The Effect of Horizontal Smooth Joints on Strength and Deformability of Sandstone

Younis Alshkane[1]

[1] Department of Civil Engineering, University of Sulaimani, Iraq
Correspondence: Younis Alshkane, University of Sulaimani, Iraq. Email: younis.ali@univsul.edu.iq

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Abstract: The Uniaxial Compressive Strength (UCS) and deformability of jointed rock are required to design structures on or in jointed rock mass. These rock masses depend on the number and orientation of joints. In this study, horizontal smooth joints were created in intact sandstone samples by cutting and grinding the end surfaces of sandstone samples collected from Birchover Quarry in the UK. In the study, 15 UCS tests on jointed and intact samples were conducted. The results showed that, although uniform sandstone block was used, there were inconsistencies in values of UCS and modulus of elasticity for the same type of tested rock. Also, the results showed that the UCS and modulus of elasticity decreased with increasing number of horizontal joints to 4 joints except for the sample of 3 joints which showed the increase in UCS and modulus of elasticity.

Keywords*: *Jointed Rock, UCS, Modulus of Elasticity, Horizontal Smooth Joint

1. Introduction

Design of structures on or in jointed rock mass requires the Uniaxial Compressive Strength (UCS) and deformation modulus (E) of intact as well as jointed rock masses. During the last decades, extensive laboratory studies have evaluated the effect of joint condition, frequency and orientation on the overall rock strength and stiffness using a variety of test methods (e.g. uniaxial compression and triaxial) and materials (e.g. plaster of Paris, sandstone, and granite) (Aroa, 1987; Roy, Ramamurthy & Kate, 1995). The research using uniaxial and triaxial tests on intact and jointed specimens of plaster of Paris, Jamarani sandstone, and Agra sandstone (Aroa, 1987; Ramamurthy & Aroa, 1994) indicated a decrease of strength ratio (ratio of UCS of horizontal jointed rock relative to that of intact rock) with the number of horizontal joints.The strength reduction decrease was 40% for samples with two horizontal joints. Also, the research using numerical methods indicated a decrease in stiffness and strength ratios as shown in Figure 1 (Trivedi, 2010). There is relatively little research available about the effect of several horizontal smooth joints on the strength and modulus of elasticity of jointed rock samples. Furthermore, most researchers used rock-like materials in their studies (Aroa, 1987; Ramamurthy & Aroa, 1994). The aim of this paper is to provide data on the response of jointed rock samples with multiple horizontal joints using real rock samples created from sandstone.

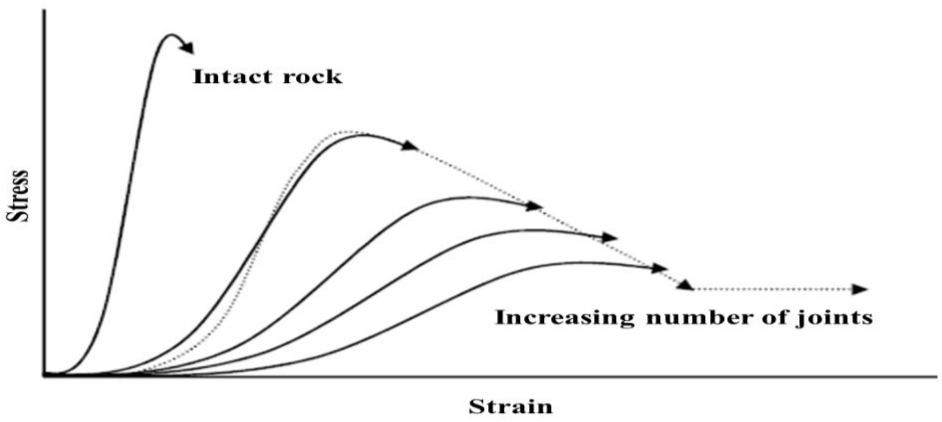

Figure 1: Stress–strain behaviour of rock mass with increasing joints (Trivedi, 2010)

2. Materials and Methods

Cylindrical cores of sandstone (100 mm long by 50 mm diameter) were prepared using samples of sandstone obtained from the Birchover quarry in the UK using diamond core drills. All samples were drilled out from one homogenous rock block. A disc cutting power saw was used to cut samples to the desired length of the core. The sample ends and joint surfaces were ground down using the Rock Grinder according to ISRM (ISRM, 1981). The height to diameter ratio of the rock samples was kept as 2.Five sample types were created with 0, 1, 2, 3, and 4 joints, as illustrated in Figure 2. Three samples were tested for each sample type, resulting in a total of 15 samples.UCS tests were conducted in a 1000 kN servo-controlled hydraulic stiff press. All tests were conducted at a displacement rate of 0.002 mm/sec. The axial displacement was measured by a pair of linear variable differential transformers (LVDTs) with a precision of ± 0.005mm mounted on opposite sides of the samples between the platens, as shown in Figure 3.

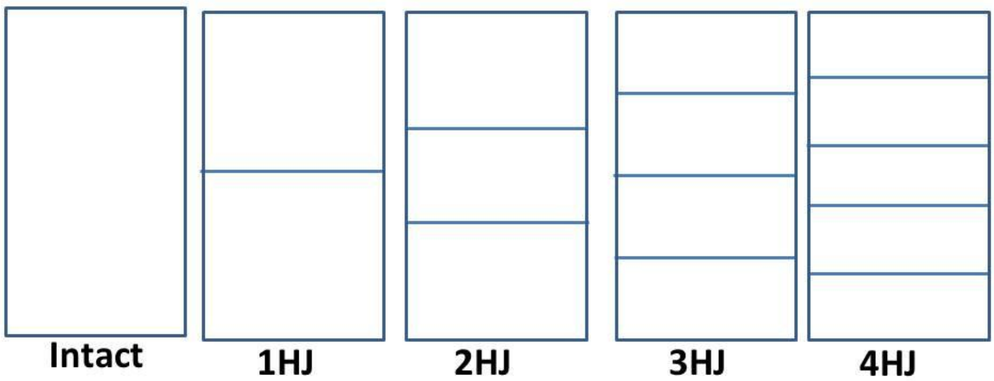

Figure 2: Type of samples

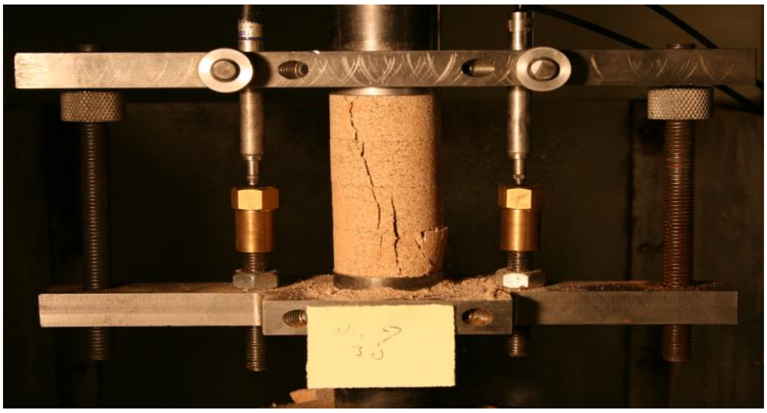

Figure 3: Sample within UCS test apparatus showing LVDTs

3. Results and Discussion

Figure 4 shows axial stress-strain relationships of intact and jointed rock samples. As can be seen that there are similarity in stress-strain behaviour for each type of samples especially when the samples were loaded up to 75% of their strength. This similarity indicates the uniformity of the material used in the study. However, there are discrepancy in UCS and modulus of elasticity for each type. Table 1 presents the average value of UCS and modulus of elasticity with their standard deviation. For UCS values, the minimum standard deviation was recorded for the sample with 2 horizontal joints whereas the maximum value was for sample with 4 joints. For modulus of elasticity, the minimum value was recorded for the sample with 1 joint whereas the maximum value was for sample of 4 joints. Unexpectedly, with increasing the number of joints, UCS and E values decreased but for sample with 3 horizontal joints the values increased relative to the sample with 2 horizontal joints. This is due to the fact that the natures of rock materials are complex and difficult to understand. The cause of this may be as a result of micro-cracks that exist within intact rock blocks.

Table 1: The average values of UCS and E with standard deviation

Samples type	Average UCS (MPa)	Standard deviation (MPa)	Average E (MPa)	Standard deviation (MPa)
Intact	36.36	2.70	8791.90	503.40
1HJ	28.27	2.54	7918.50	217.00
2Hj	24.37	1.43	6998.00	252.50
3HJ	32.03	2.77	7037.00	391.00
4HJ	25.52	5.16	6324.20	601.30

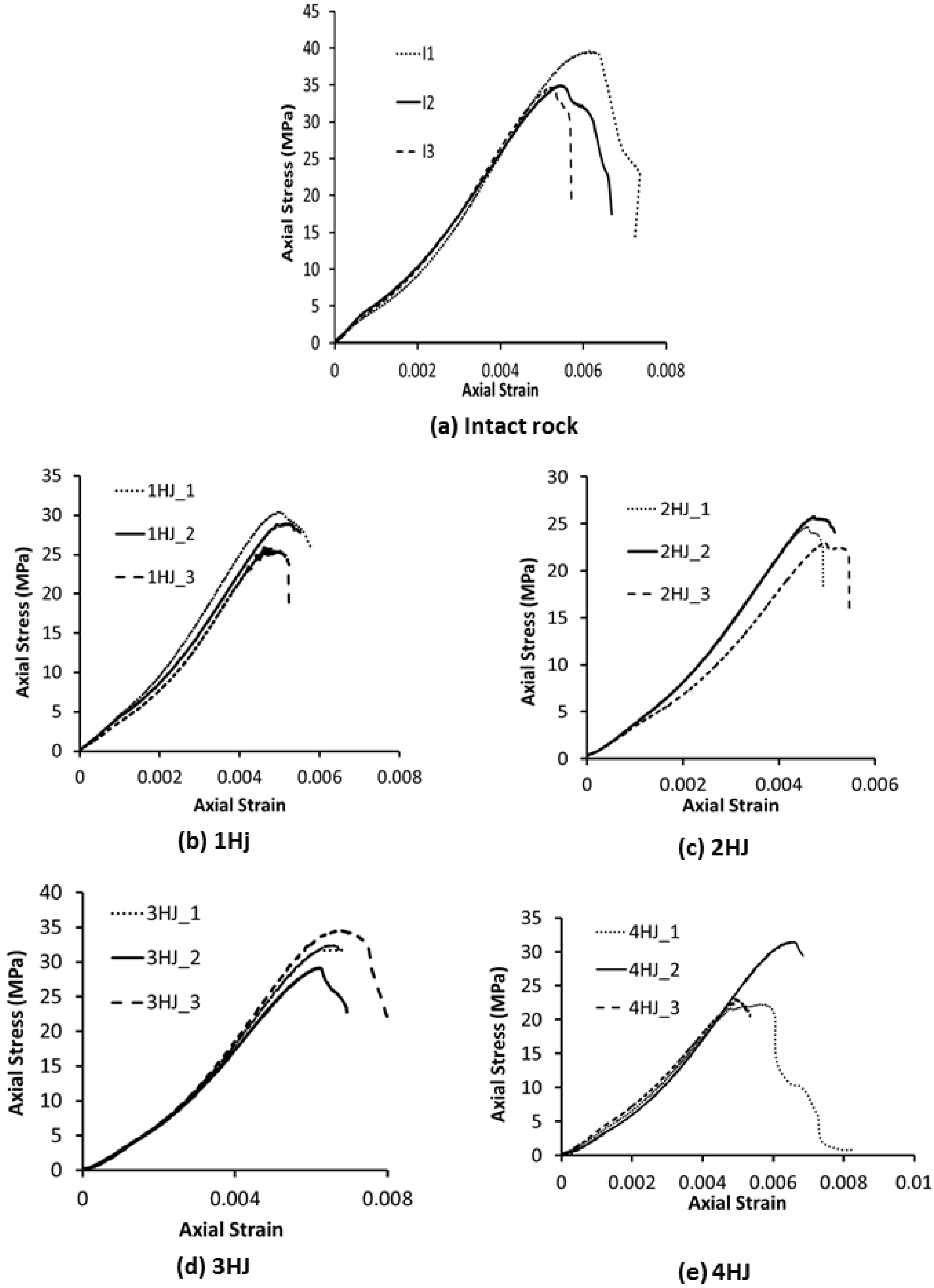

Figure 4: Stress-strain relationships of intact and jointed rock samples: (a) Intact sample, (b) 1 horizontal joint, (c) 2 horizontal joints, (d) 3 horizontal joints; (e) 4 horizontal joints

Figure 5 shows the relationsip between theUCS and number of horizontal joints within the sample. The data shows that the UCS decreases with an increasing the number of joints up to 2 and then the UCS increases when the number of joints is 3. Series 2 of sample 4HJ showed higher UCS value than the other series (1 and 3) since the nature of rock materials are complex and may be unlike even if they are taken from the same depth and location.All samples failed by shear through the intact rock blocks, as shown in Figure 6.

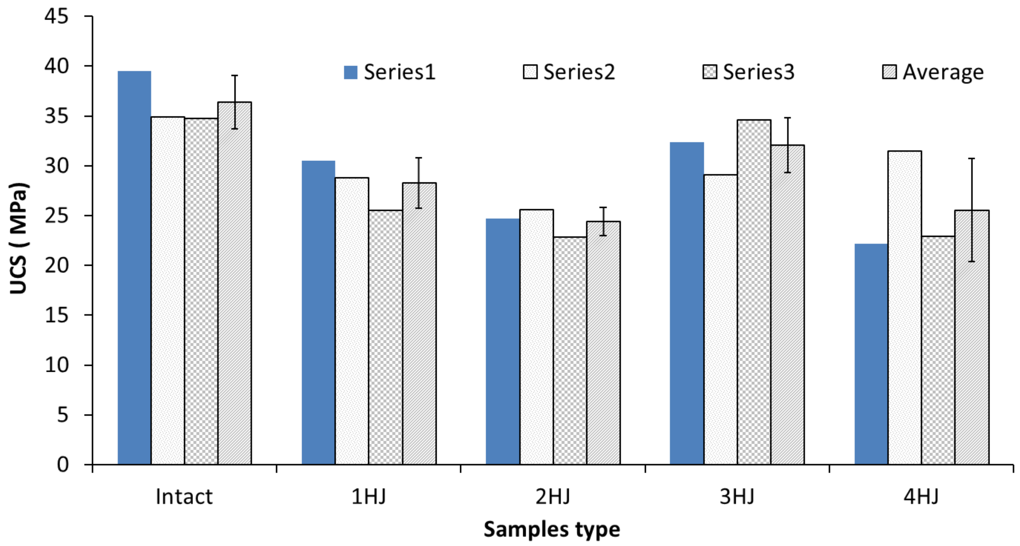

Figure 5: UCS versus samples type

Figure 6: Shear failure through the samples

Figure 7 shows the relationship between the modulus of elasticity (E) and the number of horizontal joints. The modulus of modulus was computed using the tangent modulus at 50% of the failure stress from the axialstress-strain curve (ISRM, 1981). The datashows adecrease in modulus of elasticitywith an increase in number of joints except for the sample with 3 joints which increased slightly. The cause of this may be due to micro crack that exist in rock blocks. It should be noted that initial stiffness for each type was similar but the tangent modulus was different which indicates the homogeneity of rock materials.

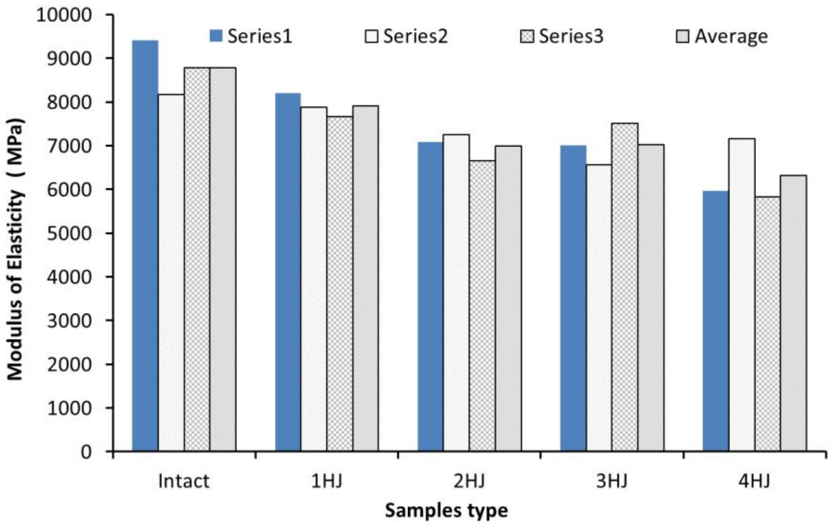

Figure 7: Modulus of elasticity versus samples type

To show the amount of reduction in UCS and the modulus of elasticity with the number of horizontal joints, the strength and stiffness ratios (ratio of values obtained for jointed rocksto that of the intact rock) are plotted against the number of joints in Figure 7. It can be seen that when there are two horizontal joints within the sample, the reduction in both ratios (strength and stiffness)is about 20%; these reductios are slightly increased to about 30% when the number of joints is increased to four. However, the sample with 3 joints increased relatively to the sample with two joint. This study suggests that, although the samples were taken from the same location and depth their mechanical behavior might be different even if they tested under similar condition.

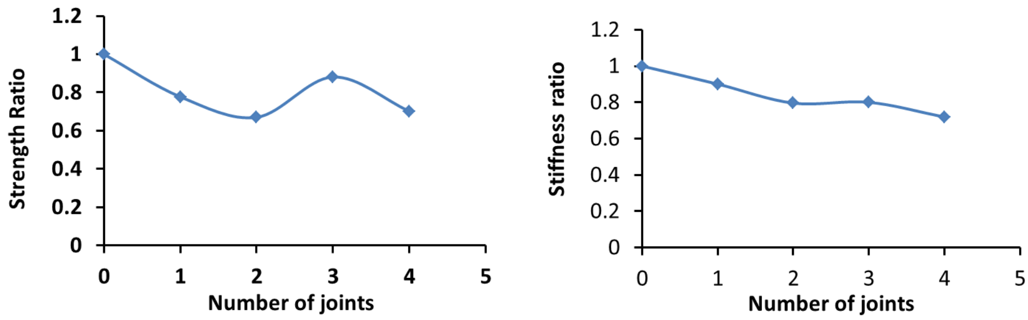

Figure 8: (left) strength ratio versus number of joints; (right) stiffness ratio versus number of joints

The results of experimental results were compared with empirical equation to predict the strength of jointed rock samples. The following equation that was developed by Ramamurthy and Arora (1984) was used in the study:

$$\boldsymbol{\sigma_r = e^{-0.008*J_f}} \qquad (1)$$

Where σ_r $(\frac{UCS_j}{UCS_i})$ is a strength ratio and J_f is a joint factor (Ramamurthy & Arora, 1984).

The results are presented in Table 2. As can be seen that the empirical equation (Eq.1) overestimates the strength of jointed rock samples when the number of joins increased to 2 whereas underestimates the strength when the number of joints is greater than 2. This results suggest that the empirical equations that were developed to predict the strength of jointed rock samples should be used with caution. It should be noted that in this study a very simple type of joint wasused, therfore, the expected percent of error by using the emiprical equation to predict strength could be more than that presented if a rough dipped joints are used.

Table 2: Experimental results of UCS and prediction of UCS using Eq. 1

Samples type	Average UCS (MPa)	UCS by Eq. (1)	% of error
1HJ	28.27	32.61	-15.4
2Hj	24.37	29.25	-20.0
3HJ	32.03	26.23	18.11
4HJ	25.52	23.53	7.81

Based on the data presented in this study a new equation (Eq. 2) was proposed to predict the modulus of elasticity of jointed rock masses with horizontal joints under vertical stress.The correlation is shown in Figure 9 (left). The proposed equation was compared with equation 3 that was developed by Arora (1987) and the results are presented in Figure 9 (right). It can be seen that the proposed equation fits the data much better that the Eq.3. This is because Eq. 3 developed for jointed rock samples that have different orientation whereas the proposed equation (Eq.2) was proposed only for horizontal joints under vertical stress.

$$E_j = E_i * 0.9786 * e^{-0.006*J_f} \quad (2)$$

$$E_j = E_i * e^{-0.0115*J_f} \quad (3)$$

Where: E_j and E_i are modulus of elasticity of jointed rock and intact rock, respectively.

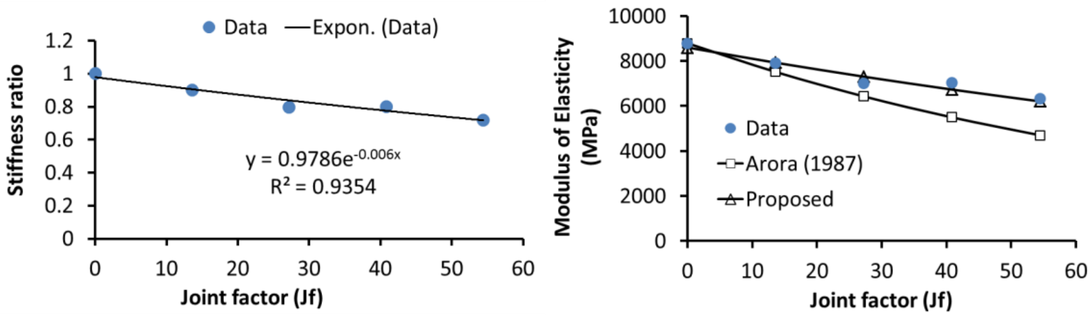

Figure 9: (left) correlation of stiffness ratio with joint factor; (right) modulus of elasticity versus joint factor (J_f)

4. Conclusion

The effect of horizontal smooth joints on the UCS and modulus of elasticity of sandstone rock samples was studied. The following conclusions can be drawn:

a. The study shows that as the number of horizontal joints increases, the strength and deformation modulus decreases except for the jointed sample of 3 joints.

b. It was concluded that the reduction of strength and stiffness ratio was about 20% from intact to 2 joints; this reduction increased to 30% when the number of joints was increased to 4, but there was an increased in stiffness and strength ratios when there were 4 joints.

c. The empirical equation overestimates the strength when the number of horizontal smooth joints increases to 2 whereas underestimates the strength when the number of joint is more than 2.

d. A new relation has been found to predict the modulus of elasticity for jointed rock mass with horizontal smooth joints.

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