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Study on anchorage effect on fractured rock

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Abstract. The effects of anchor on fractured specimens in splitting test are simulated by DDARF method, the results of which are compared with laboratory test results. They agree well with each other. The paper contents also use the laboratory model test. The main research objects are three kinds of specimens, namely intact specimens, jointed specimens and anchored-jointed specimens. The results showed that with the joint angle increased, the weakening effects of jointed rock mass are more obvious. At these points, the rock bolts' strengthening effects on the specimens have become more significant. There is a significant impact on the failure modes of rock mass by the joint and the anchorage.

Keywords: crack propagation; discontinuous deformation analysis for rock failure; jointed rock mass; random joints; anchored-fractured specimen; anchored rock mass; laboratory experiment

1. Introduction

The nature of the rock material is very complex because of its special formation process (Zhou *et al*. 2009). Generally, due to complicated geological processes, the structural features and mechanical properties of rock mass is complex with the structural planes of different sizes and the diverse nature inside (Li 2012). The mechanical properties of joints play a predominant role in determining its global stability (Lin and Lee 2009). Consequently, it has been a hot topic in the fields of geology and rock engineering fields. Although the processes and patterns of crack initiation, propagation and coalescence have been widely studied, the failure mechanism and the anchored effect of fracture rock mass are not understood yet. The effects of the initiation, propagation and evolution process of primary cracks, and the failure modes on the rock stability have become one of the hot research topics (Ma 2013). In this paper, a new DDARF (Jiao *et al*. 2010) method considering crack propagation, which is developed by Jiao *et al*. (2010) on the basis

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of the DDA method (Shi 1993), was employed to investigate the crack propagation, and the deformation and strength of rock mass. Underground cavern stability was also presented in this study using above mentioned results. In this thesis, some characteristics of fractured rock masses were studied on the basis of the modified discontinuous deformation analysis (DDA) method. Crack propagation patterns and stress-strain curves can also be obtained from the numerical simulation. Moreover, correlation data analysis and laboratory test verification were applied to investigate and verify the aforementioned cases. The rock bolt element and material lines of DDA were applied to simulate the anchored effect of several types of specimens subjected to compressive stress (Li and Cao 2012). Four kinds of specimens, including intact specimens, fractured specimens with one crack, fractured specimens anchored perpendicular to the crack and fractured specimens anchored perpendicular to the pressure, were carried out to simulate anchorage effect on mechanical properties of fractured specimens. The simulation results of four kinds of specimens were in good agreement with the laboratory test results.

Compared with intact specimen, jointed specimen is a specimen with three prefabricated joints with different certain angles, and anchored-jointed specimen is a specimen with resolvable anchor holes joints and bolt which is anchored to the anchor holes after the specimen reaches a certain strength. The joints were prefabricated with 3 angles (the angle between joints and the horizontal plane) of 30 degree, 45 degree, 60 degree. Uniaxial compression tests of three types of specimens were carried out to assess the uniaxial compressive strengths and splitting tensile strengths. The weakening effects of joints and the strengthening effects of rock bolts on the mechanical properties of specimens were also be analyzed using the uniaxial compression tests.

2. Simulation of anchorage effect of rock bolt on fractured specimens under splitting test

It is an important research about how to anchor fracture rock mass in order to improve its strength. Zhang (2009) has done some reaches about anchored-fractured specimen's strength and crack propagation process in splitting test. In this paper, according to the splitting test of Zhang (2009), a new research was done using DDARF program. A model with the same dimensions as those of the splitting test was built. The same displacement load was applied along the vertical direction of the model. To investigate the influence of anchorage angles on rock behavior, the anchorage angles (the acute angle between the direction of anchor and fissure plane) were designed as 30°, 45°, 70° and 85°, respectively.

The axial load-displacement curves of the different anchored-fractured specimens were obtained using the program of DDARF (Zheng 2010) as shown in Fig. 1. The curves do not appear the residual strength as the numerical simulation cannot simulate the slide of rock bolts, which cannot simulate the slide of rock bolts. The peak strengths of axial load-displacement curves are showed in Table.1. It can be concluded that the peak strength decreases with increasing angle. The failure process was analyzed using a scheme of anchored-fractured specimen with anchor angle of 45°, as shown in Fig. 2.

The process of crack propagation can be sumarized as follows: (1) the initial wing cracks appear firstly at two ends of the original fractures; (2) the wing cracks extend gradually along the axial direction as the loading increases; (3) a number of secondary cracks appear and expand toward two adjacent sides of the model; (4) more and more secondary cracks form the region of destruction, which cause the rock destruction.

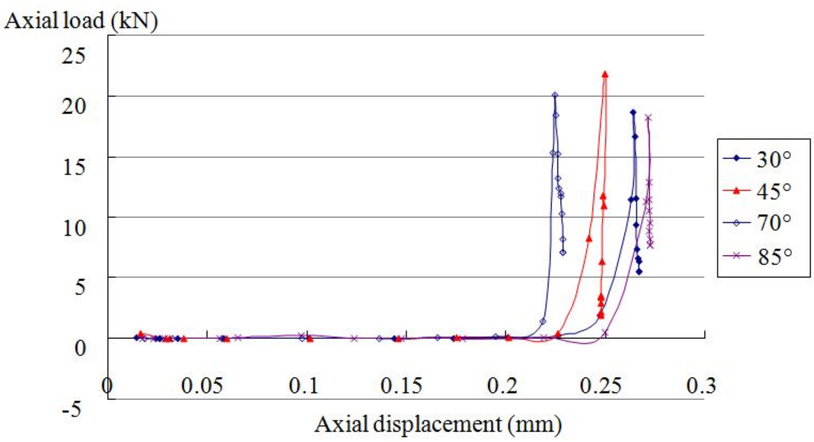

Fig. 1 Axial load-displacement curve

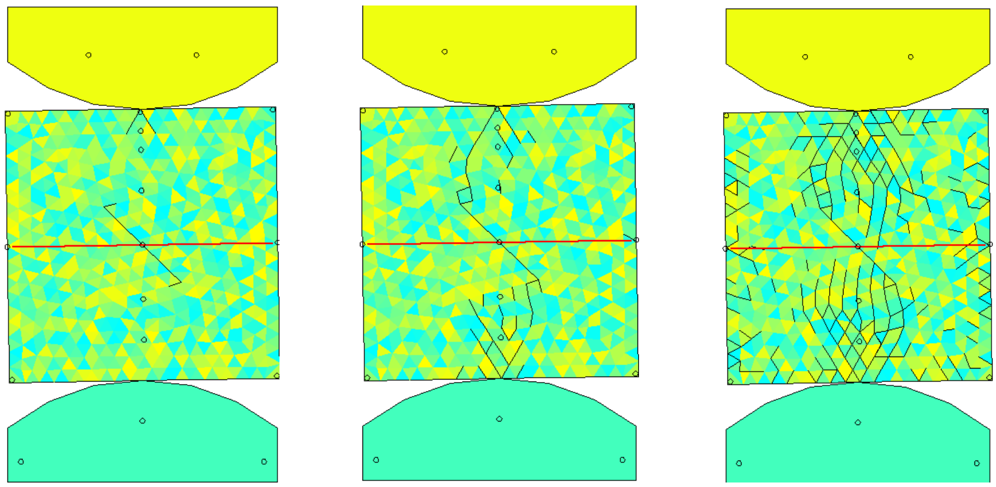

Fig. 2 Crack propagation process

In the splitting tests of Zhang (2009), the axial load-displacement curve and the process of crack propagation are obtained, as shown in Figs. 3-4. The peak strengths are listed in Table. 1. The process of crack propagation shows that the cracks increase with increasing axial load. The specimen was completely broken as a result of the slippage of the bonding interface of the rock bolt and the mortar. Moreover, the similar process of destruction of the specimen can be seen in the numerical simulation of DDARF program.

The results of numerical simulation obtained from DDARF program were compared with the existing splitting test results. The comparison of the peak strenghes of axial load-displacement carves are shown in Table. 1. Note that the relative difference value amplitude is in the range of 1%~10%. Generally, there is a good agreement between simulation results and test reulsts. The laws of the crack propagation of the numerical simulation are consistent with the phenomena observed in the splitting tests, as shown in Figs. 2 and 4.

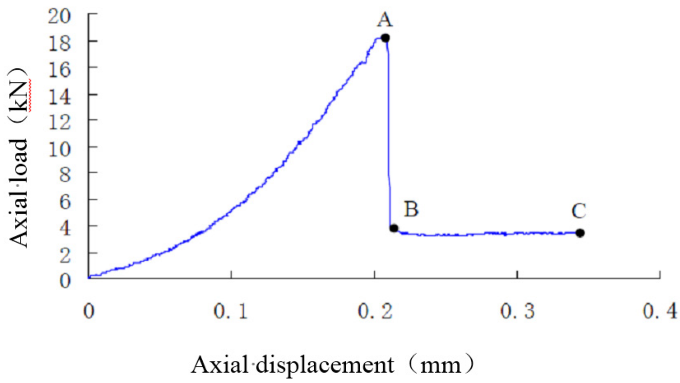

Fig. 3 Axial load-displacement curve in splitting test

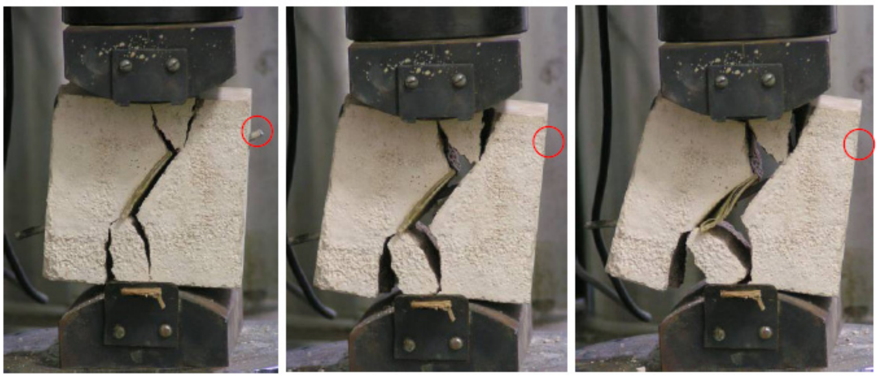

Fig. 4 Crack propagation process in splitting test

Table 1 Peak strength of the anchor specimens (kN)

Anchor angle condition	30°	45°	70°	85°
Test results	20.1	20.23	19.82	19.41
Simulation results	18.69	21.87	20.06	18.21
Relative difference value (%)	7.01	8.11	1.21	6.18

3. Main contents and research methods of laboratory experiment

According to certain geometrical and physical relationship, model test can be used to simulate the prototype of testing research. The proportion relationship of real and model in physical mechanical parameters is adopted as 5:1 in this experiment, such as cenment mortar and anchor bolts material. The geometric dimension relationship of materials was also required.

3.1 Test objectives and programs

The special mortar formula was used as the specimen raw material in this study. The specimens

Fig. 5 Experimental raw material

were made in different mix proportions and tested using the Servo Press of Shandong University to capture the uniaxial compressive strength and splitting tensile strength of the specimens. The mix proportion which suits the similar ratio best was selected to make three types specimens. These three types specimens were tested to obtain the uniaxial compressive strength and splitting tensile strength. Based on the test results, the weakening effect of joints and the strengthening effect of rock bolts on the mechanical properties of specimens were assessed.

3.2 Raw material

This experiment use white Portland cement, quartz sand, water reducing accelerator and water to make the fine concrete (Fig. 5).

(1) Cement: The whiteness of the white Portland cement was adopted as 87, and the labeling of the white Portland cement was taken as 325. The main chemical components are listed in Table 2.

(2) Sand: The main chemical components of quartz sand are shown in Table 3.

(3) Additive: Water reducing accelerator was adopted as an additive in this study.

(4) Water

3.3 Mortar's mix-proportion design and mechanical-Parameter test

In the expriment, the similar materia and the real rock should be in the relationship of 5:1. To

Table 2 White Portland cement's main chemical components

Material	Chemical components (weight percent)					
	CaO	SiO2	Al2O3	Fe2O3	MgO	SO3
White Portland cement	65.59	25.2	4.2	0.18	2.39	2.44

Table 3 Quartz sand's chemical components

Material	Chemical components (weight percent)			
	SiO_2	Al_2O_3	Fe_2O_3	other
Quartz sand	97.9	0.5	1.5	0.1

achieve this requirement, many specimens with different mix proportions were made. The mechanical parameters were obtained from the uniaxial compression test and split test (see Figs. 6-7). To be simplified, a few of the mechanical parameters are listed in Table 4.

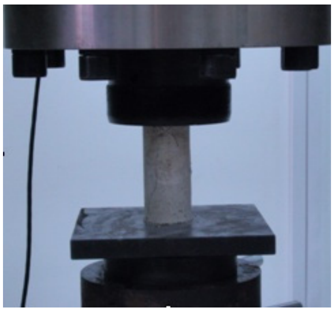

Fig. 6 Uniaxial compression test

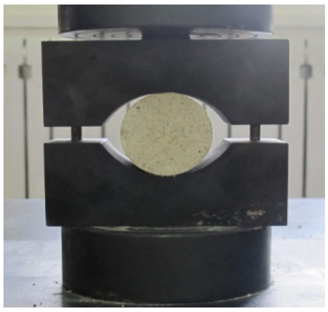

Fig. 7 Split test

Table 4 Mechanical parameters of different mix proportions

Numbering	Mix proportions (cement : water : sand : accelerator)	Specimen's number	Compressive strength/ tensile strength (MPa) / elastic modulus (GPa)	Remarks
1	1 : 0.45 : 2.73 : 0.03	3	22.18 / 2.4 / 8	Plus
2	1 : 0.5 : 3.25 : 0.03	3	16.8 / 1.8 / 4.5	
3	1 : 0.55 : 3.6 : 0.03	3	12.7 / 1.4 / 4.2	
4	1 : 0.6 : 3.9 : 0.03	3	9.1 / 1.1 / 3.5	

Table 5 Mechanical parameters of real rock

Real rock	Compressive strength (MPa)	Elastic modulus (GPa)	Tensile strength (MPa)
	92	20	11

Fig. 8 Duralumin robust

Table 6 Physical and mechanical parameters of duralumin robust

Anchor material	Tensile strength(MPa)	Diameter(mm)	Elastic modulus(GPa)	Shear modulus(GPa)
Real anchor	510	16	210	80
Duralumin robust	120	3	50	18

Fig. 9 PVC

Fig. 10 Anchor solidifying agent resin

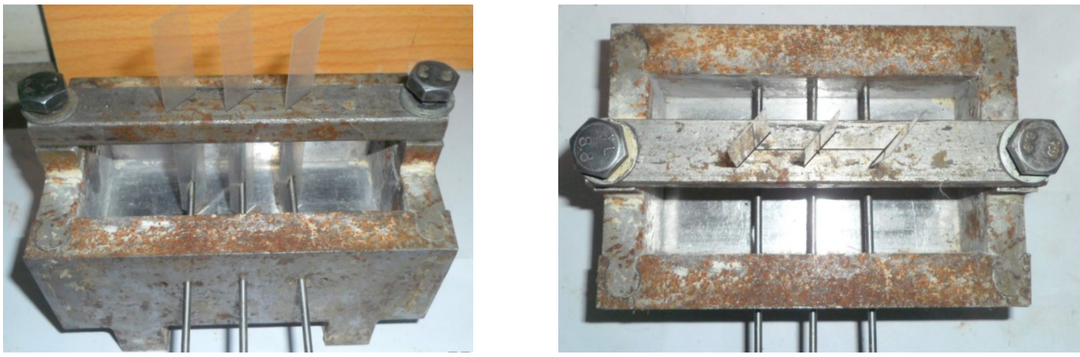

Fig. 11 Module of anchor and joint

Based on the mechanical parameters of the real rock shown in Table 5, the mix proportion of cement, water, sand and accelerator was adopted as 1: 0.5: 3.25: 0.03.

3.4 Similar rock bolt

Duralumin robust was used to simulate the anchor (see Fig. 8). The physical and mechanical parameters are listed in Table 6.

3.5 Preset jointed

The PVC was used to preset opening through joint with the thickness of 0.5 mm, the length of 6 cm and the width of 1.5 cm (see Fig. 9).

3.6 Anchoring type

The thin section of PVC was fixed in the module to simulate rock mass with penetrative cracks. Three types of specimens with the cracks of 30°, 45° and 60° were made using the module of joint and anchor (see Fig. 11). These specimens were tested to capture the uniaxial compressive strength and splitting tensile strength.

3.7 Experimental results and analysis

Rock bolt's anchorage effect upon fractured specimen under uniaxial compression.

It can be seen from Figs. 12-14 that the anchor can improve the bearing behavior of the rock mass, and the compressive strength and ductility of the anchored specimen significantly increase.

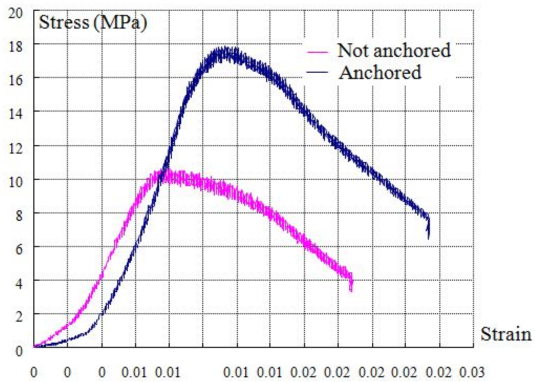

Fig. 12 Stress-strain diagram of 30° joint specimens with anchored or not

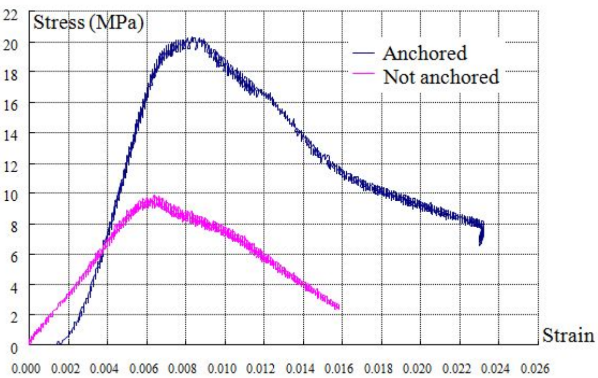

Fig. 13 Stress-strain diagram of 45° joint specimens with anchored or not

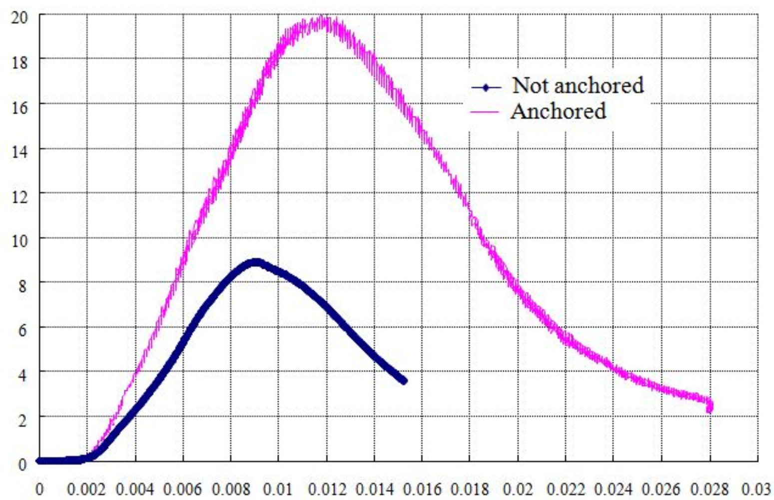

Fig. 14 Stress-strain diagram of 60° joint specimens with anchored or not

Table 7 Strength test results of three degrees with anchored or not

Specimens types		Maximum stress (MPa)	Peak strain (%)	Percentage of strength increasing with anchored
30°	not	10.64	0.8	67.9%
	anchored	17.87	1.2	
45°	not	9.88	0.6	105%
	anchored	20.3	0.8	
60°	not	8.91	0.9	123.9%
	anchored	19.95	1.2	

(a) (b) (c)

Fig. 15 45°anchored specimen's failure mode

(a) (b) (c)

Fig. 16 60°anchored specimen's failure mode

3.8 Failure models of anchored-fractured specimen under uniaxial compression

The failure models of different specimen with the cracks of 45° and 60° are shown in Figs. 15 and 16, respectively.

In the failure mod of the anchored specimen, the wing cracks initially appear at the tips of the primary cracks. The new cracks then extend towards the loading direction and gradually develop to the end of another primary crack. Subsequently, the local failure occurs under large loading level. The cracks coalesce through the specimen and the global failure occurs. However, the anchored specimens with the cracks of 60° have some different from the anchored specimens with the cracks of 45°. The wing cracks of the anchored specimens with the cracks of 60° don't initially appear at the tips of the primary cracks. It can be concluded that the anchor have inhibitory effect on the extension of the tips of the primary cricks.

4. Conclusions

Based on the numerical simulation results and the experiment results, the following conclusions are obtained:

(1) The results of DDARF programs are compared with the existing splitting test results. The peak strengths of the load-displacement curves show a favorable agreement, and the laws of the crack propagation are in accordance with the phenomena observed in the tests.

(2) In the similar simulation test, the physical and mechanical parameters of the similar material and the real rock should be in the similar ratio, the selection of the similar rock bolt should be based on the similar ratio. The similar ratio of this paper is 1:5, the similar material and the similar rock bolt meet the requirements of the test.

(3) In the failure mod of the anchored specimen, the wing cracks initially appear at the tips of the primary cracks. The new cracks then extend towards the loading direction and gradually develop to the end of another primary crack. Subsequently, the local failure occurs under large loading level. The cracks coalesce through the specimen and the global failure occurs.

(4) The wing cracks of the anchored specimens with the cracks of 60° don't initially appear at the tips of the primary cracks. It can be concluded that the anchor have inhibitory effect on the extension of the tips of the primary cricks.

Acknowledgments

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