Mechanism and mitigation of earth fissure in China

Chang'an University Jianbing Peng

e-mail:dicexy_1@chd.edu.cn

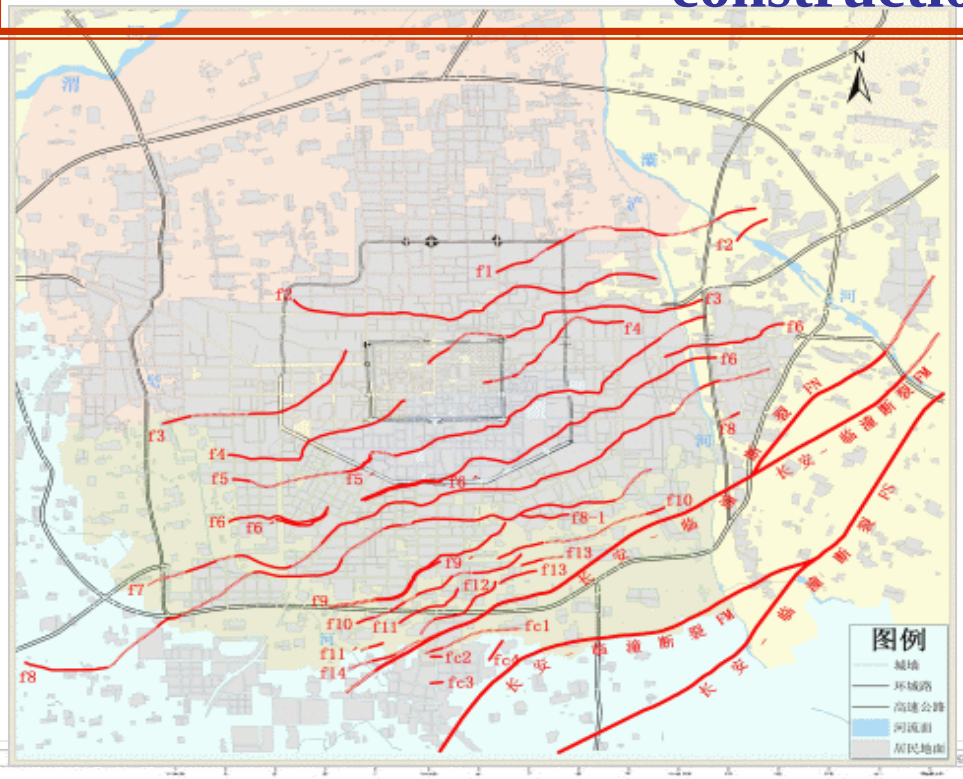
April. 2017

Main achievement

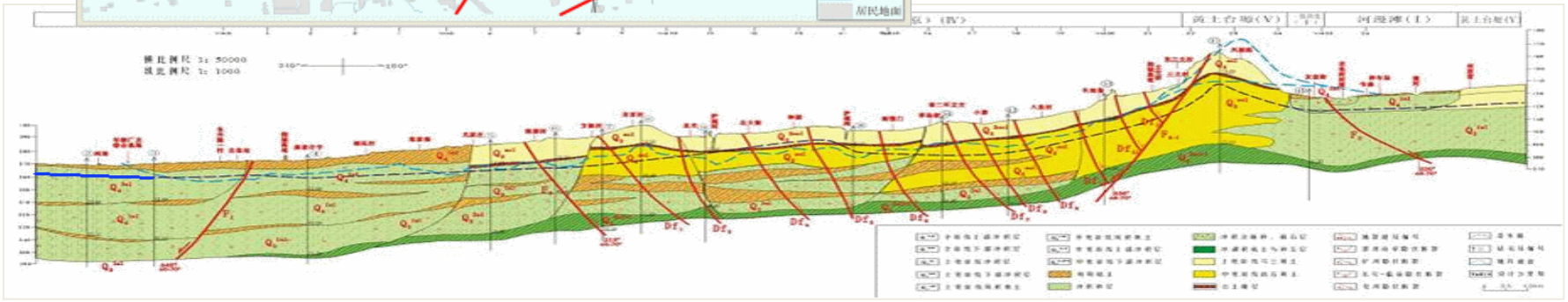
6: Failure modes of high-speed railway and metro. Engineering construction design.

Main achievement

The intersections of Xi′an Metro and ground fissures up to hundreds, which makes a serious threat on Xi′an metro construction.

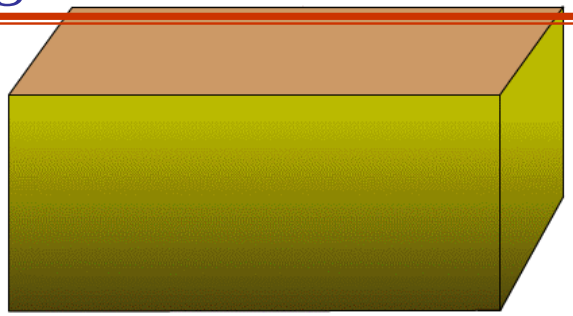


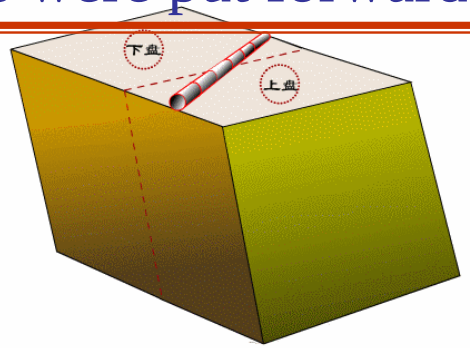
1. fortified length?
2. Failure modes?
3. Countermeasures?



Main achievement

The calculation formula and design values of parameters for tunnel passing through the ground fissure active zones were put forward.





Reserved displacement :

$$a'b = oa' \cdot \sin(90^0 - \theta) = \frac{H}{tg\beta}\cos\theta$$

（horizontal）

$$ab = oa' \cdot \cos(90^0 - \theta) = \frac{H}{tg\beta}\sin\theta$$

（longitual）

Longitudinal fortified length of tunnel：

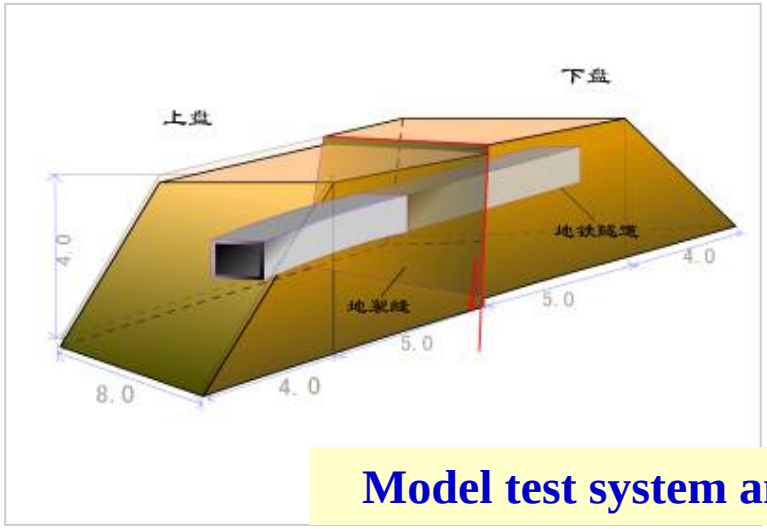
$$L = L_1 + L_2 = \frac{D_1}{\sin\theta} + \frac{D_2}{\sin\theta} = (D_1 + D_2)/\sin\theta$$

Average vertical dislocations in design lifetime of 100 years (cm)

地裂缝名 称	f_2	f_3	$f_{朝阳门外}$	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}	f_{11}	f_{12}
地铁2号线	225	300			450	500	300	300	300	225	450	150
地铁1号线		500/150	150	150	600	600/300						

Main achievement

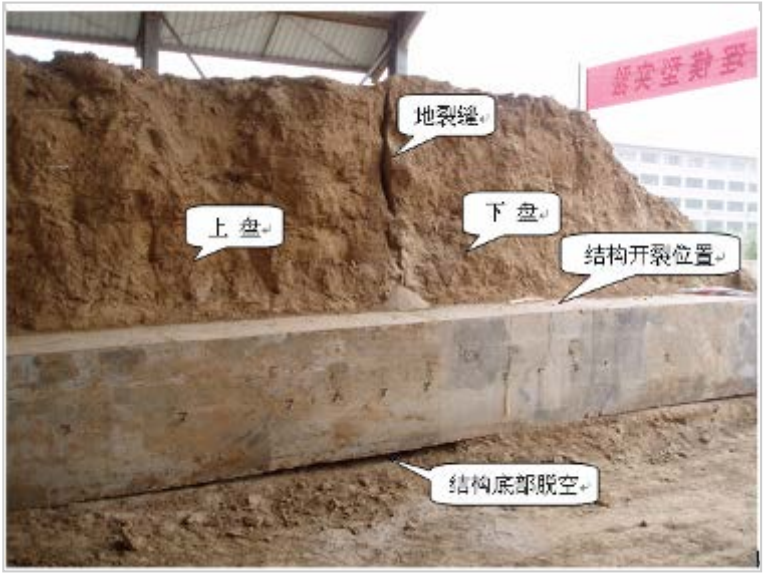
Large-scale model test of ground fissures was developed, and the mechanism as well as failure process on metro tunnel was simulated.

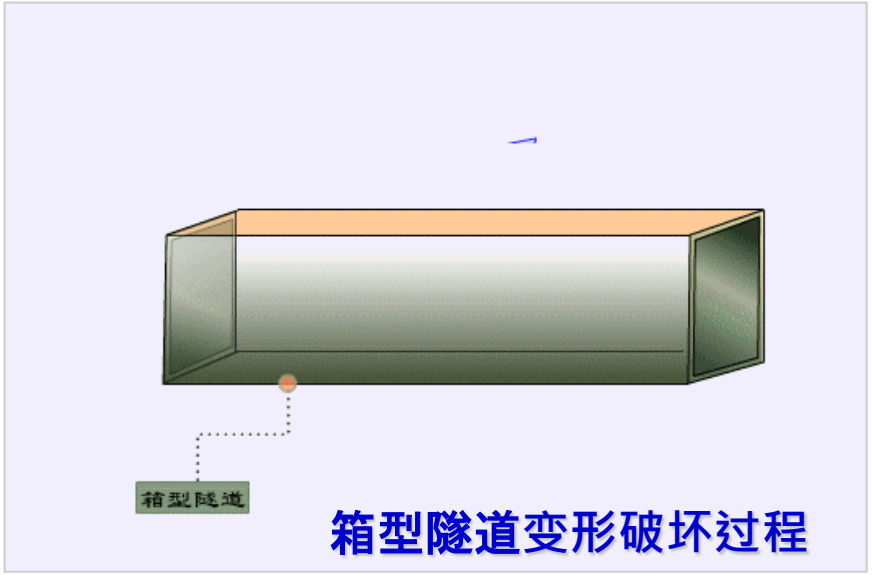


Model test system and full view of model test

Main achievement

Large-scale model test of open excavation metro tunnel passing through the active ground fissure (1:5)



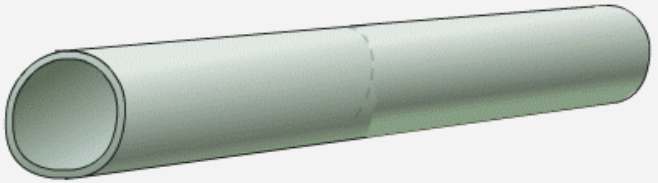


箱型隧道变形破坏过程

Annular cracks occurred on the footwall.

Main achievement

Large-scale model test of horseshoe tunnel passing through the active ground fissure (1:5)

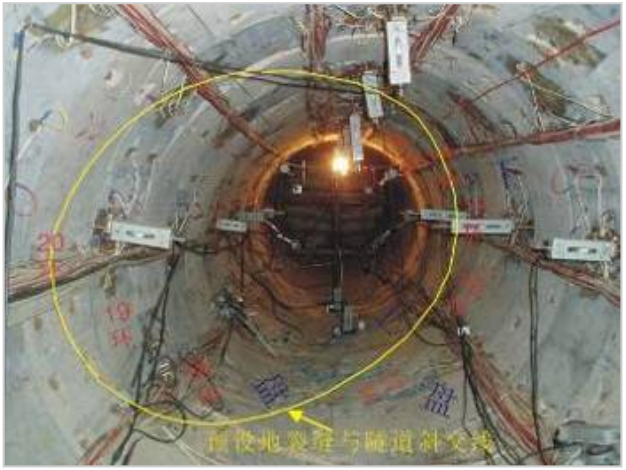


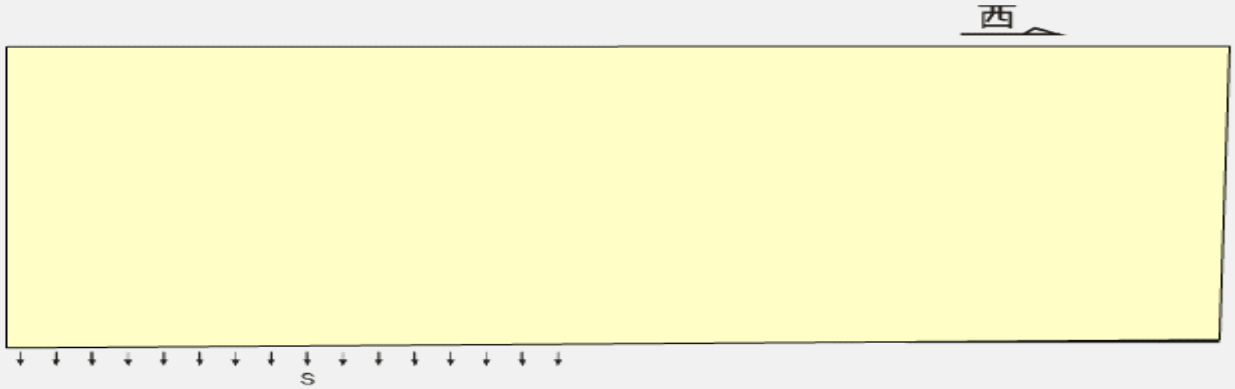
马蹄形隧道变形破坏力学过程

Annular and longitudinal cracks occurred on the hanging wall and footwall

Main achievement

Large-scale model test of shield tunnel passing through ground fissure (1:5)





Deformation and failure process

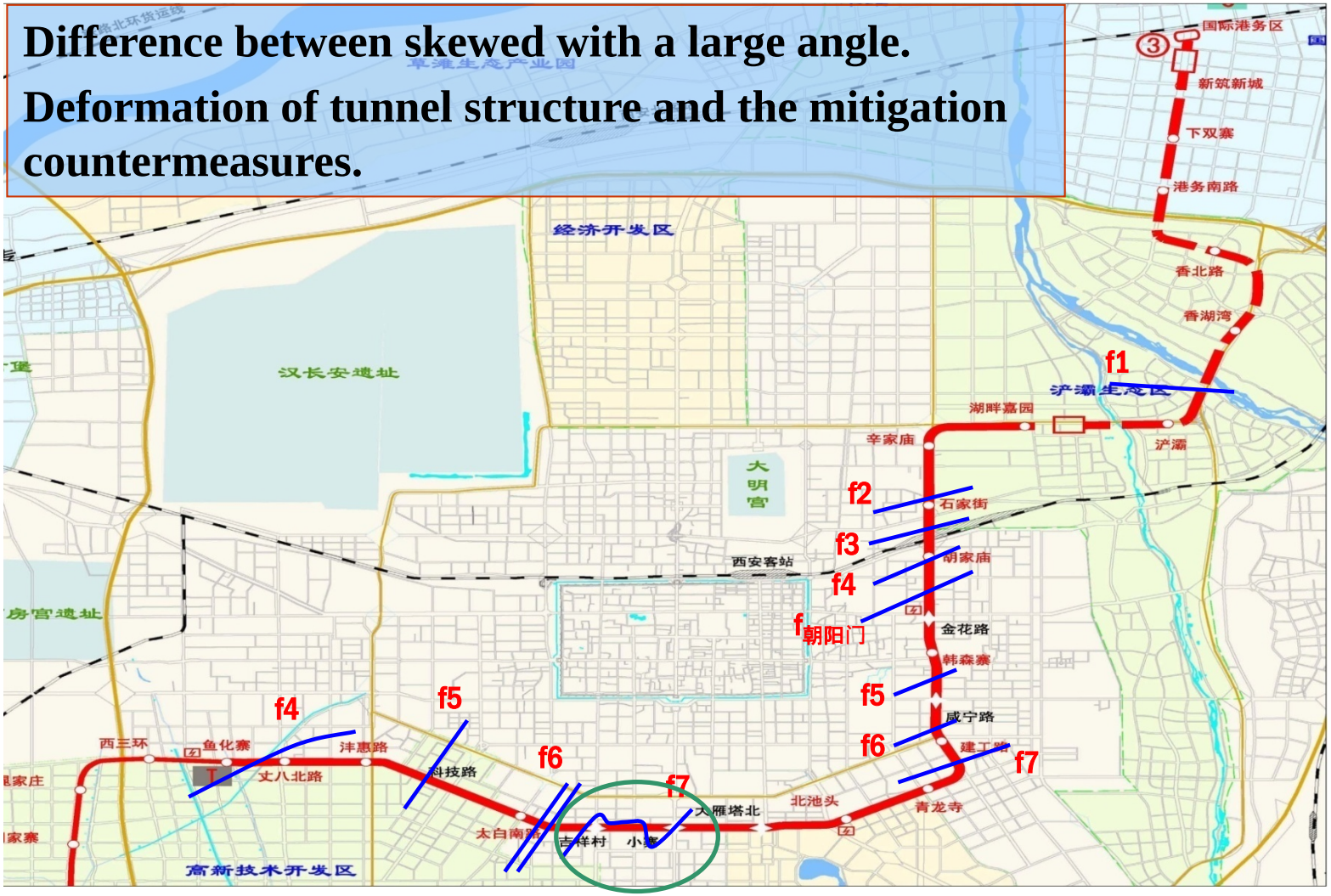
Annular and longitudinal cracks occurred on the hanging wall and footwall

Main achievement

Metero tunnel passing through the ground fissure with a small angle.

Difference between skewed with a large angle.

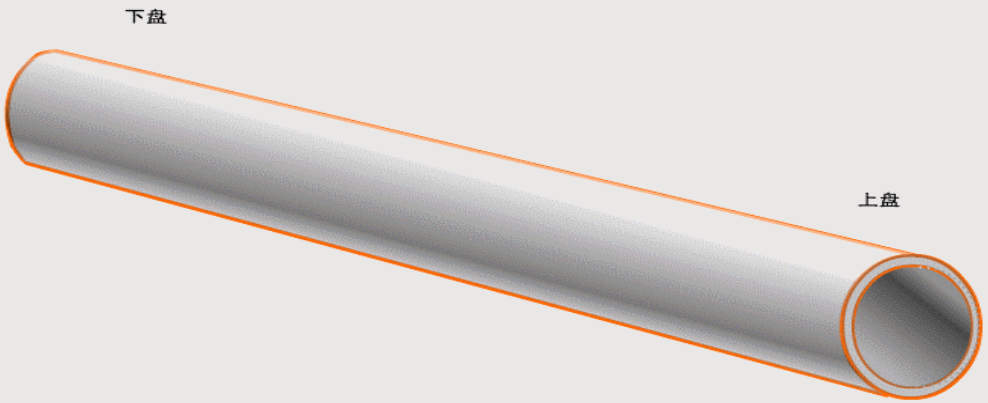
Deformation of tunnel structure and the mitigation countermeasures.



Location diagram of metro line 3 and ground fissures.

Main achievement

Large-scale model test of horseshoe tunnel passing through the active ground fissure with a small angle

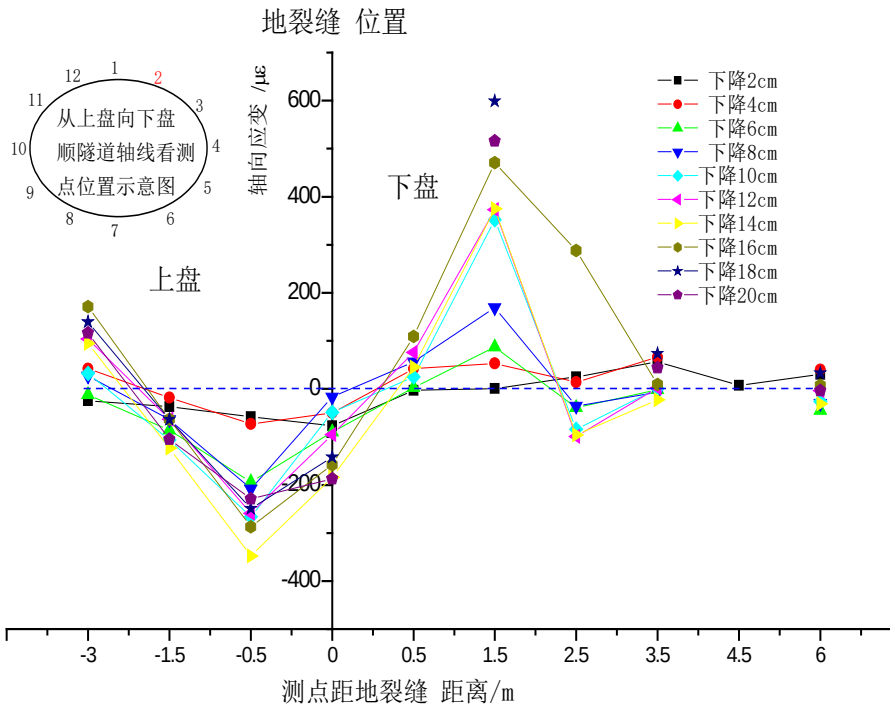


The process of deformation and failure of tunnel

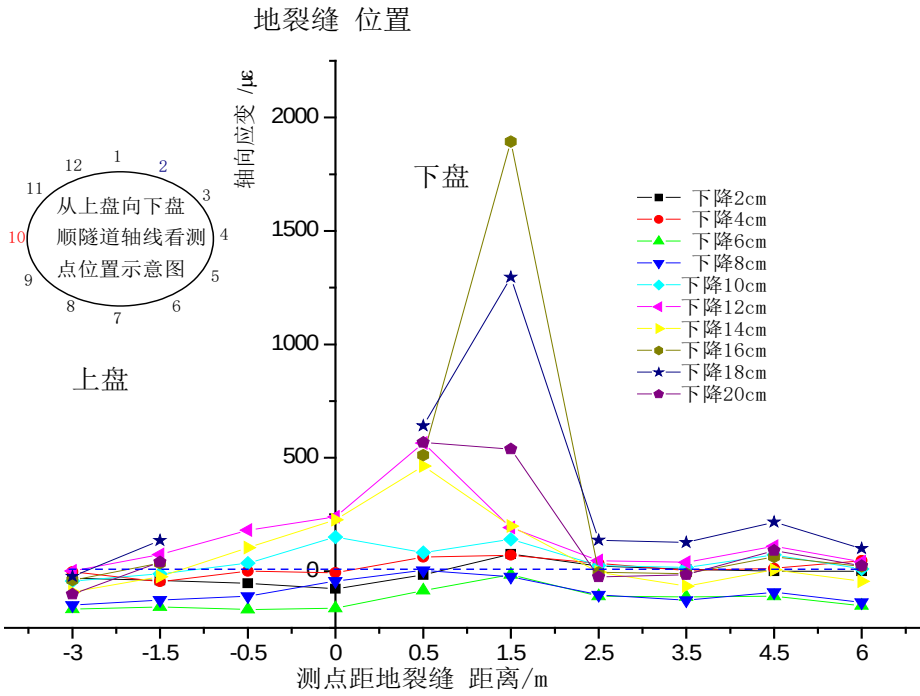
Annular, longitudinal, and torsional cracks

Main achievement

The tunnel tensed near the footwall of the ground fissure, and deformed asymmetrically with the characteristic of torsion.



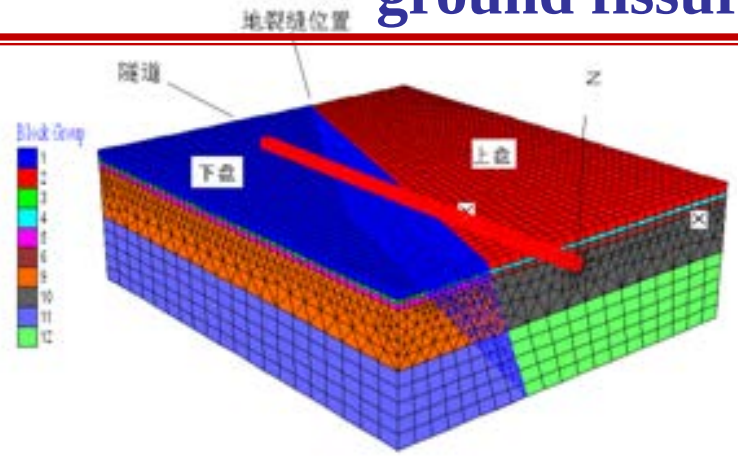
Axial strain curve of the concrete (No.2)

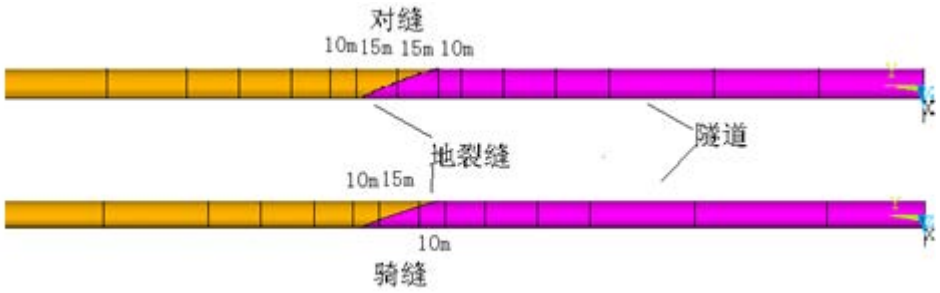


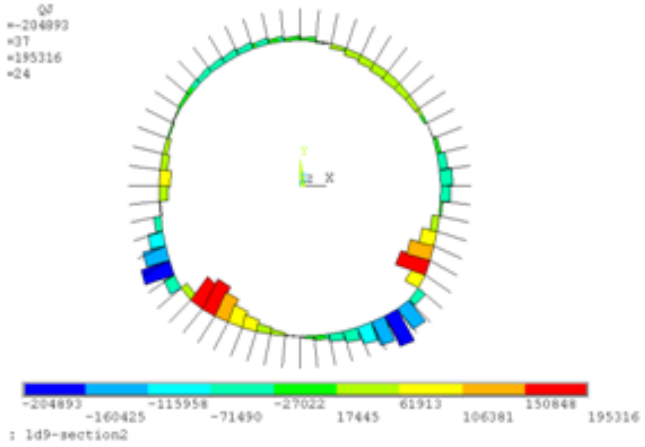
Axial strain curve of the concrete (No.10)

Main achievement

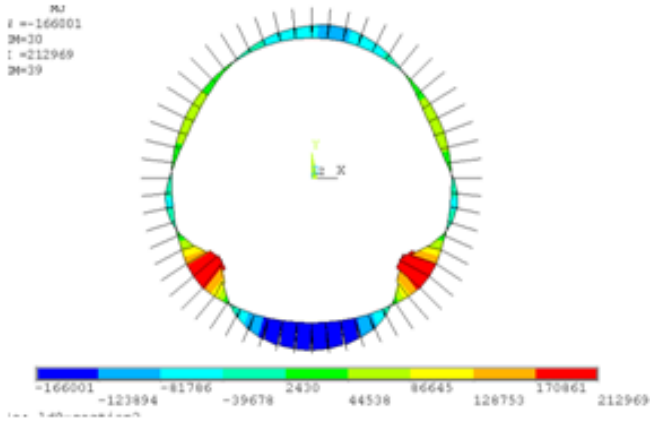
Numerical simulation on metro tunnel passing through the ground fissure with a small angle







a.剪力分布图（N）



b.弯矩分布图（Nm）

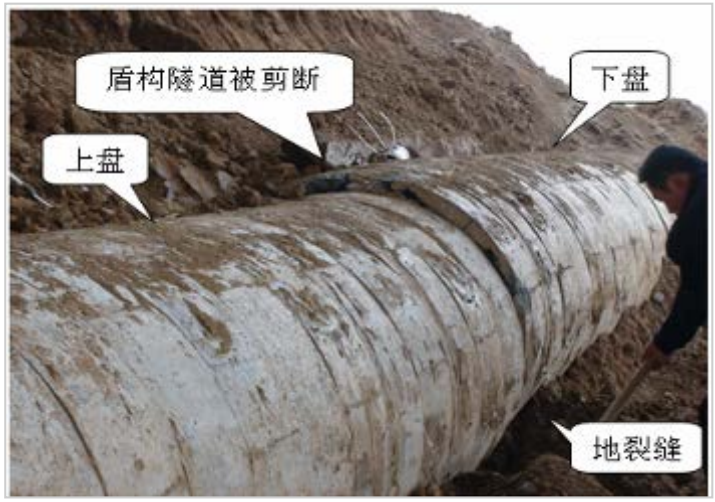
发现对缝和骑缝等两种变形缝设置都是可行的

Main achievement

4 metro tunnel deformation failure modes caused by earth fissure.

Tensile failure of integral lining

Tensile-torsional failure of integral lining



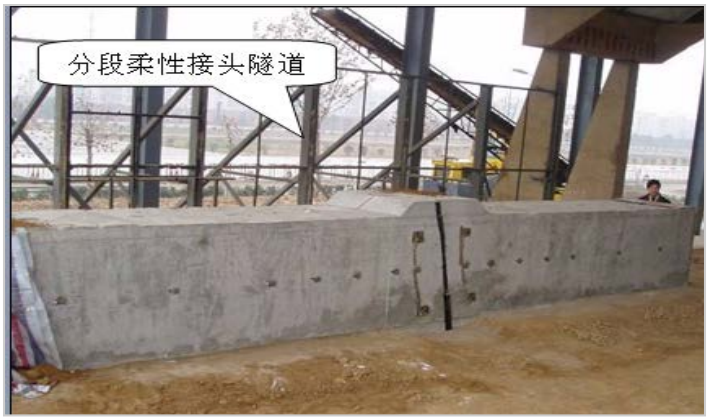
Shear failure of tunnel

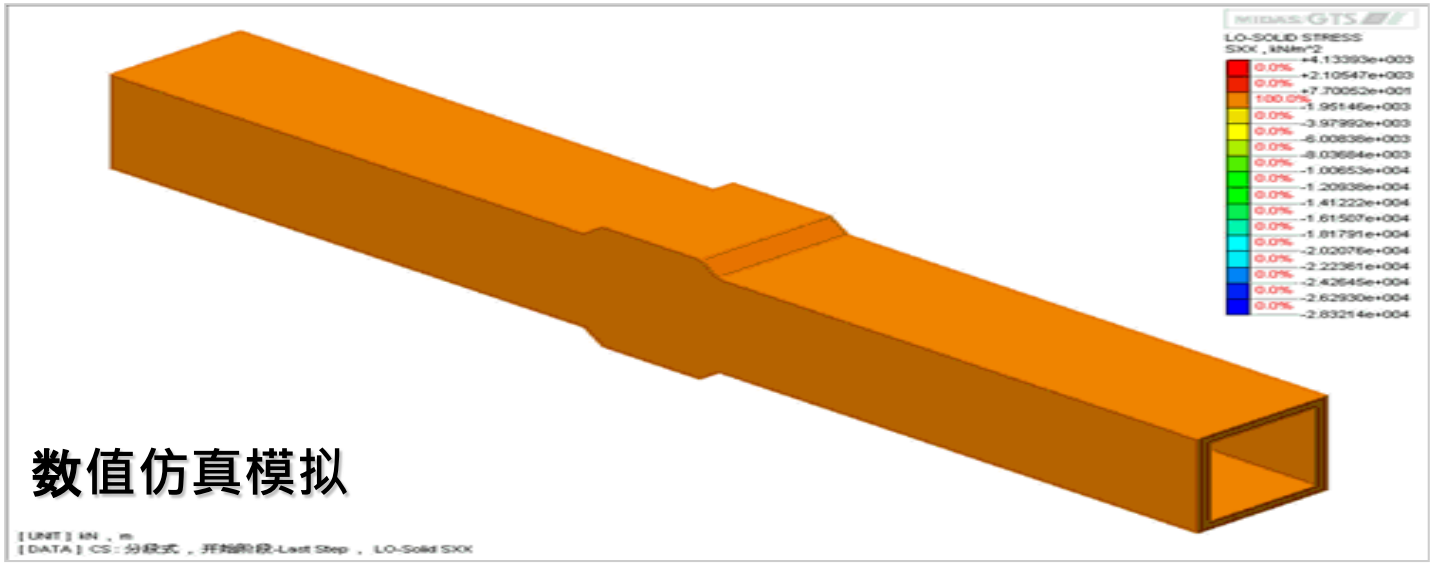
Torsional-shear failure of tunnel

Main achievement

Structural measures for the metro tunnel to adapt to the ground fissure deformation

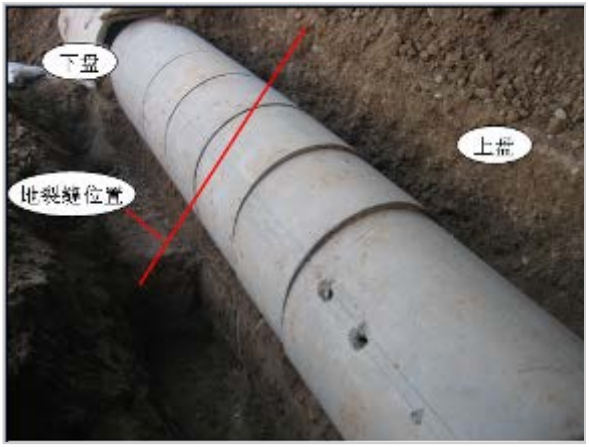
Verification model test of Segmented box tunnel (1:5)

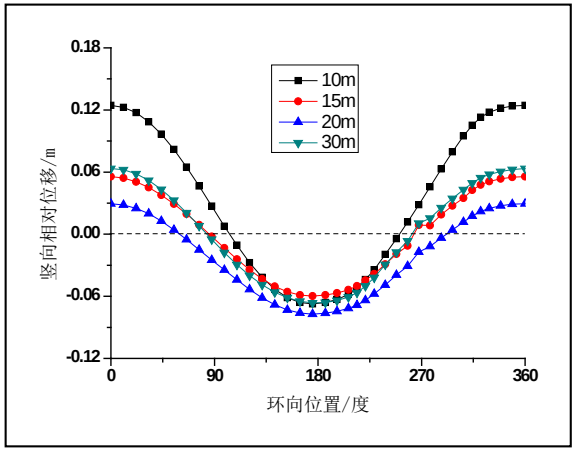


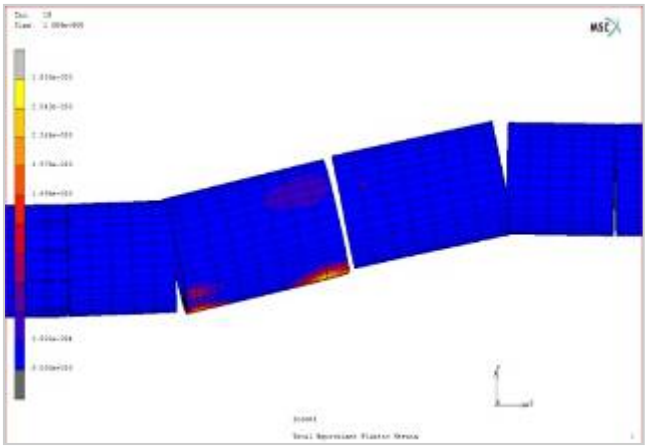


Main achievement

Large-scale model test of Segmented horseshoe tunnel (1:5)





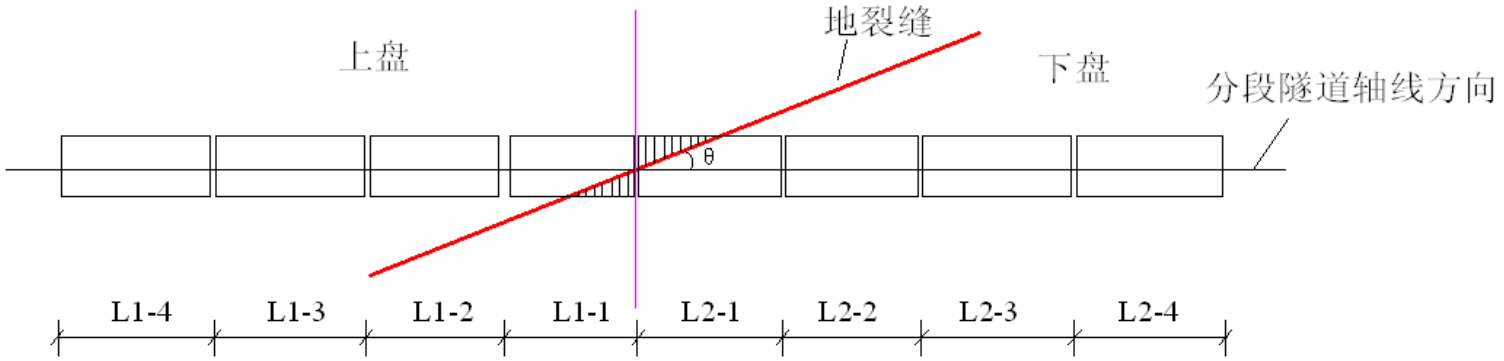


发现分段设缝的马蹄形隧道为穿越地裂缝带的首选结构型式

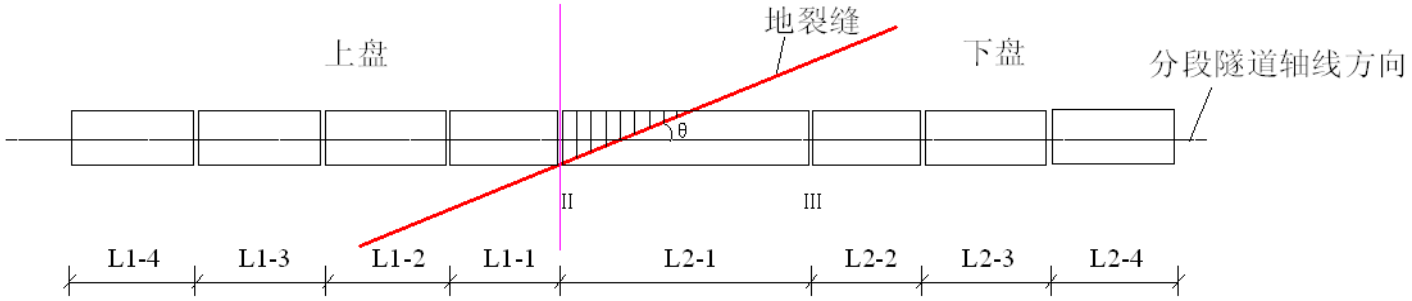
Main achievement

How to segment: segmented tunnel was used to adapt to the deformation of ground fissure.

when θ≤45°, the length of segmented tunnel (crossing the ground fissure) was 15m;

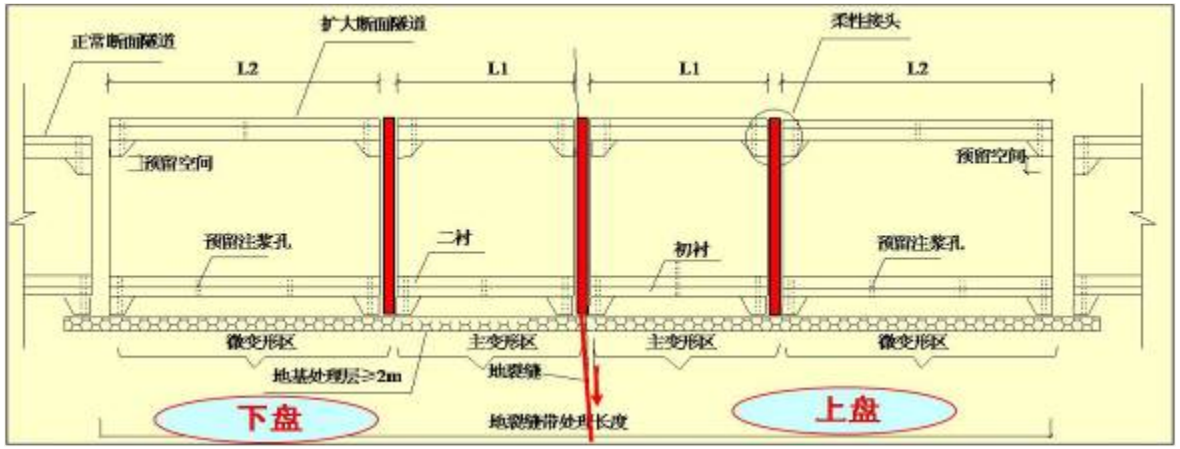


when θ > 45°,the length of segmented tunnel (crossing the ground fissure) was 20m.

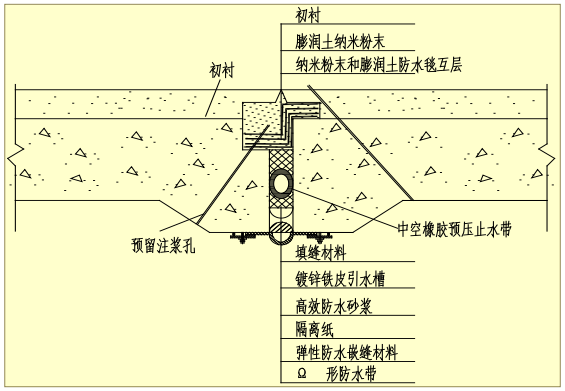


Main achievement

4 kinds of structural countermeasures

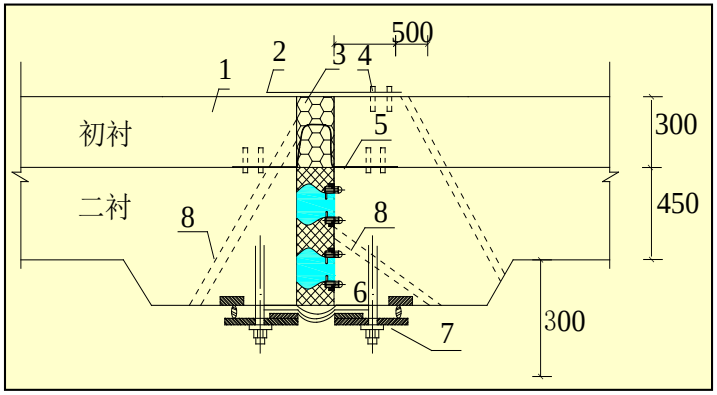


Setting up deformation joints in segmentation on the tunnel



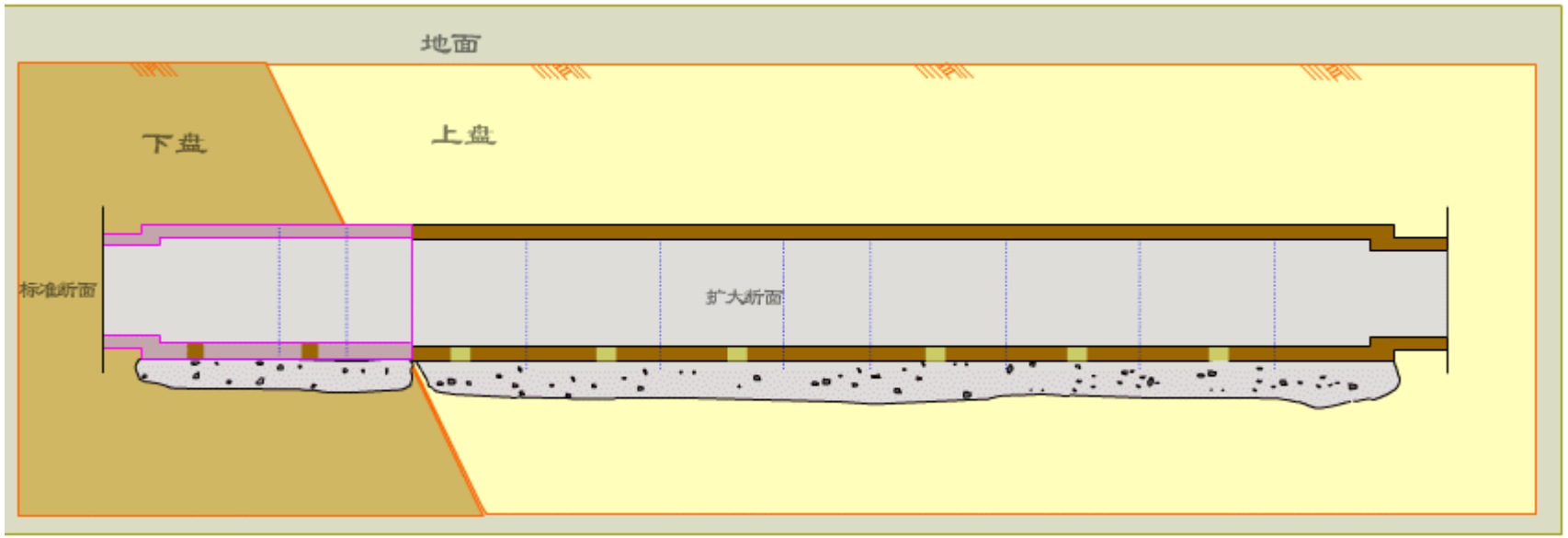
Enlarged Cross-section

Track adjustment



Waterproof structure

Main achievement

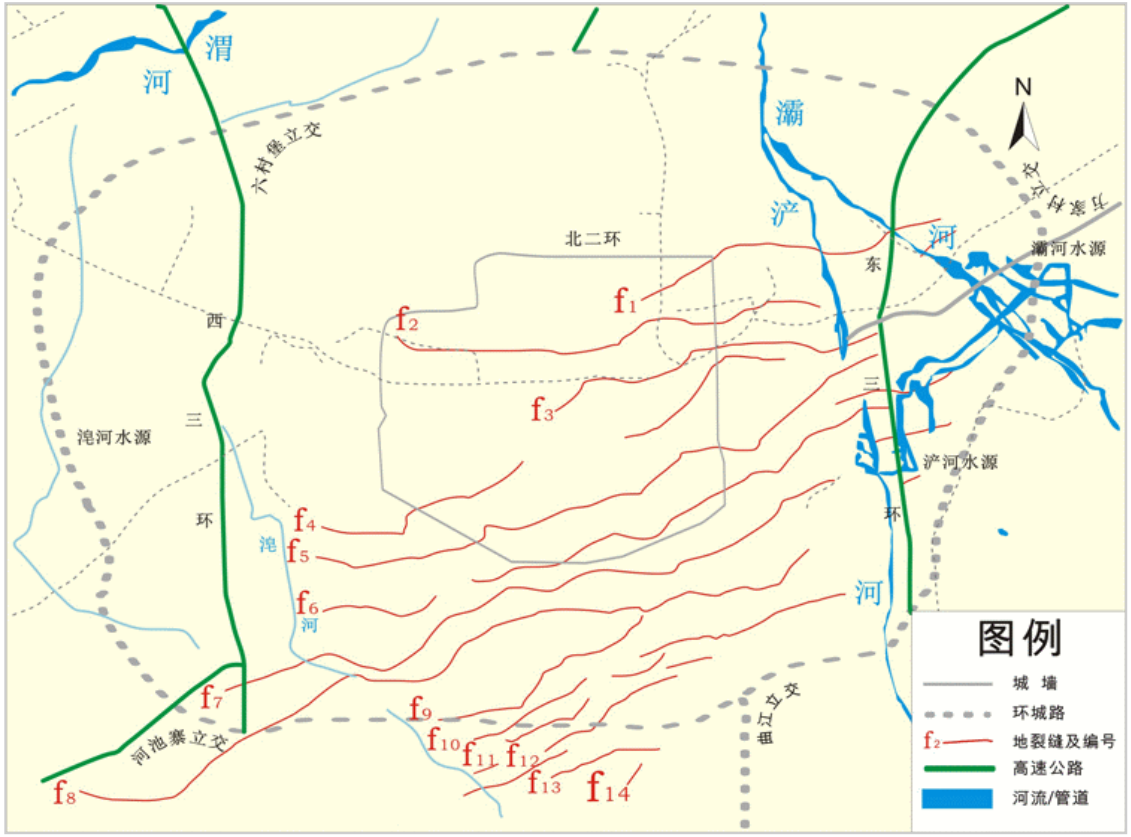


Structural measures of metro tunnel against ground fissure in Xi’an

The above results have been applied to the design and construction of Xi′an metro and will support the construction of other metro lines in Xi′an.

Main achievement

Disaster preventation and treatment issue was solve in underground pipeline, and became a demostration project of underground space development in Xi'an.



Distribution of earth fissure and underground pipeline

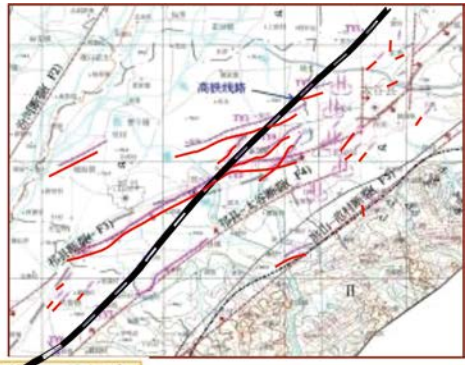
Physical simulation

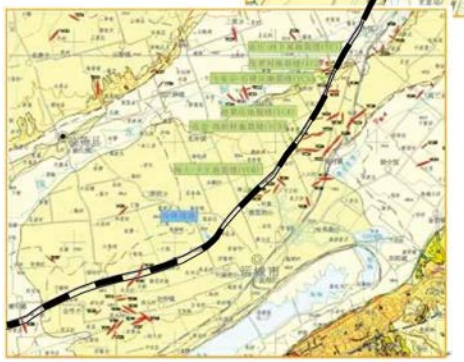
主要创新成果

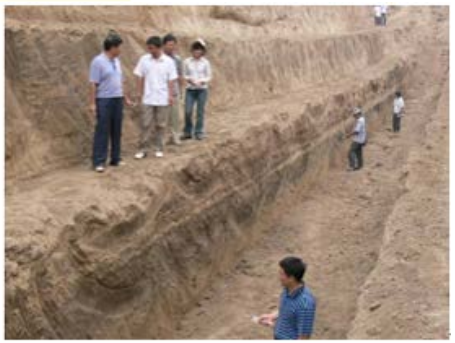
中国多条高速铁路面临地裂缝威胁，如何保障其运营安全

Main achievement

Datong-Yuncheng high-speed railway has 36 intersections with the ground fissures.

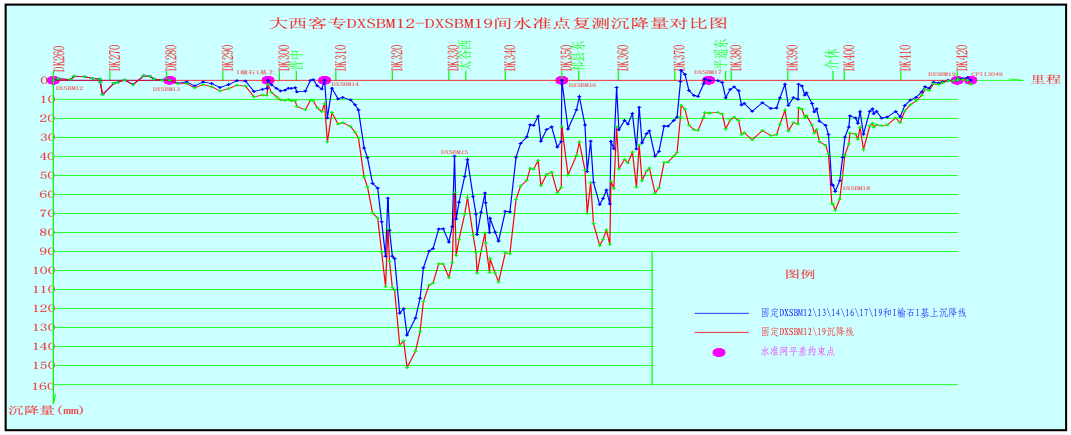






Main achievement

The maximum vertical displacement=4cm/a, the designed differential settlement of high-speed railway basement≤5mm, and the differential settlement of bridges≤5m.

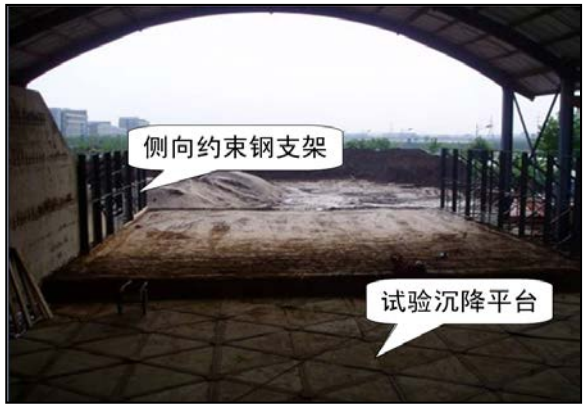


Subsidence funnels along high-speed railway

Activity rate 4 cm/a

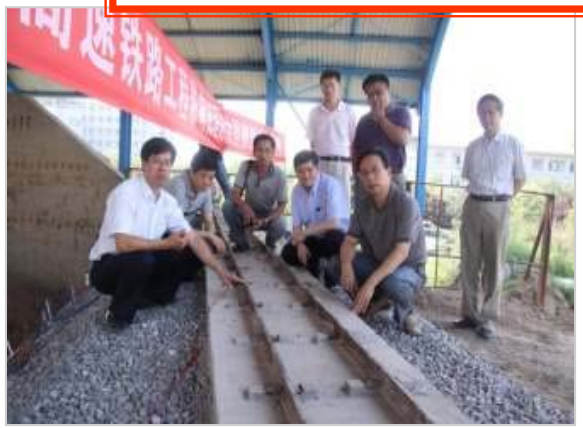
Main achievement

Large scale model test of high speed railway subgrade affected by the activity of ground fissure (1:5, for the first time)



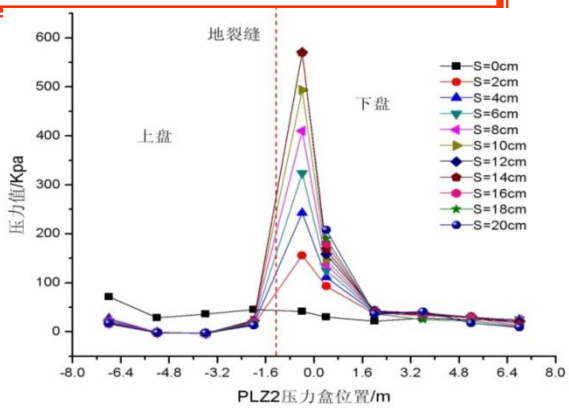
Main achievement

The formation and evolution process was reappeared via large-scale physical model tests.



Field discussion

Cavity of piles



Pressure of CFG-pile tip

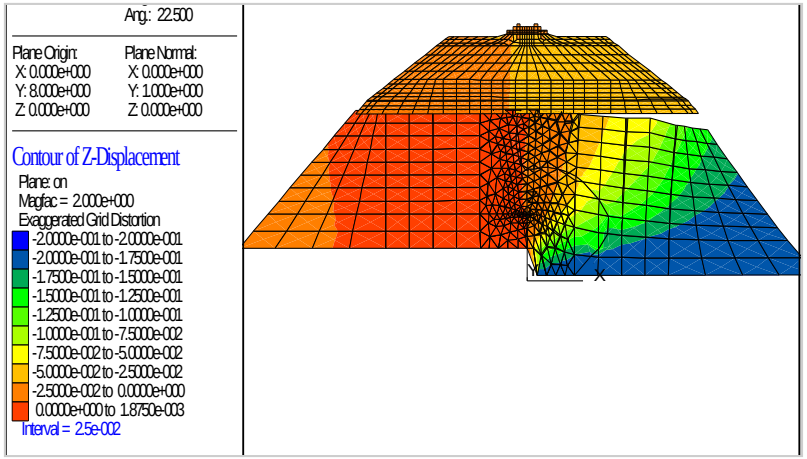
Failure of piles

Failure of basement

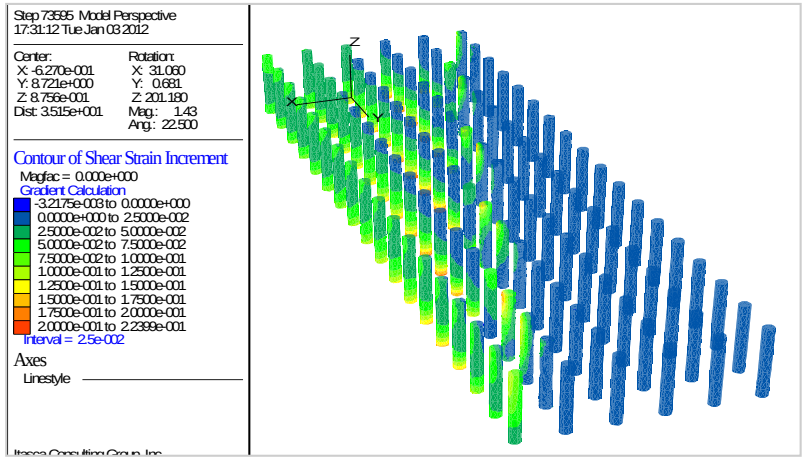
Failure of subgrade

Main achievement

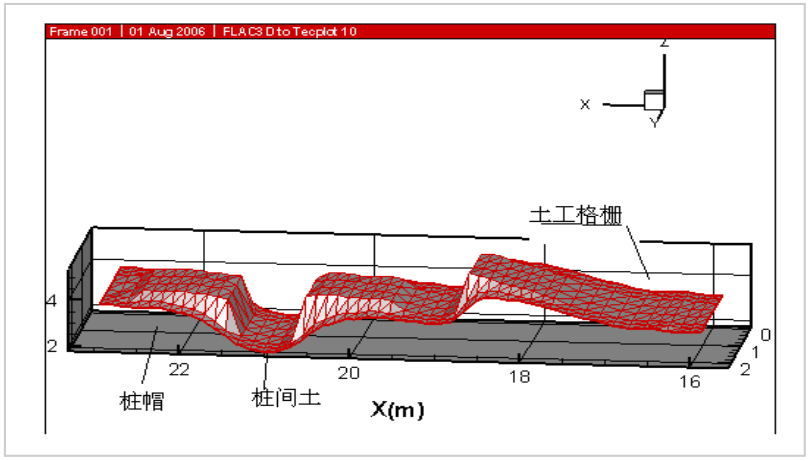
Numerical simulation confirmed the deformation and failure mechanism



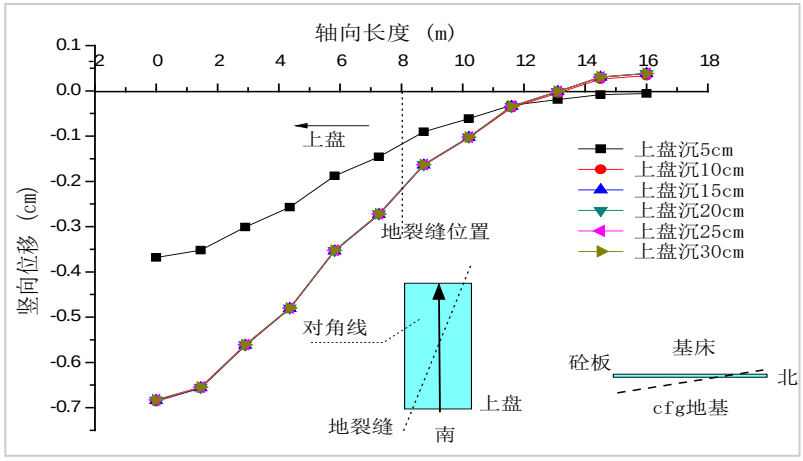
Cavity of piles



Stress of CFG-pile



Simulation of geotechnical grille



Deformation of concrete floor

Main achievement

Large scale model tests, combined with numerical simulation, disclosed the influence ground fissure had on high-speed railway bridge.

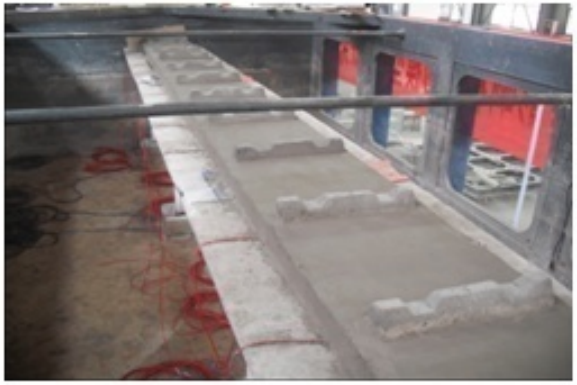


图 10.76 道床板、轨枕、轨道施工图

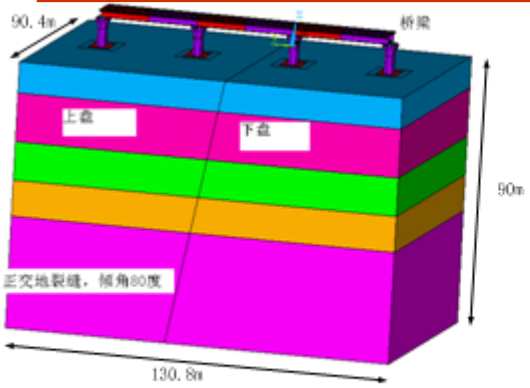
Cracks appeared on the slab when the settlement =3cm

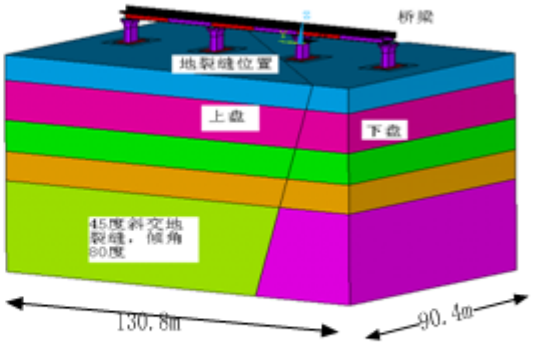
图 10.77 试验模型完工图

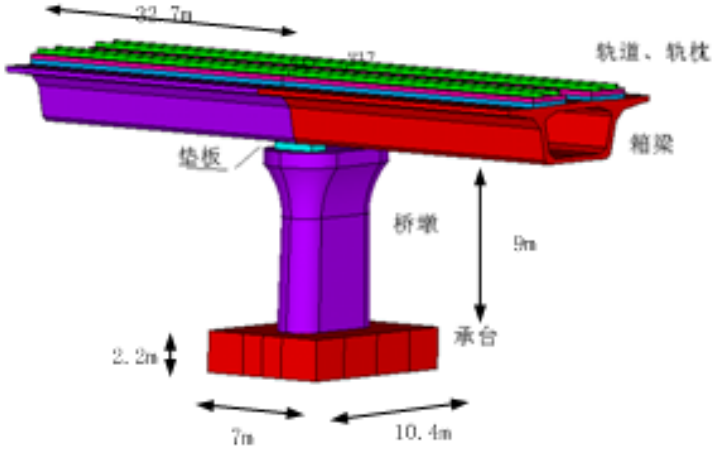
The maximum cavity displacement = 20%, and the maximum opening width = 5%.

Main achievement

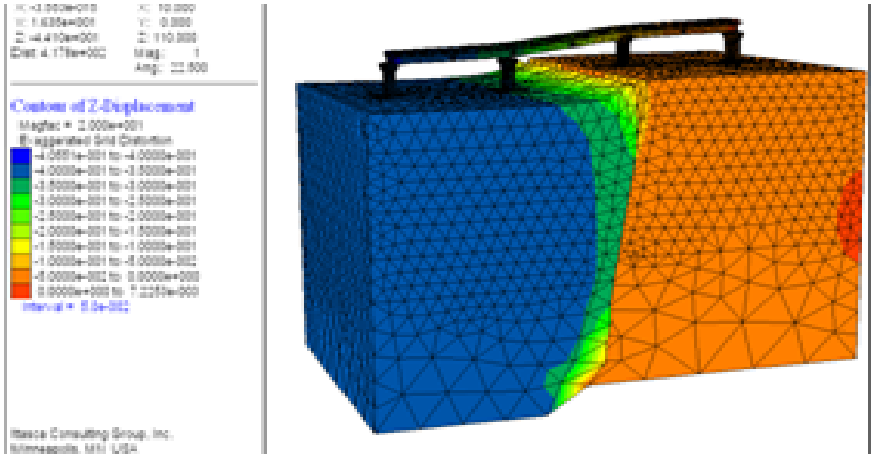
Deformation and failure process of the bridge was simulated by numerical simulation.

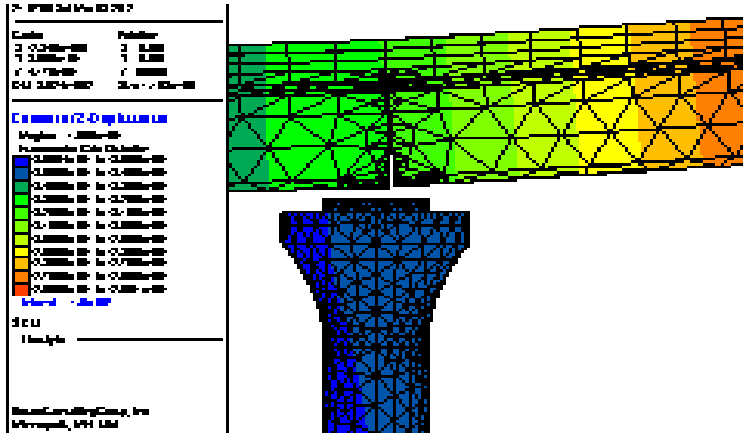






（a）正交模型　　（b）45°斜交模型





（a）整体变形云图　　（b）上盘桥墩垫板处局部变形云图