Numerical analysis of reasonable distance between tunnel faces for twin tunnel

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Abstract. Based on the MIDAS-GTS numerical analysis platform, the construction characteristics of the left and right holes of the newly-built twin tunnel with a large section and a small distance were systematically analyzed, and the evolution laws of the displacement changes of the tunnel and the mid-rock pillar under the left and right full-section tunnel method were studied. The results show that: (1) with the increase of the lag distance, the surface settlement decreases gradually. When the lag distance is greater than 2.0D, increasing the lag distance has little effect on the maximum settlement value. (2) The maximum value of the surface settlement trough occurs between the left and right tunnels, which is the superposition area affected by the two tunnels. (3) The increase of lag distance has little effect on the final horizontal displacement of arch waist and mid-rock pillar. Considering that the influence range of face excavation on the surrounding rock of the tunnel is within 15m, the lag distance should not be too large and should not be less than 15m. (4) With the decrease of the lag distance, the superposition effect of the twin tunnel becomes more and more obvious. With the increase of lag distance, this phenomenon begins to weaken obviously, and obvious separation phenomenon appears.

1. Introduction
Parallel tunnel with small clear distance can overcome the problems of separated tunnel in line extension and wiring outside the tunnel, as well as the problems of high cost, complex construction technology and difficult quality control of twin arch tunnel [1-2]. In the 1980s, domestic scholars carried out related researches on small clear distance tunnel. Liu Yanqing et al. [3] through the research on the construction technology of parallel super small clear distance tunnel, obtained many parameters and safety measures which are of great value for the construction of small clear distance tunnel; Kong Xiangxing [4] studied the surface deformation caused by the successive construction of the left and right tunnels of the tunnel, and the interaction between the soil mass and surrounding rock of the tunnel face; Yan Qixiang et al. [5] studied the force and deformation of small-distance tunnels through numerical simulation, and the results showed that the later the middle rock pillar is formed, the more favorable the stability of the surrounding rock; Tian Guobin et al. [6] used Ansys to study the lag distance of small clear tunnels and found that the best lag distance of small clear tunnels is 12m~24m; Gao Yijie [7] studied the lag distance of shallow buried tunnels and found that the dome
settlement, ground settlement and internal force of the supporting structure of the double-track tunnel are all greater than those of a single tunnel.

The structure of large cross-section and small clear distance tunnel is complex, and the construction process has a significant interaction. Especially for the area with rock column in the middle, the excavation of double tunnels will inevitably cause many disturbances to the rock column in the middle. As the most important part of the stability of the small clear distance tunnel, the mid-rock will have a crucial impact on the safety of the whole tunnel [8]. In order to ensure the stability of the tunnel, the selection of tunnel lag distance is very important, so it is of great significance to study the reasonable lag distance of small clear distance tunnel.

2. Project profile
The starting and ending mileage of the tunnel is 0+992.700~1+871.500, with a total length of 878.8m, of which 859m is the underground section. The cross-section of the two tunnels is the same, with the excavation width of about 13m, the height of about 11m, and the excavation section area of 123 square meter, which belongs to the super large section tunnel. The minimum clear distance between the two tunnels is 11.5m, which is a small clear distance tunnel. The buried depth of the tunnel portal is 7m ~ 27m, and the minimum buried depth is located at the portal, which belongs to the shallow buried single tunnel. The strata that the tunnel passes through are represented by pink gray granite, metamorphic granite and granodiorite, which are characterized by hardness. The grade of surrounding rock is grade III ~ IV.

3. Calculation model

3.1. Physical and mechanical parameters of surrounding rock and lining
Take the 48m range of the tunnel entrance section for analysis. The surrounding rock in the calculation range is granite as a whole, and the surrounding rock grade is III ~ IV. Refer to the geological survey report for parameter values, see Table 1 for details.

| Table 1. Physical and Mechanical Parameters of Surrounding Rock and Lining Materials. |
|---------------------------------|-------------|----------------------|-----------------|------------------|------------------|-----------------|
| Thickness/cm | Density ρ/(kN/m³) | Deformation modulus E/GPa | Poisson's ratio μ | Friction angle θ/° | Cohesion c/kPa |
|----------------|-----------------|----------------|-----------------|-----------------|-------------|
| Granite (III-IV) | 25 | 1.0 | 0.25 | 54 | 100 |
| Initial support | 20 | 24 | 68.0 | 0.2 |  |
| Final lining | 80 | 25 | 31.5 | 0.2 | |

3.2. Finite element model

In order to eliminate the calculation error, the left and right boundary of the model is about 4 times the width of the tunnel, which is 42m. The total width is 121m. The longitudinal length of the model is 48m. The distance between the lower boundary and the bottom of the tunnel is 3 times of the tunnel.
height, which is 28m. The upper boundary of the model is the actual surface elevation. The buried depth of the portal is about 7m, and the buried depth of 48m is about 27m.

The Mohr Coulomb elastic-plastic constitutive model is used for the surrounding rock, and the linear elastic constitutive model is used for the lining. 3D solid element is used for surrounding rock, and 2D plate element is used for primary support and secondary lining. The boundary conditions of the model are as follows: the surrounding of the finite element model is fixed by horizontal constraints, and the bottom of the model is fixed by a combination of horizontal and vertical constraints. Considering the accuracy of the calculation results, the local scope of the tunnel excavation is densified. The finite element model and mesh size of the tunnel are shown in Figure 1.

3.3. Selection of target section and key points
The entire tunnel is 48m long and is divided into 24 steps for excavation, that is, each cycle has a footage of 2m. The section 24m away from the tunnel portal is taken as the target section of numerical simulation, so as to compare the influence of different tunnel face staggering distance on the tunnel construction process. The specific key points are shown in Figure 2.

3.4. Different simulation conditions

In order to highlight the research purpose, the construction method and supporting lining are not analyzed, and the influence of longitudinal spacing of tunnel face on the stability of tunnel surrounding rock is mainly analyzed. Several simulation conditions are shown in Table 2.

| Different simulation conditions | Staggered distance between two faces | Excavation method |
|--------------------------------|-------------------------------------|------------------|
| Condition 1                   | 0.5D                                | After the left tunnel was excavated 6m, the two tunnels were excavated at the same time |
| Condition 2                   | 1.0D                                | After the left tunnel was excavated 12m, the two tunnels were excavated at the same time |
| Condition 3                   | 1.5D                                | After the left tunnel was excavated 18m, the two tunnels were excavated at the same time |
| Condition 4                   | 2.0D                                | After the left tunnel was excavated 24m, the two tunnels were excavated at the same time |
| Condition 5                   | 3.0D                                | After the left tunnel was excavated 36m, the two tunnels were excavated at the same time |

Note: D refers to the diameter of tunnel excavation.

4. Calculation results and analysis

4.1. Analysis of surface lateral settlement trough
Taking the section at 24m in the longitudinal direction as the target section, the comparison of settlement troughs under various working conditions is shown in Figure 3.
It can be seen from Figure 3 that when the lag distance is 0.5D, the maximum settlement value is 4.98mm. When the lag distance is 2.0D, the maximum settlement value is 4.58mm. Compared with 0.5D, the maximum value is reduced by 8%. When the lag distance continues to increase, the maximum value basically does not change.

The maximum value of the lateral settlement of the parallel tunnel is located at the rock column of the two tunnels, which is caused by the superposition effect of the excavation of the parallel tunnel. Therefore, it is necessary to monitor this position in the construction.

4.2. Analysis of vertical displacement of vault

Figures 4 and 5 show the vertical displacement curves of vault of key point 1 of left tunnel and key point 3 of right tunnel of target section.

It can be seen from Fig. 4 and Fig. 5 that the final settlement values of the left and right tunnel vault are basically the same under different lag distances, and are finally stabilized at a fixed value. From the calculation results, when the construction face is close to the target section, the settlement value begins to change obviously, and the lag distance of different face has little influence on the final settlement value.

From the vertical displacement curve of the left tunnel vault, it can be seen that the vertical displacement of the vault is consistent with different lag distances. Taking the lag distance of 1.0D for analysis, the curve is roughly divided into 3 sections, namely slow-steep-slow, corresponding to the 3 different settlement change rates. As the excavation progresses, the construction face gradually approaches the target section, and the rate of settlement change gradually increases. The position where the settlement of the key point changes the most is the position where the excavation reaches the target section. After reaching the target section position, as the construction face continues to be excavated, the settlement change rate gradually decreases. After approximately 15m, the settlement change rate becomes very small, that is, the face construction no longer affects the target section. Similarly, the vertical displacement of the right tunnel vault has the same law.

The variation of peak displacement of each lag distance in total settlement displacement value is shown in Table 3.

| Monitoring location | Settlement proportion under different lag distance |
|---------------------|---------------------------------------------------|
|                     | 0.5D | 1.0D | 1.5D | 2.0D | 3.0D |
| Left tunnel         | 24.27% | 24.03% | 23.84% | 23.79% | 23.79% |
| Right tunnel        | 25.12% | 25.00% | 25.15% | 24.74% | 24.74% |

It can be seen from Table 3 that as the lag distance of the excavation face increases, the proportion of the maximum settlement value of the excavation cycle in the total settlement displacement value has a decreasing trend. In conclusion, when the lag distance is kept above 2.0D, the settlement proportion is the smallest and tends to be stable, and the influence of the excavation of the subsequent tunnel on the first tunnel can be reduced.
4.3. Analysis of horizontal displacement of surrounding rock

4.3.1. Analysis of Horizontal Displacement of Arch Waist of Left and Right Tunnel

Figures 6 and 7 are graphs of the horizontal displacement of key point 2 of the left tunnel and the horizontal displacement of key point 4 of the right tunnel on the target section.

![Figure 6. Horizontal displacement curve of arch waist.](image)

![Figure 7. The final horizontal displacement curve of the arch waist.](image)

It can be seen from Fig. 6 that the trend of the horizontal displacement of the arch waist with the lag distance under different lag distances is basically the same, but the range of fluctuation increases with the increase of the lag distance. Take the lag distance 1.0D for analysis. When the tunnel face is far away from the target section, as the tunnel face advances, the convergence of the target section monitoring point is basically stable. When the excavation of the target section is completed, the key points appear obvious Horizontal displacement, and the affected range of key points is the excavation of the tunnel face within 15m. It can be seen from Figure 7 that the lag distance basically has no effect on the final horizontal displacement of the arch waist.

In summary, the lag distance basically has no effect on the final horizontal displacement of the arch waist, but has an impact on the horizontal displacement of the arch waist during the construction process. Considering the influence of the excavation work on the surrounding rock of the tunnel, the lag distance should be greater than 15m.

4.3.2. Analysis of horizontal displacement in core area of middle rock pillar

Figure 8 shows the horizontal displacement curve of key point 5 in the core area of rock pillar in the target section.

It can be seen from Figure 8 that the range of horizontal displacement fluctuation in the core area of the middle rock pillar increases with the increase of the excavation lag distance. The horizontal displacement value fluctuates from left to right. As the excavation progresses, the tunnel fluctuates to the left and then to the right, and the final horizontal displacement is basically unchanged.

![Figure 8. Horizontal displacement curve of the mid-rock pillar core area.](image)
5. Conclusion
In this paper, through the numerical simulation of parallel tunnels with large cross section and small clear distance at the entrance of Georgia, based on different lag distances, the following conclusions are drawn:

(1) For surface settlement, with the increase of lag distance, the value of lateral settlement gradually decreases, but when the lag distance is greater than 2.0D, the increase of lag distance has no effect on the maximum settlement.

(2) For the settlement of the tunnel vault, with the increase of the lag distance, the final settlement value of the tunnel vault basically does not change, but the proportion of the tunnel excavation cycle settlement gradually decreases, that is, the deformation of the vault at the completion of the tunnel construction step tends to decrease, which is more conducive to the stability of the tunnel construction process.

(3) The results show that the variation trend of horizontal displacement with the lag distance is basically the same at the arch waist and the core area of the rock pillar under different lag distances. Although the increase of the lag distance has no effect on the final horizontal displacement, the fluctuation range increases with the increase of the lag distance, which is not conducive to the stability of the tunnel. Considering that the influence range of tunnel excavation on tunnel surrounding rock is within 15m, the lag distance should not be too large and should not be less than 15m.

To sum up, the lag distance between two faces of parallel tunnel with large section and small clear distance should not be too small, and should be more than 15m of the influence range of excavation on the face. At the same time, the lag distance should not be too large. Too large lag distance will increase the horizontal fluctuation of surrounding rock, which is not conducive to the stability of the tunnel, but also affects the construction progress and the extension of construction period. In terms of safety, progress and economy, 2.0D is the most suitable lag distance.

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