Study on the influence of Peripheral Hole Interpolation Angle on Tunnel Overcut and Undercut

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Abstract. The parameters that control the smooth blasting effect of tunnel driving include peripheral hole spacing, charge structure and external interpolation Angle, among which the peripheral hole external interpolation Angle is an important parameter to ensure the quality of smooth blasting. This paper uses the finite element software LS-DYNA to establish the optical explosion model of the peripheral hole based on a granite tunnel driving project, and simulates the optical explosion effect under five kinds of external interpolation angles. The results show that the influence of external interpolation Angle on over digging is great. With the increase of 1.25°, the average overcut value at the bottom of the hole increases by about 5cm. The expression of the function relation between the average overcut value of the section and the position of the hole, the position of the section, the Angle of the extrapolation, the uncoupling coefficient and the depth of the hole can be derived. The research results can provide reference for the selection of optical explosion parameters in similar projects.

Keywords: peripheral hole; External interpolation Angle; LS-DYNA; Overcut and undercut; Average overcut value

1   Introduction

Smooth blasting technology is widely used in the excavation of highway and railway tunnels in China. Reasonable parameters of smooth blasting can not only improve the tunnel contour forming effect and reduce overcut and undercut, but also reduce the vibration of blasting on tunnel surrounding rock, which not only ensures the construction safety but also improves the construction economy [1]. Sellers[2] believed that the appropriate amount of charge and type of explosive were essential for both blasting of the rock inside the excavation profile and damage to the rock outside the excavation profile. Liu et al. [3] established a tunnel blasting model by using the finite element software LS-DYNA, studied the influence of blasting parameters such as different peripheral hole spacing, resistance line size and linear charge density on the smooth blasting effect in karst tunnels. Xu et al. [4] studied the blasting parameters of large-section tunnel in horizontal stratified rock mass with joint fissure development. Jiang et al. [5] adopted the numerical simulation method to simulate and analyze the explosive stress of the

charge with water interval and air interval in the peripheral holes, and then selected the appropriate charge structure to optimize the parameters. Manke et al. [6] designed a peripheral hole layout scheme for establishing interspaced holes and carried out a smooth blasting test. Park et al. [7] proposed a method of uncoupled charging with air cushion, which can be used to reduce the vibration caused by explosions along the tunnel direction. Li et al. [8] studied the contour control of full-section excavation and the optimization of blasting parameters of large-section tunnels. At present, research on the influence of peripheral hole parameters on tunnel over excavation and under excavation control mainly focuses on uncoupling coefficient, borehole spacing, minimum resistance line, and line charge density. There is relatively little research on the impact of peripheral hole external insertion angle on tunnel over excavation and under excavation. In view of the shortcomings of the above studies, this paper will study the influence of the peripheral hole external insertion angle on the over-undercutting of tunnels, with the intention of improving the effectiveness of this project, and also providing a reference role for similar projects.

Based on a granite roadway excavation project, this paper aims to study the rule of influence of external interpolation Angle of peripheral holes on tunnel over excavation. ANSYS/LS-DYNA finite element analysis software is used to simulate the smooth blasting process of peripheral holes, and fluid-structure coupling analysis method is used to conduct three-dimensional simulation of the blasting process of peripheral holes, realizing million-unit grid division. The smooth blasting effect of peripheral holes with different interpolation angles and the influence law on overcut and undercut are obtained.

2   Material selection and calculation model establishment

2.1   Air and Explosive Material Model

In this paper, ANSYS/LS-DYNA is used to carry out numerical simulation calculation of tunnel peripheral holes, Lagrange algorithm is used for rock mass, ALE algorithm is used for air and explosives are fluids, and the coupling between fluid and solid is carried out by fluid-structure coupling keywords to realize load transfer.

The air inside the gun hole is simulated by the empty matter material[9], the key word is *MAT_NULL, and the aerodynamic properties of the air are characterized by the linear polynomial equation of state, the key word is * EOS_LINEAR_POLYNOMIAL. Its equation of state is:

$$p = (C_0 + C_1\mu + C_2\mu^2 + C_3\mu^3) + (C_4 + C_5\mu + C_6\mu^2)E_0 \qquad (1)$$

Formula: μ is the specific volume; $C_0 \sim C_6$ are constant. Air material parameters are shown in Table 1 below.

Table 1. NULL air material model parameters

ρ /(kg·m⁻³)	C_0	C_1	C_2	C_3	C_4	C_5	C_6	E_0 /MPa
1.29	0	0	0	0	0.4	0.4	0	0.25

The 2# rock emulsion explosive was used in the blasting process of the surrounding holes of Mingyueshan Tunnel, and its material model parameters are shown in Table 2 below.

Table 2. Model parameters of explosive materials

ρ /(kg·m⁻³)	D /(m·s⁻¹)	A /GPa	B / GPa	R_1	R_2	ω	E_0 /GPa
1050	3400	214.4	0.182	4.2	0.9	0.15	4.192

2.2   Grid division and boundary conditions

The method of sweeping is used to divide the grid, and the calculation amount can be kept in a reasonable range under the condition of being refined as much as possible. Due to the large size of the model, the number of divided units is large, reaching 1606320, and the number of bodies is 2586, of which 544 are explosives and 68 are mud, as shown in Figure 1. The model consists of four parts: air is Part1, explosive is Part2, rock is Part3 and mud is Part4. Between Part1 and Part2, ALE multi-material group is defined by the keyword *ALE_MULTI-MATERIAL_GROUP to ensure the mutual flow of fluid materials. In addition to the surface excavated inside the tunnel, all the other surfaces are set with non-reflective boundary conditions to simulate infinite rock mass to prevent the influence of reflected tensile stress waves on the calculation, as shown in Figure 2.
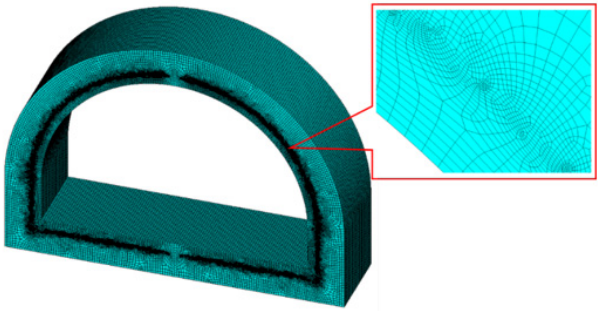

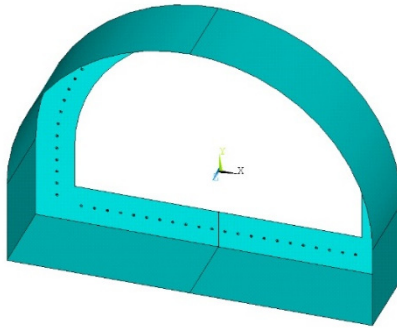**Fig. 1.** Meshing of the perimeter hole model

Fig. 2. Non-reflective boundary surface

3   Probe into the influence of external interpolation Angle of peripheral holes on overcut and undercut

3.1   External interpolation Angle condition

In order to study the influence of extrapolation Angle on overcut and undercut, based on the general situation of a tunnel project, the control decoupling coefficient =1.5, hole spacing =0.5 and other blasting parameters remain unchanged, and the extrapolation Angle=2.5°~7.5°. The specific values of extrapolation Angle and overcut depth are shown in Table 3 below.

Table 3. Angle interpolation conditions

Working condition	Extrapola- tion Angle θ /°	Orifice position e/cm	Hole depth L/m	Overdig depth h/cm
1	2.50	-10	3	3.1
2	3.75	-10	3	9.7
3	5.00	-10	3	16.2
4	6.25	-10	3	22.9
5	7.50	-10	3	29.5

3.2   Numerical simulation results

The output d3plot file after numerical simulation is imported into the LS-PREPOST post-processor, and the damage isosurface is displayed by selecting lsos view, and the damage cloud image with different extrapolation angles at the end when the uncoupling coefficient is 1.5 is extracted, as shown in Figure 3 below.
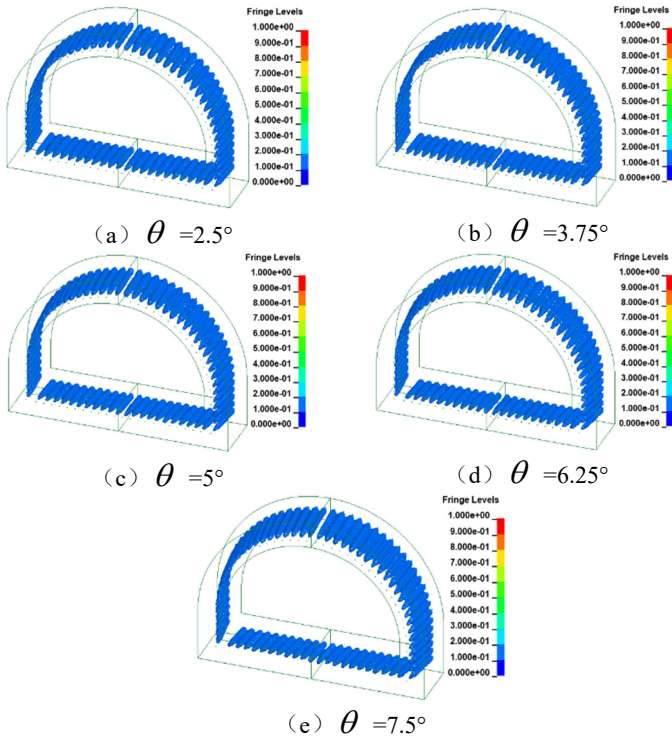
（a）θ =2.5°

（b）θ =3.75°

（c）θ =5°

（d）θ =6.25°

（e）θ =7.5°

Fig. 3. Damage equimeter at different moments

It can be seen from the above figure that the damage zone can be penetrated under all the five conditions of the extrapolation Angle, indicating that a flat tunnel profile can be formed. Moreover, with the increase of the extrapolation Angle, the outward expansion part of the damage zone will be larger, resulting in greater overdigging.

3.3   Analysis of numerical results

In order to study the overcutting condition of tunnel under different interpolation angles, the average overcutting value can be obtained by calculating the ratio of the overcutting area of each section to the circumference of the designed excavated section (excluding the tunnel bottom). The overdigging conditions of each section under 5 different interpolation angles are plotted in Figure 4.
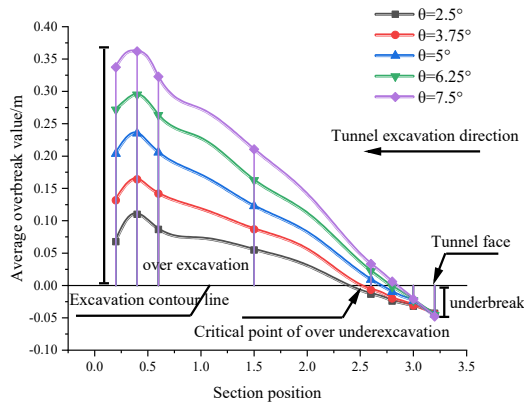
Fig. 4. Relationship between section position and average over-digging value under five inter-polation conditions

As can be seen from the figure above, the influence of external interpolation Angle on over digging is huge. The average overcut value at the bottom of the hole increases by about 5cm for every 1.25° increase in the interpolation Angle, so it is necessary to prioritize the control of the interpolation Angle. When the uncoupling coefficient remains unchanged, the average overcut value has a linear relationship with the location of the section, which is mainly affected by the 5 degrees of extrapolation Angle. Different uncoupling coefficients lead to different lengths of the palm surface from the critical point of overcutting and undercutting, ranging from 0.5 m to 0.8 m, and increasing with the decrease of the interpolation Angle. The average overcut value at the bottom of the hole reaches a maximum, and then there is a downward trend, because the damage to the rock to be exploded in the next cycle is between 10 and 15 cm.

It can be seen that as the section continues to advance along the tunneling direction, the average overcut value increases linearly, which is very similar to the relationship between the overcut depth and the hole depth. Therefore, the average overcut value is closely related to the overcut depth caused by the extrapolation Angle. In order to study this relationship, the average overcut value of each section is subtracted from the overcut depth to obtain the difference value, and the functional relationship between the section position Z and its difference value is drawn, as shown in Figure 5 below.
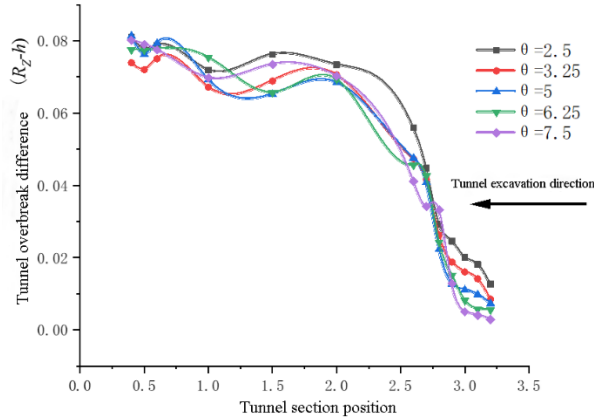
Fig. 5. Section position Z as a function of

It can be seen from the above figure that the difference between the average overcut value of the section and the overcut depth increases linearly in the range of 1/3 hole depth along the tunneling direction, and becomes stable in the range of the remaining 2/3 hole depth, and the difference is stable at 0.07m. The reason why the difference between the average overcut value and the overcut depth increased rapidly at first and then leveled off was that the hole blockage with a length of 0.44m reduced the charge concentration of this part of rock, resulting in the difference from small to large.

4   Field optimization application

The surrounding rock of a tunnel excavation project is grade III, and the engineering geology is mainly granite with good integrity. The external insertion Angle of the original blasting scheme is 5°. The extrapolation Angle is limited by the thickness of the initial branch, the distance from the initial branch to the face of the palm and the offset distance. Under the condition that the thickness of the initial support shotcrete is 10cm, the maximum design extrapolation. Angle is calculated based on equation (3.6) for different offset distances and follow-up distances between the initial support and the face of the face, and is arranged as shown in Table 4 below.

Table 4. Maximum design interpolation angle at different offset distances and initial support follow-up distances

θ / l/m e/cm	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
1	42.0	24.2	16.7	12.7	10.2	8.5	7.3	6.4	5.7	5.1
2	38.7	21.8	14.9	11.3	9.1	7.6	6.5	5.7	5.1	4.6
3	35.0	19.3	13.1	9.9	8.0	6.7	5.7	5.0	4.4	4.0
4	31.0	16.7	11.3	8.5	6.8	5.7	4.9	4.3	3.8	3.4

5	26.6	14.0	9.5	7.1	5.7	4.8	4.1	3.6	3.2	2.9
6	21.8	11.3	7.6	5.7	4.6	3.8	3.3	2.9	2.5	2.3
7	16.7	8.5	5.7	4.3	3.4	2.9	2.5	2.1	1.9	1.7
8	11.3	5.7	3.8	2.9	2.3	1.9	1.6	1.4	1.3	1.1
9	5.7	2.9	1.9	1.4	1.1	1.0	0.8	0.7	0.6	0.6

According to the above table, it can be seen that the extrapolation Angle is more reasonable in the range of 2°~3°. But the appropriate bias distance e should also be considered. The under-dug area can produce cracks with sufficient density due to blasting, so that it can be cleaned by pickaxes, excavators or hydraulic crushing hammers, etc. At the same time, the follow-up distance between the initial support and the palm surface should be as small as possible, so as to avoid excessive follow-up distance leading to excessive tunnel deformation. Comprehensive analysis shows that $e=7cm$、L $=0.6m$ and $\theta = 3°$ degrees are more reasonable.

In summary, after optimizing the tunnel blasting, the extrapolation $\theta = 3°$ and e $=7cm$ offset distance are obtained. The appeal conclusion is applied to the field blasting, and the specific parameters of the peripheral holes are shown in Table 5.

Table 5. Table of perimeter hole blasting parameters

Hole position	Hole depth /m	Pitch of holes /m	Plugging length /m	Single hole charge /kg	Uncoupling coefficient	Extrapolation Angle
Peripheral hole	3.2	0.45	0.44	0.6	1.5	3°

According to the field test results, the residual hole rate of smooth blasting in this stage reaches 92%, which indicates that the test parameters are reasonable. The amount of over-excavation is reduced by 19.3%, and the amount of under-excavation is reduced by 33.9%. For the under-excavation area, explosive blasting will produce cracks in the actual project, and the radius of the crack area is 10 to 15 times that of the charge radius. The rocks in the under-excavation area will inevitably produce cracks and cracks, and then the broken rocks will be separated from the surrounding rock by simple mechanical treatment. After simple treatment, the area can be basically free of undercut. The optimized blasting scheme is less undercut, which greatly reduces the work of prying the top of the arch and leveling the side wall.

5   Conclusions

In this paper, ANSYS/LS-DYNA numerical simulation technology is used to study the blasting parameters that have a great influence on the blasting effect of the peripheral holes, namely, the outer insertion Angle of the peripheral holes. The influence law of the external interpolation Angle on the tunnel overcut and undercut is obtained, and the

important significance of the external interpolation Angle of the peripheral holes on the smooth blasting effect is clarified. Specific conclusions are as follows:

(1) Through the simulation study, it is found that the average overcut value at the bottom of the gun hole increases by about 5cm when the interpolation Angle increases by 1.25°. Under the condition that the uncoupling coefficient remains unchanged, the average overcut value has a linear relationship with the section location.

(2) Through the simulation study, it is found that the average overcut value of the section is influenced by the overcut depth affected by the extrinsic Angle, the bias distance, and the charge structure (that is, the uncoupling coefficient) on the rock damage. According to the functional relation expression between the uncoupling coefficient of each section and the average overcut value under the two influencing factors, the functional relation expression between the average overcut value of the section and the hole position, the section position, the extruded Angle Angle, the uncoupling coefficient and the hole depth can be derived, and the average overcut value of each section can be calculated theoretically.

(3) The extrinsic Angle Angle can not be arbitrarily changed, it is limited by the thickness of the initial branch, the distance from the initial branch to the palm surface and the opening position, the actual extrinsic Angle Angle should be less than or equal to the maximum allowable extrinsic Angle.

Acknowledgements

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