Research on Influence Zoning of New Tunnels Crossing Existing Urban Roads by Orthogonal Design Considering Horizontal and Longitudinal Effects

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Abstract. The influence of this proximity system is essentially within the stress superposition region, the stability of the new tunnel underneath the existing urban road is analyzed by strength reduction method, and the ultimate shear strain is selected as the criterion of instability of surrounding rock. By comparing the single tunnel with the adjacent system of the tunnel to the existing urban road, at a safety factor difference of 0, as a partition threshold of the influence region, the mechanical calculation models of different tunnels near the existing urban roads are established under 192 working conditions. Through multifactor analysis of the calculation results, at the same time, considering that the influence of new tunnel excavation on existing urban roads is mainly longitudinal effect, and the influence of existing urban roads on new tunnels is mainly transverse effect, the influence range diagram of longitudinal and transverse effect is established, which provides reference for similar projects in the future.

1. Introduction
Tunnel excavation will break the original equilibrium state, cause a certain degree of disturbance to the surrounding rock and soil, make the urban road too large settlement, and finally destabilize. At present, most of the relevant researches on the impact zoning of tunnel approach to existing urban roads are based on a certain project, and the results obtained are not applicable and universal, and have no reference value for a large number of underpass and approach projects in China. In this thesis, at the same time, the ultimate shear strain is introduced as the criterion of safety factor, and the influence of different underpass position (orthogonal underpass, parallel underpass), different tunnel section form, different surrounding rock grade and other factors on the existing urban road is discussed in multi-dimension, and the general rule is summarized, which provides the corresponding technical reference for the future proximity engineering[1-5].
2. Strength Reduction

In the numerical limit analysis of rock and soil mass, the physical and mechanical strength index of rock and soil material (cohesion force and internal friction angle of rock and soil mass are reduced synchronously according to a certain proportion) or incremental loading is continuously reduced, so that the rock and soil material finally reaches the failure state and forms the failure surface in the numerical calculation. This finite element numerical limit analysis method is the strength reduction method.[6-7]

Taking Mohr-Coulomb material widely used in geotechnical engineering as an example,

$$\tau = \frac{c + \sigma \tan \varphi}{w} = \frac{c}{w} + \sigma \frac{\tan \varphi}{w} = \frac{c}{w} + \sigma \tan \varphi$$  \hspace{1cm} (1)

Of which

$$c = \frac{c}{w}, \tan \varphi = \frac{\tan \varphi}{w}$$  \hspace{1cm} (2)

Where: $c$ - is the cohesion of the geotechnical material itself; $\tau$ - is the reduced cohesion of the geotechnical material; $\varphi$ - is the angle of internal friction of the geotechnical material itself; $\varphi$ - is the reduced internal friction angle of the geotechnical material; $w$ - is the safety factor for strength reduction, i.e. Strength reserve factor for rock and soil.

3. Zoning Analysis of the Influence of Tunnels Crossing through Existing Urban Roads under Orthogonal Design Considering the Transverse and Longitudinal Effects.

3.1. Computational models and mechanical parameters

As shown in Figure 1, the Mohr-Coulomb yield criterion is used in numerical calculation. Considering the stress field according to the self-weight stress field, in order to weaken the boundary effect, the tunnel diameter of 5 times on both sides of the model tunnel and 3 times on the bottom of the model tunnel is taken. Many scholars have done sufficient research on the calculation of vehicle loads on the existing roads, and the value of 10kPa ~ 20kPa recommended by the Metro Code can be applied. In this calculation, 20kPa is taken as the equivalent static load. The stratum parameters are shown in Table 1.

![Figure 1. Schematic calculation model](image-url)
### 3.2. Calculation conditions

The working conditions of the tunnel crossing the existing urban roads are as shown in Table 2, with a total of 192 working conditions.

#### Table 2. Summary of working conditions of tunnels crossing existing urban roads under orthogonal conditions

| Surrounding rock grade | Tunnel Type | Span Ratio |
|------------------------|-------------|------------|
| III<sub>up</sub>, IV<sub>up</sub>, IV<sub>low</sub>, V<sub>low</sub> | Two-lane | 0.08 D, 0.16 D, 0.24 D, 0.40 D, 0.80 D, 1.2 D, 1.6 D, 2.0 D, 2.4 D, 2.8 D, 3.2 D, 3.6 D, 4.0 D, 4.4 D, 4.8 D, etc |
| III<sub>up</sub>, IV<sub>up</sub>, IV<sub>low</sub>, V<sub>low</sub> | Three-lane | 0.06 D, 0.12 D, 0.18 D, 0.30 D, 0.40 D, 0.60 D, 0.80 D, 1.2 D, 1.5 D, 1.8 D, 2.0 D, 2.4 D, 2.6 D, 3D, 3.2 D, etc |

### 3.3. Calculation results

Through the numerical calculation of the tunnel orthogonal underpass existing urban road under the influence factors of different lanes, different surrounding rock levels and different burial depths, the calculation results are summarized in Table 3.

#### Table 3. Summary of Safety Zoning of Tunnels Crossing Orthogonal Underpass Existing Urban Roads

| Surrounding rock grade | Influence zoning | Cover span ratio (H/D1) | Depth range (m) | Surrounding rock grade | Influence zoning | Cover span ratio (H/D2) | Depth range (m) |
|------------------------|------------------|------------------------|----------------|------------------------|------------------|------------------------|----------------|
| III                    | Strong influence | 0<K<0.3                | 0<H<3.7        | III                    | Strong influence | 0<K<0.4                | 0<H<6.8        |
|                        | Weak influence   | 0.3<K<1.2              | 3.77<H<15.1    |                        | Weak influence   | 0.4<K<1.2              | 6.84<H<20.53   |
|                        | No impact        | 1.2<K                  | 15.10<H        |                        | No impact        | 1.2<K                  | 20.53<H        |
| IV                     | Strong influence | 0<K<1.2                | 0<H<15.10      | IV                     | Strong influence | 0<K<1.2                | 0<H<20.53      |
|                        | Weak influence   | 1.2<K<2.0              | 15.1<H<25.16   |                        | Weak influence   | 1.2<K<1.8              | 20.53<H<30.80  |
|                        | No impact        | 2.0<K                  | 25.16<H        |                        | No impact        | 1.8<K                  | 30.80<H        |
| V                      | Strong influence | 0<K<2.0                | 0<H<25.16      | V                      | Strong influence | 0<K<1.8                | 0<H<30.80      |
By integrating the data and selecting the buried depths of 5m, 10m and 30m for consideration, the change rule of safety factor under different surrounding rocks and different tunnel spans is obtained as shown in Figure 2:

![Graph showing the change of safety factor under different tunnel depths and surrounding rock levels.](image)

**Figure 2. Variation of safety factor under multi-factors**

Selecting the maximum shear strain cloud picture of the partial buried depth, the failure mode of the tunnel crossing the existing urban road orthogonal to the change of the buried depth is obtained as shown in Figure 3. The failure mode of the tunnel crossing the existing urban road orthogonal to the change of the buried depth is as follows:

![Graph showing the variation of ultimate shear strain.](image)

**Figure 3. Variation of ultimate shear strain of proximity system under different burial depths**

Summarize the critical values of the strong and weak influence areas under different surrounding rock levels, and obtain the general zoning map of the tunnel crossing the existing urban roads orthogonal to each other, as shown in Figure 4:

![Zoning map of tunnels crossing existing urban roads.](image)

**Figure 4. Standard zoning diagram of two-lane and three-lane tunnels crossing the existing urban roads**

### Table: Influence Areas

| Influence | 2.0<\(K\)<2.8 | 25.16<\(H\)<35.2 |
|-----------|----------------|------------------|
| Weak      |                |                  |
| No impact | 2.8<\(K\)     | 35.22<\(H\)     |

Weak influence: 1.8<\(K\)<2.5

No impact: 2.5<\(K\) 42.78<\(H\)
3.4. Influence distribution considering longitudinal effects
Through numerical calculation and literature investigation, according to the Mohr-Coulomb criterion, the rupture angle is taken \(45^{\circ} + \phi/2\) as the oblique line drawn from the corner of the tunnel to the horizontal direction of \(45^{\circ} + \phi/2\), and the transverse effect can be approximately considered as the case of overloading above the tunnel. Similarly, the rupture angle is taken as \(45^{\circ} + \phi/2\) the oblique line drawn from the corner of the tunnel to the horizontal direction of \(45^{\circ} + \phi/2\), and the longitudinal and transverse influence distribution diagram is shown in Figs. 5.

![Figure 5](image_url)  
(a) Horizontal impact area(III, two-lane)  
(b) Vertical impact area(III, two-lane)  
(a) Horizontal impact area(IV, two-lane)  
(b) Vertical impact area(IV, two-lane)

4. Conclusion
The main conclusions are as follows:
1. With the increase of the buried depth, the overall safety factor of the adjacent system is the same as that of the single tunnel excavation when the new tunnel crosses the existing urban road orthogonally, and both of them increase at first and then decrease;
2. The influence of the tunnel on the existing urban roads is caused by the stress redistribution caused by the tunnel excavation and the superposition of the "bulb line" stress field of the existing urban roads. With the increase of tunnel buried depth, the range of stress superposition area shows a distribution rule of "large-scale superposition-reduction of superposition area-tangent of stress field boundary-no superposition of stress field";
3. The better the surrounding rock is, the less the influence of overlying span ratio (H/D) on the influence zone is. The range of strong influence and weak influence of three-lane tunnel is larger than that of two-lane tunnel.

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