Study of Influence of Tunnel Construction on Performance of Spread Foundation Bridge Structure

Presented By

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Outline of Presentation

1. Introduction

2. Ground surface movement and influence of tunnel construction on performance of spread bridge foundation

3. Assessment of spread foundation bridge damage due to tunnel construction


5. Conclusion and recommendation
Chapter 1 Introduction

Presentation of problems

- In Beijing subway, Line 1 crosses 27 bridges and Line 5 crosses 25 bridges
- Ground settlement
- Bearing Capacity
- Bridge Performance will change
- It is necessary to research the influence of tunneling on bridge performance
  - few previous research results about spread foundation bridges
  - lack of the bridge system (superstructure-foundation-soils) assessment due to tunneling

The reasons and significance of study of the thesis
Literature Review

- Ground movement due to tunnel construction

**Empirical formulae**

- Horizontal movement

- Vertical movement
  - Attewell & Woodman (1982); Jianhang Liu (1991)

- Volume loss
  - Borms & Bennermark (1967)

- Trench width

- Subsurface movement
  - Mair, R.J. (1993)

- Multi-arch etc.

**In Summary:**
Lock strict theories can’t show the influence due to construction methods.

However, simple and direct-viewing have gotten widespread availability.
Analytic method

Elastic –plastic mechanics .

In summary:

has strict theories.

However,

for complex tunnel shape and geology conditions, it is difficult and inconvenient to analyse the settlement with analytic method.
Numerical analysis methods

① Random medium theory
Poland scholar J. Litwiniszyn (late 1950s).

② Finite element and Finite difference methods

Development outline:
Transition from 2D to 3D
The research of dynamic analysis for simulating the construction orders
Numerical simulation of the multi-arch tunnels
Inversion analysis for several fields coupling cases.

Other methods
• Model test method, gray theory pre-estimate method and dual exponent curve method etc.
• Analysis method of influence of tunneling

- Interaction?
  - no: Impose the displacement on the foundation of structures
  - yes: Whole model
    - Relative rigid method (Potts & Addenbrooke (1997))

• If the interactions are not considered:
  - available for independent foundation;
  - convenient.

Limitation:
  - pile foundation
• Assessment of structure damage due to tunneling

The critical value of ground surface settlement or structure strain

Several main stages

- Burland & Worth (1974) presented some parameters: relative deviation, horizontal strain, etc.
- Mair (1993) presented the three-stage damage assessment system.
- Potts & Addenbrooke (1997) applied the relative rigid method.

Limitation:
The above methods are mainly to analyse the damage of buildings but bridges. Due to the simple structure types compared with the ones of building, it is not suitable to apply the system of building damage assessment to analyse the damage of bridges.
1.3 Scope of research

① Mechanics of settlement, Peck formula;

② The influence of spread foundation bridges due to displacement and deformation;

③ System of bridge damage assessment;

④ Midas/Civil, modify bridge damage assessment;

⑤ The influence of Guang-fu Over due to Jinshazhou Tunnel, critical value of ground surface settlement.
Chapter 2  Movement of ground surface and influence of tunneling on performance spread foundation bridge

Ground surface Settlement

Mechanism of ground surface settlement

• Excavation settlement
• Consolidation settlement
• Secondary consolidation settlement
Calculation formulae

According to Peck formula.

Settlement :

\[ S_v(x) = \frac{\pi V_L D^2}{2} \exp\left(-\frac{x^2}{2i^2}\right) \]

Inclination :

\[ T(x) = \frac{dS_v(x)}{dx} = \frac{\pi V_L D^2}{4i} \exp\left(-\frac{x^2}{2i^2}\right) \]

\[ = -\frac{x}{i^2} S_v(x) \]

Horizontal displacement in the transversal direction :

\[ S_{hx}(x) = -\frac{x S_v(x)}{Z_0} \]
Equivalent circle method, Shihui Li (1999)

a. Radius of circumcircle (Fig. (a))

\[ R_0 = \frac{\sqrt{AD^2 + BD^2}}{2 \cos(\tan^{-1} \frac{BD}{AD})} \]

b. Radius of arch (Fig. (b))

\[ R_0 = \frac{b}{2 \sin(\frac{\alpha}{2})} \]

c. Half of the large and small dimensions (Fig. (c))

\[ R_0 = \frac{a_1 + a_2}{2} \]

d. 1/4 of sum of height and span (Fig. (d) ~ (f))

\[ R_0 = \frac{h + b}{4} \]
Ratio of Volume loss

The ratio of the difference between volume of excavated soil and tunnel volume over the tunnel volume.

0 - 5.5%

Trench width

The distance between central line and point of inflection.

The empirical formulae of trench width

<table>
<thead>
<tr>
<th>Scholar</th>
<th>Year</th>
<th>Trench width</th>
<th>Ground conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peck</td>
<td>1969</td>
<td>( i/R = (Z_0/2R)^n ) ((n = 0.8 \sim 1.0))</td>
<td>-</td>
</tr>
<tr>
<td>Attewell &amp; Farmer</td>
<td>1974</td>
<td>( i = \frac{H + R}{\sqrt{2\pi \tan(45^\circ - \varphi/2)}} )</td>
<td>-</td>
</tr>
<tr>
<td>Clough &amp; Schmidt</td>
<td>1981</td>
<td>( i/R = (Z_0/2R)^n ) ((n = 1.0))</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( i = 0.43Z_0 + 1.1 )</td>
<td>clay soil, 3m ( \leq Z_0 ) 34m</td>
</tr>
<tr>
<td>Atkinson &amp; Potts</td>
<td>1977</td>
<td>( i = 0.25(Z_0 + R) )</td>
<td>Loose sand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( i = 0.25(1.5Z_0 + 0.5R) )</td>
<td>Dense sand and OC clay soil</td>
</tr>
<tr>
<td>Mair</td>
<td>1983</td>
<td>( i = 0.5Z_0 )</td>
<td>Clay soil</td>
</tr>
<tr>
<td>Leach</td>
<td>1985</td>
<td>( i = (0.75 + 0.47Z_0) \pm 1.01 )</td>
<td>The consolidation is obvious</td>
</tr>
<tr>
<td>Jinli Qu</td>
<td>2006</td>
<td>( i = 4.35 + 7.29 \times 10^{-9} x^8 )</td>
<td>Shanghai soft soil</td>
</tr>
<tr>
<td>Xuan Han</td>
<td>2007</td>
<td>( i = \frac{0.5 - 0.325\varepsilon}{1 - \varepsilon} ) ((\varepsilon_0 - \varepsilon))</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \varepsilon = 0 \sim 1 )</td>
<td>Clay soil, ( a = 0.65 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \varepsilon = 0.50 )</td>
<td>Sandy soil, ( a = 0.50 )</td>
</tr>
</tbody>
</table>

Note: R—Tunnel radius; H—Thickness of cover layer; \( \varphi \)—Ground inner friction; \( Z \)—Tunnel depth
Influence of bridge construction states due to ground surface movement and deformation

Analysis method

- Tunnel construction
- Don’t consider the interaction
- Calculate the displacement and deformation
- Impose the movement and deformation on the foundation of bridge
- Analyse the forces and deformations of bridge
Definition of characteristic points' displacement and deformation

① Displacement of characteristic points
   a. settlement
   b. horizontal displacement

② Deformation of characteristic points
   a. inclination
   b. curvature
   c. horizontal deformation
The association of two or more damage types.

- Uniform settlement
- Horizontal displacement
- Inclination
- Curvature
- Deformation

Large settlements induce the trench to become a *pool zone* when the water level is shallow. The water *influences the bearing capacity* of ground.

Subsidiary stresses appear for the continuous beams. Large displacements make the free beams *out of the bridge piers*.

Large inclination can influence the *stability of bridge piers*.

Induce the foundation center or two extremities to *suspend*, so the crevices may appear.

Tension deformations make the foundation *crack*.
Chapter 3 Assessment of spread foundation bridge damage due to tunnel construction

Upper structure states

(1) Free beam

Uniform settlement \( \leq 2.0\sqrt{L} \)

Settlement difference \( \leq 1.0\sqrt{L} \)

(2) Continuous beam

The limit state of bearing capacity:

Bearing capacity of right section, bearing capacity of oblique section

The limit state of normal service:

anti-crack ability of right section, anti-crack ability of oblique section and deflection

To satisfy the safety of structure, each correspondence should be less than the corresponding resistance.

\[ r_0S < R \]

Safety coefficient: \[ N = \frac{R}{\gamma_0S} \]
Bearing capacity

a. Bearing capacity of right section

When $\Delta > 0$, $N \uparrow$ the range near the central support and $N \downarrow$ during other ranges. When $\Delta < 0$, the results are opposite to the above.

b. Bearing capacity of oblique section

When $\Delta > 0$, $N \uparrow$ the range near the left support and the right range near the central support and $N \downarrow$ during other ranges. When $\Delta < 0$, the results are opposite to the above.

Anti-cracking capacity and deflection

- Because the safety coefficients of anti-cracking capacity and deflection are related with the forces of right and oblique sections, they should be influenced by settlement difference.
Substructure states

Horizontal displacement of pier top

\[ U' = \theta(H_1 + H_2) + S_h \]

When \( \theta \) and \( S_h \) ↑, \( N \) ↓

Eccentricity on bottom of foundation

\[ e = \frac{M}{F} = \frac{M_1}{F_1 + F_2 + F_3} + \frac{F_1(H_1 + H_2) + F_2(H_1/2 + H_2) + F_3H_2/2}{F_1 + F_2 + F_3} \theta \]

When \( \theta \) ↑, \( N \) ↓

Stability on bottom of foundation

a. Anti-toppling coefficient:

\[ K_0 = \frac{b_2 \cos \theta / 2}{b_2 \cos \theta / 2 + \frac{F_1(H_1 + H_2) + F_2(H_1/2 + H_2) + F_3H_2/2}{F_1 + F_2 + F_3} \theta} \]

When \( \theta \) ↑, \( K_0 \) ↓

b. Anti-sliding coefficient:

\[ K_c = \frac{f \cos \theta \sum F_i}{P + \sin \theta \sum F_i} = \frac{f \cos \theta(F_1 + F_2 + F_3)}{P + \sin \theta(F_1 + F_2 + F_3)} \]

\( f \) - friction coefficient

When \( \theta \) ↑, \( K_c \) ↓

Fig. Sketch of substructure

Fig. Sketch of composite forces on the bottom of foundation
Bridge damage assessment

- Tunnel construction
  - Ground surface settlement
    - Upper structure
      - Free beam
        - Uniform settlement
        - Settlement difference
        - Bearing capacity of right section
        - Bearing capacity of oblique section
      - Continuous beam
        - Anti-cracking capacity of right section
        - Anti-cracking capacity of oblique section
        - Deflection
    - Substructure
      - Horizontal displacement of pier top
      - Eccentricity of foundation base
      - Stability of foundation base
      - Stability of foundation base
Sensibility analysis of bridge states and modification of bridge damage assessment system

Choose of bridge case
Two equal spans continuous beam bridge, span=25m.

Fig. Numerical model (top view)

Fig. Section type and dimension of continuous beam (Units: cm)

Fig. Substructure type and dimension (Units: cm)
Sensibility analysis results

Continuous beam

(a) Settlement only on one side support

(b) Settlement on one side support and central support

Fri State-settlement relationship curve for different cases

Choose the anti-cracking capacity of right section as the control state for bridge damage assessment.

Substructure

The influence degree of horizontal displacement of pier top is largest.
Modification of bridge damage assessment system

- Tunnel construction
  - Ground surface settlement
  - Tunnel construction
- Upper structure
  - Free beam
    - Uniform settlement
    - Settlement difference
  - Continuous beam
    - Uniform settlement
    - Settlement difference
    - Anti-cracking capacity
      - of right section
      - of oblique section
    - Horizontal displacement of pier top
    - Anti-cracking capacity
      - of right section
      - of oblique section
    - Eccentricity of foundation base
    - Stability of foundation base
- Substructure
  - Horizontal displacement of pier top
Chapter 4 Analysis of influence of Jinshazhou Tunnel construction on performance of Guang-fu Overpass

Engineering outline
Spacial relation between tunnel and bridge

Fig. Horizontal relation between Jinshazhou Tunnel and Guang-Fu Overpass
Fig. Vertical relation between Jinshazhou Tunnel and Guang-Fu Overpass
(Along the direction of bridge. Unit of dimensions: cm. Unit of others: m)
Outline of Guang-fu Overpass

(a) Left part

(b) Middle part

(c) Right part

Fig. Structure type and dimension of Guang-Fu Overpass

(Left+Middle+Right. Unit of dimensions: cm. Unit of others: m)

18 years,
Good performances
(a) Free beam

(b) Continuous beam

Fig. Section type and dimension of the beams

(Unit of dimensions: cm)
The piers' heights:
2#: 6.21 11#: 8.45
3#: 6.78 12#: 8.06
4#: 7.26 13#: 7.58
5#: 7.65 14#: 7.01
6#: 7.94 15#: 6.41

Elevation Figure

(a) 1~6#, 11~15#
(b) 7# and 9#
(c) 8#
(d) 10#

Fig. Diagrammatic sketch of the understructures
(Unit of dimensions: cm. Unit of others: m)
Outline of Jinshazhou Tunnel section below Guang-fu Overpass

Stratum lithology

Fig. 4-7 The cross section of DK2194+650~DK2194+700 of Jinshazhou Tunnel along the strike of the tunnel

(Unit of dimensions: cm. Unit of others: m)
<table>
<thead>
<tr>
<th>Classification code</th>
<th>Stratum name</th>
<th>State</th>
<th>Ground bearing ability (kPa)</th>
<th>Compressive Modulus (MPa)</th>
<th>Cohesive strength (kPa)</th>
<th>Internal friction angle(°)</th>
<th>Natural density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>Filling</td>
<td>Loose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2(4)</td>
<td>Slity clay</td>
<td>Soft plastics</td>
<td>120</td>
<td>4.0</td>
<td>8.54</td>
<td>17.83</td>
<td>1.86</td>
</tr>
<tr>
<td>2 ( 5)</td>
<td>Slity clay</td>
<td>Stiff plastics</td>
<td>150</td>
<td>5.51</td>
<td>28.57</td>
<td>13.53</td>
<td>1.96</td>
</tr>
<tr>
<td>7(1)</td>
<td>Carbon limestone</td>
<td>Completely weathering</td>
<td>200</td>
<td>4.41</td>
<td>18.2</td>
<td>4.20</td>
<td>1.95</td>
</tr>
<tr>
<td>7(2)</td>
<td>Carbon limestone</td>
<td>Strong weathering</td>
<td>300</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8(2)</td>
<td>Limestone</td>
<td>Strong weathering</td>
<td>500</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8(3)</td>
<td>Limestone</td>
<td>Weak weathering</td>
<td>1000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10(1 )</td>
<td>Breccia</td>
<td>Completely weathering</td>
<td>8.76</td>
<td>46.75</td>
<td>27.50</td>
<td>2.01</td>
<td></td>
</tr>
</tbody>
</table>
### Classification of the tunnel adjacent rock

<table>
<thead>
<tr>
<th>Section of tunnel</th>
<th>Length</th>
<th>Classification of adjacent rock</th>
<th>Main geology character</th>
<th>Structure character and integrality</th>
<th>Stability of adjacent after tunnel is excavated</th>
</tr>
</thead>
<tbody>
<tr>
<td>DK2194+650 ~ DK2194+685</td>
<td>35</td>
<td>V</td>
<td>Soft plastic~stiff plastic clay resulting from alleviation, saturated sandy soil and soft soil. The <strong>groundwater is abundant</strong>. There is a bit residual soil which will become soft and disintegrated</td>
<td>The Slity clay exists as loose sand. Besides the clay, there are sand which is loose~dense</td>
<td>The slide and deform happen badly easily in the adjacent rock. The soil and sand easily flood with water. The slide may not stop until it touch the ground when the depth is a shadow.</td>
</tr>
<tr>
<td>DK2194+685 ~ DK2194+700</td>
<td>15</td>
<td>VI</td>
<td>The adjacent rock has become soil or semi-rock and semi-soil or block due to strong weathering. The groundwater exists but heavily.</td>
<td>The adjacent rock exists as loose structures, which is a bit cohesive. The rock body is very cracked.</td>
<td>Slide happen easily. It may be serious when it isn’t delt with right. The small slides often happen in the side of tunnel. The slide may not stop until it touch the ground when the depth is a shadow.</td>
</tr>
</tbody>
</table>
Support structure

Preliminary support:
- steel net: 20cm*20cm (radial*longitudinal)
- anchor: 4.0m(length), 80cm*100cm (radial*longitudinal)
- steel frame: I20a, 80cm(longitudinal)
- sprayed concrete

Secondary support: C35 reinforced concrete

Note: 1. Unit: cm
2. Systemic bolts:
   - arch: grouting hollow bolt
   - side: common mortar bolt

Fig. V compound lining in the section DK2194+650 ~ DK2194+675

Fig. VI compound lining in the section DK2194+675 ~ DK2194+700
Curtain grouting technology is used to strengthen the stratum during the section DK2194+650~DK2194+700; The strengthening boundary is located in the 5m away from the excavation line in the transverse direction; φ108 steel piles are used.

Table 4-3 The expolated angulars and length of injected holes

<table>
<thead>
<tr>
<th>Hole position</th>
<th>Expolated angular</th>
<th>Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>0°0'0&quot;</td>
<td>30.00</td>
</tr>
<tr>
<td>1st ring</td>
<td>4°17'21&quot;</td>
<td>30.08</td>
</tr>
<tr>
<td>2nd ring</td>
<td>8°31'51&quot;</td>
<td>30.34</td>
</tr>
<tr>
<td>3rd ring</td>
<td>12°40'49&quot;</td>
<td>30.75</td>
</tr>
<tr>
<td>4th ring</td>
<td>16°41'57&quot;</td>
<td>31.32</td>
</tr>
<tr>
<td>5th ring</td>
<td>20°51'21&quot;</td>
<td>21.40</td>
</tr>
<tr>
<td>6th ring</td>
<td>26°8'11&quot;</td>
<td>15.59</td>
</tr>
</tbody>
</table>

Fig.4-10 Position of grouting holes (Units: cm)
Construction method

**Construction processes:**
1. Excavate the part 1, construct the preliminary supports and temporary supports;
2. Excavate the part 2, construct the preliminary supports and temporary supports;
3. Excavate the part 3, construct the preliminary supports and temporary supports;
4. Excavate the part 4, construct the preliminary supports and temporary supports;
5. Excavate the part 5, construct the preliminary supports;
6. Excavate the part 6, construct the preliminary supports;
7. Excavate the part 7;
8. Excavate the part 8;
9. Remove the temporary steel bracket construct the IX, inverted arch;
10. Fill the part X in the bottom of tunnel;
11. According to the result of monitoring, construct the secondary support after the preliminary supports stop deforming.

---

**(a) Transversal section figure (Unit: cm)**

- Spray 8 cm thick C20 concrete to seal face
- Sprayed concrete
- Spray in temporary supports
- Spray in preliminary supports
- Secondary supports in archs
- Filling in the inverted arch

---

**(b) Longitudinal section figure**

- Spray 8 cm thick C20 concrete to seal face
- Secondary supports in archs
- Spray in preliminary supports
- Spray in temporary supports

---

**(c) Plane figure**

- Spray 8 cm thick C20 concrete to seal face
- Secondary supports in archs
- Spray in preliminary supports
Calculation of ground surface displacement and deformation

(1) Equivalent radius

\[(H+b)/4=7.02\text{m}\]

(2) Trench width

Embedded depth: Z0 = 25.85\text{m}

### Table Trench width coefficient of each layer

<table>
<thead>
<tr>
<th>Layer</th>
<th>Soft plastic slity clay</th>
<th>Stiff plastic slity clay</th>
<th>Soft plastic slity clay</th>
<th>Stiff plastic slity clay</th>
<th>Completely weathering Breccia</th>
<th>Strong weathering Limestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness ( m )</td>
<td>1.73</td>
<td>3.59</td>
<td>3.01</td>
<td>0.73</td>
<td>9.77</td>
<td>0</td>
</tr>
<tr>
<td>Trench width coefficient</td>
<td>0.25</td>
<td>0.45</td>
<td>0.25</td>
<td>0.45</td>
<td>0.9</td>
<td>-</td>
</tr>
</tbody>
</table>

Considering the different layers comprehensively, the trench width is: \( k = 0.60, i = kZ_0 = 0.60 \times 25.85 = 15.10\text{m} \)

According to Peck formulas:

\[S_y(x) = 3.982V_L \times \exp(-0.002x^2)\quad \theta(x) = \arctan(-0.017xV_L \times \exp(-0.002x^2))\]
\[S_{hs}(x) = -0.154xV_L \times \exp(-0.002x^2)\]
Assessment of influence of tunneling

Free beam

Table 1 Settlement (Units: cm)

<table>
<thead>
<tr>
<th>Location</th>
<th>Distance (m)</th>
<th>0.5%</th>
<th>1.0%</th>
<th>2.0%</th>
<th>2.6%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1~3</td>
<td>-</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>-55.12</td>
<td>0.00</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>5</td>
<td>-38.18</td>
<td>0.11</td>
<td>0.22</td>
<td>0.43</td>
<td>0.56</td>
</tr>
<tr>
<td>6</td>
<td>-21.24</td>
<td>0.81</td>
<td>1.62</td>
<td>3.23</td>
<td>4.20</td>
</tr>
<tr>
<td>7</td>
<td>-4.3</td>
<td>1.92</td>
<td>3.84</td>
<td>7.67</td>
<td>10.00</td>
</tr>
<tr>
<td>9</td>
<td>47.04</td>
<td>0.02</td>
<td>0.05</td>
<td>0.10</td>
<td>0.12</td>
</tr>
<tr>
<td>10~16</td>
<td>-</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

The critical values of settlement and settlement difference between two adjacent foundation base are respectively 10cm and 5cm.

Table 2 Settlemenent difference (Units: cm)

<table>
<thead>
<tr>
<th>Location</th>
<th>Distance (m)</th>
<th>0.5%</th>
<th>1.0%</th>
<th>2.0%</th>
<th>2.2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1~3</td>
<td>-</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4~3</td>
<td>-55.12</td>
<td>0.00</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>5~4</td>
<td>-38.18</td>
<td>0.10</td>
<td>0.21</td>
<td>0.41</td>
<td>0.45</td>
</tr>
<tr>
<td>6~5</td>
<td>-21.24</td>
<td>0.70</td>
<td>1.40</td>
<td>2.80</td>
<td>3.08</td>
</tr>
<tr>
<td>7~6</td>
<td>-4.3</td>
<td>1.11</td>
<td>2.22</td>
<td>4.44</td>
<td>5.00</td>
</tr>
<tr>
<td>9~10</td>
<td>47.04</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>10~16</td>
<td>-</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Continuous beam

a. Anti-cracking capacity of right section

Table 1 Safety coefficients of anti-cracking capacity of right section for different cases

<table>
<thead>
<tr>
<th>Location</th>
<th>Settlement (cm)</th>
<th>Ratio of volume loss</th>
<th>Safety coefficient</th>
<th>Location</th>
<th>Settlement (cm)</th>
<th>Ratio of volume loss</th>
<th>Safety Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
<td>1.899</td>
<td>7</td>
<td>2.69</td>
<td>0.7%</td>
<td>1.221</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>0</td>
<td>1.567</td>
<td>8</td>
<td>1.12</td>
<td>0.9%</td>
<td>1.007</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>0.5%</td>
<td>0.02</td>
<td>9</td>
<td>0.03</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1.92</td>
<td>0.5%</td>
<td>1.567</td>
<td>7</td>
<td>3.45</td>
<td>0.9%</td>
<td>1.007</td>
</tr>
<tr>
<td>8</td>
<td>0.80</td>
<td>0.02</td>
<td></td>
<td>8</td>
<td>1.44</td>
<td>0.9%</td>
<td>1.007</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td>0.04</td>
<td>0.0%</td>
<td></td>
</tr>
</tbody>
</table>

b. Deflection

Table 2 Deflection for different ratio of volume loss

<table>
<thead>
<tr>
<th>Ratio of volume loss</th>
<th>0</th>
<th>0.5%</th>
<th>1.0%</th>
<th>1.5%</th>
<th>2.0%</th>
<th>2.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection (cm)</td>
<td>2.65</td>
<td>3.23</td>
<td>3.45</td>
<td>3.57</td>
<td>3.61</td>
<td>3.67</td>
</tr>
</tbody>
</table>

Critical value: \( L/600 = 25.67/600 \text{m} = 4.28 \text{cm} \)
Substructure

The critical value of horizontal displacement of pier top: \( \Delta \leq 5\sqrt{L} = 2.53\text{cm} \)

<table>
<thead>
<tr>
<th>Location</th>
<th>Distance (m)</th>
<th>Ratio of volume loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.5%</td>
</tr>
<tr>
<td>1~3</td>
<td>-</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>-55.12</td>
<td>0.02</td>
</tr>
<tr>
<td>5</td>
<td>-38.18</td>
<td>0.32</td>
</tr>
<tr>
<td>6</td>
<td>-21.24</td>
<td>1.35</td>
</tr>
<tr>
<td>7</td>
<td>-4.3</td>
<td>0.66</td>
</tr>
<tr>
<td>8</td>
<td>20.592</td>
<td>-1.40</td>
</tr>
<tr>
<td>9</td>
<td>47.04</td>
<td>-0.09</td>
</tr>
<tr>
<td>10~16</td>
<td>-</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Final results

To satisfy the safety of the whole bridge structure, the ratio of volume loss should be less than 0.9%

Table 2 Critical settlement of each location for ratio of volume loss=0.9%

<table>
<thead>
<tr>
<th>Location</th>
<th>1~3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10~16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Settlement (cm)</td>
<td>0.00</td>
<td>0.01</td>
<td>0.19</td>
<td>1.45</td>
<td>3.45</td>
<td>1.44</td>
<td>0.04</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Jinshazhou Tunnel construction for potential damage

\[ F = \frac{\text{actual settlement}}{\text{critical settlement}} \]

- **F** ≤ 0.6: Safe state, go ahead
  - Strengthen the pipe shed
- 0.6 < **F** ≤ 0.8: Warning state, reduce the speed of construction, find the reason
  - Stop construction and take action
- 0.8 < **F** ≤ 1.0: Risky state, stop constructing and take measurement
- **F** > 1: Failure state
Chapter 5 Conclusion and recommendation

Main conclusion and content

(1) Peck and other relevant formulae have been discussed, and calculation methods of equivalent radius, ratio of volume loss and trench width have been chosen.

(2) Bridge damage comes from ground surface settlement, horizontal displacement, inclination, curvature and horizontal deformation.

(3) The system of bridge damage assessment due to tunnel construction has been established.

(4) With the Midas/Civil, the system of bridge damage assessment has been modified.

(5) The critical values of ground surface settlement and ground loss have been presented.
Recommendation

(1) Consider the consolidation and secondary consolidation

(2) Without considering the interaction between bridge and ground, the analysis result is a little conservative.

(3) Consider the influence due to construction orders and methods.

(4) If there are field test data for reference in order to choose the value of trench width, the analysis results will be more favorable.

(5) If the relative relationship between ratio of volume loss and the degree of ground reinforcement can be established through tests, the ground reinforcement will be more favorable.

(6) Analyse more than two spans continuous beam bridge.
Thank you for your attention!

- If you have some questions, please speak slowly;
- ask simple questions;
- forgive my bad English……