Study on Serviceability of Transition Section Between Road and Tunnel

Chonghui Zhong 1, Bingwei Cheng 1,2, Linhao Wang 1,2, Shijie Yu 1,2

1 China Railway No.3 Bureau Group Investment Co., Ltd. Taiyuan, Shanxi, 030006, China
2 Tianshui Sanyangchuan Tunnel Traffic Engineering Co., Ltd. Tianshui, Gansu, 741030, China

Abstract: The determination of allowable differential settlement in bridge transition is a key problem to prevent vehicle jump at bridge head, but there are few theoretical research achievements in this aspect at introduction home and abroad. In this paper, four different structures of the road surface of The Sanyangchuan tunnel and the lead project are studied. The allowable differential settlement of asphalt pavement is calculated by asphalt pavement-layer system, and the allowable differential settlement is calculated by Ladan Lasse transform.

Keywords: ITD; Trip; Deflection value; Post-construction settlement.

1. Introduction

Highways play a very important role in the development of China's transportation industry, and in recent years, bridge head jumping has become a prominent problem in the construction of highways. Bridge head jumping has a very obvious impact on the safety, stability and comfort of driving, which will cause damage to the car as well as the safety of driving if it is serious. Therefore, it is significant for highway construction to analyze and discuss the problem of bridge head jumping and propose targeted prevention and control measures.

In this paper, we mainly study the jumping problem of pavement transition section of Sanyangchuan Tunnel and lead project in Tianshui City. The asphalt pavement is subjected to the calculation of permanent deformation and bending and settlement values; the small bridge deck is subjected to the calculation of post-work settlement. The theory of asphalt pavement design in China is the theory of multi-layer elastic laminate system, which adopts the principle of bicircular vertical homogeneous load action[1], and at the same time, in order to make the actual road use condition and calculation reasonable, the contact conditions between the layers are set as a completely continuous system when calculating the road surface bending and settlement and layer bottom tensile stress[2-4].

Many domestic and foreign information to the approach road embankment of the allowable post-work settlement as a bridge head jump settlement control index. The Japanese Road Association[5] recommends that the allowable residual settlement of bridge approach roads should not exceed 10-30 cm within 3 years, and it is pointed out in the U.S. highway study "Soft Foundation Treatment of Highway Embankments"[6] that: during the economic life of a highway (10-15 years), the allowable post-work settlement of general embankments is 30-60 cm (1-2 feet), but the allowable post-work settlement of bridge approaches is 15-30 cm (0.5-1 ft).

2. Background

This project is located in Majji District of Tianshui City, which can connect the main urban area of Tianshui City and Sanyangchuan New District, and also as a part of Luojiagou - Sanyangchuan Tunnel - Magan Highway Passage, which can connect Lianhuo Expressway, Xihu Avenue of Tianshui main urban area, Chengji Avenue and Sanyangchuan New District in the long term. Technical indicators are executed according to the Technical Standards for Highway Engineering[7] (JTG B01-2014) issued by the Ministry of Transportation.

2.1 Meteorological conditions

Tianshui City is located in the northern temperate zone, a semi-arid continental climate. The natural area is divided into the arid zone in the Yang Mountain in the north, the river valley in the middle and the humid zone in the shallow mountains in the south. The general climatic characteristics of Tianshui are: rapid warming in spring; no scorching heat in summer; continuous rain in autumn; and no severe cold in winter. The climate is mild, with four distinct seasons, sufficient sunshine and moderate precipitation. The average multi-year temperature in Tianshui is 10.9℃, the extreme high temperature is 38.3℃, the extreme minimum temperature is -19.2℃, and the average temperature of the coldest month is about -
2℃; the average multi-year precipitation is 580.0mm. The annual temperature distribution in Tianshui is shown in Figure 1.

![Figure 1. The annual temperature distribution in Tianshui](image)

### 2.2 Geomorphology, Hydrogeology

The project traverses through the valley area of the river through the river, the north mountain of the river in the loess mount area to the south bank of the Wei River, the geomorphology is erosion accumulation valley landform and denudation structure hilly landform, the topography is undulating, the relative height difference of 200 ~ 400 m. The type of groundwater along the line can be divided into two types of pore water and bedrock fracture water according to their conditions and aquifer nature.

### 3. Simulation

#### 3.1 Mainline and interchange ramp pavement structure

(1) Traffic volume calculation

Class I highway; target reliability index of 1.28; annual average daily traffic volume of 1500 vehicles/day in both directions for large passenger cars and trucks in the initial year; design service life of pavement of 15 years; 15 years from opening to the first time for rutting repair[8-12].

Traffic volume annual average growth rate of 6.5%, direction factor 0.55, lane factor 0.5, integral truck proportion 25%, semi-trailer truck proportion 35%, the initial year design lane large passenger cars and trucks annual average daily traffic volume of 412/day, the design life of the design lane cumulative large passenger cars and truck traffic volume 3636514, so the pavement traffic load level for the light traffic load Grade.

Axle load calculation:

When the fatigue cracking of asphalt mixture layer and inorganic bonding material stabilization layer is tested, the cumulative number of equivalent design axle loads on the design lane during the design life is 5383818 times[13-14].

(2) Pavement structure design and calculation

The number of layers of pavement structure is 6, the design axle load is 100kN standard axle load, the design layer of pavement is 4, and the starting thickness of design layer is 320mm. The parameters of each structural layer are shown in Table 1 below.

#### Table 1. Structural layer parameters

<table>
<thead>
<tr>
<th>Layer</th>
<th>Name of structural layer material</th>
<th>Thickness (mm)</th>
<th>Modulus (MPa)</th>
<th>Poisson's ratio</th>
<th>Inorganic bonding material stabilization class</th>
<th>Asphalt mixture rutting permanent deformation amount (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fine grain type AC-13C</td>
<td>40</td>
<td>11000</td>
<td>0.25</td>
<td>9.37924E+10</td>
<td>0.029</td>
</tr>
<tr>
<td>2</td>
<td>Medium grain type AC-20C</td>
<td>60</td>
<td>10000</td>
<td>0.25</td>
<td>2.61082E+10</td>
<td>0.065</td>
</tr>
<tr>
<td>3</td>
<td>Course grain type AC-25</td>
<td>60</td>
<td>9000</td>
<td>0.25</td>
<td>6.964421E+09</td>
<td>0.041</td>
</tr>
<tr>
<td>4</td>
<td>Cement stabilized gravel (1% cement admixture)</td>
<td>80</td>
<td>7500</td>
<td>0.25</td>
<td>1.06</td>
<td>0.8</td>
</tr>
<tr>
<td>5</td>
<td>Cement stabilized gravel (1.5% cement admixture)</td>
<td>80</td>
<td>7500</td>
<td>0.25</td>
<td>1.06</td>
<td>0.8</td>
</tr>
<tr>
<td>6</td>
<td>Cement stabilized gravel soil</td>
<td>180</td>
<td>3000</td>
<td>0.4</td>
<td>1.06</td>
<td>0.8</td>
</tr>
</tbody>
</table>

When calculating the vertical compressive strain on the top surface of the roadbed: the cumulative number of equivalent design axle loads acting on the design lane during the design life is 8130594 times[13-14].

The fatigue cracking test for each inorganic bonding material stabilized layer is shown in Table 2.

#### Table 2. Fatigue cracking test for each inorganic bonding material stabilized layer

<table>
<thead>
<tr>
<th>Design layer thickness (mm)</th>
<th>Seasonal permanent area adjustment factorKA</th>
<th>Temperature adjustment factorKT2</th>
<th>Field integrated correction factorKC</th>
<th>Layer bottom tensile stress σ(MPa)</th>
<th>Fatigue cracking life of inorganic bonding material stabilization layer (Axis)</th>
<th>The cumulative number of equivalent design axle load actions on the design lane during the design service lifeNZB2 (Axis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>320</td>
<td>0.8</td>
<td>1.06</td>
<td>-1.15</td>
<td>0.029</td>
<td>9.37924E+10</td>
<td>2.814496E+08</td>
</tr>
<tr>
<td>320</td>
<td>1.8</td>
<td>1.06</td>
<td>-1.39</td>
<td>0.065</td>
<td>2.61082E+10</td>
<td>2.814496E+08</td>
</tr>
<tr>
<td>320</td>
<td>0.8</td>
<td>1.06</td>
<td>-0.83</td>
<td>0.041</td>
<td>6.964421E+09</td>
<td>2.184496E+08</td>
</tr>
</tbody>
</table>

The asphalt mixture layer permanent deformation equivalent temperature TPEF = 19.6 ℃, the opening to
the first time for rutting repair period on the design lane equivalent design axle load cumulative number of times NZB3 = 5383818 axle times, the asphalt mixture layer permanent deformation test number of layers N = 6, 1 to 6 layers RA1 were 0.34mm, 0.61mm, 1mm, 0.72mm, 0.44mm, 0.55mm. RA = 3.66mm, RAR = 15mm, so the asphalt mixture layer permanent deformation to meet the specification requirements.

(4) Calculate the accepted bending and settlement values of the designed pavement structure

Dry and wet cycles or freeze-thaw cycles under the conditions of soil modulus reduction factor KAT = 0.8, the top surface of the road acceptance bending value LG = 59.8 (0.01mm), the road surface acceptance bending value LA = 8.2 (0.01mm).

The first layer of asphalt mixture rutting test dynamic stability technical requirements for 5139 times/mm; the second layer of asphalt mixture rutting test dynamic stability technical requirements for 2412 times/mm; the third layer of asphalt mixture rutting test dynamic stability technical requirements for 2412 times/mm.

The minimum frost protection thickness of the pavement structure is 500 mm, and the calculation results show that the total thickness of the pavement structure meets the frost protection requirements.

3.2 Tunnel Pavement Structure

(1) Traffic volume calculation

The data is the same as the traffic volume calculation data of the pavement structure of the main line and interchange ramps.

(2) Pavement structure design and calculation

The number of layers of pavement structure is 6, the design axle load is 100kN standard axle load, the design layer of pavement is 4, and the starting thickness of design layer is 320mm. the parameters of each structural layer are shown in Table 3 below.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Name</th>
<th>Modulus (mm)</th>
<th>Modulus (MPa)</th>
<th>Poisson's ratio</th>
<th>tensile strength (MPa)</th>
<th>deformation amount (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AC-13C</td>
<td>40</td>
<td>11000</td>
<td>0.25</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>AC-20C</td>
<td>60</td>
<td>10000</td>
<td>0.25</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Cement stabilized steel slag</td>
<td>220</td>
<td>10000</td>
<td>0.25</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Cement stabilized gravel</td>
<td>-</td>
<td>7500</td>
<td>0.25</td>
<td>1.4</td>
<td></td>
</tr>
</tbody>
</table>

The fatigue cracking test for each inorganic bonding material stabilized layer is shown in Table 4:

<table>
<thead>
<tr>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design layer thickness H(4)(mm)</td>
<td>320</td>
</tr>
<tr>
<td>Seasonal permafrost area adjustment factor KA</td>
<td>0.8</td>
</tr>
<tr>
<td>Temperature adjustment factor KT2</td>
<td>0.888</td>
</tr>
<tr>
<td>Field integrated correction factor KC</td>
<td>-0.24</td>
</tr>
<tr>
<td>Layer bottom tensile stress σ( MPa)</td>
<td>0.041</td>
</tr>
</tbody>
</table>

(3) asphalt mixture layer permanent deformation calculation

TPEF = 19.6 ℃, NZB3 = 5383818 axle times, the asphalt mixture layer permanent deformation test number of layers N = 5, 1 to 5 layers of asphalt mixture layer permanent deformation are 0.18mm, 0.49mm, 0.89mm, 0.66mm, 0.41mm. RA=2.63mm, RAR=15mm, so the permanent deformation of the asphalt mixture layer meets the specification requirements.

(4) Calculate the acceptance bending and settlement value of the designed pavement structure KAT = 0.8, LG = 59.8 (0.01mm), LA = 9.3 (0.01mm).

3.3 Bridge deck pavement structure

Set up the lap board of the road and bridge transition section, the lap board will rotate around the abutment, although the settlement of the abutment is smaller than the settlement of the approach road embankment, but can not be ignored. In the figure, x is the length of the hitching plate; $S_0$ and $S_1$ are the post-work settlement of the foundation of the bridge deck and the hitching plate away from the soil under the end of the platform (referred to as the post-work settlement of the hitching plate); i indicates the longitudinal slope of the bridge deck, hitching plate and approach road when completed, and the longitudinal slope of the approach road when the soil settlement becomes stable; $i_0$ and $i_1$ are the longitudinal slope of the bridge deck and hitching plate when the soil settlement of the approach road becomes stable[15-16], respectively. As shown in Figure 2.

![Figure 2](image_url)

Analysis of differential settlement at the bridge head with a lap plate
From the geometric relationship shown in Figure 1.1, the longitudinal slope change of the bridge deck, i.e., the differential settlement between the abutment and the pier on the other side of the side span and the ratio between the span diameter of the side span and the slope difference between the deck and the lap slab are calculated as shown in Equation 1 and 2, respectively:

\[ \Delta l = i_1 - i \]  
\[ \Delta l_2 = i_1 - i_2 \]  

Then the longitudinal slope change value before and after the settlement of the lap slab due to post-work settlement is calculated as shown in Equation 3:

\[ \Delta l = \Delta l_1 + \Delta l_2 \]  

Then the post-work settlement of the soil under the lap slab away from the end of the platform is calculated as shown in Equation 4:

\[ S'_p = S_p^b + x \cdot \Delta l \]  

And \( S_p^b \) calculated as shown in Equation 5, for low, medium and high compressibility saturated soils \( \alpha_1 \), the foundation soil type coefficients are 0.4, 0.7 and 0.85, respectively; \( \alpha_2 \) is for bridge foundation type coefficients, for pile foundations \( \alpha_2 = 1/500 \); for expanded foundations \( \alpha_2 = 1/300 \); \( L \) is the bridge side span diameter, still calculated as 25m when the span diameter is less than 25m[17].

\[ S_p^b = \alpha_1 \alpha_2 L \]  

Therefore, the after-work settlement of the bridge deck of this small bridge is calculated as shown in Equation 6:

\[ S_p = 0.7 \cdot \frac{L}{100} \cdot 25 + 15 \cdot 0.2\% = 0.065 \text{cm} \]  

4. Summary

4.1 Data Comparison

Based on the previous parameter calculations for the four different pavement structures, the permanent deformation and bending values for the mainline and interchange ramp pavement structures and tunnel pavement structures are shown in Table 5. A comparison of the permanent deformation and bending values of the mainline and interchange ramp pavement structure and the tunnel pavement structure is shown in Figure 5.

| Table 5. Mainline pavement and tunnel pavement permanent deformation and bending and settlement values |
|----------------------------------|-----------------|-----------------|
|                                  | Mainline Pavement | Tunnel Pavement |
| RAI(1)                          | 0.34mm           | 0.18mm          | 0.16mm          |
| RAI(2)                          | 0.61mm           | 0.49mm          | 0.12mm          |
| RAI(3)                          | 1mm              | 0.89mm          | 0.11mm          |
| RAI(4)                          | 0.72mm           | 0.66mm          | 0.06mm          |
| RAI(5)                          | 0.44mm           | 0.41mm          | 0.03mm          |
| RAI(6)                          | 0.55mm           |                |                |
| LA                              | 3.66mm           | 2.63mm          | 1.03mm          |
| Total bending value             | 68.0(0.01mm)     | 69.1(0.01mm)    | -               |

The data in Table 1 shows that the difference in permanent deformation between the main line and the tunnel is small, so the transition section of the two areas will not have the problem of jumping; Chongqing Highway Science Institute of the Ministry of Communications believes that for the advanced pavement pavement within 20 years, the allowable post-work settlement of the section adjacent to the artificial structure is 10-20cm more appropriate[18]. And the road of the small bridge deck settlement after work for 0.65mm, the main line and tunnel pavement of the total bending value of 68.0mm and 69.1mm, and the small bridge deck settlement difference of 67.35mm and 68.45mm, respectively, are less than 10cm, so to meet the requirements of smooth vehicle driving; and the toll station square pavement structure for the concrete structure, its settlement is generally negligible, and the main line bending value is 68.0mm, and the settlement difference with the toll station square pavement is about 6.8cm, which satisfies the requirement of smooth driving of vehicles.

5. Conclusion

(1) The difference in permanent deformation between the main line and the tunnel is 1.03mm, and the difference in bending and settlement values is 1.1mm, both of which are small, so there will be no jumping problem in the transition section area between the two;
(2) the road of the small bridge deck after work settlement of 0.65mm, the main line and tunnel road surface of the total bending value of 68.0mm and 69.1mm, and the small bridge deck settlement difference of 67.35mm and 68.45mm respectively, are less than 10cm, so meet the requirements of smooth vehicle driving requirements;
(3) And the toll station square pavement structure is concrete structure, its settlement is generally negligible, and the main line bending settlement value is 68.0mm, and the settlement difference of the toll station square pavement is about 6.8cm, which meets the requirements of smooth vehicle driving.


6. Ye Mianshu. Study on the prevention and control measures of bridge head jumping, Annex I - Study on the post-work settlement criteria of the roadbed after the bridge platform. Institute of Transportation Engineering, Southeast University.


16. Lai Guolin. Study report of bridge head jumping prevention and control measures of Annex II a proposal on the allowable value of settlement slope difference of bridge head lap plate [J]. Institute of Transportation Engineering, Southeast University.
