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Structure Analysis for Tunnel Longitudinal Deformation Based on Segment Dislocation Mode

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Abstract

According to tunnel structure around joints, tunnel longitudinal deformation is analyzed and a three-dimensional finite element model is built based on segment dislocation mode. Tunnel structure stress analysis is conducted from two aspects of segment in the shear and bolt in the tension. The analysis results show: (1) Segment shear model. When segment dislocation reaches 0.03 mm, the principal stressσ_1 exceeds 3.0 Mpa which is over concrete's tensile strength. Therefore, when convex tenon and concave tenon generate shear, there must be horizontal slipping and bolt is tensioned. (2) Bolt tension model. When joint opening value reaches 2 mm, bolt stress exceeds 640Mpa, which is bolt's yield strength. When joint opening value reaches 6 mm, which is the waterproof control standard for tunnel, bolt stress reaches 688.7Mpa, which is less than bolt's failure strength. The subway tunnel's structure safety should be controlled from the perspective of waterproof.

Keywords: Tunnel; Longitudinal deformation; Segment, Dislocation mode; Convex tenon and concave tenon

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1. Introduction

With city modernization's rising in China, traffic congestion is becoming more and more serious. To developing rail transit has become main way to solve this social problem. At present, there are several operating subway lines in Beijing, shanghai, Guangzhou and other large cities. According to measured

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data of projects and latest research results, some metro tunnels' longitudinal settlement far exceeds the design value, and shows obviously unevenness in some local region[1-4]. Tunnel's longitudinal uneven settlement will lead to joints opening, bolt stress increasing, tunnel leaking and so on. These phenomenons will affect safety of operating subway.

At present, the main research on longitudinal deformation of subway tunnel is longitudinal equivalent continuous model. This model is clear in concept, simple in calculation and could obtain stress and deformation for segment and bolt. Based on longitudinal equivalent continuous model, Lin Yongguo [5] has studied shield tunnel structure property in Shanghai by considering segment joints, connecting bolt's plastic properties and bolt pretension. Combined with segment parameters of Shanghai subway line 1, Liao Shaoming[6] has obtained that tunnel longitudinal equivalent stiffness is of approximately homogeneous tunnel's 1/5~1/7 by considering circular joints. All above research results are obtained without considering joints' friction, segment dislocation and tenon's influence. According to longitudinal settlement measure dates for operating subway tunnel, Wang Rulu [2-3] put forward tunnel longitudinal deformation model which is developed with segment dislocation mode. The development process of tunnel deformation is also described in detail. Base on reference [2-3], tunnel longitudinal deformation with segment dislocation mode is emplaned by introducing actual segment in shanghai, and a three-dimensional finite element model is built to analysis stress condition of tunnel structure.

2. Tunnel longitudinal deformation analysis based on segment dislocation mode

Based on segment dislocation mode, tunnel longitudinal deformation can be seen as a series of different dislocation deformation's superposition for adjacent segments. Fig 1 shows tunnel longitudinal deformation based on segment dislocation mode.

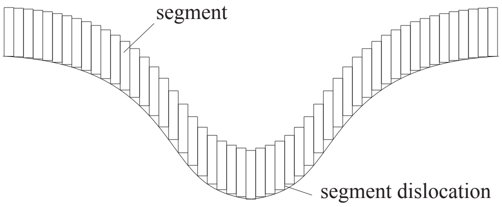


Fig 1 Diagram of tunnel deformation based on segment dislocation mode

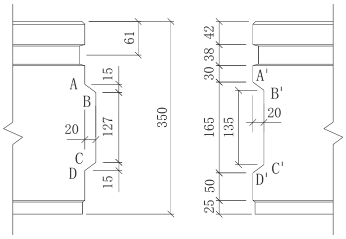
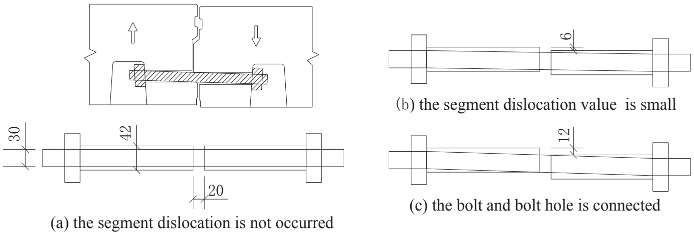


Fig 2 Diagram of convex tenon and concave tenon

In order to study segment dislocation caused by tunnel longitudinal deformation, it is needed to know structure in the segment joints. Fig 2 shows structure of convex tenon and concave tenon. Each segment is connected by bolts and generally, bolt hole diameter is lager than bolt diameter. Fig 3 shows relative position variation of bolt and bolt hole with segment dislocation value. When segment dislocation value reaches 12mm, the bolt begins to connect with bolt hole.



(a) the segment dislocation is not occurred

(b) the segment dislocation value is small

(c) the bolt and bolt hole is connected

Fig 3 Relative positional relationship of bolt and bolt hole

3. Numerical simulation for tunnel longitudinal deformation

Concrete lining is composed of segments which are connected by bolts. Around adjacent segment joints, mechanical properties are very complex, and it is difficulty to find out segment's mechanical relationship by theoretical derivation. In this paper, by means of numerical simulation method, stress analysis is done for tunnel longitudinal deformation.

3.1. Building of computational model

In this model, solid elements are used to simulate segment and bolt. Face to face contact elements are used to simulate mutual friction of adjacent segments, bolt cap and ring, bolt hole and bolt. Finite element model has 36638 elements, 36205 nodes and is built according to actual dimension. Fig 4 and fig 5 show the finite element model.

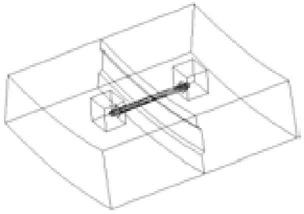
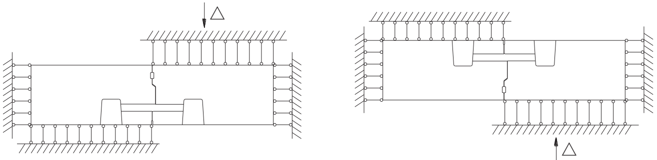


Fig 4 Structure diagram of segment joint

Fig 5 FEM model of segment joints

1. Material parameters
   Material parameters in the model are as follows:
   (1) Concrete materials:
   Elastic modulus E: 3.45×10^4Mpa.
   Poisson ratio μ: 0.2.
   (2) Bolt materials:
   Elastic modulus E: Before yielding E=2.1×10^5 Mpa, after yielding E=2.1×10^3 Mpa.
   Poisson ratio μ: 0.3.
2. Model's constitutive relationship
   Concrete segment: linear elastic model.
   Bolt: Bilinear Isotropic model.
3. Calculation model
   (1) Shear model of segment

The horizontal slipping is ignored in order to study segment's shear performance between concave tenon and convex tenon. In this paper, the shearing action is stimulated by applying displacement boundary conditions. Calculation cases can be divided into two aspects: shearing effects occurred at the top of tunnel and shearing effects occurred at the bottom of tunnel.



(a) In the top of tunnel

(b) In the bottom of tunnel

Fig 6 Shear model of segment

(2) Tension model of connecting bolt

Because tunnel longitudinal deformation isn't uniform, there is dislocation deformation between each segment, which will lead to joints opening, bolt stress increasing. The bolt's tension model is built in order to study connecting bolt's tensile properties. The shear between convex tenon and concave tenon is ignored in this model. Fig 7 shows tension model of connecting bolt.

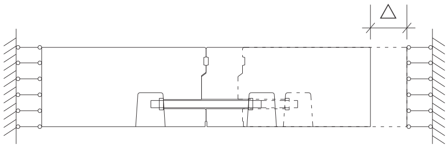


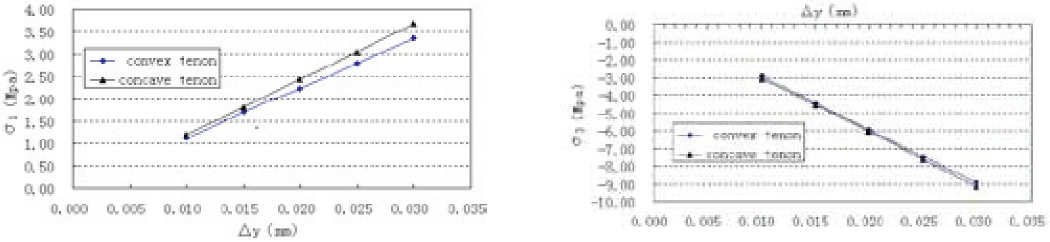
Fig 7 Tension model of connecting bolt

3.2. *Analysis of calculation results*

1. Stress analysis for shear model of segment

Without considering horizontal slipping displacement, the segment dislocation's value is induced by occlusion effect between convex tenon and concave tenon. The calculation results show that when segment dislocation's value reaches 0.03mm, the max third principal stress σ_3 is 8~12Mpa, which is less than concrete's design value of compressive strength. However, the max first principal stress σ_1 reaches 3.0 Mpa, which is more than concrete's design value of tensile strength. So small segment dislocation value could generate so large stress in the concrete segment, which is not consistent with practical engineering. Therefore, when adjacent segments generate dislocation, the horizontal slipping displacement must be occurred at the same time.

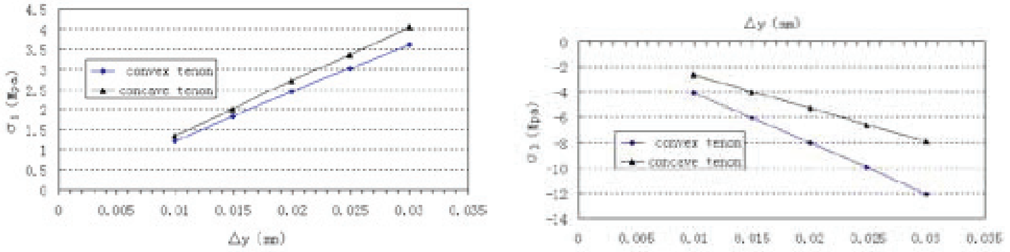
(1) In the top of tunnel



(a) (b)

Fig 8 Relationship between Principal stress and segment dislocation around tenon: (a)σ_1; (b) σ_3

(2) In the bottom of tunnel



(a) (b)

Fig 9 Relationship between max principal stress and segment dislocation around tenons: (a) σ_1; (b) σ_3

2. Stress Analysis for tension model of connecting bolt

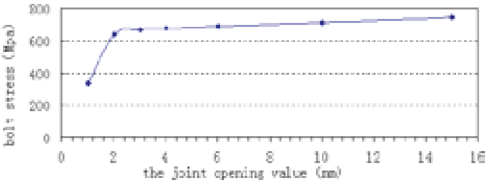


Fig 10 Relationship between bolt stress and joint opening value

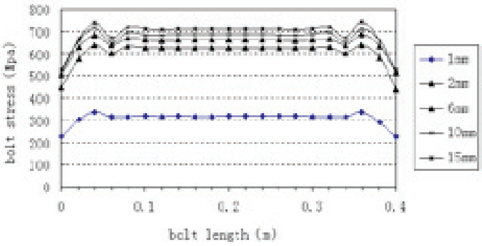


Fig 11 Principal stress σ_1 distribution along bolt's length direction

The analysis above show that when adjacent segments generate dislocation, the horizontal slipping displacement must be occurred, connecting bolt is stretched, and opening angle is generated at the same time. Fig 10 shows relationship between bolt stress and joint opening value. When joint opening value reaches 2mm, bolt stress reaches bolt's yield strength, and then the speed of stress increases is slow. When joint opening value reaches 6 mm, which is the waterproof control standard for tunnel, bolt stress is 688.7Mpa. When the joint opening value reaches 15 mm, bolt stress is 746.6Mpa, which is less than bolt's failure strength. Fig 11 shows Principal stress σ_1 distribution along bolt's length direction. Stress distribution is substantially uniform, but because of boundary condition's influence, there is stress concentration around bolt hole.

4. Conclusions

Considering tunnel longitudinal deformation with segment dislocation mode, a three-dimension finite element model is built to analysis tunnel structure's stress state, and following conclusions has concluded:

(1) Without considering segment's horizontal slipping, when segment dislocation reaches 0.03mm, the Principal stress σ_1 exceeds 3.0 Mpa which is over concrete's tensile strength. Therefore, when the convex tenon and concave tenon generate shear, there must be horizontal slipping.

(2) Without considering segment's shear, when joint opening value reaches 2 mm, bolt stress reaches bolt's yield strength. When the joint opening value reaches 15 mm, bolt stress is 746.6Mpa, which is less than bolt's failure strength--800Mpa. Therefore, the subway tunnel's structure safety should be controlled from the perspective of waterproof.

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