# Mechanism and mitigation of earth fissure in China

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# Main achievement

5: Failure modes. Engineering construction design .

# Main achievement

## The damage caused by earth fissures in Fenwei basin







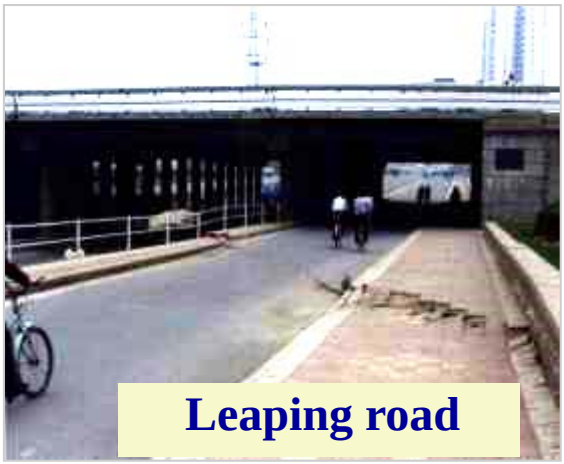


# Main achievement

## The damage caused by earth fissures in Xi'an

Damaging building

Damaging ancient city wall



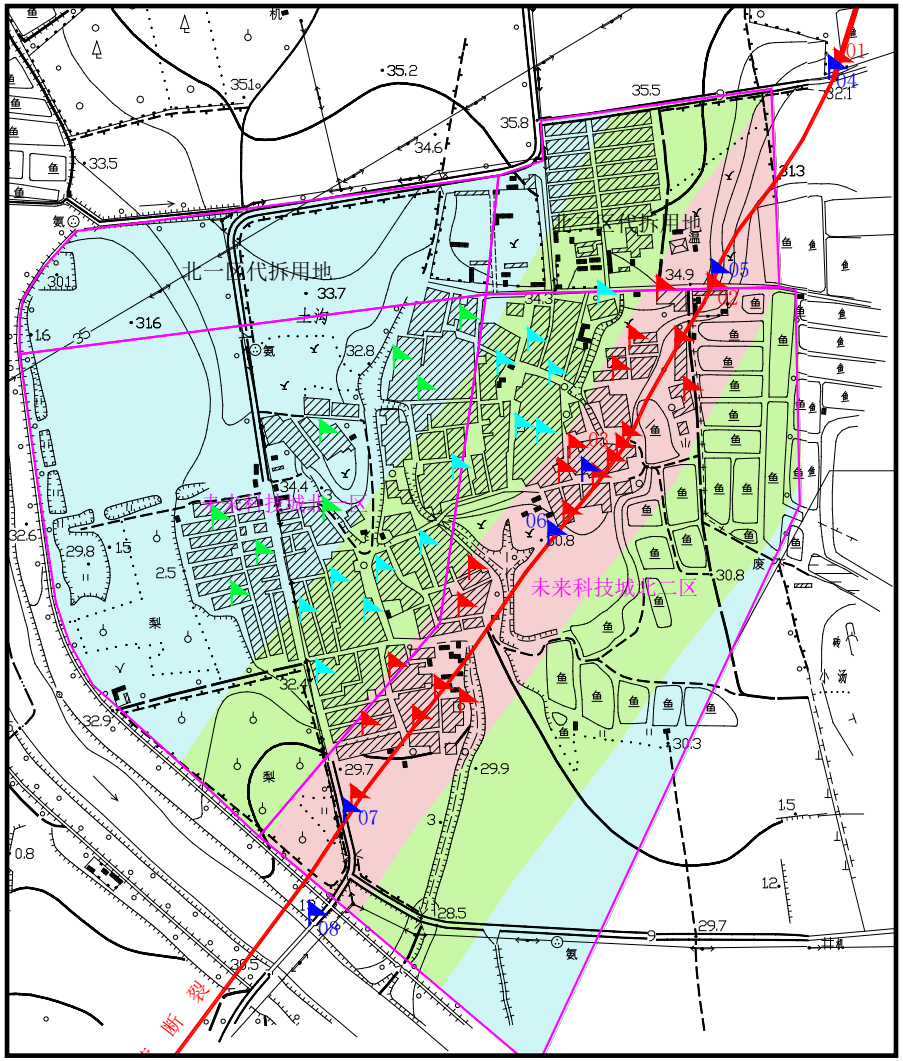
Leaping road

Leaping pipeline

Leaping bridge

# Main achievement

## The damage caused by earth fissures in Beijing



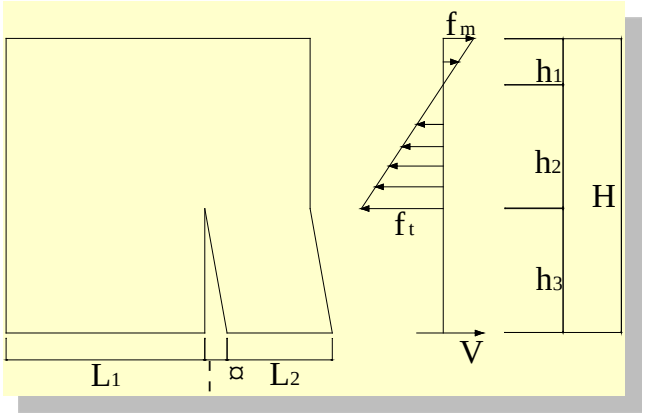

# Main achievement

**6 kinds of cracks occurred in buildings:**

**vertical tensile crack, splayed tensile crack, horizontal shear crack, planar fold crack, symmetrical crack, and 3D torsional crack.**

➢ **Vertical tensile crack**

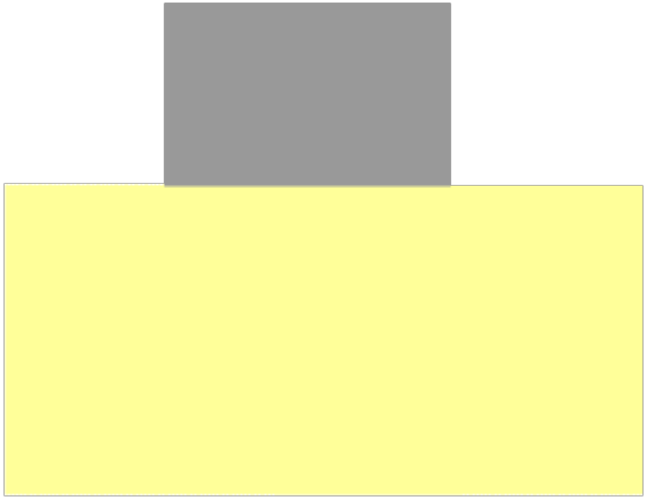
**Building desturction and the failure mode in Wanrong county, Shanxi.**



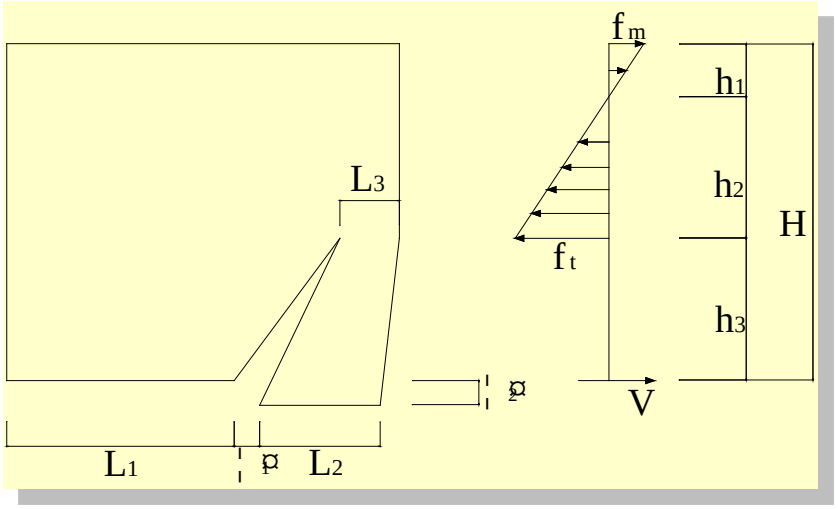

$$V=\begin{cases}\dfrac{1}{2}(f_t+f_m)(h_2+h_1)t\\ \dfrac{1}{2}(f_t h_2+f_m h_1)t\end{cases}$$

# Main achievement

## ➢Splayed tensile crack



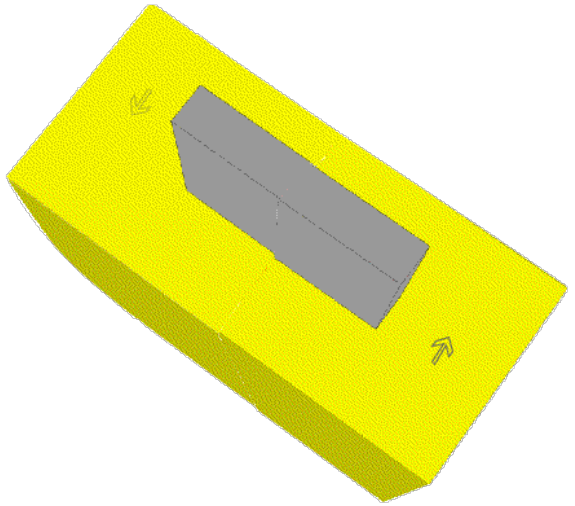
**Building desturction and the failure mode in Linfen city, Shanxi.**



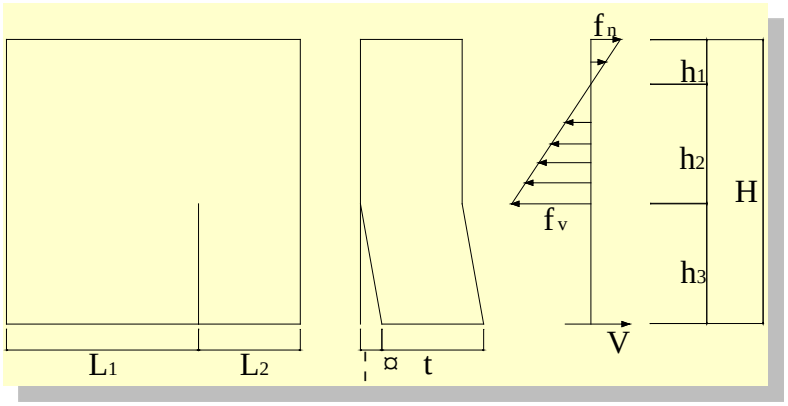

$$\begin{cases} V = K\Delta_1 = \dfrac{EL_3 t}{3h_3'}\Delta_1 \\ V = \dfrac{1}{2}(f_t h_2 + f_m h_1)t \\ VH + \dfrac{1}{6}f_m h_1^2 t - \dfrac{1}{2}f_t h_2 t(h_1 + \dfrac{2}{3}h_2) = 0 \\ \dfrac{f_m}{f_t} = \dfrac{h_1}{h_2} \\ H = h_1 + h_2 + h_3' \end{cases}$$

# Main achievement

## ➢Horizontal shear crack



**Building desturction and the failure mode in Wanrong county, Shanxi.**

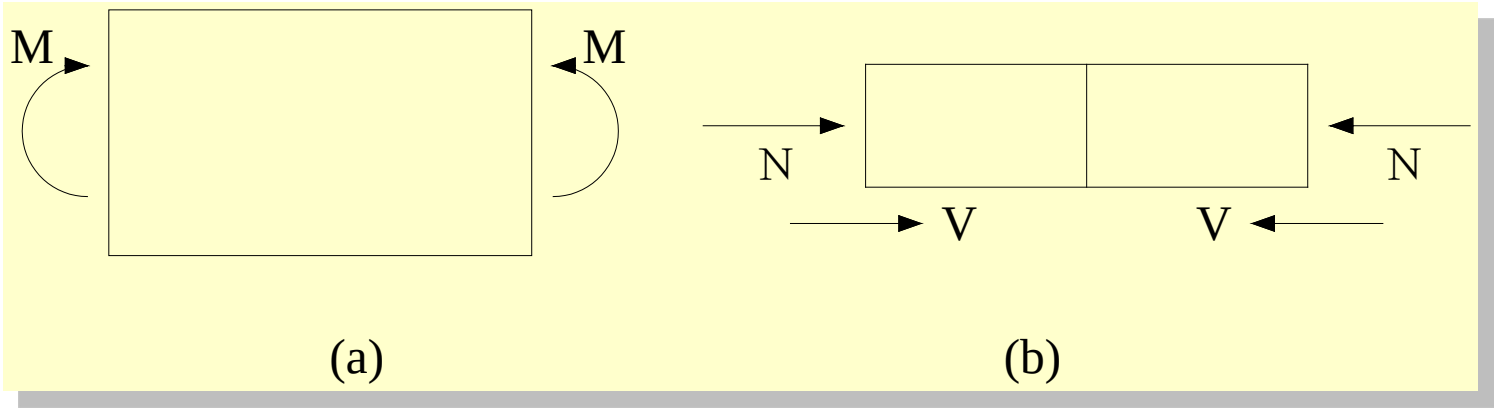



$$\begin{cases} V = K\Delta = \dfrac{EL_2 t}{3h_3}\Delta \\ V = \dfrac{1}{2}(f_v h_2 + f_n h_1)t \\ VH + \dfrac{1}{6} f_n h_1^2 t - \dfrac{1}{2} f_v h_2 t(h_1 + \dfrac{2}{3}h_2) = 0 \\ \dfrac{f_n}{f_v} = \dfrac{h_1}{h_2} \\ H = h_1 + h_2 + h_3 \end{cases}$$

# Main achievement

- Planar fold crack

**Building desturction and the failure mode in Qingxu county, Shanxi.**



# Main achievement

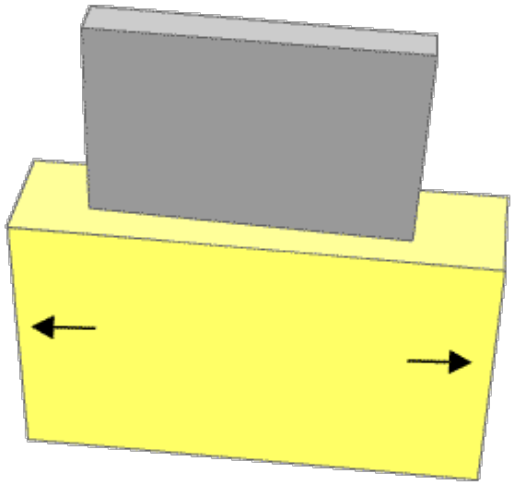
## ➢Symmetrical crack

(a) “八”　　（b） “\ /”

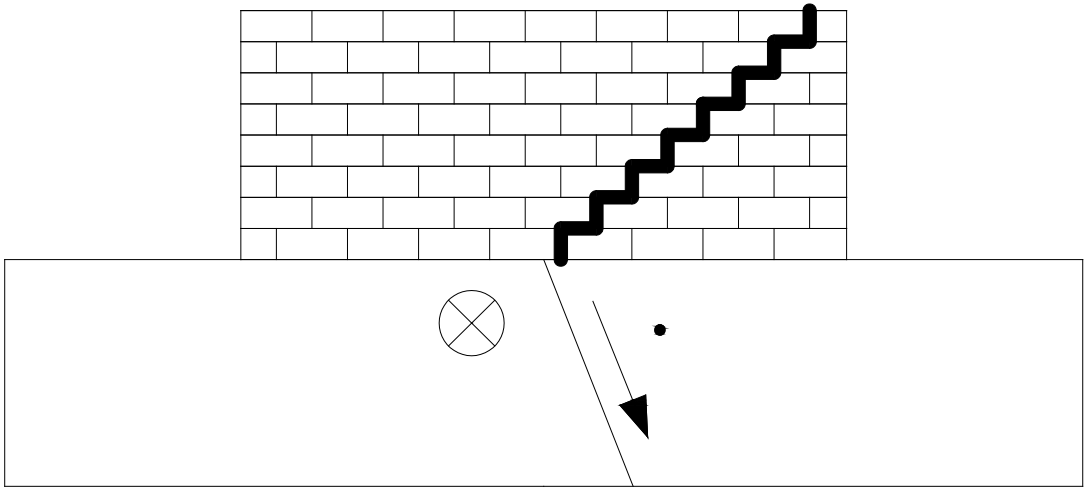
**Failure mode of symmetrical crack**

# Main achievement

## ➢3D torsional crack



**Building desturction and the failure mode in Qingxu county, Shanxi.**



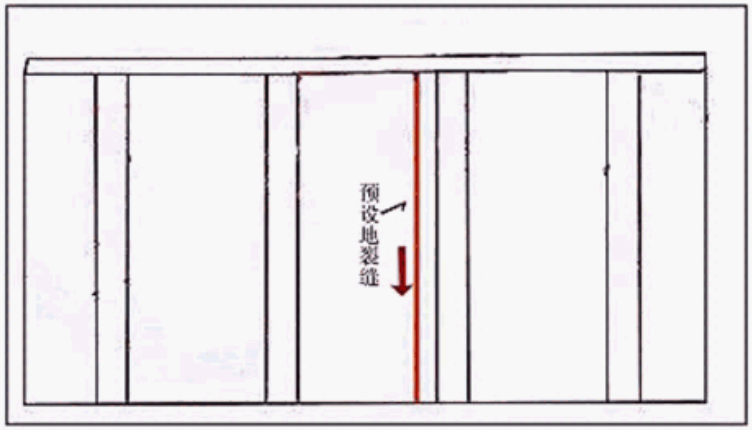
# Main achievement

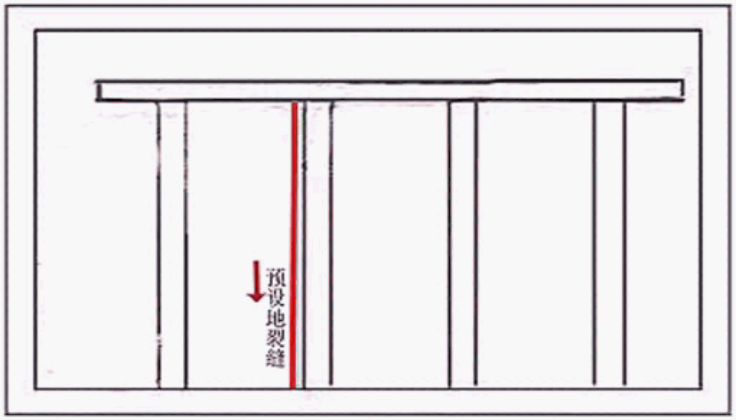
**Different kinds of failure modes of building foundations were displayed by large scale model tests and numerical analysis.**

**Photos of testing**

# Main achievement

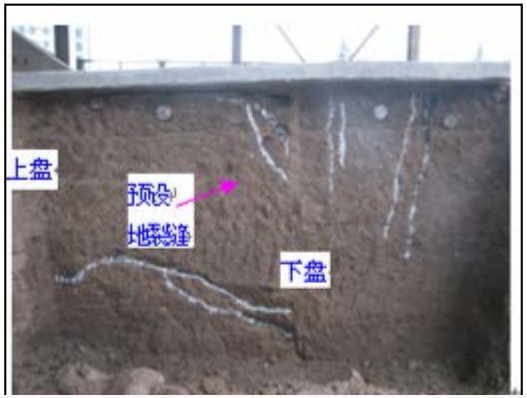
**Piled raft foundation: the activity of ground fissure cracked the tensile side of all piles and parted the raft off.**

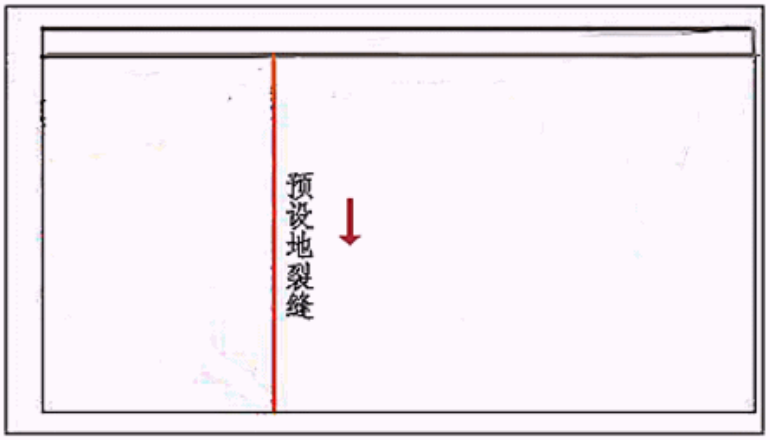



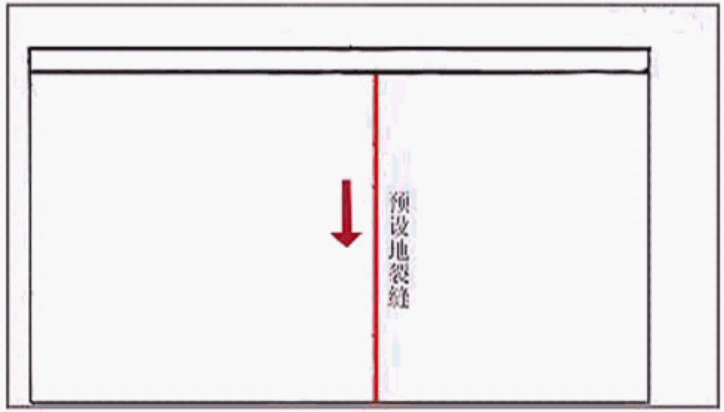



# Main achievement

Piled raft foundation: the activity of ground fissure cracked the tensile side of all piles and parted the raft off.



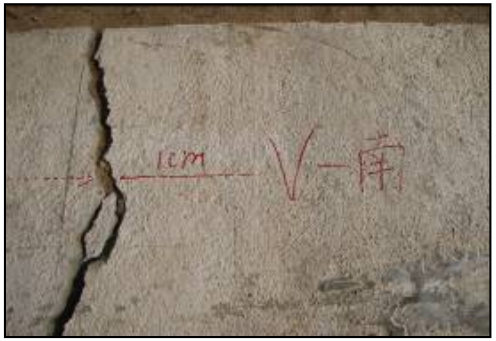



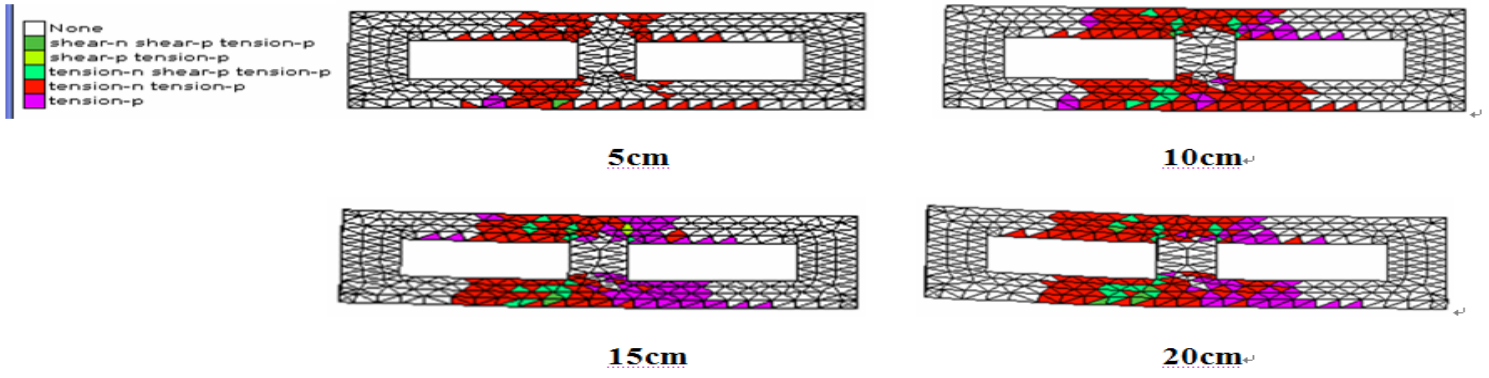



# Main achievement

**Strip foundation:** the strip foundation was quickly snapped by activity of earth fissure.


图 4.34 条基上盘随地裂缝一起沉降

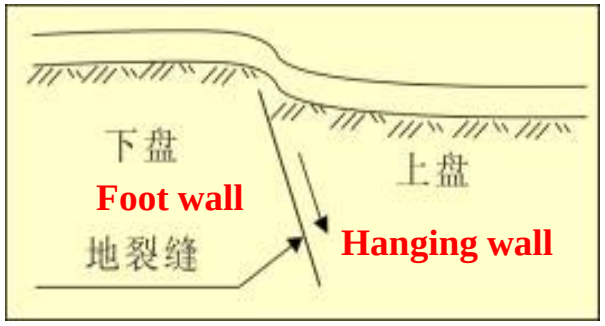


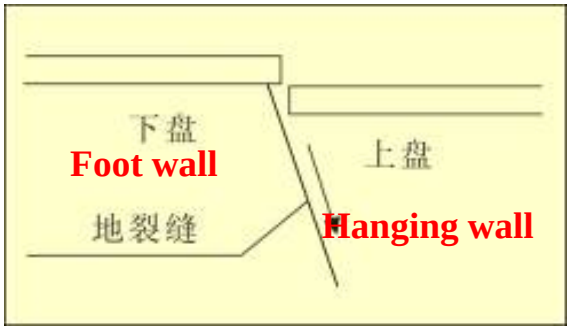



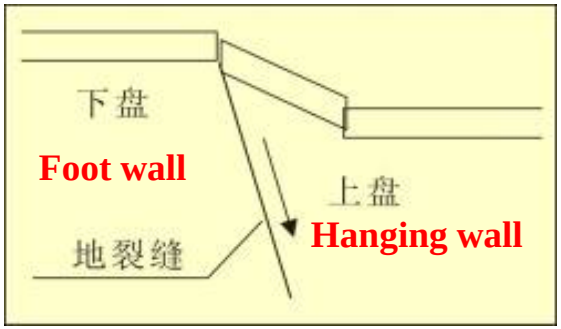

•**Numerical simulation result:** tensile and shear cracks occurred near the junction of strip foundation and ground fissure.

# Main achievement

**Flexible pavement was characterized by inclination failure, while rigid pavement was scarp failure.**

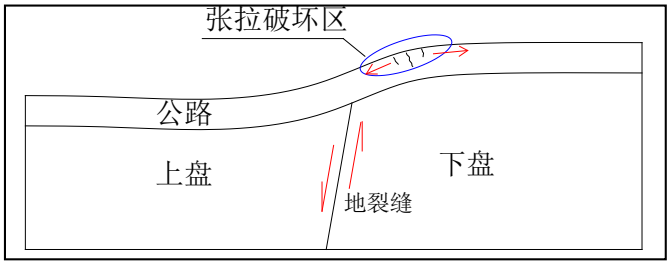


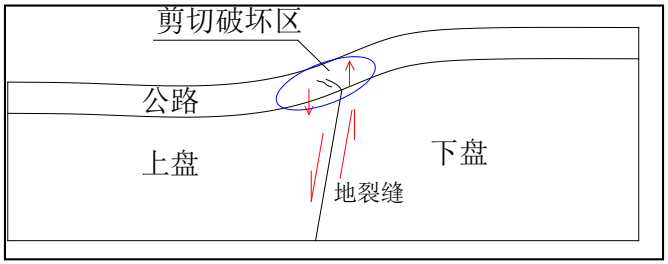



# Main achievement

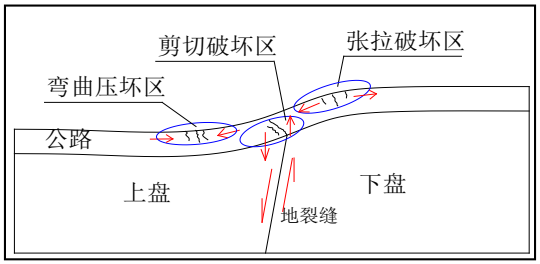
**Pavement: tensile, shear, bending and complex failure rule affected by the ground fissure.**



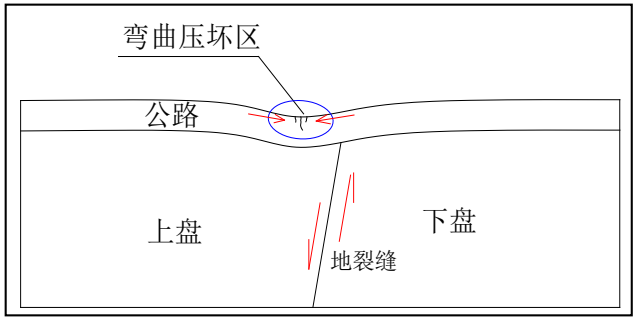

**Tensile failure**




**Shear failure**




**Complex failure**



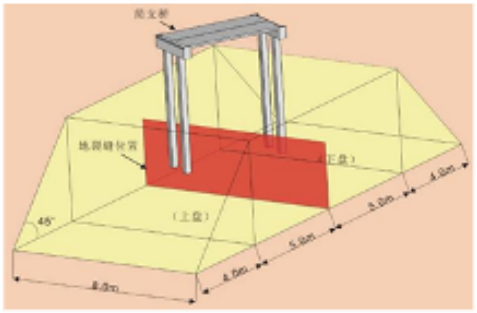

**Bending failure**

$$\begin{cases} y = e^{-\beta x}[(-\dfrac{q}{k}+\dfrac{y_0}{2})\cos\beta x+(-\dfrac{\beta y_0}{6}-\dfrac{q}{k}+\dfrac{y_0}{2})\sin\beta x] \\ M = -EI\beta^2 e^{-\beta x}[(y_0-\dfrac{2q}{k})\sin\beta x+(\dfrac{\beta y_0}{3}+\dfrac{2q}{k}-y_0)\cos\beta x] \\ Q = -EI\beta^3 e^{-\beta x}[(-\dfrac{\beta y_0}{3}-\dfrac{4q}{k}+2y_0)\cos\beta x-\dfrac{\beta y_0}{3}\sin\beta x] \end{cases}$$

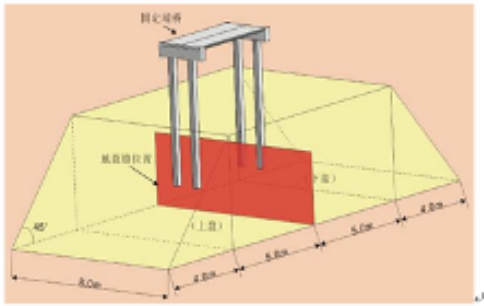
**Force and displacement calculation equations of the road affected by ground fissure**

# Main achievement

**Failure modes of bridge: lowering of girder, dislocation and rigid torsional shear**

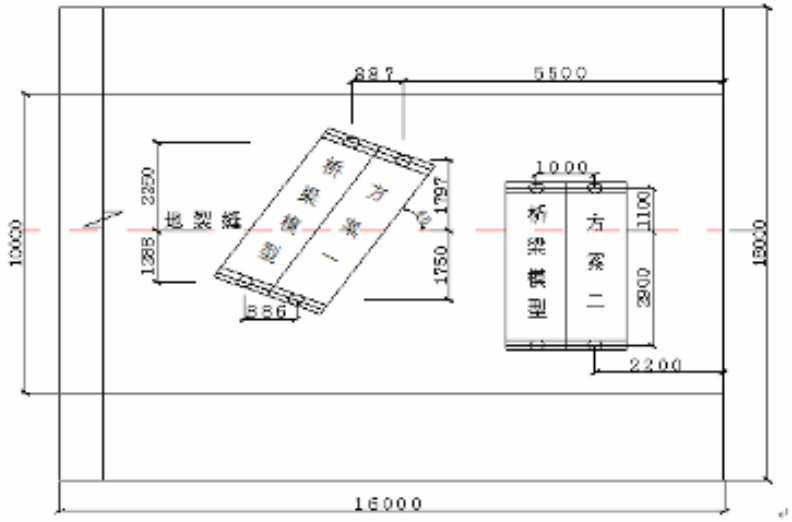


（a）简支桥立体模型



（b）刚架桥立体模型

**Model test of bridge**

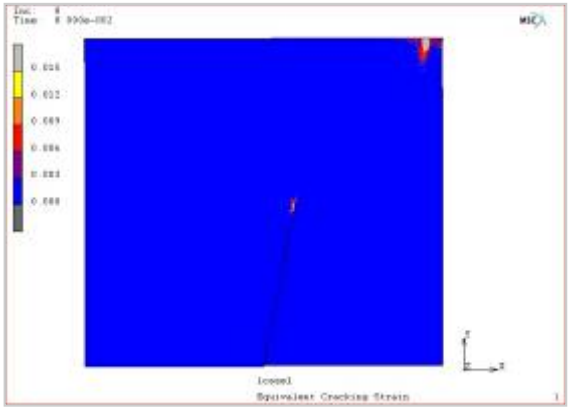




**The test section of express loop highway**

# Main achievement

1、The geo-hazard prevention and mitigation of ground fissures were applied to the buildings' design in more than 10 cities such as Beijing and Datong.



**Thickness:△T＝2.0×△T '**

**Min distance from foundation to earth fissure**

| 基础类别 | 基础位置 | 建筑物重要性类别 | | |
|---|---|---|---|---|
| | | 一 | 二 | 三 |
| 刚性基础 | 上盘 | / | / | 6 |
| | 下盘 | / | / | 4 |
| 条形基础 | 上盘 | / | 12 | 6 |
| | 下盘 | / | 4 | 4 |
| 筏形基础 | 上盘 | 16 | 8 | / |
| | 下盘 | 8 | 4 | / |
| 箱形基础 | 上盘 | 12 | 6 | / |
| | 下盘 | 8 | 4 | / |
| 桩基础 | 上盘 | 16 | 11 | / |
| | 下盘 | 4 | 2 | / |

# Main achievement

## 2、Setback distance values alone ground fissure

| 避让距离(m) 构造位置 / 建筑重要性类别 | Hanging wall | Footwall |
|---|---|---|
| 一类 | 50×1.5= 75 | 16×1.5=24 |
| 二类 | 50×1.5= 75 | 16×1.5=24 |
| 三类 | 50×1.2= 60 | 16×1.2=19.2(20) |

**Foundation form：** Box foundation, piled raft foundation and deep foundation

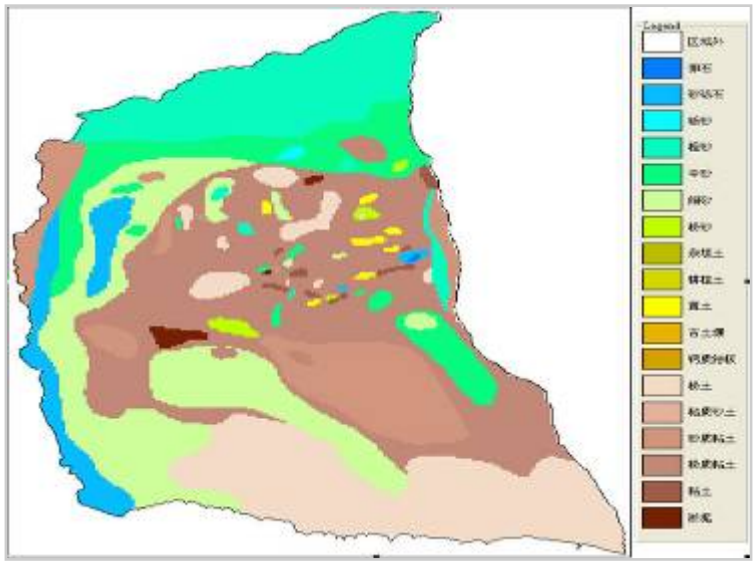
**Superstructure：** frame structure, frame-shear structure and light brickstructure

**Foundation treatment：** increased strength, decrease deformation and impermeable

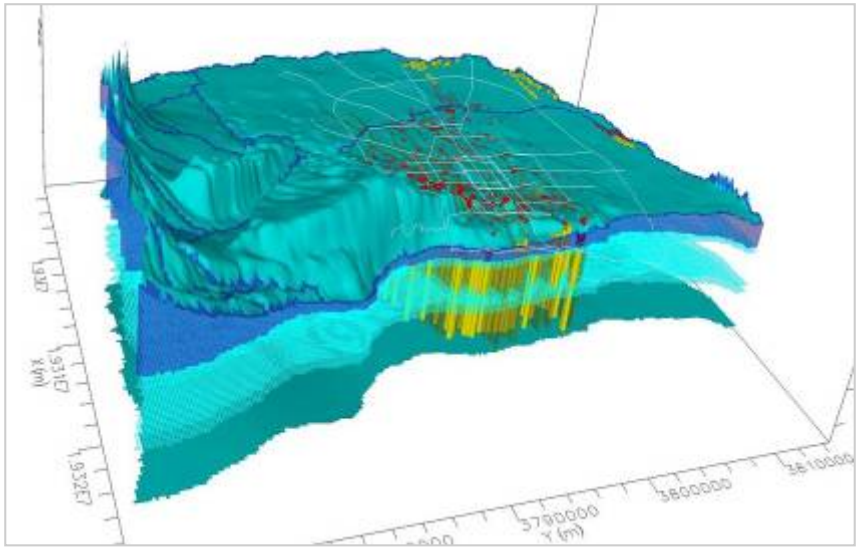
# Main achievement

3、Five optimization groundwater pumping plans were raised to mitigate the development of ground fissure.

## 3-D geological structure and soil-water coupling model



3D geological structure model of Xi'an

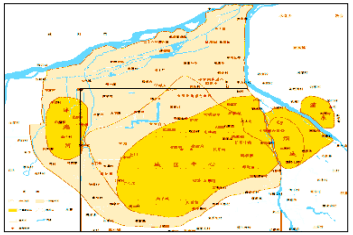


Coupled model of 3D flow field and 1D consolidation in Xi'an

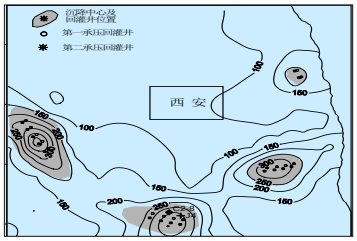
$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial H}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial H}{\partial z}\right)-\hat{q}=(1-\gamma)S_s\frac{\partial H}{\partial t}$$

# Main achievement

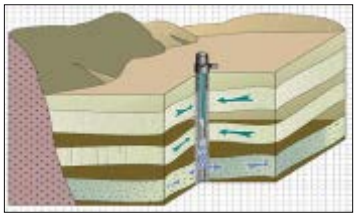
**方案一：** Reduce the amount of groundwater exploitation.



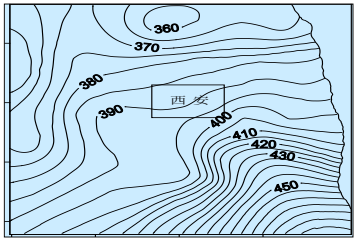
**方案二：** Recharge groundwater regularly.



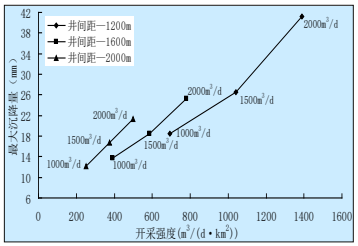

**方案三：** Increase the supplementary of confined aquifer.



**方案四：**Water pumping from shallow aquifer.

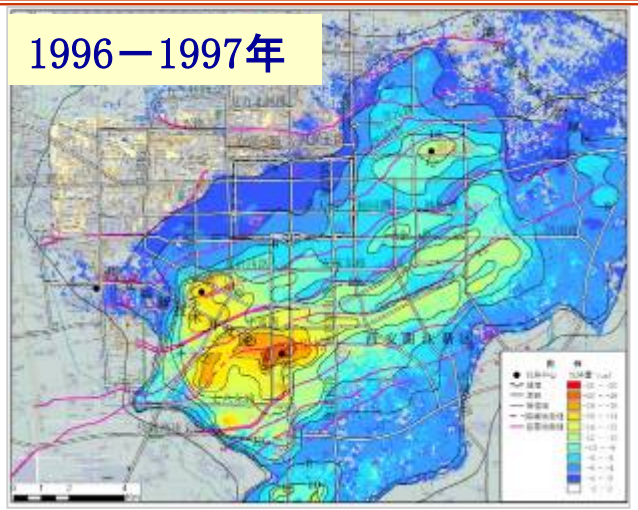


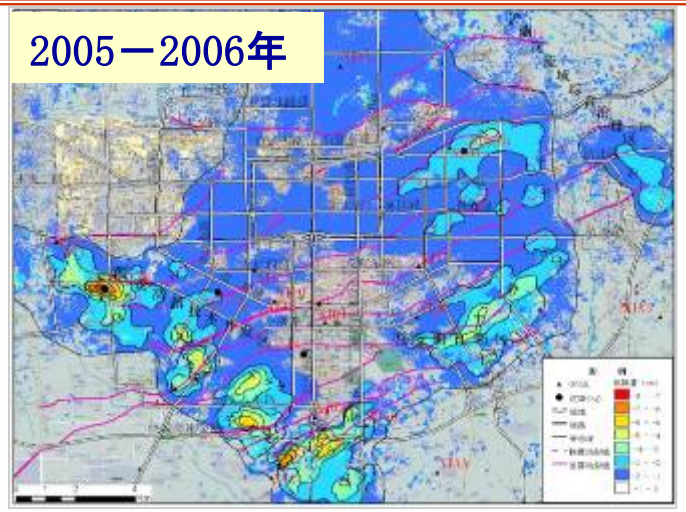

**方案五：**Adjust the layout and time of groundwater pumping.

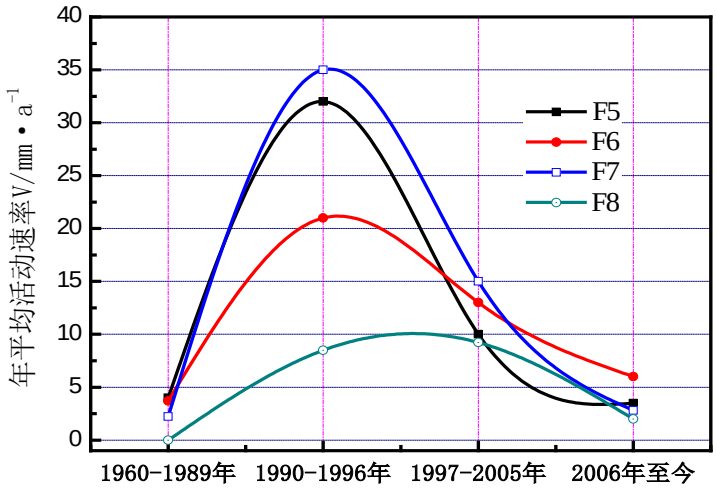


# Main achievement

**The pumping-restriction program has eased the activity of earth fissure and land subsidence.**




1960至今地裂缝年活动速率