the concrete (Figure 2-b).

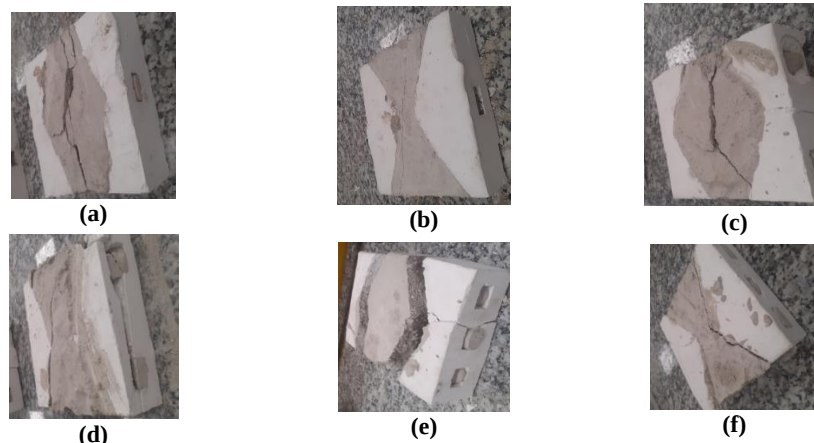


Fig. 2. Failure pattern of rock-concrete joint containing concrete injection channels in the rock.

Figure 3-a shows the changes in shear strength based on the number of injection channels in two-dimensional modeling. Figure 3-b also shows the changes in shear strength based on the number of injection channels in three-dimensional modeling [10]. With increasing injection channels, the shear strength increases. With increasing injection channels, the cross-sectional area of concrete connected to the rock increases, which leads to an increase in shear strength. Models 6 and 9 had the highest and lowest shear strength in numerical simulation and laboratory test. In model 6, the crack passes through the pristine areas of the rock, but in model 9, slip occurs at the interface.

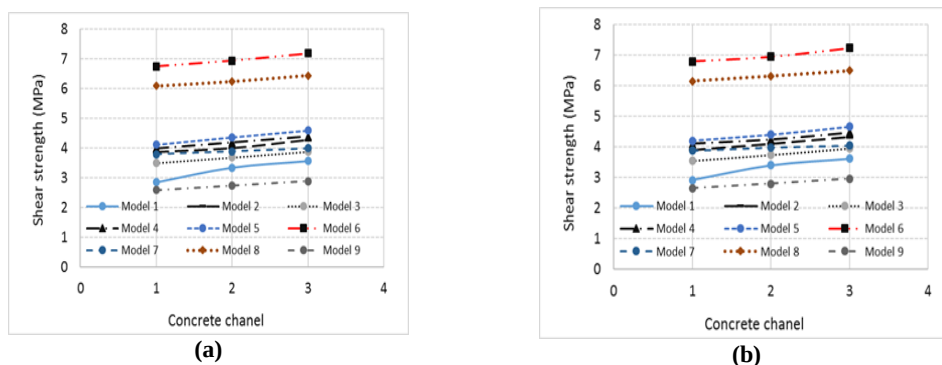


Fig. 3. Changes in shear strength based on the number of injection channels, a) two-dimensional modeling, b) three-dimensional modeling [10].



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