Investigating face stability of tunnels in clay using centrifuge model tests

Xianfeng Ma[1], C. Liu[1], L. He[2], and J. Xu[1]

[1]Department of Geotechnical Engineering, Tongji University, #1239,Siping Road, Shanghai, 200092, China
[2]Power Transmission and Transformation Engineering Research Institute, China Electric Power Research Institute, Beijing 102401, China.

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1. Introduction and test cases

Tunnel face stability has been studied through theoretical analyses (Perazzelli et al.2014), numerical approaches (Kim & Tonon 2010) and physical modellings (Le & Taylor 2016). In this paper centrifuge model tests were carried out in clay for detailed discussion. Half of the tunnel cross section was modeled taking advantages of symmetry, and electrical motor was used to push the face plate of the tunnel forward and backward, simulating conditions of excess and inadequate support pressure respectively. Fig.1 is the arrangement of the test system and Fig.2 is the tunnel model.

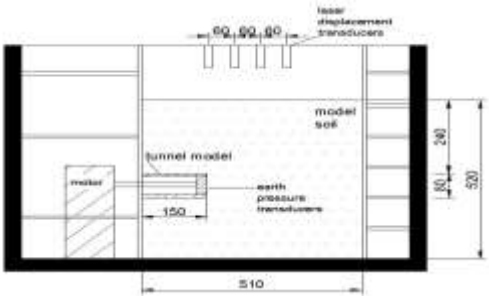

Fig. 1. Arrangement of test system

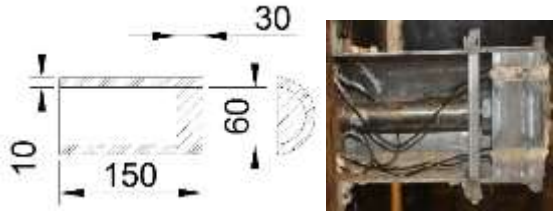

Fig. 2. Preparation of tunnel model

The parameters of the experimental soil and model tunnel are shown in Table 1 and Table 2.

Table 1 Parameters of the experimental soil

natural unit weight γ/(kN/m^3)	saturation unit weight γ_{sat}/(kN/m^3)	compression modulus E/MPa	Poisson ratio
17	18	3	0.46
cohesion c/kPa	internal friction angle φ/°	effective friction angle φ'/°	
30	18	25	

Table 2 Parameters of the shell tube

tensile stiffness EA	bending stiffness EI	inner diameter D	Length L	Thickness Δd
6.3×10^7 kN/m	4.8×10^5 kN·m^2/m	60mm	150 mm	10mm

Two test cases were carried out separately. The first one was mainly for the investigation of the passive failure pattern of the soil caused by pushing the face plate of the tunnel model to a significant distance (20mm). The second one was mainly for the investigation of the active failure pattern of the soil which caused by retreating of the face plate.

2. Test results

(a) Displacements on the ground surface

Fig.3 is the layout of displacement transducers above the ground surface and Fig.4 is the surface displacement versus face plate movement during face plate retreating.

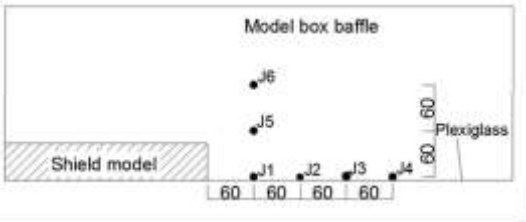

Fig. 3. Layout of laser displacement transducers (mm)

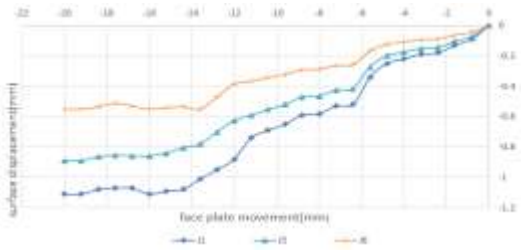

Fig.4. Surface displacement versus face plate movement during face plate retreating

In the research of Clough and Schmidt (1981), it is suggested that the relationship between the ground loss and displacement of the excavation surface is

$$V_L = \frac{\delta}{a} \tag{1}$$

Where V_L is the ground loss per unit length of the tunnel, δ is the average face displacement measured axially towards the tunnel, a is the tunnel radius.
The maximum settlement over the tunnel center-line (s_{max}) can be analyzed by Eq. (2).

$$V_L = 2.5is_{\max} \tag{2}$$

Fig. 5 shows the theoretical s_{max} calculated by Eq. (1), (2). It can be seen that the experimental value is slightly larger than the theoretical value, though generally both of them agree reasonably well.

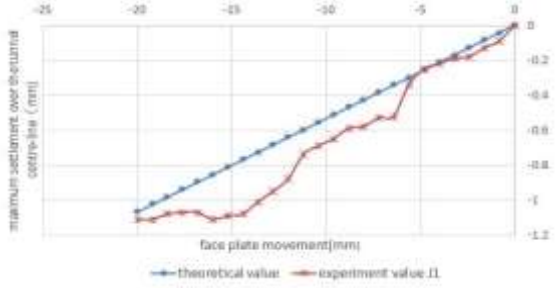

Fig. 5. Maximum settlement over the tunnel center-line versus face plate movement during tunnel model retreating

(b) Passive failure around tunnel face

The symbol λ is taken as the ratio of the supporting pressure (σ) to the calculated average earth pressure at rest (σ_0). The relationship between the pressure ratio λ and the observed maximum surface displacement were shown in Fig. 6, in which three stages can be identified.

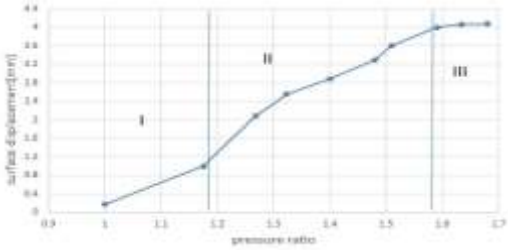

Fig. 6. Surface displacement versus pressure ratio λ during face plate advancing

In stage one, a small deformation occurs as the pressure ratio λ increases moderately from 1.0 to 1.18, indicating the tunnel face remains stable. In stage two, a dramatic increase in the surface displacement occurred, which reached 4.0 mm at λ=1.6. The majority of surface displacements that develop in this stage are accounted for until collapse, and the collapse continues to spread, which likely leads to passive failure. In stage three, the surface displacements increase slightly and remain stable afterwards. Based on the above analysis, the limit pressure ratio λ for passive failure around the tunnel face can be defined to be 1.18.

(c) Active failure around the tunnel face

Fig. 7 illustrates the three stages for the propagation of the surface settlement as the pressure ratio λ decreases. In stage one, the surface subsides only by approximately 0.2 mm, though the pressure ratio λ falls to nearly 0.4 from 1.0, down nearly 60%. However, the surface settlement has a steep drop in stage two as the pressure ratio λ changes from 0.4 to 0.1. The characteristics of this stage are a continual decrease of the ground surface, and a face instability around the tunnel should develop in this period. In stage three, the surface settlement suddenly drops to nearly 0.8 mm with a slight change in the pressure ratio λ. A face collapse is likely to occur in this period. Based on the relationship between the pressure ratio λ and the surface settlement, the limiting pressure ratio λ for active failure around tunnel face is defined to be 0.42.

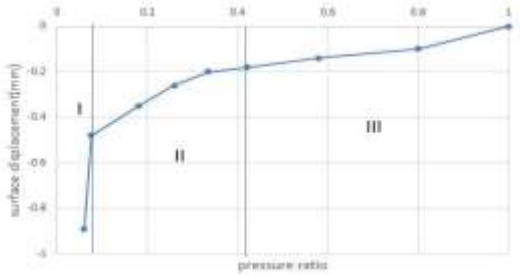

Fig. 7. Surface displacement versus pressure ratio λ during face plate retreating

3. Summary

1) The relationship between face plate movement and surface displacement was obtained. Volume loss during face plate retreating was discussed in terms of maximum settlement of the trough, and their relationship was checked against Clough's reference.

2) Limit supporting pressure ratio for passive failure of clay around tunnel face has been discussed in relation to the ground surface settlement. The recommend value of pressure ratio for tunnel construction is 1.0～1.18.

3) As for active failure, it is found that under the test condition, the ratio of face pressure to static earth pressure could be 0.42-1.0 while the surface settlement is still allowable.

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