Research on Deformation Characteristics of Tunnel Box Culvert Structure under Different Construction Loads

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Abstract: The box culvert structure is an important part of the internal structure of the tunnel. The stability of the box culvert structure directly affects the safety of the tunnel structure, so it is particularly important for the deformation analysis of the box culvert structure. This study uses the finite element software ABAQUS to establish a numerical model of soil-tunnel-assembled box culvert, and quantitatively analyzes the influence of different construction loads on the deformation of the box culvert structure. Through analysis and summary, the horizontal and vertical deformation of the box culvert structure under construction load and the force deformation performance of the junction of the box culvert structure are obtained. At the same time, the deformation performance of the connection between the internal prefabricated box culvert and the side plate under the load of the construction vehicle is also obtained. It has certain guiding significance for the research on the force of the box culvert structure inside the tunnel.

1. Introduction

With the continuous deepening of the construction of rail transit in my country, the excavation of large-diameter tunnels has become more and more common. Among them, double-deck lanes are widely used in large-diameter tunnels, and the research on the internal structure of tunnels has increasingly become the consensus of the academic community. At the same time, with the development of large-diameter and long-distance shield tunnels, fabricated internal structures also have more application requirements. Many scholars at home and abroad have done relevant research on the internal structure of shield tunnels. Huang Jun et al. [1, 2] combined the double-layer carriageway structure design of Weisan Road, Nanjing City, and prefabricate d the upper carriageway structure. A comprehensive study was carried out and the two types of prefabricated design technologies proposed emphasized the advantages of prefabricated structures in terms of construction speed and construction flexibility. Liu Nian [3] aimed at the current situation that the construction of some components of shield tunnels in China still adopts the cast-in-place form, and proposed the method of prefabricating the components by connecting them into a rigid whole, and proposed feasible prefabricated joint forms. Song Limei et al. [4, 5] analyzed the force characteristics and characteristics of various shield tunnel prefabricated double-deck lane structure systems by comparing the force models and characteristics of cast-in-place structures, and concluded that the prefabricated assembly structure joints are complicated
in force and have obvious spatial effects. The conclusion. Zhou Kun [6] used a 2.5-dimensional numerical calculation program to numerically analyze the typical cross-sections of the Wuhan Sanyang Road highway-rail joint construction of the Yangtze River tunnel project. The dynamic response verifies that the silt formation around the tunnel will not suffer from liquefaction instability. Although many scholars have done a lot of researches on the internal structure of tunnels, there are few related studies on the force characteristics and safety conditions of the internal structure of large tunnels under construction and under the action of heavy-duty vehicles such as segment transport vehicles. Therefore, this paper will take the internal structure of a tunnel in Jinan as a template and use ABAQUS three-dimensional finite element analysis software to establish a numerical model of soil-tunnel-fabricated box culvert to analyze the horizontal and longitudinal deformations of the box culvert under different construction loads. The force characteristics of the structural joints, and then the deformation characteristics of the joints of the internal prefabricated box culvert structure and the side road slab under the load of construction vehicles.

2. Model establishment
The ABAQUS three-dimensional finite element analysis software is used for simulation analysis, and the model is established according to the actual size of the tunnel. The inner diameter of the tunnel is 6.95m and the outer diameter is 7.6m. The concrete material of the tunnel segment is C50, the internal structure concrete material is C40, and the soil layer is Mohr-Coulomb elastoplastic constitutive, tunnel segments and prefabricated box culvert adopt concrete elastic constitutive.

2.1. Calculation parameters of each material of the model
The mechanical parameters of each material in the model are shown in Table 1.

| Serial number | material Layer thickness(m) | Severe(kN/m³) | Compression modulus(Mpa) | Cohesion(kPa) | Internal friction angle(°) |
|---------------|-----------------------------|---------------|--------------------------|--------------|--------------------------|
| 1 Plain fill 3 | 18.0                        | 15            | 6.00                     | 15.00        |
| 2 Silt        2.3            | 19.2                        | 19.1          | 7.00                     | 25.20        |
| 3 Cohesive soil | 12.9                      | 19.0          | 36.7                     | 16.00        | 17.70        |
| 4 Silt        11.20         | 19.0                        | 29            | 3.00                     | 26.50        |
| 5 Cohesive soil | 10.9                      | 19.0          | 35                       | 16.00        | 17.70        |

2.2. Model boundary conditions and loading methods
In this calculation model, the bottom is completely fixed, the two sides are horizontally constrained, and the upper surface is a free surface. The model uses gravity load to simulate the actual construction load by increasing the density.

2.3. Construction load simulation
The construction loads are mainly segment transport vehicles and concrete mortar transport vehicles. The specific information is shown in Table 2.
### Table 2. Specific information of construction load

|                     | Wheelbase (mm) | Wheelbase (mm) | Box culvert width (mm) | Maximum pressure of single tire (KN) | A single box culvert bears the number of tire pairs |
|---------------------|----------------|----------------|------------------------|--------------------------------------|---------------------------------------------------|
| Segment Transporter | 1600           | 2300           | 2000                   | 150.5                                | 2                                                 |
| Concrete Mortar     | 3600           | 2300           | 2000                   | 69.3                                 | 1                                                 |

Condition 1 Located in the middle box culvert  
Condition 2 Located on the side road slab  
Condition 3 Located between the box culvert and the side plate

This construction load simulation mainly considers two aspects. The first is the influence of the size of the construction load, and the second is the influence of the location of the construction load.

First, the impact of the size of the construction load. Since the load of the segment truck is larger than that of the concrete mortar truck, the simulated construction load is mainly the load of the segment truck, and the load is divided into a single pair of tires and two pairs of tires.

Second, the impact of the position of the construction load. The position of the construction vehicle is divided into three working conditions: acting on the middle box culvert, acting on the side road slab, and located between the box culvert and the road slab, as shown in the figure.

### 3. Model results and analysis

In this paper, a numerical model of soil-tunnel-fabricated box culvert is established, and the force and deformation performance of the box culvert structure under different construction load conditions is obtained. According to the simulation results, the box culvert structure under three conditions and six conditions is obtained. Deformation. This time, the deformation cloud images under various working conditions are extracted (see the figure below).
3.1. Longitudinal deformation of box culvert structure
The three working conditions will cause the box culvert structure to produce different degrees of longitudinal deformation. According to the degree of influence, condition 1 > condition 3 > condition 2. At the same time, a certain degree of junction between the box culvert structure and the side road slab will occur. Differential settlement, according to the extracted results, (1) In the absence of plastic deformation, the longitudinal deformation of the box culvert structure does not show a linear relationship with the load. This is due to the longitudinal deformation of the box culvert structure not only affected by the load, it will be affected by a variety of factors. For example, the tunnel will be affected by the pressure of the surrounding soil, which will transmit a longitudinal force to the box culvert structure, which will affect the longitudinal deformation of the box culvert structure. (2) Under the action of two pairs of tires, the three working conditions will cause differential settlement at the junction of the box culvert structure and the side road slab. According to the extracted results, the differential settlement of condition 1 is the largest (0.7mm). The second is the second (0.4mm), and the third is the smallest (0.3mm). As a result, the differential settlement is not large, but it will still have a certain impact on the structure, such as excessive local stress, stress concentration, and so on.

3.2. Lateral deformation of box culvert structure
The lateral deformation of the box culvert structure mainly considers the opening of the connection between the box culvert structure and the side road slab, and the results under each working condition are extracted as shown in the following figure. The analysis shows: (1) Under the action of a single pair of tires, each working condition is The overall effect of the opening amount appears to be working condition 1 > condition 3 > condition 2, and the opening amount at the connection of the three working conditions, the opening amount of the end is greater than the opening amount of the middle, this is because the deformation of the panel is curved and spherical. It is longer than the relative length of the middle of the board, so the opening of the end of the board is greater than the opening of the middle. (2) Compared with the action of a single pair of tires, under the action of two pairs of tires, the change law of the opening amount at the junction of the box culvert structure and the side road slab is the same, but the amount of opening change is not linear. (3) Under the same load condition, the expansion of the self-weight is larger than that when the self-weight is not considered. Therefore, in the simulation analysis, in order to be closer to the actual actual working conditions, the simulation considers the self-weight.
4. Conclusion

1) The numerical model of soil-tunnel-fabricated box culvert was established by finite element software and good analysis results were obtained, which fully demonstrated the feasibility of ABAQUS finite element software for simulating the internal structure of tunnels under stress and deformation. The simulation results can be used as an auxiliary method for further research.

2) Comparative analysis of the influence of box culvert structure under different working conditions on the force and deformation performance shows that the influence of each working condition on the box culvert structure under force and deformation performance is overall as condition 1 > condition 3 > condition 2, and no plasticity occurs. In the case of deformation, the deformation of the box culvert structure has a nonlinear relationship with the load it receives.

3) Comparative analysis of the calculation results of the expansion of the connection between the self-weight box culvert structure and the side slab under the action of the construction load. The results show that the self-weight effect has a certain effect on the opening of the box culvert structure and the side slab, and the opening is larger when the self-weight is considered than without the self-weight. At the same time, considering the self-weight effect is closer to the actual actual working conditions.

4) Through the analysis of the opening amount of the connection between the box culvert structure and the side road slab under different working conditions, the opening amount of the end is greater than the opening amount of the middle, and the deformation of the panel is curved and spherical, and the end of the slab is longer than the relative length of the middle of the slab. Long, the opening at the end is greater than the opening at the middle.

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