Analysis of mechanical behavior of double arch tunnel by CD method and benching method

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Abstract. In order to analyze the influence of different excavation methods on the stability of the tunnel, with reference to a tunnel engineering case, a three-dimensional finite element software was used for numerical simulation to study the stress variation, deformation and plastic zone distribution of surrounding rock during the excavation of the double arch tunnel under two different excavation methods, CD method and benching method. The results show that for the CD method, when the distance between left and right tunnel faces is more than 60m, the deformation, stress and plastic zone of surrounding rock and supporting structure tend to be stable. For the benching method excavation, when the distance between the left and right tunnel faces is more than 50m, the deformation, stress and plastic zone changes of surrounding rock and supporting structure tend to be stable.

1. Introduction
In the process of tunnel construction, it is inevitable to pass through areas with poor engineering geology. On one hand, the engineering geology significantly affects the stability of surrounding rock of the tunnel. On the other hand, the costs and time for tunnel construction are strongly influenced by the choice of the excavation process. Therefore, it is necessary to investigate the mechanical characteristics of tunnel structure and the selection of construction method. It is of great theoretical and practical significance to study the excavation stability of tunnel in weak surrounding rock. Some researches have been conducted on the tunnel excavation using CD method and benching method [1-3]. For example, Sharifzadeh M et al. investigated the design of sequential excavation method for large span urban tunnels in soft ground-Niayesh tunnel using three-dimensional finite element method [1].

In this paper, the finite difference software FLAC3D is used to analyze the stability of soft surrounding rock tunnels under the CD method and benching method excavation, and to study the deformation, stress and plastic zone changes of surrounding rock, which can provide reference for similar engineering cases.

2. Project description
The geological structure of a tunnel in southwestern China is complicated. The surrounding rocks at the beginning of the tunnel are mostly accumulations and mud mixed with stones. The starting mileage of the right frame is K115 + 590, with a total length of 2540m; the starting mileage of the left frame is
ZK115 + 590, with a total length of 2555m, and the maximum buried depth is about 405m. The elevation of the tunnel is between 1700-2200m, and the relative height difference is 500m. The terrain of the tunnel is steep and the vegetation on the surface is generally developed. The stratum is strongly weathered-medium weathered basalt, and the surrounding rock grade is IV and V according to comprehensive assessment.

The tunnel is a double arch tunnel without intermediate guide. The advance tunnel of grade V surrounding rock adopts the three benching partial excavation method with reserved core soil, and the latter tunnel is excavated by CD method. The first tunnel in grade IV surrounding rock is constructed by three benching excavation method with reserved core soil, and the rear tunnel is constructed by three-step method.

3. Numerical simulation of tunnel stability analysis

3.1. Modelling and parameters selection

Comprehensively considering the geological structure and geotechnical characteristics of the area, the numerical software FLAC3D is used to carry out the simulation of the construction process. During the numerical analysis, the rock and soil layers mainly considered are fully strong weathered basalt, medium weak weathered basalt and tuff. The three-dimensional geomechanical model is shown in Figure 1. The finite element mesh is divided into tetrahedral, pentahedral and hexahedral elements, with a total of 2,608,565 elements and 541,904 nodes. The constitutive relationship of each rock and soil layer adopts the elastic-plastic model, and the yield criterion adopts the Mohr Coulomb strength criterion. The boundary conditions are: the side surface of the model is normal constraint, the bottom surface is fixed constraint.

CD method excavation stage: the right tunnel is excavated 100m first, and the excavation method adopts the reserved soil three-benching method. The excavation distance of each step is 10m, totally 10 steps. Then the left tunnel is excavated. The V type surrounding rock is constructed by CD method with the excavation distance of 70m and the spacing of each step is 10m, 7 steps in total. The deformation of each monitoring point (including upper arch, waist wall and inverted arch) is monitored when the section of right tunnel is 20m, 40m, 60m and 80m, respectively. And the corresponding changes in the distribution of plastic zone and volume and stress, as well as the stress and deformation of the early supporting structure are monitored.

Benching method excavation stage: the right tunnel is first excavated from 180m to 240m. The excavation method adopts the reserved soil three benching method, with a distance of 20m in each step, with a total of 4 steps. Then, the left tunnel is excavated. The excavation distance is 160m to 210m, and the spacing of each step is 10m, 5 steps in total. The deformation of the monitoring points (including the upper arch, waist wall and inverted arch) when the right tunnel section at 120m, 140m and 160m, respectively. And the corresponding plastic zone distribution, volume and stress changes, as well as the stress and deformation of the early supporting structure are monitored.

The mechanical parameters of surrounding rock are shown in Table 1. In this paper, the negative stress means the compressive stress, and the positive stress represents the tensile stress.
### Table 1. Mechanical parameters of surrounding rock and concrete

| Rock type                  | Elastic modulus (GPa) | Passion’s ratio | Cohesion (MPa) | Internal friction angle (°) | Tensile strength (MPa) |
|----------------------------|-----------------------|-----------------|----------------|----------------------------|------------------------|
| Strongly weathered basalt  | 0.50                  | 0.28            | 0.35           | 30                         | 0.30                   |
| Moderately weathered      | 2.00                  | 0.27            | 0.50           | 38                         | 0.45                   |
| basalt IV                 | 4.50                  | 0.22            | 0.70           | 40                         | 0.65                   |
| Tuff                      | 0.30                  | 0.28            | 0.20           | 35                         | 0.15                   |
| C25 concrete              | 28.00                 | 0.20            | 25.00          | 45                         | 1.78                   |
| C30 concrete              | 30.00                 | 0.20            | 30.00          | 45                         | 2.01                   |

#### 3.2. Deformation analysis of surrounding rock

#### 3.2.1. CD method excavation.

During the excavation of the left tunnel, the displacement values of the monitoring points on the surrounding rock near the right tunnel and the early supporting structure in the tunnel change little. Among the displacement values of the surrounding rock, the monitoring points of the upper arch have the greatest change, with a maximum increase of about 0.3 mm, followed by the inverted arch and the waist wall, with the maximum increase being about 0.15 mm and 0.05 mm, respectively. On the early supporting structure, the greatest displacement change is at the upper arch, with the maximum increase of about 0.35 mm, followed by the inverted arch, with the maximum increase being about 0.15 mm, and finally at the waist wall, with the maximum increase being about 0.05 mm.

At four monitoring sections (20m, 40m, 60m, 80m), the excavation of the left tunnel has the greatest influence on the displacement of surrounding rock and early supporting structure at the 20m section, followed by 40m section, and then 60m section, while 80m section having the least impact. For simplicity, this paper only offers some of the cloud map of surrounding rock of right tunnel, which is as shown in Figure 2. When the left tunnel is excavated to the fourth step (60m apart), the displacements of the monitoring point on the surrounding rock near the right tunnel and the monitoring point on the early supporting structure increase significantly. During the excavation of the left tunnel, the displacement of the inverted arch is the largest, followed by the upper arch, and the displacement of the waist wall is the smallest. The maximum displacement of the surrounding rock near the right tunnel occurs at the inverted arch of the 60m section from the excavation of the left tunnel to the 7th step, and the upward rebound is about 6.27 mm. The maximum displacement of the early supporting structure occurs at the inverted arch of 60m section when the left tunnel is excavated to the 7th. And the upward rebound is about 7.05 mm.
3.2.2. Benching method excavation.

In the process of excavating the tunnel by the benching method, the displacement changes of the surrounding rock and early supporting structure at 180m, 200m and 220m of the right tunnel section were analyzed. Through the analysis of displacement change cloud map and displacement change curve of the surrounding rock and early supporting structure found that:

During the excavation of the left tunnel, the displacement values of the surrounding rock near the right tunnel and the monitoring points on the early supporting structure are different at different monitoring positions for the specified section. During the excavation of the left tunnel, the displacement of the upper arch is the largest, followed by the inverted arch while the displacement of the waist wall is the smallest. At 200m section, the largest change of the surrounding rock displacement is at the upper arch, with the maximum increase being 3.90mm, followed by the inverted arch monitoring point, with the maximum increase being 2.67mm, and finally at the waist wall monitoring point, the maximum increase being 1.01mm. The largest change of displacement in the early supporting structure is at the upper arch, the maximum increase is about 4.25mm of the 200m section, followed by the inverted arch, which is about 2.45mm of the 200m section, and the last is at the waist wall, which is about 0.91mm of the 180m section.

The excavation of left tunnel has the greatest influence on the displacement of surrounding rock and early supporting structure at the four sections of 200m section, followed by 180m and the 220m section is the least affected one. After the fourth step of the excavation (50m apart), the increase in the displacement of the monitoring point on the surrounding rock and the early supporting structure increased significantly. The maximum displacement of surrounding rock near the right tunnel occurs at the upper arch position of 200m section when the left tunnel is excavated to the fifth step, and the downward deformation is about 10.33mm. The maximum displacement of the early supporting structure occurs at the upper arch position of 200m section when the left tunnel is excavated to the fifth step, and the downward deformation is about 11.33mm.

3.3. Stress analysis of surrounding rock

3.3.1. CD method excavation.

Among the four sections (20m, 40m, 60m and 80m), the maximum principal stress of the surrounding rock at the 40m section is the largest, which is about 9.34MPa, and the maximum principal stress at the 60m section of the early supporting structure is the largest, which is about 6.38MPa.

Through the stress analysis of the surrounding rock, it is found that the excavation of left tunnel has little influence on the early supporting structure in the tunnel. For example, the influence is greatest at 60m section, the maximum principal stress increasing from 6.02 MPa to 6.38 MPa, and the growth rate being 5.98%.

Local tensile stress occurred in the inverted arch of the early supporting structure at the 40m, 60m section and the 20m section after the excavation to the 3rd step. The maximum value occurs at the 7th step (30m apart). The maximum values at the 20m, 40m and 60m section are about 0.03MPa, 0.05MPa, and 0.01Mpa, respectively. There is no tensile stress in the 80m section.
3.3.2. Benching method excavation.
During the excavation process of the left tunnel, the maximum principal stress distribution of the three sections (180m, 200m, and 220m) and the maximum principal stress of the early supporting structure of the right tunnel are analyzed. Among the three sections, the maximum principal stresses of the surrounding rock and early supporting structure at the 200m section is the largest, and the maximum is about 14.20MPa.

The impact of the left tunnel excavation on the maximum principal stress value of the early supporting structure in the right tunnel is different at different sections. The maximum principal stress value of the early supporting structure at the 180m section increased from 7.60MPa to 12.40MPa. The maximum principal stress value of the early supporting structure at the 200m section increased from 12.41MPa to 14.20MPa while that increased from 12.22MPa to 13.29MPa at the 220m section. When the excavation reaches the fourth step (50m apart), the left tunnel has been excavated to the 180m section, and the maximum principal stress value on the surrounding rock increases sharply. When the excavation reaches the fifth step (40m apart), local tensile stress appears at the inverted and upper arches of the early supporting structure at the 200m section, the maximum value being 47.834KPa. Meanwhile, during the excavation of the left tunnel, local tensile stress appears at the inverted and upper arches of the early supporting structure at the 220m and gradually decreases with the excavation of the left tunnel until the sixth step (30m apart) of the left tunnel excavation. The maximum tensile stress is 114.47KPa, and there is no tensile stress in the other sections.

3.4. Plastic zone analysis of surrounding rock

3.4.1. CD method excavation.
During the excavation of the left tunnel, the plastic zone distribution change cloud map of the surrounding rock at 20m, 40m, 60m, and 80m in the right tunnel section are analyzed.

The excavation of the left tunnel has little effect on the plastic zone of the surrounding rock of the right tunnel. This is mainly because the distance between the two tunnels is very close, and when the right tunnel was excavated, the plastic zone had already appeared between the two tunnels. However, the excavation of the left tunnel increases the distribution of the plastic zone, mainly because there is also a plastic zone distribution in the area around the left tunnel. After the excavation of the left tunnel, the plastic zone is mainly distributed on the waist wall, inverted arch and the area between the two tunnels. elevation of the tunnel, and mainly appears within the scope of the early supporting structure. During the excavation of the left tunnel, the total volume of the plastic zone in the calculation model increases from 58220.57m³ to 85891.35m³, with an increase rate of 47.53%.

3.4.2. Benching method excavation.
In the process of excavating the left tunnel using the benching method, the cloud map of the plastic zone distribution of the surrounding rock at 180m, 200m, and 220m are analyzed.

The impact of the excavation of the left tunnel on the plastic zone of the surrounding rock around the right tunnel is different at different sections. With the excavation of the left tunnel, the plastic zone of the right tunnel increases significantly at the 180m and 200m sections, but has little effect at the 220m section. The excavation of the left tunnel increases the plastic zone distribution in the entire calculation area, mainly because the plastic zone distribution also appears around the left tunnel. After the excavation of the left tunnel, the plastic zone is mainly distributed around the tunnel and between the two tunnels, with a thickness of about 2-3m. During the excavation of the left tunnel, the total volume of the plastic zone of the calculation model increases from 68501.34m³ to 77821.03m³, with an increase rate of 13.61%.
4. Conclusion
In this paper, the finite difference software FLAC3D is used to simulate the excavation process of soft surrounding rock tunnel. The influence of CD method and benching method on the stability of tunnel excavation is analyzed. The deformation, stress change and plastic zone distribution of surrounding rock are summarized and analyzed. It is found that when the distance between left and right tunnel faces is more than 60m during the construction of the double arch tunnel, the deformation, stress and plastic zone of surrounding rock and supporting structure tend to be stable. For the benching method excavation, when the distance between the left and right tunnel faces is more than 50m, the deformation, stress and plastic zone changes of surrounding rock and supporting structure tend to be stable.

The results in this paper can effectively guide the deformation prediction of surrounding rock and support design, and have important practical significance for the flexible selection of excavation methods for similar weak surrounding rock tunnels.

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