Study on the bearing capacity of embedded chute on shield tunnel segment

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Abstract. The method of perforation and steel implantation is often used to fix and install pipeline, cables and other facilities in the shield tunnel, which would inevitably do damage to the precast segments. In order to reduce the damage and the resulting safety and durability problems, embedded chute was set at the equipment installation in one shield tunnel. Finite element models of segment concrete and steel are established in this paper. When water-soil pressure calculated separately and calculated together, the mechanical property of segment is studied. The bearing capacity and deformation of segment are analysed before and after embedding the chute. Research results provide a reference for similar shield tunnel segment engineering.

1. Introduction
With the increase in urban traffic pressure and the shortage of land resources, development and utilization of underground space are raising more and more attention. Shield technology has been developed on a large scale. In shield construction method, lining segments are the main stress components. So the stress characteristics and safety performance of the segment are always the key points in engineering research. In recent years, many scholars have done a lot of research on concrete segment, including the stress characteristics, the destruction process and the calculation and analysis of its strength and destruction [1-4]. In some developed countries in Europe, Embedded technology for lining structure has been applied. By contrast, related research is still blank in domestic. The text, based on a subway project, made a preliminary analysis and study on the bearing capacity of shield tunnel segment respectively before and after the embedded chute. To validate whether the proposed embedded chute can meet the design force and durability requirements, the mechanical properties of segment was studied. We hope that the article could provide a reference for similar projects.

2. Geological condition
The original landform of the subway line is the platform and the valley area. The area is artificially filled and leveled. Now the terrain is undulating. The elevation is 19.00 ~ 31.26m and the ground slope is 0~5 °. The ground is covered by buildings and roads. The original landform is gone. Geotechnical stratification and its physical mechanical parameters are shown in table 1.

| Age Cause | Q4ml | Q4al | Q4al+pl | Q4al+pl | Qel | Qel | Z | Z | Z | Z |
|----------|------|------|---------|---------|-----|-----|---|---|---|---|
| Horizontal Kx | - | 8 | 35 | 25 | 45 | 90 | 150 | 180 | 450 | 1000 |

Table 1. Physical and mechanical indexes of rock and soil.
The quaternary strata are composed of Qhml, Qhapl and elurium. The bed rock is migmatite in Sinian Yunkai Group. The interval tunnel is basically located in the hard plastic sticky soil layer, completely weathered zone and intensely weathered zone. The thickness of the tunnel roof soil is 8.5m~18.5m. The variation of groundwater table is controlled by topography, groundwater recharge sources and other factors. During surveying, the steady water level of underground water Buried deep 2.80 ~ 6.30m.

3. Structure of concrete segment

The outer diameter of shield tunnel lining is 6000mm and the inner diameter is 5400mm. The lining ring width is 1500mm and the thickness is 300mm. The lining ring consists of a top block K (Angle 20), two adjacent blocks B, C (Angle 62), and three standard blocks A (Angle 72). The top block is located in the smallest position of the wedge. The top block, adjacent block and standard block are made of reinforced concrete. Longitudinal and circular bolts are all common bolts of φ24. There are 10 longitudinal bolts on each ring surface and the ring is evenly arranged along the lining. Longitudinal bolts are not set on the top block. There are two ring bolts on each longitudinal seam, which is 400mm from the centre line of the segment. The segment ring is assembled in staggered form. When assembling, the top block should be connected to the radial direction by two thirds. Then it will be pushed radially and inserted longitudinally.

4. Analysing and modelling

Finite element calculation program Abaqus6.10 is used to simulate and analyse slotting segments, adopting non-linear calculation method. In order to simulate gravity, the vertical acceleration field is applied to the structure. Load was applied according to actual loads. The numerical simulation adopts the method of separating modelling. Longitudinal reinforcement, stirrup area and configuration position are arranged according to design. The model has about 20,000 units.

Concrete uses Solid element C3D8R. The rebar uses Truss element T3D2. The constitutive model of concrete adopts Concrete Damaged Plasticity Model. This is a plastic continuum damage model, which is mainly used to simulate the mechanical properties of concrete in reinforced concrete structures. The non-elastic properties of concrete are represented by the basic parameters of concrete and the plastic properties of tensile and compression.

The formula from our domestic Code for Design of Concrete Structures is used as the Stress-strain curve equation of concrete uniaxial compression. The rebar adopts the ideal two-fold elastic-plastic model. It is constrained in solid concrete by Embedded Region. The elastic modulus of steel yielded is 1% of that before the steel is yielded. The rebar is a truss unit. The values of material parameters and model plastic parameters are shown in table 2.

Table 2. Parameters of material and model.

| Material Property                  | Value            |
|-----------------------------------|------------------|
| Prismatic compressive strength of concrete $\sigma_{cu}$ | 32.4MPa          |
| Prismatic tensile strength of concrete $\sigma_{tu}$ | 3.24MPa          |
| Density                           | 2400kg/m$^3$     |
| Elastic modulus                   | 3.45e10N/m$^2$   |
| Yield strength                    | 452MPa           |
| Eccentricity ratio                | 0.1              |
| Initial yield stress              | $0.3\sim0.4\sigma_{cu}$ |
| Elastic modulus of steel          |                  |
| Initial equivalent biaxial compressive |            |
| Poisson ratio of concrete         |                  |
| Poisson ratio of steel            |                  |
| Viscosity coefficient             |                  |
| Dilation Angle                    |                  |
| Material parameters of concrete   |                  |
| $K_c$                             |                  |
According to the relevant parameters in Table 1, the horizontal and vertical springs are set to simulate the effect of the foundation. The finite element model of single ring segment is shown in Figure 1.

| stress/Initial equivalent uniaxial compressive stress |
|--------------------------------------------------------|
| 2e5MPa | 1.16 | 0.2 | 0.3 | 0 | 30° | 0.66667 |

Figure 1. Finite element model of segment concrete and steel mesh.

5. Analysis of the calculation result
In the case of safety consideration, the combination conditions of the maximum load was taken and the simulation was carried out in the open slot and unslotted condition.

5.1. The recheck of tunnel segment deformation
The deformation calculation of the tunnel segment is shown in Figure 2. The deformation increased by 4.4% after slotting.

Figure 2. Deformation nephogram of tunnel segment.

A) Deformation of the segment when the pressure water and soil are calculated separately (unslotted)  
B) Deformation of the segment when the pressure of water and soil are calculated separately (slotted)
5.2. The recheck of concrete stress at the slotted segment

The Mise stress calculation of the tunnel segment is shown in Figure 3. Concrete stress increased by 8% in slotted area.

![Stress nephogram of tunnel segment.](image)

A) Stress of the tunnel concrete when the pressure of water and soil calculated separately (unslotted)

B) Stress of the tunnel concrete when the pressure of water and soil calculated separately (slotted)

Figure 3. Stress nephogram of tunnel segment.

5.3. The recheck of tunnel segment steel

The stress calculation of the tunnel segment steel is shown in Figure 4. Maximum reinforcement stress increased by 0.5%.

![Deformation nephogram of tunnel segment.](image)

A) Maximum steel stress when the pressure of water and soil are calculated separately (unslotted)

B) Maximum steel stress when the pressure of water and soil are calculated separately (slotted)

Figure 4. Deformation nephogram of tunnel segment.

6. Conclusion

(1) Under the equivalent load, the deformation of the unslotted tunnel segment is about 0.03%. It is very small. When the segment is slotted, the deformation increases a little, but still not exceeds 0.05% of the whole.

(2) Through the finite element simulation of two working conditions, the segment slotted and unslotted, compared with the concrete stress in the slotted area, the concrete stress is not large. Concrete in slotted area increases a little, but not exceeds 8%. Maximum tensile stress of steel varies less than 10% before and after slotting. Under the action of the calculation load, the slotted segment of the shield tunnel was calculated. When the segment is slotted according to the design documentation,
the whole force of the tunnel segment changes a little. Its bearing capacity and deformation all meet the requirement of the checking load. After actual inspection and measurement, we compared the construction technology of embedded technology and traditional drilling technology. It shows that the embedded technology is feasible and has certain reference significance.

References
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