Analyzing of Reinforcement Effect of Bolt-Grouting in Squeezing Tunnel

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Abstract. For the weak rock liable to squeezing deformation, it is a very meaningful matter to seek a new reinforcement method. Bolt-grouting support is a new type of active method combine bolting and grouting, its principle is to reinforce the unloading loosening rock behind primary support composed of steel and spraying concrete by grouting way using hollow bolt. Bolt-grouting colligated filling and cementing effects by grouting and combined, suspension effects by anchor, is effective to improve the mechanical properties of surrounding rocks. In this paper, based on the surrounding rock self-supporting arch principle, the bolt-grouting support effect is analyzed using the finite element method. The results show that: the stress concentration state of surrounding rock approaches equilibrium after bolt-grouting, which is useful to promote the formation of surrounding rock self-supporting arch, and improve the stress condition significantly.

Introduction

Squeezing ground refers to the ground that undergoes substantial time-dependent deformation in the vicinity of the tunnel as the result of load intensities exceeding its strength. As a consequence of the squeezing ground, the tunnel supports will experience loads that may increase for weeks or even months to a value several times higher than the initial ones[1]. The International Society of Rock Mechanics (ISRM) defined squeezing deformation as the time dependent large deformation which occurs around the tunnel and is essentially associated with creep caused by exceeding a limiting shear stress [2]. Squeezing deformation has features such as:①large deformation amount; ②fast deformation speed;③deformation continued for a long time;④large damage zones;⑤various damage forms, it seriously restricts the tunnel construction safety, cost and schedule [3].

There are two basic principles maintaining the stability of surrounding rock, one is passive support principle, means to prevent the surrounding rock deformation by providing enough resistance [4].The other one is active principle, which means to give full play to the surrounding rock self-supporting ability to reduce the deformation by strengthening the surrounding rock and improving its stress state [5].The bolt-grouting support is a new type of active method, to reinforce weak or broken rocks by grouting way using hollow bolt, which combines the support effects of bolting and grouting [6].

The self-supporting arch of surrounding rock

Surrounding rock itself has a certain self-support capacity. After tunnel excavation, surrounding rock deform along the unloading direction, and in the tangential direction, there occurs squeezing load. On the one hand, the originally continuous rock rupture, on the other hand, various fissures inner surrounding rock become interconnection, and rock mass structure begin to deteriorate, finally, an unloading circle is formed in surrounding rock.

In the unloading circle, a self-supporting arch similar to masonry arch is formed because of the occlude rock blocks, it undertakes the load from itself and above rocks, is a structural body with mechanical properties of arch to ensure surrounding rock stability. The surrounding rock self-supporting arch just is a phenomenon of stress self-regulation to resist uneven deformation happened in rock mass.

Principle of bolt-grouting

The principle of bolt-grouting is to reinforce the unloading loosening rock behind primary support composed of steel and spraying concrete by grouting way using hollow bolt. Relative to rock pore, grout flows more easily during rock mass discontinuity distribution, can re-cement loosen and broken rocks into a whole. As shown in Fig.1, is a schematic diagram of bolt-grouting principle.

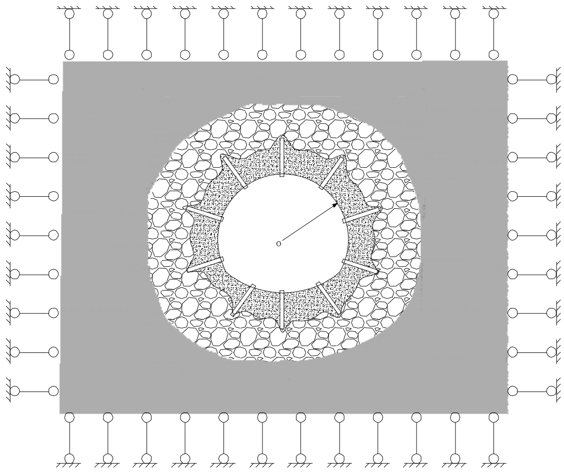

Fig.1 Schematic diagram of bolt-grouting

Reinforcement effect of bolt-grouting

Here selecting a plane strain model to analyze the reinforcement effect of bolt-grouting, the calculating model is established based on actual construction parameters of Jiu-Pu tunnel. As shown in Fig.1, the tunnel excavation section is horseshoe-shaped ,Width × Height = 13.84m × 12.22m, Width × Height of calculating model is 100m × 100m, the horizontal initial ground stress is 11MPa, and vertical is 9MPa. Surrounding rock and bolt-grouting area select Mohr-Coulomb elastic-plastic constitutive model, 2-D element, bolt-grouting reinforced thickness is 2m, supporting structure use elastic constitutive model, beam element. The calculation parameters are shown in Table.1.

Table 1 Values of the calculation parameter

Parameters	Elastic module(MPa)	Poisson	Cohesion (MPa)	Friction (°)	Unite weight (kN/m^3)
Surround rock	700	0.35	2.6	26.7	24
Reinforced area	1000	0.3	3.2	32	24
Primary lining	10000	0.25			22

The decrease of surrounding rock displacement and internal stress of supporting structure, is just result of bolt-grouting, we should analyze its reinforcement mechanism from rock self-supporting capacity. According to the theory of surrounding rock self-supporting arch, the effective pressure arch around tunnel, plays a key role in surrounding rock stability, its typical feature is stress concentration within arch body.

As Fig.2 (a) shows, when no bolt-grouting, there are two significant compressive stress concentration zones at tunnel vault and bottom respectively, but no significant compressive stress concentration zone exist at side walls. At vault, the stress concentration factor is 1.7 to 2.0, in range of 5m from inside to outside, and at bottom it is 1.2 to 1.3 in range of 10m. Fig.2 (b) shows that, when after bolt-grouting, the stress concentration state of surrounding rock approaches equilibrium, and significant compressive stress concentration zones also exist at side walls. At vault, the stress concentration factor is 1.5 to 2.5, at bottom is 1.3 to 1.8, and it improves from 1.0 to 1.2~1.5 after bolt-grouting at wall waist. The stress concentration range is significantly associated with bolt-grouting support range, thickness is about 2m.

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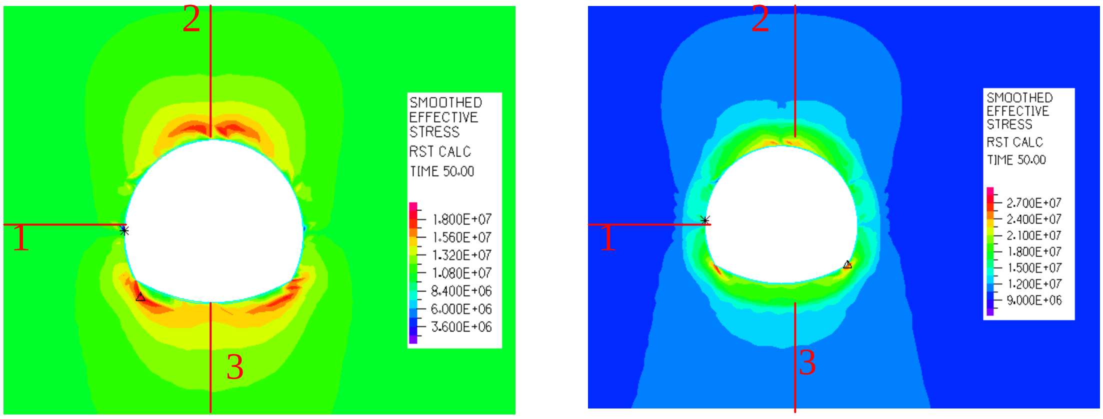
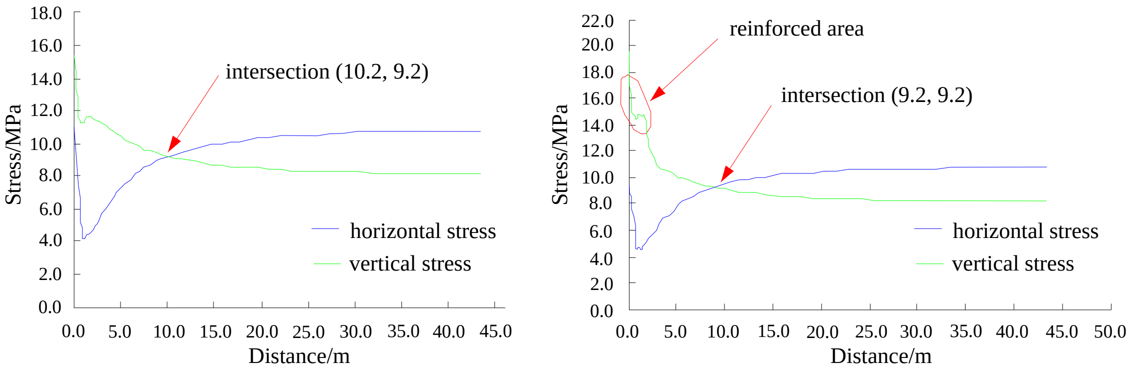


(a)no bolt-grouting (b)after bolt-grouting

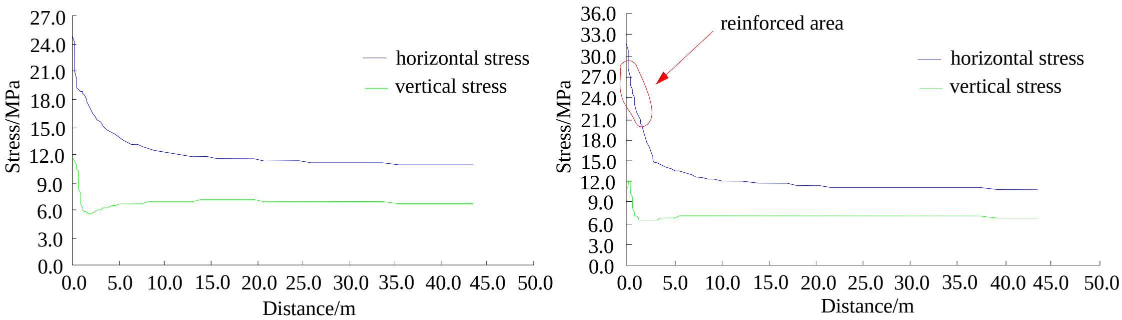
Fig.2 Cloud charts of effective stress around tunnel



(a)no bolt-grouting (b)after bolt-grouting

Fig.3 Stress path curves in horizontal and vertical directions (path 1)

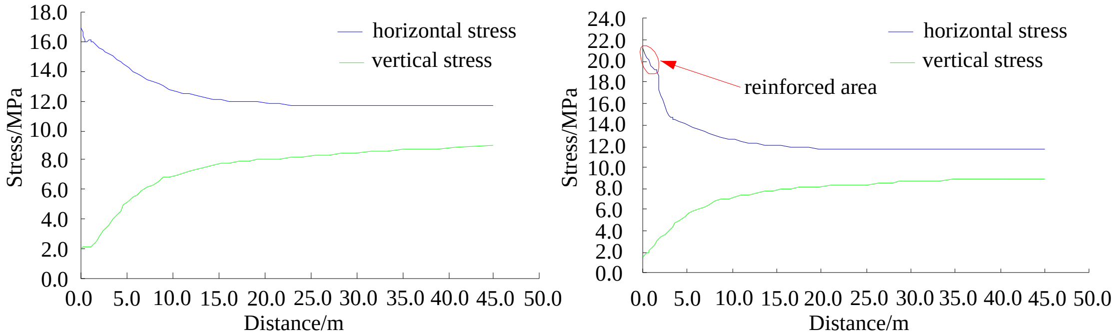
The boundary of self-supporting arch can be determined according to the stress path analysis way [7]. Respectively, Fig.3, Fig.4 and Fig.5 show stress path curves in horizontal and vertical directions of the three paths (as shown in Fig.2).At vault and bottom, the maximum principal stress is in horizontal direction, the maximum value of stress concentration factor exists in internal border, and the value equal to1 at outer edge. At side wall, the maximum principal stress is in vertical direction, but still is in horizontal direction out of the self-supporting arch, which means the direction of maximum principal stress is restored at the arch outer edge, corresponds to the intersection point as shown in Fig.3.



(a) no bolt-grouting (b)after bolt-grouting

Fig.4 Stress path curves in horizontal and vertical directions (path 2)

For path 1 (Fig.3), when no bolt-grouting, the thickness of self-supporting arch is approximately 10.2m, after bolt-grouting, it changes to 9.2m, and the average compressive stress also changes from 11MPa to 14MPa within arch. For path 2 (Fig.4), the bolt-grouting support has slight effect on the arch range, its thickness maintained at 5m, but the maximum principal stress improves about 25% in bolt-grouting range. For path 3 (Fig.5), the bolt-grouting support also has slight effect on the arch range, its thickness maintained at 10m, the average compressive stress increases from 14MPa to 19MPa, improves about 36%. Therefore, bolt-grouting has significant effect on the form of surrounding rock self-supporting arch.



(a) no bolt-grouting (b)after bolt-grouting

Fig.5 Stress path curves in horizontal and vertical directions (path 3)

Conclusion

Ideal surrounding rock self-supporting arch should be ring shape. In squeezing tunnels, the horizontal initial ground stress is often higher than the vertical stress, in another word, the side pressure coefficient $\lambda > 1$.As result, significant compressive stress concentration zones will exist at vault and bottom, but not at side walls, where easy to appear shearing and sliding deformation, or even tensile stress zones. Pressure arch located at vault and bottom can not be effective connection, often lead to a great decrease of surrounding rock self-supporting capacity. So, for squeezing tunnel, bolt-grouting is a useful way to improve the stress concentration state and the capacity of surrounding rock self-supporting arch significantly.

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