Development of a Testing Machine with a Large Tunnel Lining Model

Noriyuki OKANO
Senior Researcher, Tunnel Engineering, Structures Technology Division

1. Introduction

In evaluating the soundness of a tunnel and designing ground reinforcement work, it is extremely important to understand the mechanical behavior of the tunnel lining. However, the deformation of tunnel linings is difficult to understand since it depends largely on the action of the ground surrounding the tunnel, the occurrence of cracking in the lining, and other factors.

So far, the Railway Technical Research Institute (RTRI) has studied, with some tangible results, the influences of various loading patterns and structural defects, using a testing machine comprising 1/30 scale lining models with a standard Shinkansen tunnel cross section in experiments focused on the mechanical behavior of tunnel lining. However, since it was not always possible to quantitatively evaluate the mechanical behavior of the lining using a 1/30 scale model, the RTRI has developed a new testing machine with a larger lining model—a 1/5 scale model with a standard Shinkansen tunnel cross section.

2. Testing Machine

The scale of the testing machine is 1/5 of the standard cross section of a Shinkansen tunnel (Photo 1, Fig. 1). The testing machine is provided with a total of 27 loading points—nine loading points in the tunnel circumferential direction in each of three rows in the tunnel axial direction. Servo-actuators are used to apply loads. The system configuration and specifications of the apparatus are shown below.

(1) Loading equipment
- Hydraulic jacks for applying loads (with displacement and load meters)
  - Maximum working pressure:
    - Pressing force 500 kN (5.6 MPa)
  - Maximum stroke: 250 mm
  - Loading plate:
    - 300 mm sq. (lining-side curvature R = 1,075 mm)
- Hydraulic cylinders for applying reaction force (with ground springs)
  - Cylinder inside diameter: 125 mm
  - Maximum stroke: 200 mm
  - Rated pressure:
    - Normal 16.3 MPa (equivalent to 200 kN)
  - Conical spring:
    - OD 200 mm x ID 102 mm x thickness 12 mm
    - 20 pieces/point; spring constant 30 kN/cm

  After a hydraulic cylinder load is set, the load is retained by a stop valve. Any deformation load after that is received by the conical spring deformation.
- Reaction force frame
  - Dimensions:
    - 5,600 mm W x 1,200 mm D x 3,860 mm H
  - Mass:
    - Approx. 30 kN (main frame only)

(2) Hydraulic equipment
- Air-cooled hydraulic unit (rated pressure: normal 20.5 MPa)

(3) Lining model
- 1/5 scale model (R = 925 mm) of standard cross section of a Shinkansen tunnel
  - Dimensions:
    - Width 1,850 mm (within SL) x height 1,175 mm (inside height) x wall thickness 150 mm x depth 300 to 1,200 mm

3. Example of Load Test

An example of a one-point vertical load test is given below. A test load was applied stepwise, with displacement control for 0.5 mm push of the loading plate in each step. After a displacement was given, the test piece was left for one minute. Then the measurement data was input and the test piece was examined for cracks. The lining material was plain concrete (fck = 21 MPa), and the model depth was 300 mm—the width of the row of loading plates. The load-displacement curve obtained is shown in Fig. 2 and the conditions of cracking and deformation are shown in Photo 2 and Fig. 3.

In this particular example, the lining that was subjected to the test load showed elastic behavior at first. Even after it cracked and flexural compressive fracturing occurred, the load continued increasing, although the rate of increase declined. The lining remained in a state of ductile fracture for some time even after the peak load was reached, and then the load began decreasing, resulting in the ultimate state of the lining.

4. Conclusion

In the future, the RTRI intends to use the new testing machine to establish methods for evaluation of mechanical soundness and for reinforcement of tunnel linings.

Photo 1 Appearance of newly developed testing machine

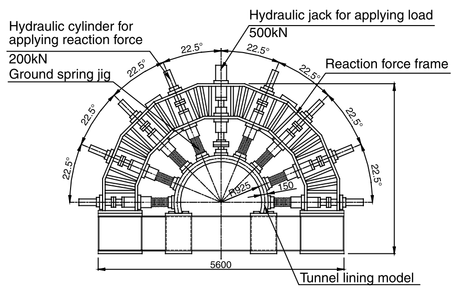

Fig. 1 Outline of testing machine

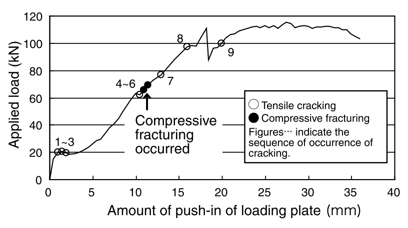

Fig. 2 Load-displacement curve

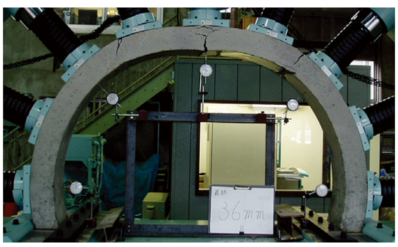

Photo 2 State of cracking and deformation (at final push-in)

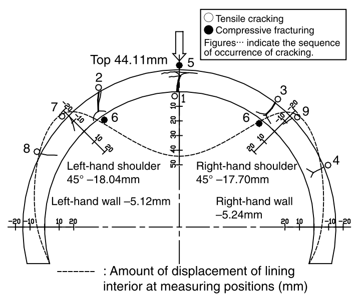

Fig. 3 State of cracking and deformation (at final push-in)