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Study of Strength of Rock Having Joints of Different Strengths and Directions

Radwan, A.M.[1]*, Allam, M.H.[2], Mahmoud, M.A.[3] and EL-Sekhely E.H [4]

[1] Professor of soil Mechanics and foundation, civil dept., Fac. of engineering at Matria, Helwan Uni.

[2] Professor in mining dept., fac. of petroleum and mining engineering, Suez Uni.

[3] Associate professor of soil mechanics and foundation, civil dept., fac. of engineering at Matria, Helwan uni.

[4] Engineer at Holding company for water and waste water, Suez sector, Egypt.

الهدف من البحث هو معرفة مدى تأثير الفواصل ومدي انتشارها والمسافات بينها ومسطحها ومقاومتها على مقاومة الصخر ودراسة سلوك الصخر فى التطبيقات الهندسية المختلفة ومقارنة هذا السلوك بما تم التوصل إليه من قبل.
لذلك فقد تم الدراسه على عينات على شكل مكعبات محضرة معمليا بمونة الاسمنت و الجبس (مواد مشابهه للصخور) مع وضع فواصل من قصاصات الورق المقوي والصنفره لمحاكاة الفواصل ذات السطح الناعم والخشن الموجوده في الكتل الصخريه في الطبيعه وذلك بوضعها أثناء صب المكعبات علي طبقات وفي كل طبقه يتم وضع الفواصل لتحقيق الفواصل الغير مستمره بأطوال و مسافات بينية مختلفه ومن ثم اجراء الضغط احادي المحور ومقارنته بمقاومة الصخر السليم وايجاد علاقات بين المتغيرات ومقاومة الضغط لتلك المكعبات لمعرفة مدي تأثير انتشار الفواصل وميولها ومقاومة اسطحها علي الانهيار.

Abstract

Natural rocks are away from being continuous and they always formed of intact masses and discontinuities. Discontinuities are changes of the homogeneity of the rock mass formed due to the movement of mass by geological and tectonic events. The surfaces of such discontinuities can be smooth or rough; their intensity may differ. Most types of joints cause weakness in rock by different degrees. In this study a cube 15 cm side length of cement/gypsum (plaster of paris) which are used as a rock-like material including pre-existing multi non- persistent joints of different sizes, orientations (systematic or staggered) and surface roughness were tested. The effect of these joints on the cube strength was studied by analyzing the charts that shows relations between uniaxial compressive strength (UCS) of cubes and each variables to understand natural rock behavior before executing engineering projects in or on rock foundation.

Keywords: Pre-existing jointed rocks; Multi non persistent joints; Rock like material; Uniaxial compressive strength

1. Introduction

Joints are the most common and generally the most geotechnical significant structural features in rocks. Joints are fractures of geological origin and it is common that such discontinuities do not occur at completely random orientations: they occur with some degree of clustering around preferred orientations associated with the formation mechanisms [1]. Hence, it is sometimes convenient to consider the concept of a discontinuity set (which consists of parallel or sub-parallel discontinuities), and the number of such sets that characterize a particular rock mass geometry a group of parallel joints is called a joint set. Joints may be open, filled or healed [2]. They frequently form parallel to bedding planes, foliations or cleavage, when they may be termed bedding joints, foliation joints or cleavage joints respectively [3].

2. Experimental Work

2.1 Specimens Preparation and used materials

Rock - Like Materials, made from artificial materials such as portland cement, and gypsum were used to make ideal rock containing planar joints for investigation the effect of non-persistent joints in rock on stability of shallow foundations. The prepared blocks from rock like materials were classified sedimentary rock with moderate strength (26 MPa) and density (1.95 t/m^3). The cubic specimens with the side length 15cm of rock like material were prepared by the detachable iron molds. Non-persistent joints were produced by inserting multi cuts of emery paper and heavy paper during casting at a systematic and randomly manner into the fresh cement mortar paste at the desired location of the joints. The material used is a Portland cement and plaster of paris (gypsum) mortar. The reasons for choosing mortar were threefold: first, mortar is an ideal model rock with which a wide range of hard brittle rocks can be represented; second, any flaw patterns can be made easily and reproducibly in mortar specimens; third, it allows making a significant number of specimens in a reasonable period of time. The ratio between cement and gypsum is 9:1by weight [4]. The cement is used to increase the strength of the sample and improve the workability so as to be able to form the sample. On the other hand, gypsum is used to decrease the setting time. The water content at which maximum density is to be achieved is found by conducting number of trial tests with different percentage of distilled water. The optimum water content was found to be 40% by weight for specimens. A weight of approximately 5 kg of the dry cement and 500 gm of gypsum were put in the mixer tank (A mechanical dough mixer, Fig. (1), with a capacity of four liters) for about three minutes to form a homogeneous dry mix and then the material is poured in the casting molds. Then water was added to the mix and till getting the paste ready for pouring Joint are inserted during pouring. After 24 hrs., the specimens were removed from the mold and kept to be cured in room temperature for 7 days before testing [1].

Figure 1. Dough mixer used in specimens' preparation

2.2 Making Joints in Specimens

Before carry out the casting process and after many trials, two substances were chosen to represent the smooth surface and the rough surface which used for making joints in specimens by measuring their tilt angle. For getting rough surface it was used emery paper and for getting smooth surface it was used heavy sheet named Bristol paper which is ultra-smooth and weights 250gsm, fig. (2). The roughness of the surface of joints is determined by tilt test. The tilting test can be performed by placing a prepared rock specimen with an opened discontinuity carefully on a horizontal table designed to tilt. The upper table is slowly tilted until the upper slides over the lower portion of the specimen. The tilting angle at which sliding occurs is measured, this tilting angle can be considered equal to the angle of friction of the joint surface between the upper and lower portion of the specimen.

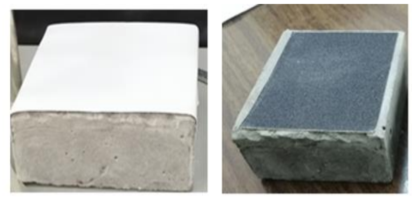


Figure 2. Joint block using rough and smooth sheets

2.3 Procedure of Tilt Test

Casting two joint blocks of size 70 mm x 70mm x 7mm; one for the smooth and one for the rough surfaces, also made of the same materials as shown in Fig. (2). The upper table is first aligned to the lower table. The protractor is adjusted so that the inclination angle of the upper table is 0◦ with the horizontal direction. Then putting each sample on the lower table and the pin rotates through the nail slowly at 10◦/minute as shown in Fig. (3). The test is repeated several times for each sample and the final sliding angle was taken as the average value for all the inclination angles. The tilt angle of the smooth surface is found to be 27° and for the rough surface is 43° [5].

Fig.3. Tilt test

2.4 Compression Testing of Rock Specimens

Unconfined compressive strength testing was performed on all extracted specimens (intact and jointed ones). Each specimen was placed between the two loading platforms in the servo-controlled uniaxial loading machine. The top and bottom boundaries were fixed in the horizontal direction. The specimens were loaded under compression till failure [6]. Fig. (4), shows the compression testing equipment during

Fig.4. UC test

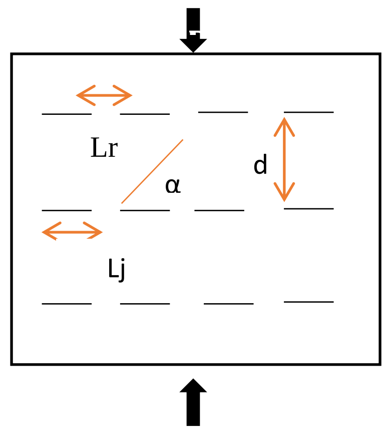
loading on a sample. The applied load at the point of failure was recorded. The load is divided by the bearing surface of the specimen which gives the uniaxial compressive strength of the specimen.

2.5 Test Parameters

The joint geometry was defined by five parameters: joint angle (β), spacing between planes (d), joint length (Lj), joint roughness and rock bridge length (Lr) ,fig. (5). As listed in Table (1), for each of the three parameters (a, b, c); three values are assigned except factor (c) is two values.

Table 1. Joint geometry paramters

parameters	a	b	c
d(cm)	3.75	7.5	-
Lj(cm)	1.5	2.5	3.5
Lr(cm)	1.37	2	2.5



Parameters description:

α: joint orientation with respect to $\sigma 1$

Lj: Joint length

Lr: Rock-bridge length

d: Spacing

Figure 5 Geometry of joints

Table2. Joint geometries of specimen series A

Series A	d (cm)	Lj (cm)	Lr (cm)	Series A	d (cm)	Lj(cm)	Lr(cm)
A1	3.75(a)	1.5(a)	1.37(a)	A10	7.5(b)	1.5(a)	1.37(a)
A2	3.75(a)	1.5(a)	2(b)	A11	7.5(b)	1.5(a)	2(b)
A3	3.75(a)	1.5(a)	2.5(c)	A12	7.5(b)	1.5(a)	2.5(c)
A4	3.75(a)	2.5(c)	1.37(a)	A13	7.5(b)	2.5(c)	1.37(a)
A5	3.75(a)	2.5(c)	2(b)	A14	7.5(b)	2.5(c)	2(b)
A6	3.75(a)	2.5(c)	2.5(c)	A15	7.5(b)	2.5(c)	2.5(c)
A7	3.75(a)	3.5(c)	1.37(a)	A16	7.5(b)	3.5(c)	1.37(a)
A8	3.75(a)	3.5(c)	2(b)	A17	7.5(b)	3.5(c)	2(b)
A9	3.75(a)	3.5(c)	2.5(c)	A18	7.5(b)	3.5(c)	2.5(c)

Two sets of tests were designed: series A and series B. Based on orthogonal experimental design for series A, series A contains 18 cubes to explore the influence of geometric factors on the strength of specimens Table (2). In each cube, only one geometric parameter changed among three factors (d, Lj, Lr), while the others remained constant. Therefore, we could determine the influence of every factor. Series A was executed four times to represent four cases of joints; i) smooth surface – $\alpha=0^{\circ}$, ii) smooth surface – $\alpha=90^{\circ}$, iii) rough surface – $\alpha=0^{\circ}$ and rough surface – $\alpha=90^{\circ}$. Series B

Table 3. Joint geometries of specimen series B

Series B	B1	B2	B3
Lj / cm	1.5	2.5	3.5

v)

also contains 3 cubes in order to study the influence of joint that randomly distributed on the strength of specimens Table (3) [7] [8]. Series B was executed twice to represent two cases; i) smooth joints and ii) roughly joints.

2.6 Joint Intensity

Intensity (joint surface area per unit volume of rock) of a multiset system of joints can be calculated from measurements of perpendicular spacing between adjacent joints in the same sets. Table 4 shows no. of joints calculated each series of A [9].

Table 4. Estimating the joint no. needed for specimens

Series A	Area of joint (Lj*Lj)	No. of joints	Total area of joints	Series A	Area of joint (Lj*Lj)	No. of joints	Total area of joints
A1	1.5*1.5	75	168.75	A10	1.5*1.5	50	112.5
A2	1.5*1.5	48	108	A11	1.5*1.5	32	72
A3	1.5*1.5	48	108	A12	1.5*1.5	32	72
A4	2.5*2.5	48	300	A13	2.5*2.5	32	200
A5	2.5*2.5	27	168.75	A14	2.5*2.5	18	112.5
A6	2.5*2.5	27	168.75	A15	2.5*2.5	18	112.5
A7	3.5*3.5	27	330.75	A16	3.5*3.5	18	220.5
A8	3.5*3.5	27	330.75	A17	3.5*3.5	18	220.5
A9	3.5*3.5	12	147	A18	3.5*3.5	8	168.75

Series B consist of three groups of different joint lengths. Series B was executed twice (a case for smooth surface of joint and another for rough surface) as shown in Table (3) with 3D random distribution in the mold during casting, Fig. (6) and table (5) show calculated no. of joints and ratio of joints per cubes.

Table 5. Estimating the joint no. needed for specimens

Series no.	Joint area (cm2)	No. of joints	Total area of joints	Joint area/volume of mass
B1	2.25	75	168.75	0.050
B2	6.25	48	300	0.089
B3	12.25	27	330.75	0.098

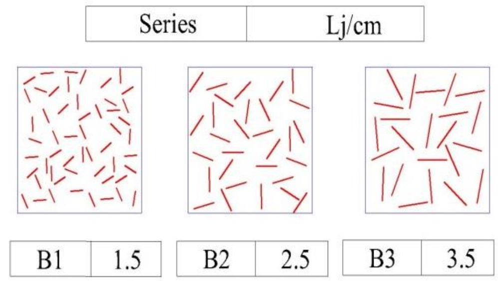


Fig.6. Joint geometry of specimens of series B

3. Results and Analysis

Before analyzing the influence due to the change in the parameters of the study, all the uniaxial compressive strengths of the jointed specimens are less than the intact mass specimen and the reason as we declaimed before is that joints weaken the specimens bearing capacity, as shown in fig. (7) to (9).

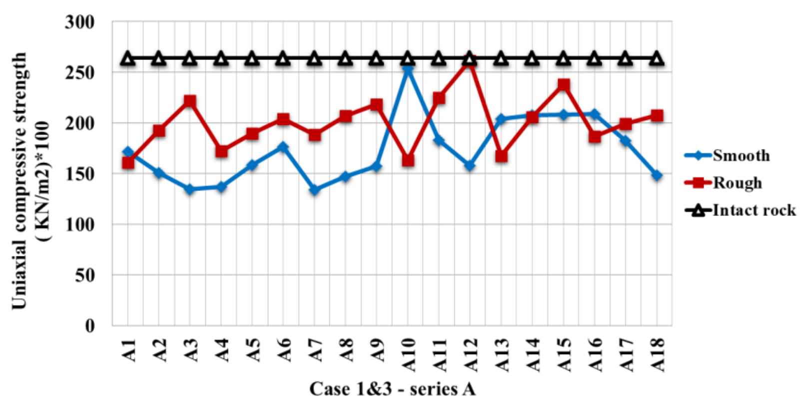


Fig.7. Strength comparison between intact rock case 1&3 – A series

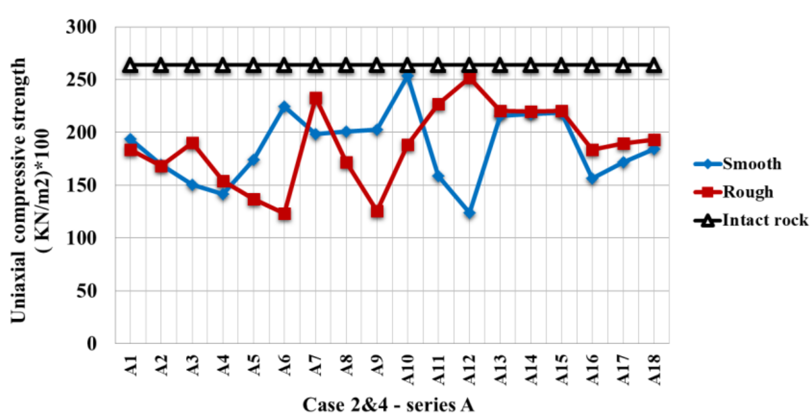


Fig.8. Strength comparison between intact rock case 2&4 – A series

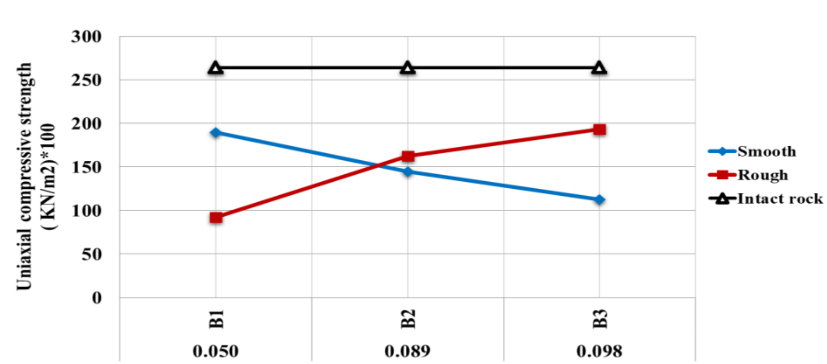


Fig.9. Strength comparison between between intact rock and case 1&2 - series B

3.1 The Influence of Total Area of Joints/ Volume of Cube on Series A

The point of analyzing the ratio is to study the obsession of joints' effect. Fig. (10) with fig. (11), show that when the ratio of total area of joints per cubic volume of specimen is increasing, the uniaxial compressive strength of that case (joints is horizontal oriented with rock bridge (Lr) = 1.37) is decreasing. This explained by the fact that increasing in spacing (rock length between levels of weakness (d)) leads to increasing in strength. In this study spacing varies from 3.5 to 7 cm, so there were three levels of joints (more levels of weakness) in cubes (A1, A4 and A7) then became two levels of joints (less level of weakness) in cubes (A10, A13 and A16), subsequently the obsession ratio of joints has decreased through varying from three planes to two planes of weakness.

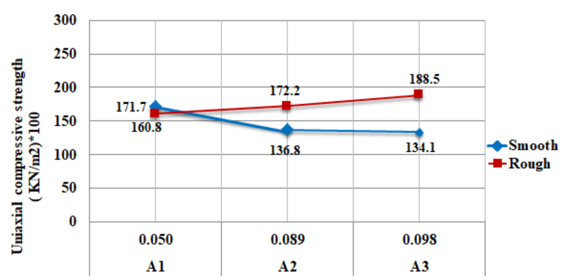


Fig.10. Analysis of horizontal 3 planes rock bridge (Lr) = 1.37

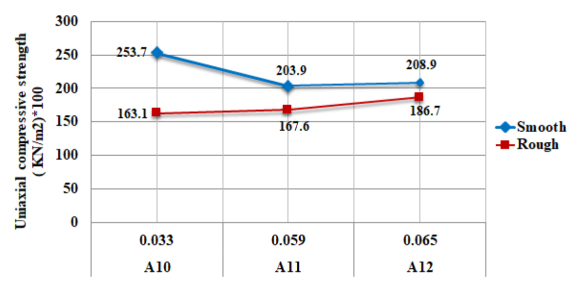
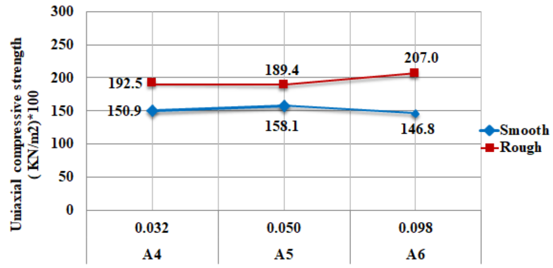


Fig.11. Analysis of horizontal 2 planes rock bridge (Lr) = 1.37

By observing the curves of the vertical oriented joints and random jointed cubes (series B), it is found that the same behavior applies to from figure (12) to figure (21). Therefore, the large obsession of joints, the less cube's strength.



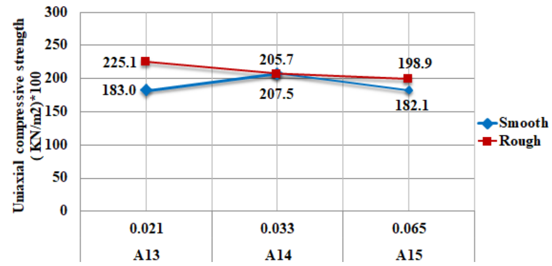
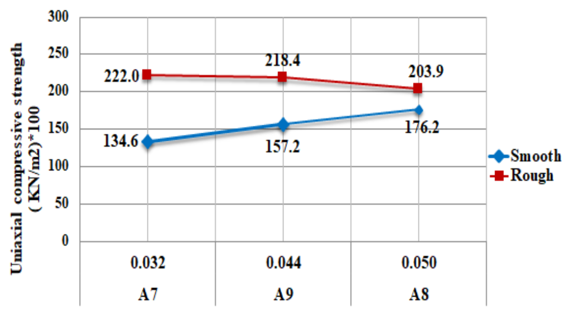


Fig.12. Analysis of horizontal 3 planes rock bridge (Lr)= 2

Fig.13. Analysis of horizontal 2 planes rock bridge (Lr)= 2



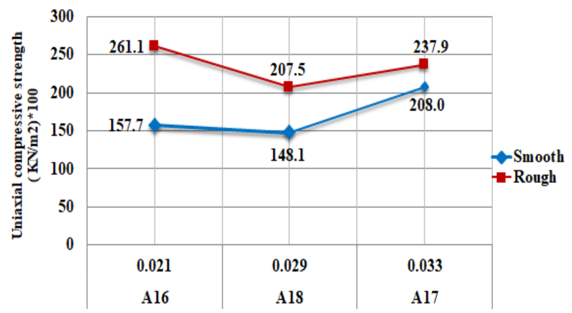
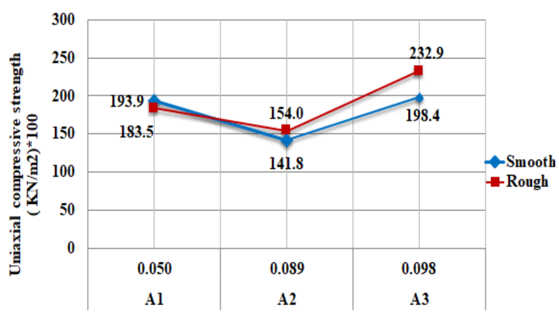


Fig.14. Analysis of horizontal 3 planes rock bridge (Lr) = 2.5

Fig.15. Analysis of horizontal 2 planes rock bridge (Lr) = 2.5



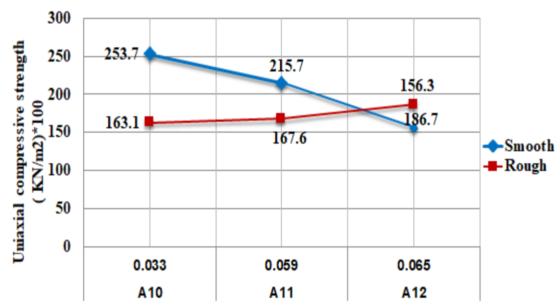
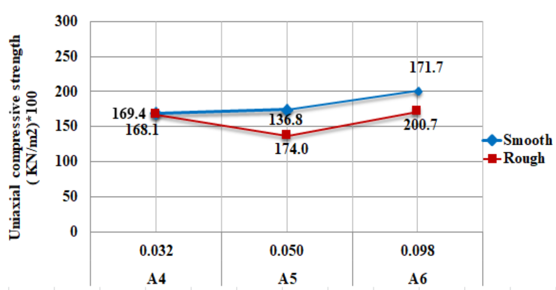


Fig.16. Analysis of vertical 3 planes bridge (Lr) = 1.37

Fig.17. Analysis of vertical 2 planes rock

rock bridge (Lr) = 1.37



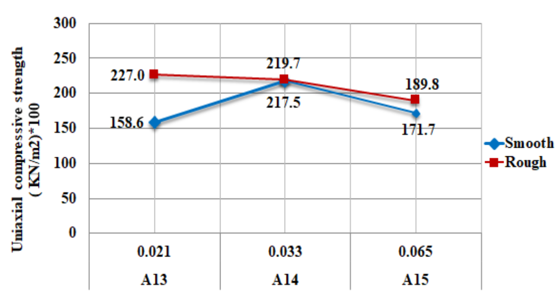
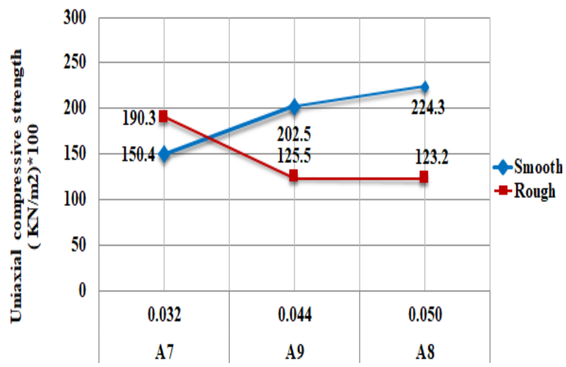


Fig.18. Analysis of vertical 3 planes bridge (Lr) = 2

Fig.19. Analysis of vertical 2 planes rock

rock bridge (Lr) = 2



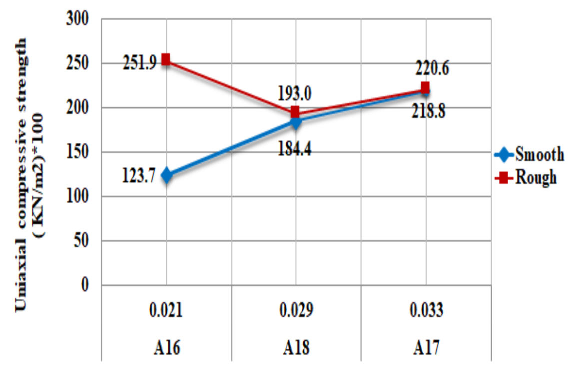


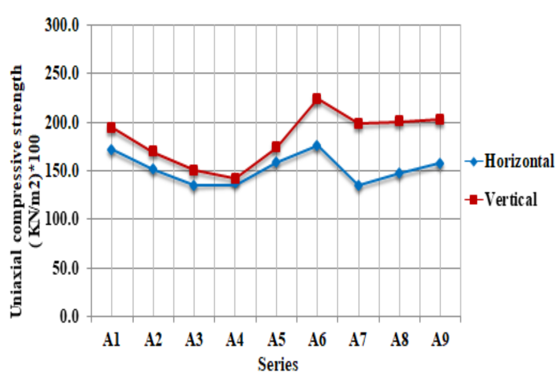
Fig.20. Analysis of vertical 3 planes **Fig.21. Analysis of vertical 2 planes** **rock**
bridge (Lr) = 2.5 **rock bridge (Lr) = 2.5**

3.2 The Influence of Total Area of Joints/ Volume of Cube on Series B

Fig. (9) shows that while the ratio is increasing in cubes of smooth surface joints, the uniaxial compressive strength is decreasing unlike cubes of rough surface joints, while the ratio is increasing as the UCS is increasing.

3.3 The Influence of Angle of Inclination of Joint

1- In case of joints with smooth surface as shown in Fig. (23), the presence of vertical oriented joints on three levels, gives uniaxial compressive strength results much higher than their presence in horizontal orientation and the variation percentage is calculated and illustrated in table 6(for the 1st nine cubes in smooth jointed surface case – 3 planes of weakness. The maximum UCS is obtained when orientation angle (β) = 90˚ as loading was mainly carried by rock matrix when it was loaded parallel with pre-existing joints and thus these joints have the least influences.



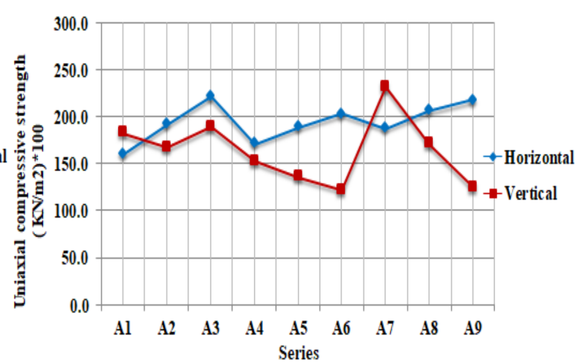


Fig.22. Influence of orientation **Fig. 23. Influence of orientation** **rock**
(smooth surface - 3 planes) **(rough surface - 3 planes)**

Table 6. Strengths variation of smooth surface - 3 planes

Test No	ΔUCS (uniaxial compressive strength) (0° - 90°)	Result comment	variation %
S1	-22.20	UCS 0 < UCS 90	12.9%
S2	-18.58	UCS 0 < UCS 90	12.3%
S3	-15.86	UCS 0 < UCS 90	11.7%
S4	-4.98	UCS 0 < UCS 90	3.6%
S5	-15.86	UCS 0 < UCS 90	10.0%
S6	-48.02	UCS 0 < UCS 90	27.2%
S7	-64.33	UCS 0 < UCS 90	47.9%
S8	-53.91	UCS 0 < UCS 90	36.7%
S9	-45.31	UCS 0 < UCS 90	28.8%

2- In case of joints with rough surface as shown Fig. (23), it is noted that in the case of the presence of horizontal oriented joints on three levels, gives uniaxial compressive strength results much higher than their presence in a vertical orientation and the variation percentage is calculated and illustrated in table 7 for the 1st nine cubes in rough jointed surface case – 3 planes of weakness. .

3- In case the joints are distributed in two levels (rough and smooth-2p) as shown in fig. (24&25), the resulting uniaxial compressive will have an advantage in the case of the horizontal orientation The variation percentage is calculated and illustrated in table 8 and table 9 for the 2nd nine cubes in rough and smooth jointed surface case – 2 planes of weakness..

Table 7. Strengths variation of rough surface - 3 planes

Test No	ΔUCS (uniaxial compressive strength) (0° - 90°)	Result comment	variation %
S1	-22.65	UCS 0 < UCS 90	14.08%
S2	24.46	UCS 0 > UCS 90	14.56%
S3	31.71	UCS 0 > UCS 90	16.67%
S4	18.12	UCS 0 > UCS 90	11.76%

S5	52.55	UCS 0 > UCS 90	38.41%
S6	80.64	UCS 0 > UCS 90	65.44%
S7	-44.40	UCS 0 < UCS 90	23.56%
S8	35.34	UCS 0 > UCS 90	20.58%
S9	92.88	UCS 0 > UCS 90	74.01%

Table 8. Strengths variation of smooth surface - 2 planes

Test No	ΔUCS (uniaxial compressive strength) (0° - 90°)	Result comment	variation %
S10	0.00	UCS 0 < UCS 90	0.0%
S11	24.46	UCS 0 > UCS 90	15.4%
S12	33.98	UCS 0 > UCS 90	27.5%
S13	-11.78	UCS 0 < UCS 90	5.8%
S14	-7.70	UCS 0 < UCS 90	3.7%
S15	-10.87	UCS 0 < UCS 90	5.2%
S16	52.55	UCS 0 > UCS 90	33.6%
S17	10.42	UCS 0 > UCS 90	6.1%
S18	-36.24	UCS 0 < UCS 90	24.5%

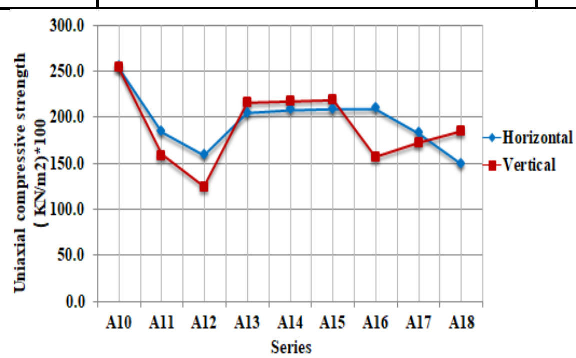


Fig.24. Influence of orientation rock(smooth surface - 2 planes)

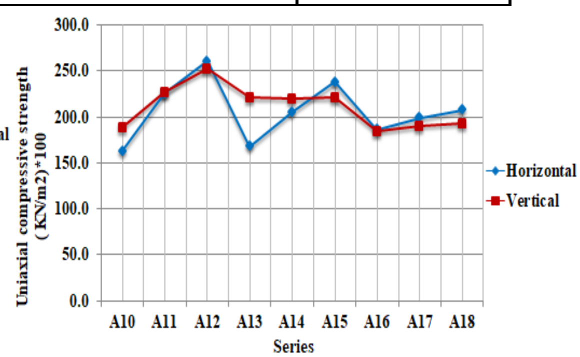


Fig.25. Influence of orientation (rough surface - 2 planes)

Table 9. Strengths variation of rough surface - 2 planes

Test No	ΔUCS (uniaxial compressive strength) (0° - 90°)	Result comment	variation %
S10	-25.37	UCS 0 < UCS 90	15.56%
S11	-1.90	UCS 0 < UCS 90	0.85%
S12	9.19	UCS 0 > UCS 90	3.65%
S13	-53.01	UCS 0 < UCS 90	31.62%
S14	-14.04	UCS 0 < UCS 90	6.83%
S15	17.22	UCS 0 > UCS 90	7.80%
S16	3.17	UCS 0 > UCS 90	1.73%
S17	9.06	UCS 0 > UCS 90	4.77%
S18	14.50	UCS 0 > UCS 90	7.51%

3.4 The Influence of Roughness of Joint Surface

By observing the results, it turns out that:

1. The rough surface of the joints has a significant and higher effect on uniaxial compressive strength than the smooth surface.

2. The case of horizontal oriented joints (0°- 2 planes), was noted that the smooth surface of joints gives better results than the rough surface in case of the use of small areas (S10, S13 and S16) of joints (Lj = 1.5cm) however, if we checked the path of Fig. (28), each group of a specific area with changeable rock bridge length (Lr) we'll find that UCS of cubes of roughed surface is getting high with a decrement in the strength of the cubes of smoothed joints.

3. In the case of vertical orientation fig. (29&30), the smooth surface of the joints gives better results than the rough surface of the joints if the joints are used on three levels.

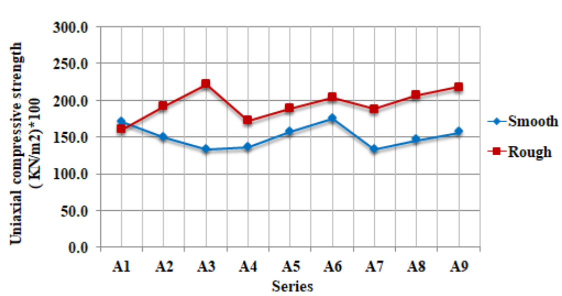


Figure 27. Influence of roughness rock (horizontal surface - 3 planes)

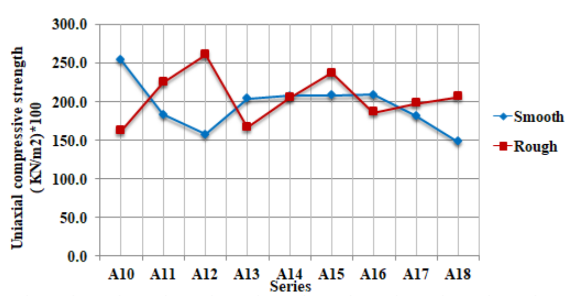


Figure 28. Influence of orientation (horizontal surface - 2 planes)

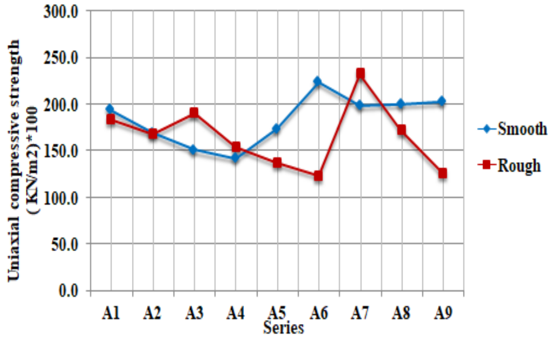


Figure 29. Influence of roughness (vertical angle - 3 planes)

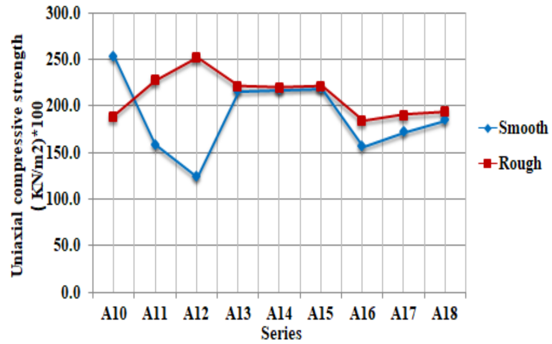


Figure 30. Influence of roughness (vertical angle - 2 planes)

5.2 Conclusion

1. The uniaxial compressive strength of jointed rocks increase and decrease according to distribution, size and surface roughness of joints in different degrees compared with intact specimens:

(a) The strength of discontinuities is significantly smaller than that of the intact rock.

(b) The influence of joint roughness has declared that roughly surface gives higher UCS values than joints with smoothed surface.

(c) The influence of joint orientation is that maximum UCS is obtained when orientation angle (β) = 90° and the minimum UCS when orientation angle is (β) = 0° in case of three planes of smoothed joint surface (smooth – 3p) and maximum UCS is obtained when orientation angle (β) = 0° and the minimum UCS when orientation angle is (β) = 90° in case of three planes and two planes of roughly joint surface (rough – 3p) and (rough – 2p).

(b) According to the influence of ratio of joint area / volume in all cases of joints (rough, smooth in vertical and horizontal condition), the increasing in ratio leads to decreasing in cubes strength.

2- The results show that the joint roughness has the greatest influences on UCS followed by joint orientation followed by spacing between levels of weakness.

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