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Numerical Simulation Research on the Stress Response of the Bent Rockbolt with the Shear Displacement of Rock Mass

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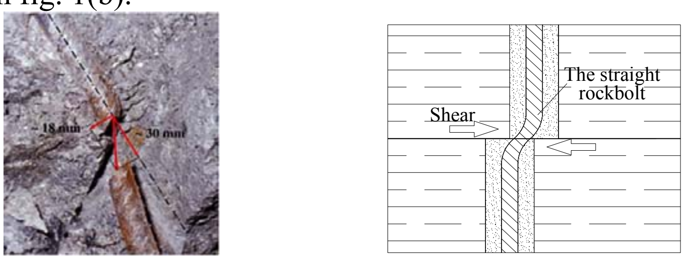
Abstract. More and more attentions have been paid to the problem of the shear failure in the conventional straight rockbolt support for underground excavations. Different bolting innovations have been tried over the years. The bent rockbolt with promise is a new mean of rock support. Through numerical simulation software, the shear characteristics of the bent rockbolt is analyzed. Three-dimensional numerical models of the bent rockbolt and the straight rockbolt are established. both of which are subjected to a shear displacement of rock mass. Their stress and deformation characteristics results show that stress concentration easily occurs at the intersection point of anchored portion and non-anchored portion along the bolt. In the case of the mises equivalent stress, the bent rockbolt has a smaller one than the straight rockbolt under the same shear displacement of rock mass. So the bent rockbolt is not easy to be damaged and can better adapte to the shear damage of rock mass.

Introduction

It is widely accepted that joints in rock mass can affect the safety and stability of underground excavations including mining, tunneling, and other type of engineered caverns[1]. The rockbolt plays a key role in the mechanical properties, deformation characteristics and instability modes of rock mass support[2]. For instance, the shear test showed that the anchored surrounding rock mass obviously had tensile, shear and compression zone along the tunnel radius[3]. According to the rock-like simulation test, the shear deformation occurred in the middle of the rockbolt due to interlayer shear dislocation in the roof of deep surrounding rock[4]. In addition, in the investigation of hard brittle rock mass support, it was found that the failure of anchored rock mass was caused by the combined action of tensile and shear force. When the bolt had a small transverse deformation, The bolt would snap before it achieved the best support effect in the axial deformation[5], shown in fig.1(a).The maximum horizontal stress theory partly explained the shear failure of bolt[6]. Under the maximum horizontal stress, the roof and floor of the tunnel easily suffered shear load, the rockbolt is used to control the shear movement of rock mass in the direction perpendicular to the axialdirection, shown in fig. 1(b).



(a) (b)

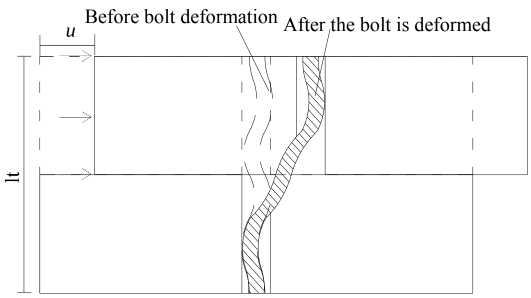
Figure 1. Shear failure of the straight rockbolt in rock mass and its reason[5,6]

Ludvig believed that the reinforcement capacity of the rockbolt is determined by its maximum radial deformation capacity and shear strength, the former depends on the direction of the rockbolt relative to the shear plane, and the latter depends on the strength parameters of the rockbolt[7]. Bjurstrom has systematically studied the shear behavior of granite under full-length anchorage. It is pointed out that the tangential shear resistance of rockbolt can significantly improve the stability of rock mass[8]. Similarily, through laboratory experiment and theoretical analysis, it was emphatically discussed the influence of rockbolt on shear performance and the mechanism of rockbolt to prevent relative dislocation of rock mass[9]. The results show that the shear strength of anchored rock mass increases with the enhancement of shear deformation of rockbolt, even if the shear deformation is small, its shear function can be fully exerted.

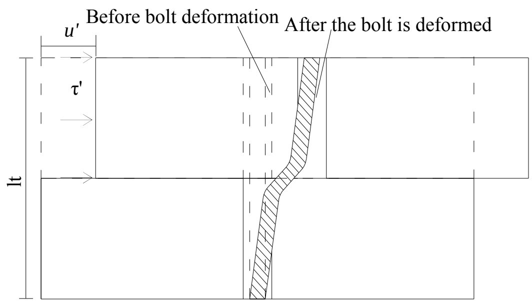
At present, some scholars have carried out experiments on new types of rockbolt to research the promoted influence of the anchoring performance of rock mass[2]. The bent extensible bolt is a promising one made of the rebar, the bent section of which can be straightened due to the deformation of rock mass, providing resistance and deformation for the rock[6]. For instance, the D-bolt was invented to solve the shear failure of the straight bolt in rock mass by using the bent section. Laboratory tests showed that compared with the straight bolt, the shear strength of the D-bolt was unchanged, but the shear deformation increases by 42.6%. The application of D-bolt in Swedish metal mines has more stable supporting effect than the straight bolt[5]. In addition, the static and dynamic combined rockbolt (SD rockbolt) was anther new one, invented not only to maintain high bearing capacity but continuous yielding and deformation capacity. The SD rockbolt was applied to Kaiyang phosphate mine in Guizhou, the deformation of surrounding rock of deep roadway is effectively controlled[10]. The engineering applications have proved that the bent rockbolt is expected to become a new method of rock mass support. The stress of the bent rockbolt and the straight rockbolt caused by the shear displacement of rock mass is analyzed by numerical simulation in this paper, and the advantages of the bent rockbolt in resisting shear displacement of rock mass are verified by numerical simulation

Determination of Parameters and Establishment of Model

The test data show that when rock mass is subjected to shear failure, the straight rockbolt will be subjected to shear stress under the compression of rock mass, tangential deformation of the rockbolt occurs, which is macroscopically manifested as " S" type deformation near the fracture surface of rock mass[2]. Fig. 2 is the diagram which shows the shear deformation of rock mass under “τ” when supported by the bent rockbolt and the straight rockbolt. “Lt” is the effective length for shear deformation of the bolt, u and u' are shear deformations of rock mass.



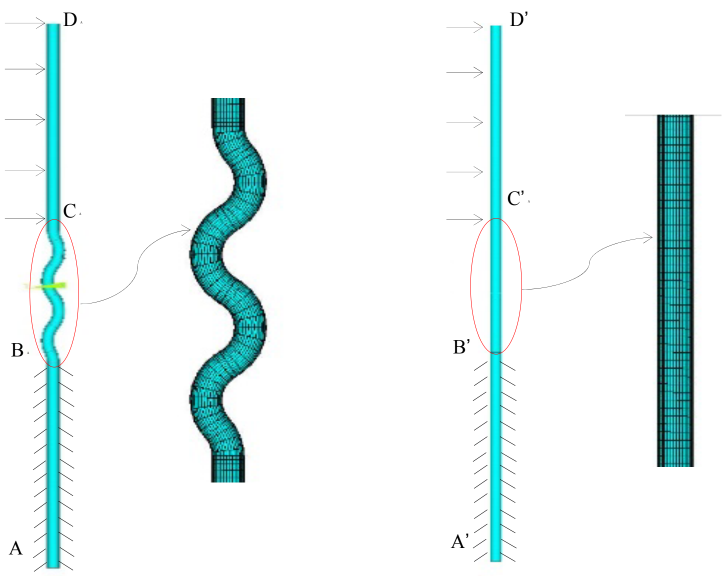
(a)The bent rockbolt



(b) The straight rockbolt

Figure 2. Deformation of rockbolt caused by the shear displacement of rock mass

In this paper, the bent rockbolt and the straight rockbolt are compared and analyzed, and the models established by numerical analysis soft have the same anchor method. All bolts are made of steel material, their diameter are 18mm and their length are 900mm with the elastic modulus E=210Gpa, the poisson's ratio $\mu = 0.3$, and the density ρ=7960 kg/m^3. Besides, the weight of the bolt material is ignored. In the numerical analysis model, the bent rockbolt is divided into 27404 finite elements, the straight rockbolt 24798 finite elements which are Solid65 type. The analysis models of the bent rockbolt and the straight rockbolt are shown in fig.3. AB section and A'B' section of the bolt models are restrained respectively. The BC section and the B'C' section of the models are denoted by “lt” in fig 2, and it is the effective lengths of shear deformation occurring on the rockbolt. The CD section and C'D' section of the models suffer the shear deformation loads which are expressed by *u* and *u’* are also shown in fig 2 respectively.



(a) The bent rockbolt (b) The straight rockbolt

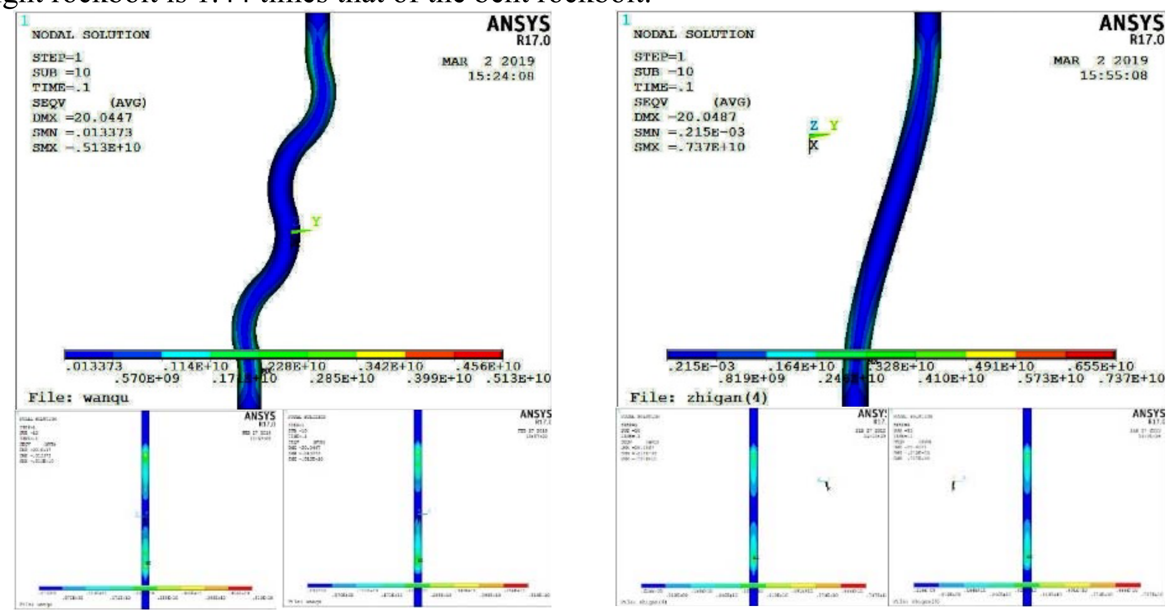
Figure 3. Numerical models of both kinds of rockbolts

Simulation Results and Analysis of Bolt Stress

Mises Equivalent Stress of the Bolt Model

The breakage of the rockbolt observed by Li Chunlin[5] when it undergoes 18mm shear deformation is analyzed in this paper. So the value of *u* and *u'* in fig. 2 equal 20 mm. The mechanical analysis of the three-dimensional models under the shear deformation of 20mm show the Mises equivalent stress distribution of the bolt as shown in fig. 4.

The shear deformation of rock mass is shown in fig.4 which is 20mm, the mechanical characteristic of the bent rockbolt near the fracture surface is similar to those of the straight bolt. Stress concentration occurs at the intersection point of anchored portion and non-anchored portion along the bolt, and the stress at the crack position is small. Compared with the maximum Mises equivalent stress of the bent rockbolt and the straight rockbolt, the maximum value of the former is 5.13Gpa, the maximum value of the latter is 7.37 Gpa, and the Mises equivalent stress of the straight rockbolt is 1.44 times that of the bent rockbolt.



(a) The bent rockbolt (b) The straight rockbolt

Figure 4. Mises equivalent stress nephogram of the rockbolt

Stress Analysis of Bolt under Shear Displacement

The shear dispalcement of rock mass supported by the bent rockbolt and the straight rockbolt are 10mm, 20mm, 30mm, 40mm and 50mm respectively. Through the numerical simulation analysis, the Mises equivalent stress curves of the bent rockbolt and the straight rockbolt under different shear deformation conditions are respectively obtained as shown in fig.5.

As can be seen from fig.5, compared with the straight rockbolt, the bent rockbolt has smaller shear modulus. The bent rockbolt can minish the supporting stress by reducing the shear modulus of rock, and dissipate the strain energy accumulated in the rock body by reducing the stress concentration degree. This method is very beneficial to the yielding support of hard and complete rock mass in depth[11], which is the mechanism of yielding rockbolt[6].

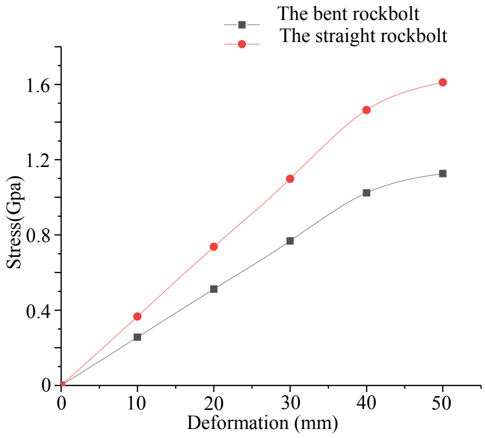


Figure 5. Stress curves of the bent rockbolt and the straight rockbolt under shear displacement of rock mass

Conclusion

Based on the simulation test results, when the supported rock mass has the same shear displacement, the bent rockbolt bears less stress than the straight one, so it is less prone to be broken. If the bent rockbolt is used to support the deep rock mass which is intact and brittle, the problem that the bolt is easy to be snpped due to shear deformation of rock mass can be effectively avoided. The bent bolt better adapts to the shear failure of rock mass.

Acknowledgments

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