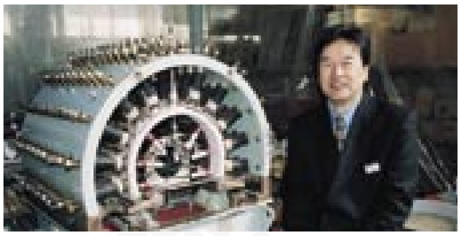
Evaluation of Tunnel Face Stability by the Rigid Plasticity Finite Element Method

Konishi, Shinji
Senior Researcher, Laboratory Head, Tunnel Engineering,
Structures Technology Division



The stability of tunnel faces is one of the most important subjects in the tunnel construction even in urban areas. We have been studying a method to evaluate the conditions for face stability through model tests and numerical analysis by the rigid plasticity finite element method. While taking note only on the plastic state of the ground, the rigid plasticity finite element method uses the upper bound theorem to formulate limit analysis by the finite element method, which aptly expresses the current state at the moment when the ground starts collapsing and, therefore, is effective for the evaluation of the bearing capacity and the stability of slopes and tunnel faces.

Figures 1 and 2 show the face collapsing process and the final state of collapse of the sandy ground observed in a model test, respectively. Figure 3 shows the results of simulation by the two-dimensional rigid plasticity finite element method, in which the arrow mark represents the displacement velocity vector. The result of simulation and the first stage of collapse are in good agreement.

In urban areas in Japan where alternate sand and cohesive soil layers are dominant, however, there are few homogeneous ground conditions. Therefore, we expressed the conditions for the face stability in the ground of alternate layers with apparent cohesion, internal friction angles, and cohesion of soil layers (Fig. 4). The zone on the left hand side indicates a combination of the conditions for face stability, and that on the right hand side a combination of the conditions for the face instability.

Figures 5 and 6 show the results of three-dimensional analysis. The distribution of vertical earth pressure in the horizontal section when the face collapses shows that the vertical earth pressure in the sliding area decreases due to stress re-distribution and that around it increases (Fig. 5). In the transversal section (Fig. 6), the vertical earth pressure decreases in the sliding area ahead of the face, and the stress in the ground increases around the shoulder outside the tunnel covering work. This means that the ground shall be reinforced at this position before excavation, if it is so desired, in order to secure face stability.

It is possible to apply the rigid plasticity finite element method to the evaluation of tunnel face stability even if it is under complicated ground conditions.

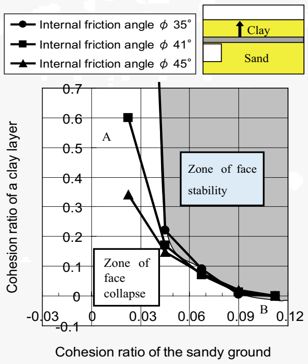


Figure 4. Conditions of cohesion in the sandy ground, internal friction angles, and cohesion of soil layers for the face stability in the ground of alternate sand and cohesive soil layers. The cohesion is normalized by the initial vertical earth pressure at the middle level of the tunnel. All the marks indicate the values dependent on the internal friction angle of the sandy ground.

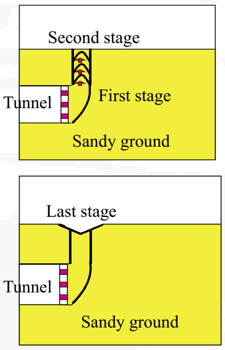


Figure 1. Process of face collapse in the sandy ground.

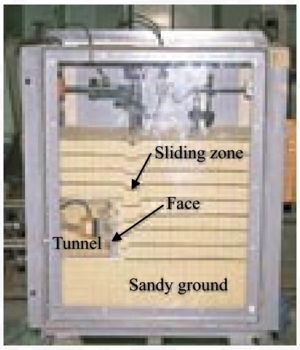


Figure 2. Face collapse in the sandy ground.

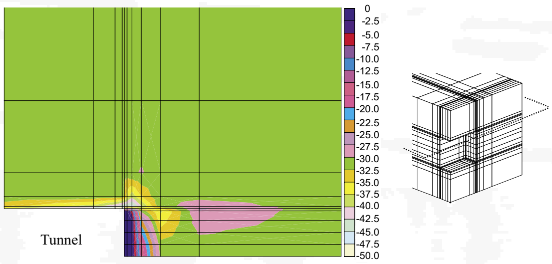


Figure 5. Distribution of vertical earth pressure in the horizontal section at face collapse (sandy ground, on the crown level). The graduation of the scale on the right hand side divides the maximum vertical earth pressure (8.49 kPa) into 20 fractions.

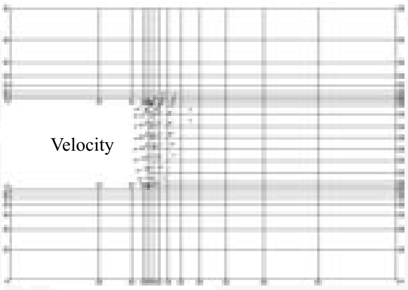


Figure 3. Results of analysis by the rigid plasticity finite element method (face collapse in the sandy ground).

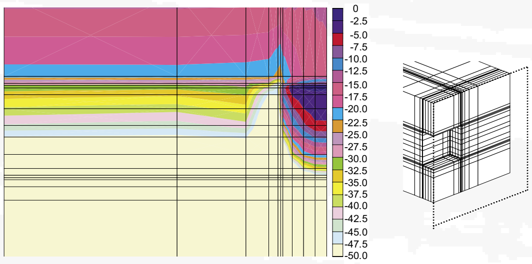


Figure 6. Distribution of vertical earth pressure in the transversal section at face collapse (sandy ground, ahead of the face). The graduation of the scale on the right hand side divides the maximum vertical earth pressure (8.49 kPa) into 20 fractions.