Study on the effect of cement grouting on the shear behaviour of rock joints

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Abstract
To improve the mechanical behaviour of rock mass, the joints can be grouted using cement grouts or chemical grouts. Grouting increases the shear strength of the joints and enhances the deformation modulus of the rock mass. In this article, the effect of cement grouting on the shear behaviour of rock joints is investigated using direct shear test. The tests are performed on the rocks of different type and the effect of various parameters including joint aperture and water cement ratio on the shear strength of the joints are evaluated.

RÉSUMÉ
Pour améliorer le comportement mécanique de la masse de roche, les joints peuvent être scellés au ciment utilisant des coulis de ciment ou des coulis de produit chimique. Le jointoiement augmente la résistance au cisaillement des joints et augmente le module de déformation de Massachusetts de roche. En cet article, l'effet de l'injection de ciment liquide sur le comportement de cisaillement des joints de roche est étudié utilisant l'essai direct de cisaillement. Les essais sont réalisés sur les roches du type différent et l'effet de divers paramètres comprenant le rapport commun de ciment d'ouverture et d'eau sur la résistance au cisaillement des joints sont évalués.

1 INTRODUCTION

In most geotechnical projects such as dam foundations, underground powerhouses and rock slopes, the behaviour of rock mass is mainly controlled by the properties of the joints; especially when the intact rock has a high strength.

Joints may be filled with infillings of different origins and types. These infillings can have a major effect on the shear strength of the joints. Various investigations have been performed on the joints filled with different types of infillings; but the shear behaviour of grouted joints has not been dealt with so far. The studies show that as the thickness of the gouge increases, the shear strength of the joint decreases (Papaliangas et al., 1993; de Toledo & de Freitas, 1993).

Tulinov and Molokov (1971) studied the shear strength of rock joints using different types of rocks such as limestone, sandstone and marl filled with layers of sand and clay of 5 and 6mm thicknesses. They concluded that a thin layer of sand does not have a significant influence on the shear strength of hard rocks but has a major effect on the internal friction angle of soft rocks. Papaliangas et al. (1993) made several tests on plaster and cement joints filled with kaolinite, marble powder and powder fly ash (PFA). The results showed that the shear strength of joints filled with kaolinite reaches a constant value at the t/a ratio of 0.6 while the shear strength of joints filled with marble powder or PFA becomes constant at the ratios of 1.25 to 1.5.

In the present article the shear behaviour of cement grouted joints are studied using direct shear test. The tests are performed on travertine and sandstone (containing slight amounts of limestone) specimen of 5x5cm dimensions with flat surfaces. The direct shear test apparatus used in the tests is shown in Figure 1.

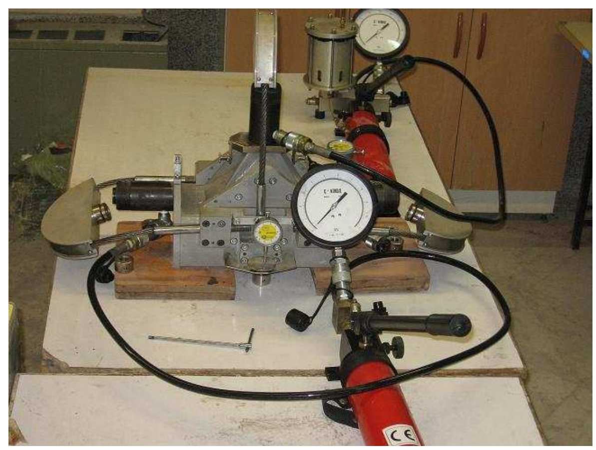

Figure 1. Direct shear test apparatus used in the tests

2 SAMPLE PREPARATION

Rock samples with a surface of 7x7cm^2 and thickness of 4cm were obtained and their surfaces were made smooth using rock grinder. U shape aluminium pieces with internal size of 5×5cm and with thicknesses of 1, 2 and 3mmm were fabricated. This piece was placed between two blocks of rock and was sealed by silicone sealant from three sides. This provided a space with a base size of 5×5cm and different thicknesses of 1, 2 and 3mm. The grout was inserted to this space. After about 24 hours, the silicone sealant was detached from the sample and the sample was moulded and after a specific period of time it was used in the direct shear strength test.

3 GROUTING MATERIAL

The solid particles of a suspension would precipitate after a while. This precipitation can be examined in a glassy cylinder. Low rate of precipitation makes the cement grout more workable in terms of grouting techniques. The average rates of precipitation of cement suspensions are presented in Figure 2. Low rates of precipitation (5-10%) are called stable suspensions while higher rates are called unstable suspensions.

According to Figure 1, only fine cement suspensions with water cement ratio of less 0.8 have low and satisfactory precipitation rates. In this research water cement ratios of 0.5 and 0.8 have been used which correspond to the stable suspensions.

4 TEST RESULT

4.1 Effect of Grout Thickness on the Shear Strength of Joints

Three thicknesses of grout comprising 1mm, 2mm and 3mm were examined. Normal stresses of 0.8MPa, 1.6MPa and 3.2MPa were involved. In the normal stress of 0.8MPa, a specific pattern is not observed. However, for the normal stresses of 1.6MPa and 3.2MPa it is noted that as the grout thickness increases, the shear strength decreases. Another point that can be observed is that for the grout thickness of 2 and 3mm, the residual stresses are almost the same, but the grout thickness of 1mm has higher residual strength. These tests were made both on travertine and sandstone specimens and the results were the same (Figure 3).

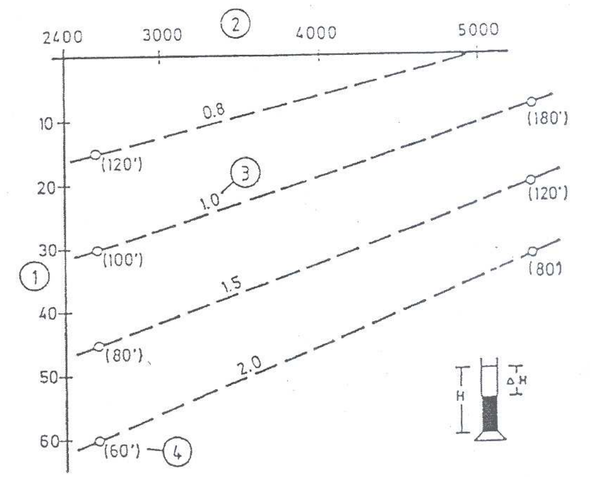

Figure 2. Average precipitation rates of cement suspensions in a cylinder; 1. Precipitation rate, 2. Specific surface, 3. w/c, 4. Time period for final precipitation (min) (Kutzner, 1996)

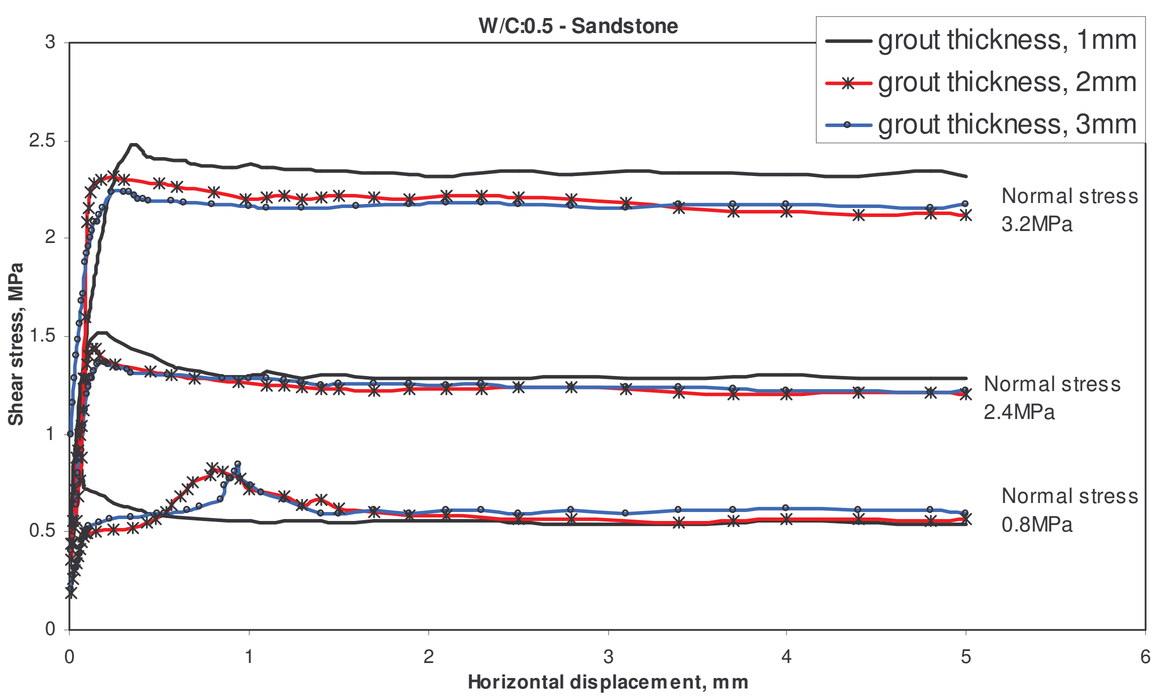

Figure 3. Effect of grout thickness on the shear strength

4.2 Effect of Rock Type

To examine the effect of rock type on the shear strength of grouted joints, two rock types including travertine and sandstone (containing slight amounts of limestone) were used. They were tested under three normal stresses of 0.8, 1.6 and 3.2MPa and three grout thicknesses of 1, 2 and 3mm were involved. It can be seen that in all cases, the sandstone specimen show higher shear strengths (Figure4).

4.3 Effect of Water Cement Ratio

To evaluate the effect of water cement ratio (w/c) on the shear strength of grouted joint, two ratios of 0.5 and 0.8 were used and the shear strengths of 3 day and 7day grout were measured under different normal stresses. As expected, in all cases the water cement ratio of 0.5 results in higher shear (Figure 5).

4.4 Comparison of Grouted and Ungrouted Joints

To compare grouted and ungrouted joints, a series of tests using travertine and sandstone specimen without grouting were performed. The results were compared with the results obtained from the tests on samples with grout thickness of 1mm and water cement ratio of 0.8. In the normal stress of 0.8MPa, the shear strength of ungrouted rock is more than grouted rock. But with the increase of normal stress to 1.6MPa, grouted rock shows higher shear strength. By increasing the normal stress to 3.2MPa, again ungrouted rock shows higher strength (Figure 6).

4.5 Comparison of Cohesion and Internal Friction Angle

By drawing the shear strength envelope for the normal stresses of 0.8, 1.6 and 3.2MPa, the values of C and φ were determined for the grouted and ungrouted joints (Table 1). The values mentioned for the grouted joint correspond to the joint with a grout thickness of 1mm and water cement ratio of 0.8. It can be noted that for the ungrouted joint the value of cohesion is very low compared with the grouted joint but the value of internal friction angle is higher.

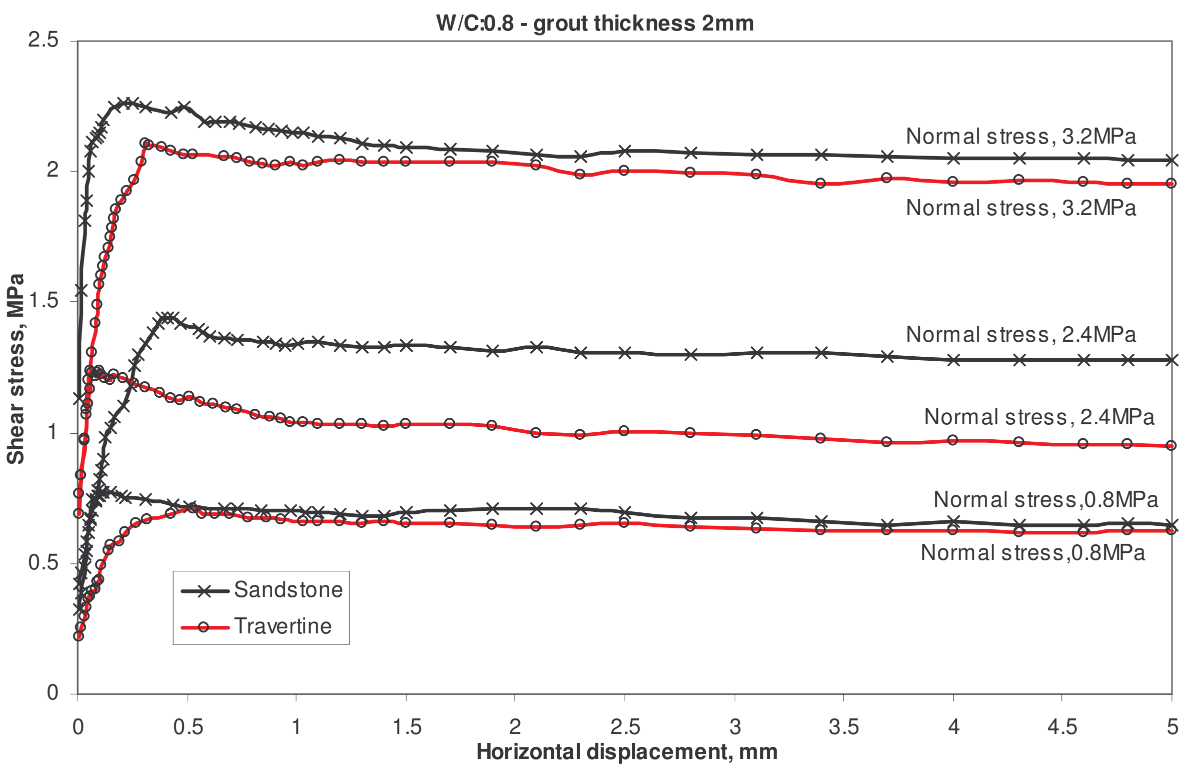

Figure 4. Effect of rock type on the shear strength

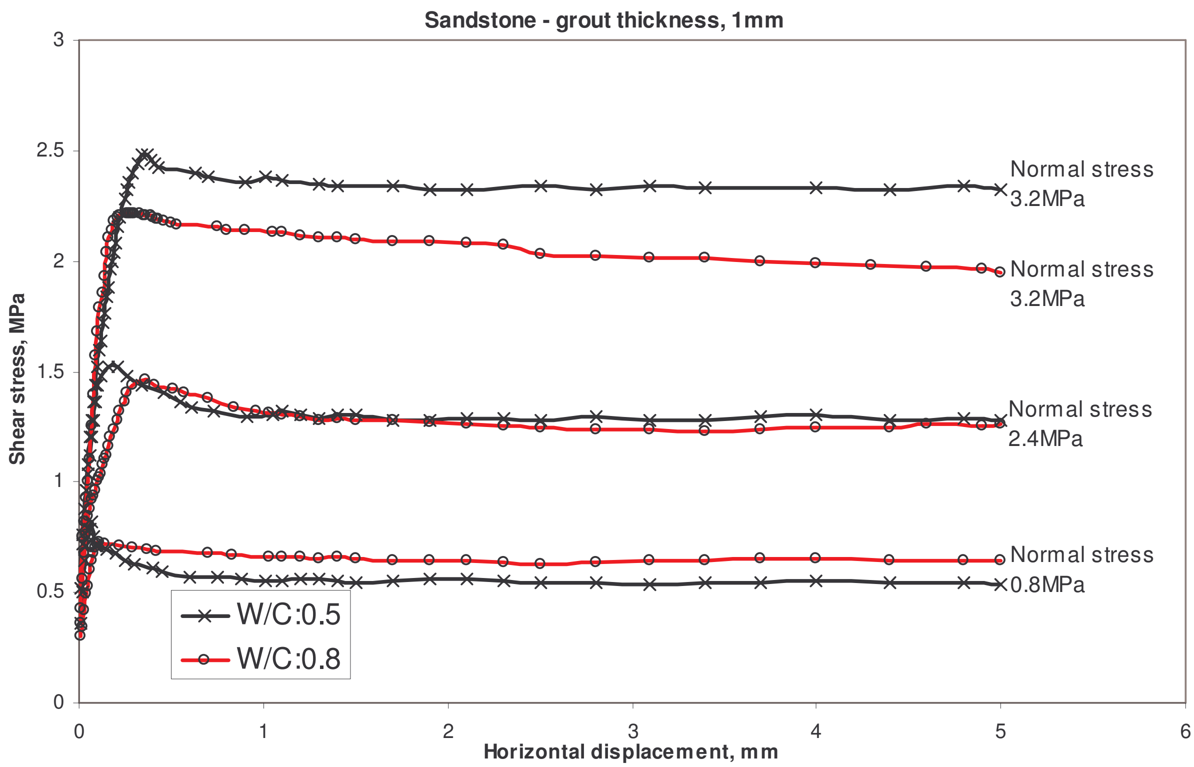

Figure 5. Effect of water cement ratio on the shear strength

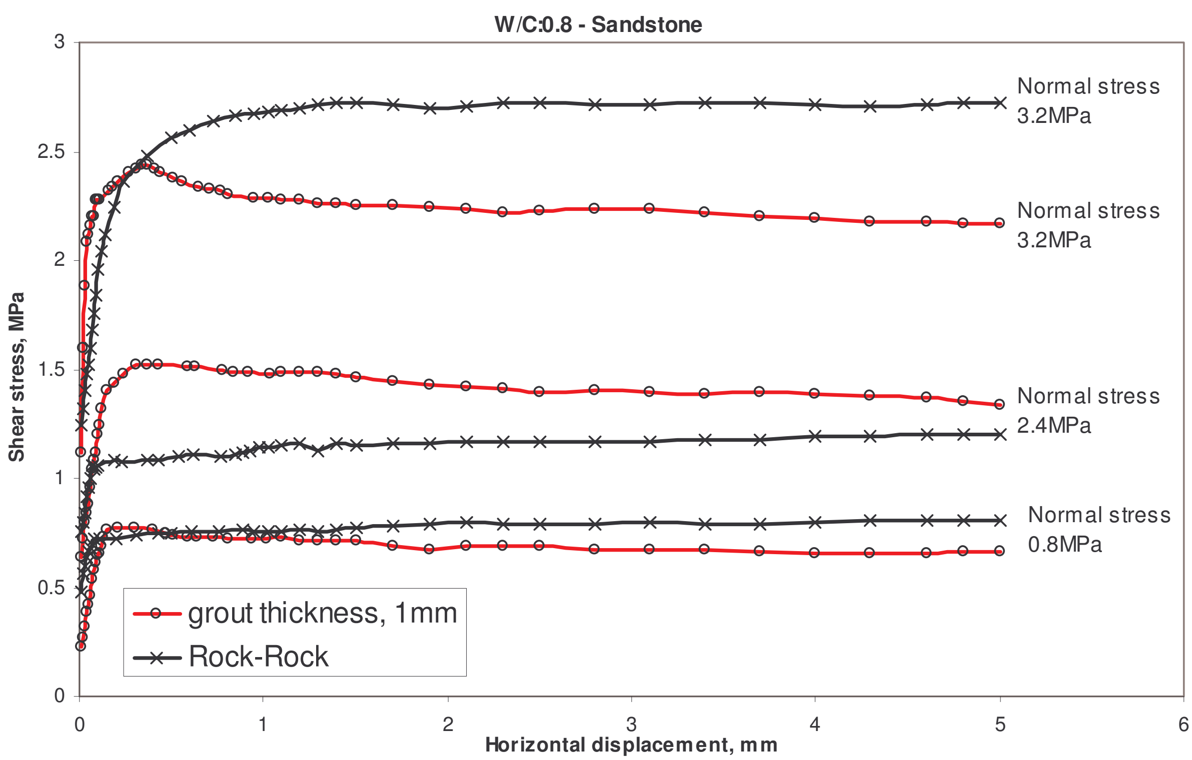

Figure 6. Comparison of grouted and ungrouted joints

Table 1. Shear strength parameters for grouted and ungrouted joint

	C(MPa)	φ (degree)
Sandstone (Rock-Rock)	0.06	41.70
Travertine (Rock-Rock)	0.09	37.70
Sandstone (Grouted)	0.32	35.54
Travertine (Grouted)	0.30	32.74

5 CONCLUSIONS

In this article, the effect of cement grouting on the shear behaviour of rock joints was evaluated using direct shear test. The tests were performed on travertine and sandstone specimen and the effect of various parameters including grout thickness and water cement ratio on the shear strength of the joints were assessed.

6 REFERENCES

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