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Soil effect on the bearing capacity of a double-lining structure under internal water pressure

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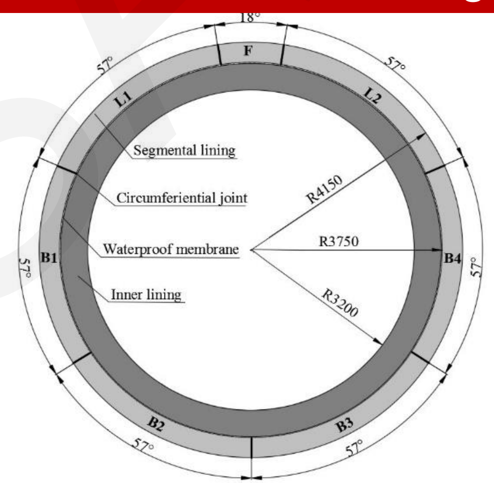
Engineering background

- **The development of long-distance and large-scale water conveyance projects has become a hot spot of national infrastructure construction**

Shield tunnel with double-lining structure

Challenges

- **Deep buried**
- **High internal water pressure**
- **Complex soil conditions**
- **High performance requirements**



Pearl River Delta water resources allocation Project

- **So far, the effect of surrounding soil has been conventionally regarded as an external load. In fact, the soil also provides resistance to constrain tunnel deformation under internal water, which has been ignored.**
- **In this study, the soil effect on the double-lining structure under internal water pressure is investigated through model tests and an analytical solution**

Design of model test

■ Loading system

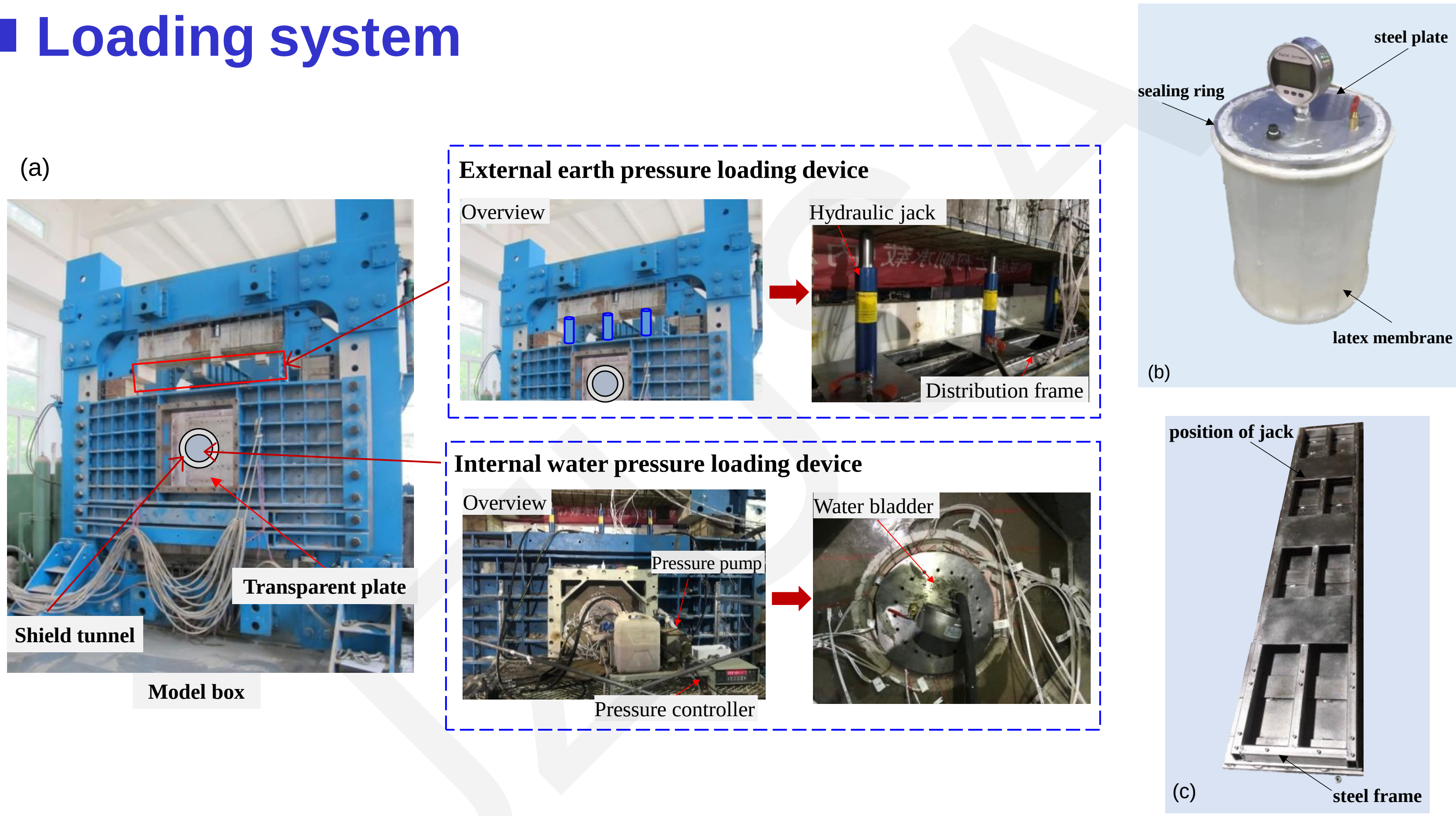


Fig. 1. Loading system designed for the model test under internal water pressure conditions: (a) system composition; (b) water bladder; (c) distribution frame

Design of model test

■ Modelling of double-lining

Fig. 4. Schematic of the double-lining model: (a) three-dimensional view; (b) cross sectional view (Unit: mm)

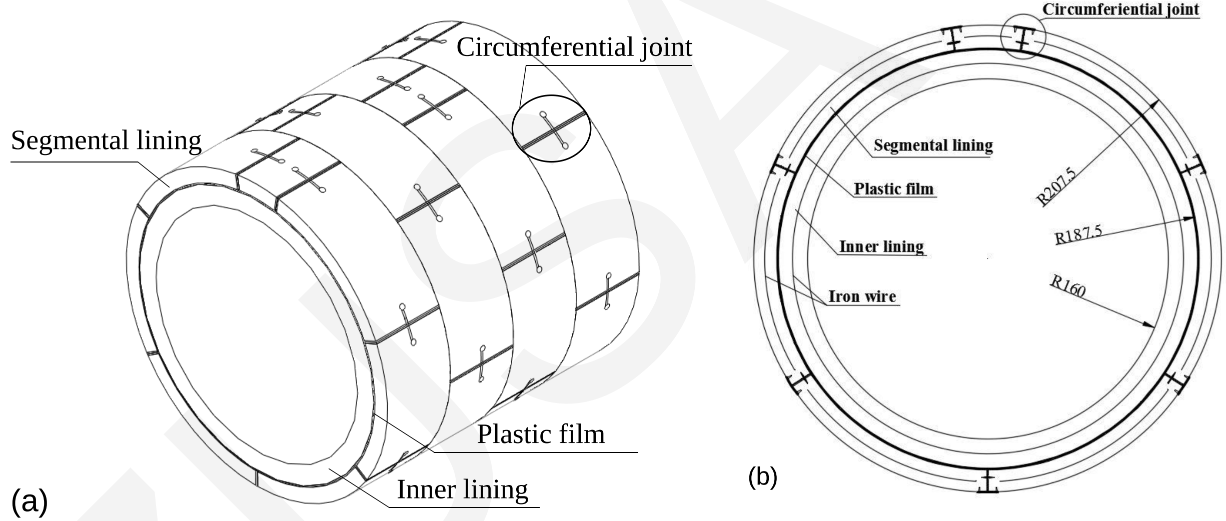
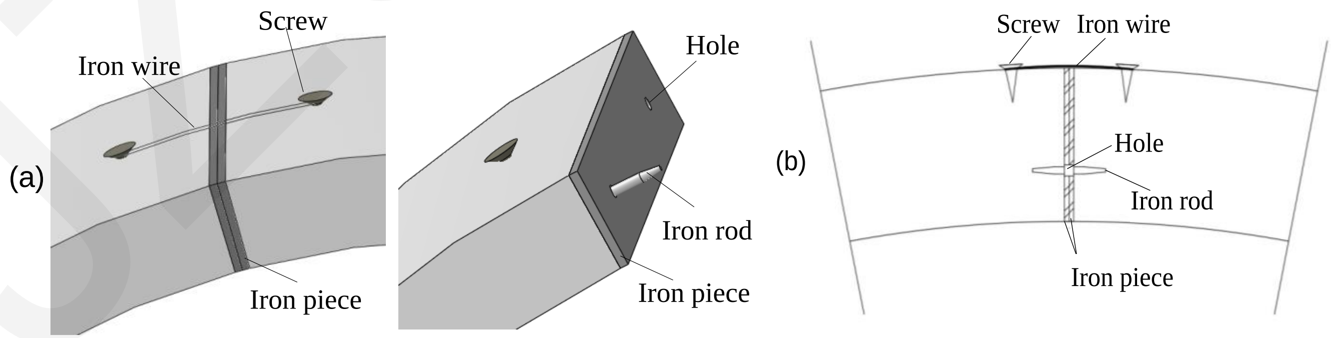


Fig. 6. Detailed illustration of the circumferential joint: (a) three-dimensional view; (b) cross sectional view



Result of model test

■ Variation of earth pressure

Contribution of soil to internal water pressure: $\eta = \frac{\Delta S}{p_w}$

ΔS → **Increment of earth pressure**

p_w → **internal water pressure**

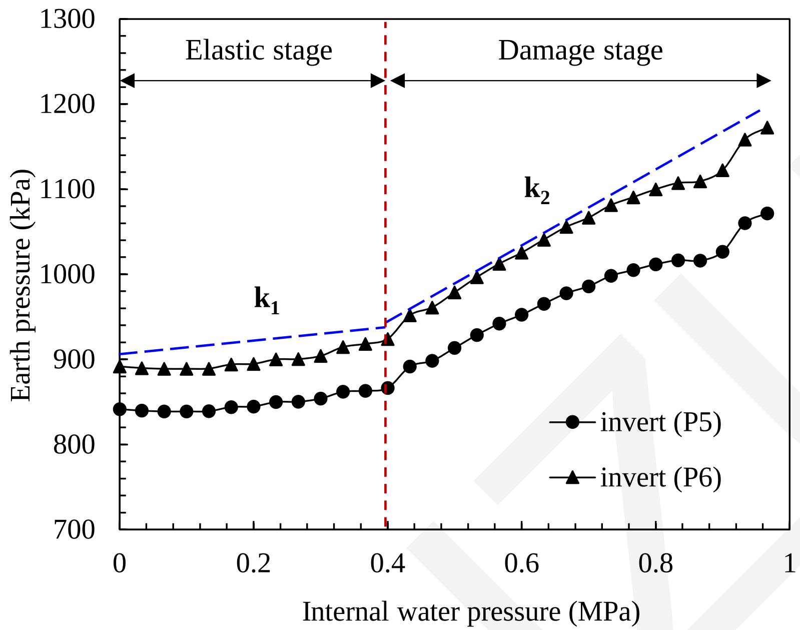


Fig. 12. Variation of earth pressure with internal water pressure under the highly weathered argillaceous siltstone condition

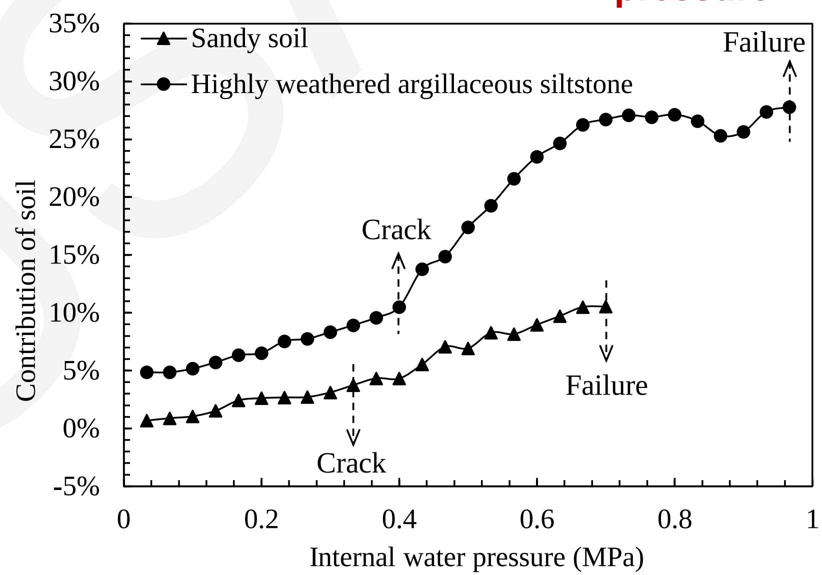
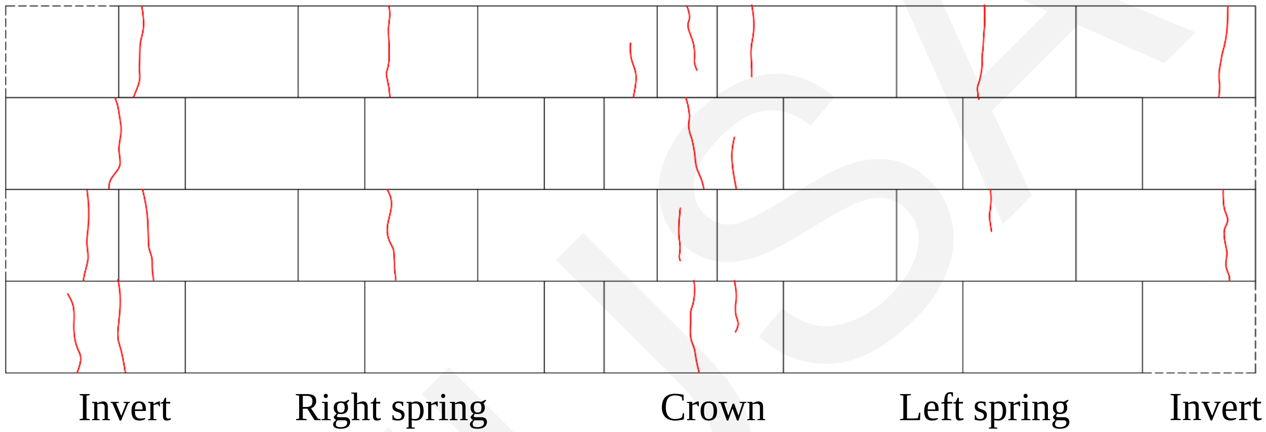


Fig. 14. Contribution of soil under different soil conditions

Result of model test

■ Failure mode

(a)



(b)

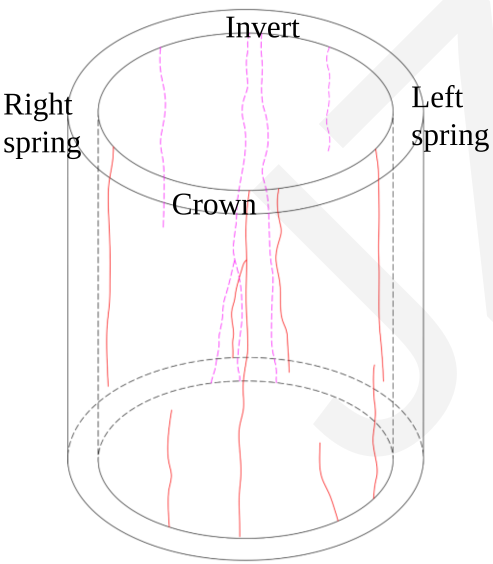


Fig. 15. Crack distribution in the double-lining structure: (a) segmental lining; (b) inner lining

Analytical solution

Analytical model for double-lining

- Based on thick-walled cylinder theory
- Considering the axial stiffness of the segmental lining influenced by the circumferential joint
- Considering the reduced axial stiffness of the inner lining after cracking

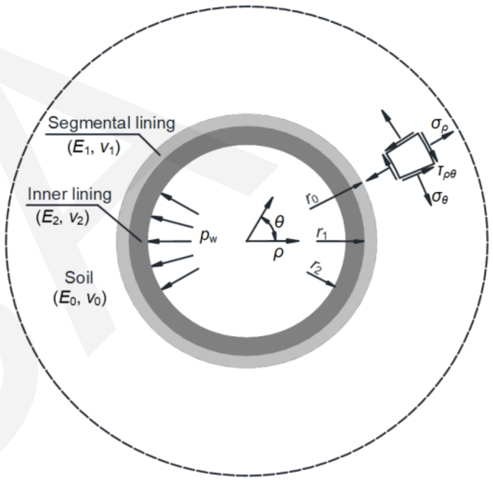


Fig. 18. Mechanical model of the double-lining under internal water pressure

Verification of analytical solution

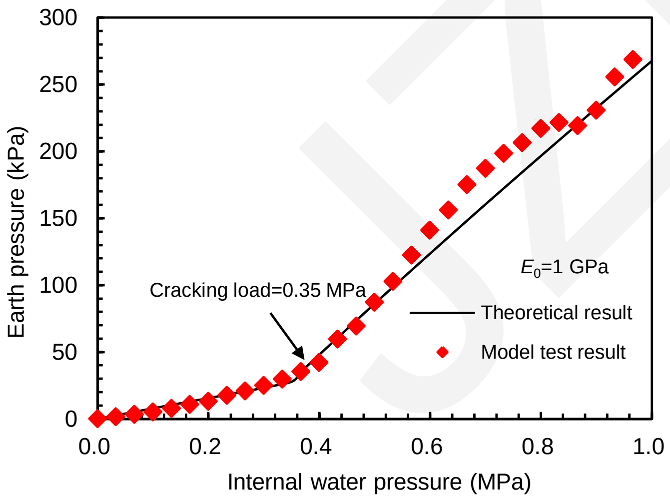


Fig. 21. Comparison between model test and theoretical results

Analytical solution

■ Soil contribution

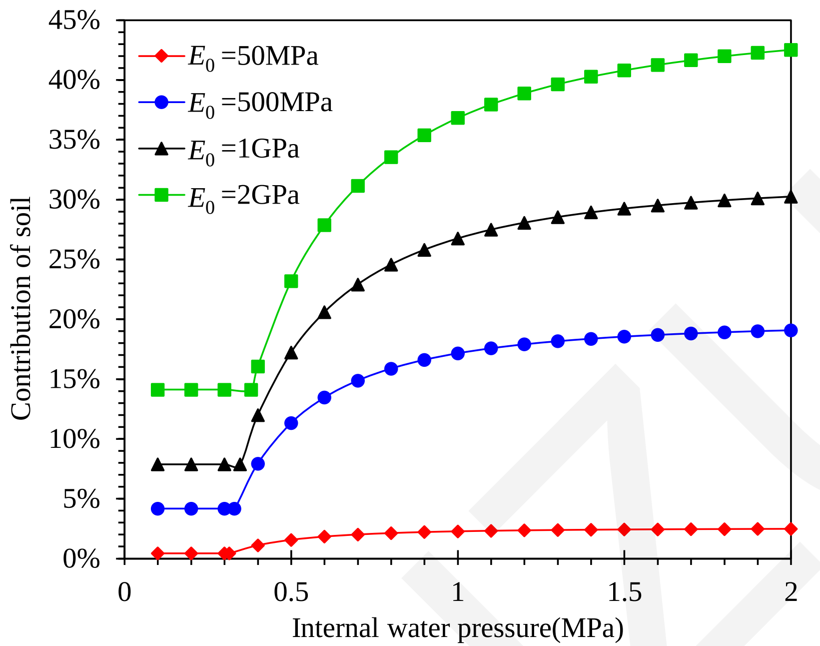


Fig. 22. Variation of soil contribution with internal water pressure

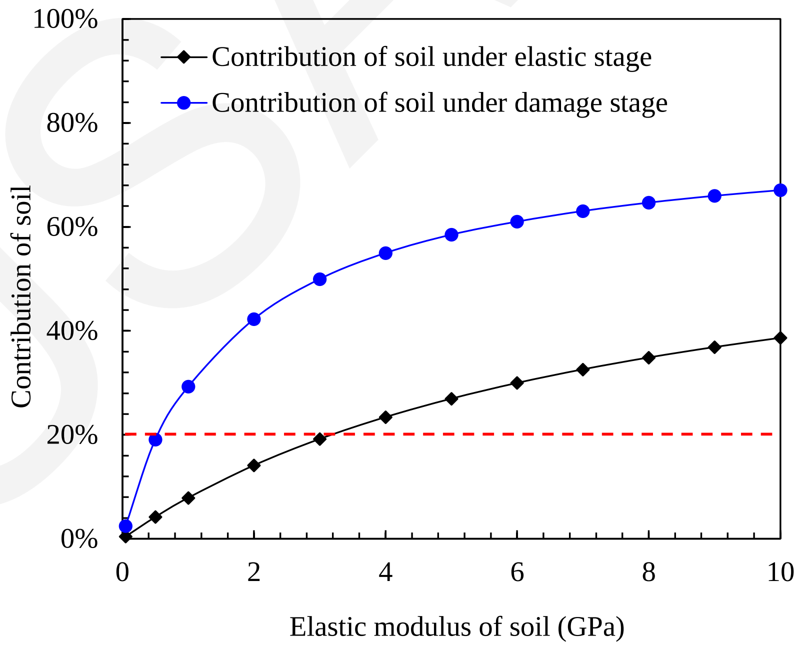


Fig. 23. Variation of soil contribution with the elastic modulus of soil

Conclusions

- Before the double-lining cracks, the contribution to the bearing capacity of the tunnel is 3.7% for the sandy soil; it increases to 10.4% for the highly weathered argillaceous siltstone. As a result, the double-lining cracks when the internal water pressure is 0.33 MPa under sandy soil, while it cracks at 0.40 MPa under highly weathered argillaceous siltstone.
- After the double-lining cracks, the soil plays a more vital role in bearing internal water pressure. The contribution increases to 10.5% for the sandy soil, and 27.8% for the highly weathered argillaceous siltstone. Thus, the ultimate bearing capacity of double-lining rises from 0.70 MPa to 0.97 MPa when the soil condition changes from sandy soil to highly weathered argillaceous siltstone.
- The contribution of soil to the bearing capacity increases with the elastic modulus of soil. As the elastic modulus of soil increases to 3 GPa in the elastic stage and 500 MPa in the damage stage, the contribution of soil reaches about 20%, which should be considered at the design stage.