Study of failure mechanisms of the face stability of shield tunnel

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Abstract

The tunnel working face easily collapses when tunneling is conducted in the composited formation, thus it is important to maintain the proper support pressure for the working face stability. The upper bound analysis is applied to analyze the working face stability by using the improved 3D kenimatically admissible mechanisms, and the formula of the minimum support pressure for the working face stability is obtained. The calculated results are a good agreement with the previous studies and engine practice. Results show that the failure mechanisms could be applied in evaluating the face stability of shield tunnel.

Keywords

tunnelling, face stability, shield, failure mechanisms.

1. Introduction

With the development of urban traffic congestion more and more, the city underground traffic is developping rapidly. In the current urban underground traffic tunnels construction, shield machines are widely used. Due to the complicated geological conditions, the subway construction in the process of surface instability caused by the surrounding soil of shield excavation collapse accidents sometimes happen[1,2]. Mostly adopted shield tunnel excavation face stability research lies in the determination of supporting pressure. The supporting pressure has lead to the collapse of the soil excavation surface, cause ground subsidence [3]; supporting stress will lead to the uplift of the soil excavation surface damage.

Domestic and foreign scholars have made corresponding study for shield tunnel excavation face stability. Silo theory is first applied to the shield excavation stability analysis by N. Horn[4]. On the basis of that, many scholars consider the influence of factors such as the soil arch effect and groundwater seepage and the silo model theory was improved[5]. B. b. Broms and h. Bennermark[6] hypothesis 2D destroy the motor field, and the limit analysis to get the minimum supporting force; . Jancsecz[7] by using the wedge body limit equilibrium model of shield tunnel excavation face minimum limit supporting force is studied.

Shield tail grouting is one of the most important measures to control the ground subsidence during the construction of shield tunnel. The main function of shield tail grouting is: (1) to fill in the gap of construction, control the formation damage; (2) the lining and the surrounding soil contact more evenly; (3) to enhance the effect of the water plugging. Bad shield tail grouting is divided into two kinds: grouting quantity is small and big. The grouting amount is too small will cause the subsidence of ground; grouting amount is too big will cause the ground elevation.

Based on shield under complex geological conditions of the construction, the excavation face stability limit analysis research, and puts forward the condition of shield excavation face the minimum supporting force calculation method.

2. Failure mechanisms of the face stability

Shield tunnel excavation stability question is generally: consider the tunnel excavation face at least need to exert much supporting pressure can maintain the excavation face stability. Shield tunnel excavation face are round.

This study based on the 3D limit analysis upper bound method.the logarithmic spiral failure model, as shown in Fig. 1.

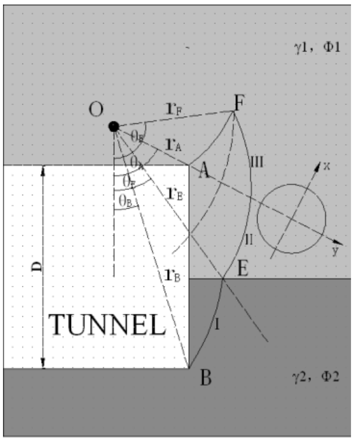

Fig. 1 Profile of logarithmic spiral failure model

2.1 Geometry deduce

The model is composed of three logarithmic spiral *AF, EF* and *BE*, point *O* is the center of the logarithmic spiral. Assuming that destroyed the logarithmic spiral area is angular velocity *Ω* for sliding. Tunnel diameter is *D*.

AF, EF, BE mathematical expressions are:

$$AF: \; r_1(\theta) = r_{OA} \exp[(\theta - \theta_A)\tan\phi_1] \tag{1}$$

$$EF: \; r_2(\theta) = r_{OE} \exp[(\theta_E - \theta)\tan\phi_1] \tag{2}$$

$$BE: \; r_3(\theta) = r_{OB} \exp[(\theta_B - \theta)\tan\phi_2] \tag{3}$$

Among them, r_{OA}, r_{OB}, r_{OE} are respectively the length of the *OA, OB* and *OE;* θ_A, θ_B, θ_E are respectively the angle of *OA, OB , OE* and initial heading Angle.

In the triangle *OAB* by sine theorem are:

$$r_{OA} \sin\theta_A = r_{OB} \sin\theta_B \tag{4}$$

$$D \sin\theta_A = r_{OB} \sin(\theta_A - \theta_B) \tag{5}$$

On the logarithmic spiral line *BE*, are:

$$r_{OE} = r_{OB} \exp[(\theta_B - \theta_E)\tan\phi_2] \tag{6}$$

On the logarithmic spiral line *AF*, are:

$$r_F = r_{OA} \exp[(\theta_F - \theta_A)\tan\phi_1] \tag{7}$$

On the logarithmic spiral line *FE*, are:

$$r_F = r_{OE} \exp[(\theta_E - \theta_F)\tan\phi_1] \tag{8}$$

Thus:

$$\theta_F = \frac{\ln\dfrac{\sin\theta_A}{\sin\theta_B} + (\theta_B - \theta_E)\tan\phi_2 + \theta_A \tan\phi_1 + \theta_E \tan\phi_2}{\tan\phi_1 + \tan\phi_2}$$

$$=\frac{\ln\frac{\sin\theta_A}{\sin\theta_B}+\theta_B\cdot\tan\phi_2+\theta_A\cdot\tan\phi_1}{\tan\phi_1+\tan\phi_2} \tag{9}$$

2.2 Geometry deduce

Soil gravity power calculation

Soil gravity power calculation mathematical expressions is:

$$W_\gamma=\int_V v_i\gamma_i dV=\gamma_i\int_{V_i} v_i\sin\theta dV_i \tag{10}$$

For each variable diameter circular cross section to establish right Angle coordinate system, the speed can be represented as:

$$v_i=\left(r_{m_i}+y\right)\omega \tag{11}$$

$$W_\gamma=\begin{bmatrix}2\omega\gamma_2\int_{\theta_B}^{\theta_E}\int_{a_1}^{R_1}\int_0^{\sqrt{R^2{}_1-y^2}}(\mathrm{r}_{m1}+\mathrm{y})^2\sin\theta dxdyd\theta\\ +2\omega\gamma_1\int_{\theta_E}^{\theta_A}\int_{a_2}^{R_2}\int_0^{\sqrt{R^2{}_2-y^2}}(\mathrm{r}_{m2}+\mathrm{y})^2\sin\theta dxdyd\theta+2\omega\gamma_1\int_{\theta_A}^{\theta_F}\int_{-R_2}^{R_2}\int_0^{\sqrt{R^2{}_2-y^2}}(\mathrm{r}_{m2}+\mathrm{y})^2\sin\theta dxdyd\theta\end{bmatrix} \tag{12}$$

Supporting pressure power

$$W_T=2\omega c\begin{bmatrix}\cot\phi_2\int_{\theta_B}^{\theta_E}\sqrt{R_1^2-a_1^2}\cdot\left(\frac{r_{OB}\sin\theta_B}{\sin\theta}\right)^2\cos\theta\frac{d\theta}{\sin\theta}+\\ \cot\phi_1\int_{\theta_E}^{\theta_A}\sqrt{R_2^2-a_2^2}\cdot\left(\frac{r_{OB}\sin\theta_B}{\sin\theta}\right)^2\cos\theta\frac{d\theta}{\sin\theta}\end{bmatrix} \tag{13}$$

Internal energy dissipation power

The collapse of the region can damage power dissipation can be expressed as:

$$D_\gamma=2\omega c\begin{bmatrix}\cot\phi_2\int_{\theta_B}^{\theta_E}\sqrt{R_1^2-a_1^2}\cdot\left(\frac{r_{OB}\sin\theta_B}{\sin\theta}\right)^2\cos\theta\frac{d\theta}{\sin\theta}+\\ \cot\phi_1\int_{\theta_E}^{\theta_A}\sqrt{R_2^2-a_2^2}\cdot\left(\frac{r_{OB}\sin\theta_B}{\sin\theta}\right)^2\cos\theta\frac{d\theta}{\sin\theta}\end{bmatrix} \tag{14}$$

Speed section between the *AF*:

$$\begin{aligned}D_{AF}&=\int_{\theta_A}^{\theta_F}c\left(\frac{r_1(\theta)}{\cos\phi_1}d\theta\right)\cdot\left[\omega r_1(\theta)\cos\phi_1\right]\\&=\frac{\omega c\left(r_{OA}\right)^2}{2\tan\phi_1}\left\{\exp\left[2\left(\theta_F-\theta_A\right)\tan\phi_1\right]-1\right\}\end{aligned} \tag{15}$$

According to upper limit theorem of limit analysis, the external force system, and internal energy dissipation power are equal, namely:

$$W_\gamma+W_T=D_\gamma+D_{AF}+D_{BE}+D_{EF} \tag{16}$$

The kinds are substituted into, the plastic may have to maintain a balance of support pressure:

$$\sigma_T=\sum\gamma_i\cdot D\cdot N_{\gamma i}-\sum c_i N_{ci} \tag{17}$$

3. Calculation model

Based on the above failure model of 3 d solid of revolution, when calculating in viscous layer of land collapse, the limit of the supporting force, and compared the results with previous scholars.

Assuming that the tunnel diameter D to 10 m, soil bulk density gamma=18.0 kN/m3, soil parameters are:

(I) phi = 17 °c = 7 kpa (soft clay); (ii) phi = 25 °, c = 10 kpa (hard clay).

The calculation results as shown in Fig. 2. We can see that: In this paper, the rotation of the damage model and the Mollon (2011, 2009) and Leca & Dormieux (1990) proposed by multiple block model for the limit of the supporting force results better. Compared with Mollon (2011), in the limits of soft clay and hard clay supporting force increase rate of 24.1% and 35.7% respectively. And the Mollon (2009) and Leca & Dormieux (1990) the limit support force compared to the results, improve the amplitude is more apparent.

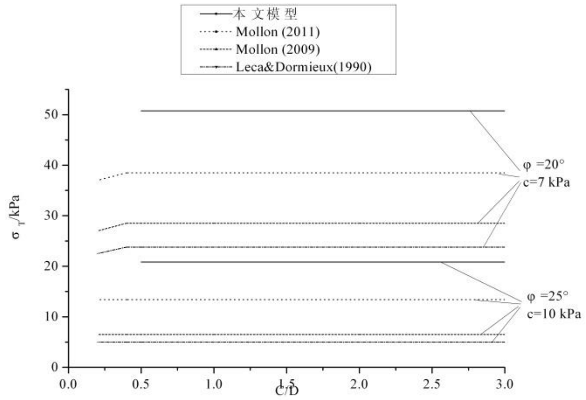

Fig. 2 Profile of calculation results

4. Conclusion

In this paper, based on limit analysis, and put forward the suitable for composite sandy soil layer is the precision estimation formula of shield tunneling face supporting force, expand the limit analysis in the scope of the application of shield excavation face stability analysis. The results show that: the number of excavation face spiral failure mode can be used in shield tunnel excavation face stability evaluation.

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