Research on Influencing Factors of Reasonable Distance of Shallow Buried Close Tunnel in Weak Surrounding Rock

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Abstract: In order to study the influence of different spans, depths, heights and initial stresses on the reasonable clearance of shallow tunnels in weak surrounding rock. This article uses numerical simulation technology. The judging standard is whether the plastic zone of the middle rock pillar is through. The factors affecting the reasonable clear distance of the small clear tunnel are analysed. The results show that the reasonable clear distance of small-distance tunnels under shallow buried conditions gradually increases as the tunnel depth increases. The reasonable clearance distance of the tunnel increases as the lateral pressure coefficient of the surrounding rock decreases. For small-distance tunnels with the same buried depth and same span, the reasonable clearance increases as the tunnel height increases.

1. Introduction
At present, small-distance tunnels have become a common structural form in expressways and high-speed railways, and the influence of the excavation of the upward and downward pilot tunnels on the stability of surrounding rocks has become an important research content [1-3]. In recent years, the key technologies for the construction of small-clear-distance tunnels have been studied by many scholars, and there have been more results in the discussion of the reasonable clearance of small-distance tunnels. To determine the reasonable net distance, some researchers use methods such as yield proximity, intermediate rock column stress and strain to determine the reasonable net distance, and some scholars try to derive a simplified analytical solution [4-6].

In the current tunnel design specifications, the two factors of tunnel span and surrounding rock grade are used to define small-distance tunnels and separated tunnels. There are fewer factors considered, especially the safe clearance of large-section and small-distance tunnels [7-10]. However, there are many factors that determine the reasonable clear distance of a small clear distance tunnel. No matter what kind of research method currently has a certain limit to the study of this problem, many research results try to establish the relationship between the tunnel span and the reasonable clear distance, but simply establish the relationship between tunnel span and reasonable clear distance is of limited reference [11]. This paper will consider the conditions of different spans, depths, heights, and initial ground stresses, carry out a comparative analysis of numerical simulations, and study the influence of various factors on the reasonable clearance of small clearance tunnels.
2. Reasonable clear distances for different types of tunnels

2.1 Modeling

The "Code for Design of Highway Tunnels" provides two-lane and three-lane highway tunnel standard internal profile cross-section drawings. The "Code for Design of High-speed Railways" also provides 250km/h and 350km/h high-speed rail tunnel standards. The design results are generally slightly different from the standard drawings under the condition of meeting the requirements of the tunnel construction boundary. The different section tunnels in Table 1 are used as the objects of this numerical calculation. The tunnel excavation section parameters are derived from the actual engineering design drawings.

The V-level surrounding rock tunnel model is established through FLAC. The strength criterion is the Mohr-Coulomb criterion. The surrounding rock calculation parameters are shown in Table 2.

| Tab.1 Tunnel excavation section |
|-------------------------------|
| Tunnel type                     | Span/m | Height/m |
| Ordinary highway two-lane tunnel | 9.30   | 8.45     |
| Single-track high-speed rail with 250km/h | 9.66   | 9.96     |
| Single-track high-speed rail with 350km/h | 10.90  | 9.91     |
| Highway two-lane tunnel         | 12.60  | 10.60    |
| Highway three-lane tunnel       | 16.46  | 11.06    |

According to the "Code for Design of Highway Tunnels", the depth of the boundary between shallow tunnels and deep tunnels is related to the span of the tunnel. The two-lane secondary road tunnel in Table 1 has a boundary depth of about 26m in grade V surrounding rock. Based on this analysis, the remaining boundary depth of the tunnel is greater than 26m, so the buried depth of the model tunnels is uniformly taken as 25m, and all tunnel models are theoretically shallow tunnels.

The left and right boundaries of the model are 200m, the upper and lower boundaries are 100m, and the footage is 1m. The initial ground stress is formed by its own weight, and the lateral pressure coefficient (horizontal ground stress coefficient) \( \lambda \) is 0.5.

Considering the most unfavorable situation, all models do not apply supporting structures and excavate at one time. For the convenience of description, the expressway two-lane tunnel model in this group of models is called model 1 below. The model grid is listed in the following analysis results and is no longer listed here.

2.2 Calculation results

Establish small clear distance tunnel models with different clear distances for various types of tunnels. The plastic zone of the middle rock pillar is not connected as the safe clear distance. The distribution characteristics and reasonable clear distances of various tunnels are shown in Table 3.

| Tab.2 Physical and mechanical parameters of surrounding rock |
|-------------------------------------------------------------|
| Surrounding rock grade | V |
| Gravity / (kN \( \cdot \) m\(^{-3} \)) | 2.0 |
| Bulk modulus / GPa | 1.5 |
| Shear modulus / GPa | 0.562 |
| Internal friction angle / (°) | 26 |
| Cohesion / MPa | 0.1 |
| Tensile strength/ MPa | 0.045 |

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2.3 Result analysis

Figure 1 shows the relationship between the spans of different types of tunnels and the reasonable clear distances. Figure 2 shows the plastic zone when the two-lane tunnels on the secondary road and
the 250km/h single-track high-speed rail tunnel are separated from each other. The calculation results show that as the tunnel span increases, the reasonable clear distance also increases, but there is a non-linear relationship between the span of different types of tunnels and the reasonable clear distance. Compare the two-lane tunnels on the secondary highway and the 250km/h single-track high-speed rail. It can be seen that the reasonable clear distance of the tunnel is inappropriate to express the reasonable clear distance as a multiple of the span. From the perspective of the development depth of the plastic zone, the lowest point of the penetration zone is not much different, but the net distance of the tunnel is increasing during the calculation process, so the angle of the development direction of the plastic zone of the middle rock pillar is also increasing, which is determined in the tunnel design process. The sliding fracture angle should be corrected when surrounding rock pressure is applied.

![Fig.1 The relationship between tunnel span and reasonable clear distance](image)

**Fig.1** The relationship between tunnel span and reasonable clear distance

![Fig.2 Distribution of plastic zone in different tunnel spans](image)

**Fig.2** Distribution of plastic zone in different tunnel spans

3. The effect of buried depth on reasonable clearance

3.1 Modeling
The tunnel type is a two-lane highway tunnel. The surrounding rock is grade V. The parameters are shown in Tables 1 and 2. The lower boundary of model 1 remains unchanged, and the height of the upper boundary is increased to create a total of 25, 27, 29, 31, 33m respectively. For a buried deep tunnel model, see model 1 for initial ground stress and excavation support.

3.2 Calculation results
Establish models of different clear distances for various buried depth tunnels with small clear distances. The plastic zone in the middle rock pillar is not connected as the safe clear distance. The distribution characteristics and reasonable clear distances of the plastic zone under various buried depth conditions are shown in Table 4.

| Buried depth/m | Clear distance /m | Plastic zone /m |
|---------------|-------------------|-----------------|
| 25            | 20                | 78.5            |
| 27            | 21                | 80.6            |
| 29            | 22                | 81.7            |
| 31            | 24                | 82.7            |
| 33            | 25                | 83.5            |

3.3 Analysis of results
Figure 3 shows the relationship between the buried depth of the tunnel and the reasonable clear
distance. Figure 4 shows the plastic zone of surrounding rock with buried depths of 27 and 33 m. The calculation results show that the buried depth of the tunnel has a linear relationship with the reasonable clear distance. The greater the buried depth, the larger the reasonable clear distance. The height of the plastic penetration zone increases with the increase of the buried depth. As the buried depth of the tunnel increases, the pressure on the surrounding rock will increase, and the safe clear distance will increase accordingly. Within the foreseeable range, the reasonable clear distance of the small clear tunnel will change according to this law. The Mohr-Coulomb strength criterion determines the shear fracture angle of the surrounding rock by the principal stress. The calculation results also show that the angle of the development direction of the plastic zone of the middle rock pillar increases with the increase of the buried depth. Therefore, the design calculation of the surrounding rock pressure of the tunnel with small clear distance is carried out. At the same time, the effect of buried depth on the fracture angle should also be considered.

Fig.3 The relationship between tunnel buried depth and reasonable clear distance

Fig.4 Distribution of plastic zone in different tunnel buried depths

4. The influence of tunnel height on reasonable clear distance

4.1 Modeling
With reference to the span and height of the two-lane tunnel on the expressway, four tunnel models with a span of 12.6 m and a height of 10.6, 11.6, 12.6, and 13.6 m were established to facilitate the establishment of the model. The side walls of the tunnel are straight walls without inverts. The model is grade V surrounding rock. The parameters are shown in Table 2. The buried depth of the tunnel is 25m, and the lateral pressure coefficient \( \lambda = 0.5 \). The model boundary, initial ground stress and excavation support are the same as model 1.

4.2 Calculation results
Models of different clear distances are established for small clear distance tunnels of different heights, and the plastic zone in the middle rock pillar is not connected as the safe clear distance. The distribution characteristics and reasonable clear distance of the plastic zone under various conditions are shown in Table 5.

Tab.5 Characteristics of plastic zone and reasonable clear distance of different tunnel heights

| Tunnel heights/m | Clear distance /m | Plastic zone /m |
|------------------|-------------------|-----------------|
| 10.6             | 23                | 77.7            |
| 11.6             | 25                | 79.9            |
| 12.6             | 27                | 81.7            |
| 13.6             | 29                | 82.5            |
4.3 Analysis of results
Figure 5 shows the relationship between the tunnel height and the reasonable clear distance, and Figure 6 shows the plastic zone of the surrounding rock when the tunnel height is 10.6 and 13.6m. Under the condition of constant buried depth, there is a strong linear relationship between tunnel height and tunnel buried depth. Generally, the height increases by 1m, and the reasonable clear distance increases by 2m. This result is similar to the two-lane tunnel on the secondary road and the 250km/h single-track high-speed rail tunnel. The calculation results of reasonable clearance are similar. The calculation result when the tunnel height is 10.6m is different from the calculation result in Table 2. In Table 2, the reasonable clear distance calculation result of the two-lane tunnel on the secondary road is 20m. Here the calculation result of the tunnel model with the same span and height is 23m. It shows that the shape of the section has a significant impact on the redistribution of the surrounding rock stress field, and thus has a significant impact on the reasonable clear distance. The height of the plastic penetration zone of the middle rock column increases with the increase of the tunnel height, which also shows that the angle of the development direction of the surrounding rock plastic zone increases with the height. The design and calculation of the surrounding rock pressure should consider the influence of the shape and height of the tunnel section.

5. The influence of initial ground stress on reasonable clear distance

5.1 Modeling
The type of tunnel is a two-lane highway tunnel. The surrounding rock is grade V. The parameters are shown in Tables 1 and 2. The buried depth of the tunnel is 25m. The lateral pressure coefficient $\lambda = 0.5, 0.45, 0.4$. There are 4 tunnel models in total of 0.35. The model boundary and excavation support are the same as model 1.

5.2 Calculation results
Establish models of different clear distances for small clear distance tunnels with different lateral pressure coefficients. The plastic zone of the middle rock pillar is not connected as the safe clear distance. The distribution characteristics and reasonable clear distance of the plastic zone under various conditions are shown in Table 6.
Tab.6 Characteristics of plastic zone and reasonable clear distance of different lateral pressure coefficient

| The lateral pressure coefficient | Clear distance /m | Plastic zone /m |
|---------------------------------|-------------------|-----------------|
| 0.50                            | 20                | 78.5            |
| 0.45                            | 21                | 80.5            |
| 0.40                            | 23                | 84.4            |
| 0.35                            | 24                | 85.7            |

5.3 Analysis of results

Figure 7 shows the relationship between the lateral pressure coefficient and the reasonable clear distance of the tunnel, and Figure 8 shows the plastic zone distribution of the surrounding rock of the reasonable clear distance model when $\lambda = 0.4$ and $\lambda = 0.35$. As the lateral pressure coefficient decreases, the reasonable net distance increases, and the height of the plastic penetration zone on the upper part of the middle rock pillar increases, and the plastic zone at the arch toe of the middle rock pillar is obviously deeper than the arch waist. $\lambda = 0.35$ When the tunnel spacing reaches 28m, the plastic zone at the arch toe still penetrates. The lateral pressure coefficient determines the initial stress field of its own weight. The above calculation results show that the lateral pressure coefficient has a great influence on the stability of the surrounding rock. Therefore, the lateral pressure coefficient should be paid attention to when selecting a reasonable clear distance and supporting structure when designing a small clear distance tunnel.

Fig.7 The relationship between the lateral pressure coefficient and reasonable clear distance

![Fig.7 The relationship between the lateral pressure coefficient and reasonable clear distance](image)

Fig.8 Distribution of plastic zone in different lateral pressure coefficient

![Fig.8 Distribution of plastic zone in different lateral pressure coefficient](image)

6. Conclusion

Through numerical simulation and analysis of shallow-buried small-distance tunnels in weak surrounding rock under conditions of different spans, buried depths, heights and initial stresses, the following conclusions are obtained:

1. Span, as an important factor influencing the reasonable clear distance of a small clear tunnel, should not be the only decisive factor. The reasonable clear distance of a small clear tunnel increases as the tunnel span increases.

2. The reasonable clear distance of small clear tunnels will gradually increase as the buried depth of the tunnel increases. Within a foreseeable range, the reasonable clear spacing of small clear tunnels will change according to this rule.

3. The pressure coefficient of the surrounding rock decreases, and the reasonable clear distance of the tunnel with small clear distance increases, and the plastic penetration zone at the arch foot of the
middle rock column even appears before the arch waist. Pay attention to the side pressure coefficient.

(4) The height of the tunnel also has a certain impact on the reasonable clear distance of the small clear distance tunnel. For the small clear distance tunnel with the same buried depth and the same span, the reasonable clear distance increases with the height.

References
[1] Duan Huiling, Zhang Lin. Comparative study of reasonable excavation methods for large span highway tunnel[J]. Journal of Civil Engineering, 2009, 42(9): 114–119.
[2] Guo Jie. Analysis on construction safety of optimized double side drift method[J]. Tunnel Construction, 2014, 34(6):525.
[3] Gao Feng, Tan Xukai. Stability analysis on large section tunnel with double-side-drift method[J]. Journal of Chongqing Jiaotong University: Natural Science, 2010(3): 363.
[4] Hou Fujin, Sun Keguo, Zhao Ran, et al. Applicability study on construction method of super-large section neighborhood tunnel[J]. China Civil Engineering Journal, 2017, 50(S1): 111-116.
[5] Li Songtuo, Tan Zhongsheng, Du Wentao. Analysis on the mechanical behavior of the small spacing highway tunnel with super large cross section[J]. China Civil Engineering Journal, 2017, 50(S2): 292-296.
[6] Gao Haihong. Application of double side drift method in construction of extra-large cross-section hard rock station tunnel located in busy urban area[J]. Tunnel Construction, 2008, 28(2): 191.
[7] Huang Haibin, Zhou Ping, Chen Peng, et al. Theoretical research on different construction methods for double-line highway tunnel under-passing existing railway tunnel[J]. Railway standard design, 2016, 60(11):104.
[8] Zhang Tiezhu. Analysis of mechanical response of four-lane small clear spacing highway tunnel with super-large cross-section[J]. China Civil Engineering Journal, 2015, 48(S1): 302-305.
[9] Li Kexian, Li Shucai, Zhao Jizeng. Study on optimizing excavation construction of large span subway station[J]. Chinese Journal of Underground Space and Engineering, 2017, 10(13):72.
[10] Chen Qinghua. Construction technology for three-lane highway tunnels with large cross-sections located in soft ground[J]. Tunnel Construction, 2009, 29(S2): 77.
[11] Zhao Ying, Gao Mingsheng. On Tunneling Stability of Composite Initial Arch of Underground Metro Station in Karst Area [J]. Municipal Engineering Technology 2019, 37(03):137-140+144.