The Study of the Pavement Settlement Standard Induced by Shallow Buried Tunnel

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ABSTRACT

Now the surface settlement induced by shallow buried tunnel to under-traverse highway, mostly adopt the empirical value, 3 centimeters, acquired from Beijing or Shenzhen metro, which is regarded as the controlling standard. But to more project, tunnel to under-traverse highway, we must decide the controlling standard flexibly, which should base on the pavement service function and the pavement condition. The thesis, based on the pavement evenness and running comfort ability in the view of completing the pavement service function, supposes the longitudinal pavement settlement cross section as a quadratic parabola, and gets the maximal settlement value in the range of longitudinal pavement influence when the tunnel is under-traverse highway perpendicularly. Then the controlling standard is decided. As Minxiang Tunnel under-traverse Lianhuo Freeway on Zhengzhou-xian PDL for an example, the settlement controlling standard is acquired, and we hope it has an direction and reference value to similar tunnel construction.

1. INTRODUCTION

Recently, with the enlargement of our infrastructure construction, the grade of railway and road and the density of road network increase sharply, and lots of shallow buried tunnel intersect with road. How to assure the safety of driving on road pavement, the passengers’ comfort and the permitted maximum value of surface settlement would be well worth studying.

According to data research, now the surface settlement induced by shallow buried tunnel under-traverse highway, mostly adopt the empirical value, 3 centimeters, acquired from Beijing or Shenzhen metro, which is regarded as the controlling standard. It is blind to some extent. The controlling standard should choose flexibly with the road grade, automobile speed, passengers’ comfort and so on. Nowadays, the controlling standard of the uneven settlement of highway foundation usually calculates with the bend stress of pavement bottom, which is suitable for pavement structure performance. But according to this method, the result would be a little big, which is not good for car driving. Especially with the sharp development of the highway now, people’s need transfer from structure property to comfort property slowly. Through researching on the driving comfort property of the car, this thesis takes driving comfort as the controlling standard of the surface settlement induced by tunnel excavation. It is a change to satisfy the road pavement functionality.

2. ESTABLISHMENT OF ANALYTIC MODEL

When the tunnel excavates under the highway, it has a lot of intersection angles. Based on the worst condition, this research began with the intersection vertically, which influence the pavement mostly. The tunnel excavation under the highway will cause the longitudinal settlement curve surface of the pavement surface, so our basic hypotheses are the following: the cross section of the settlement is the quadratic parabola; points on curve are continuous and smooth; curvatures are continuous, and
any point on curve would not have two curvature values; the maximum feeler gauge clearance is in the end of 3 meters ruler; the longitudinal section of settlement is horizontal, without considering the influence of highway longitudinal grade. Fig.1 is the Analytic Model.

![Diagram](image)

**Fig.1 The model of pavement settlement cross section**

We put the origin on the maximum settlement position to simplify the calculation, which means the maximum settlement happens in the origin. Semiparabolic ODBP simulate the concave cross section of settlement. OA and OB simulate 3 meters ruler. Then we measure the road Smoothness after settlement. Considering the worst situation, the maximum clearances of continuous two independent measurements OA and OB are also on the top, that is OA=AB=3m. AD is the maximum value of surface settlement. According geometry theory, CD=AD. Then the assumption of parabola equation is:

$$y = ax^2$$  \hspace{1cm} (1)

Where, $Y$ is the uneven settlement value from road surface edge to any point in curve; $X$ is the distance from the edge of the cross section of pavement settlement to any point in parabola curve; $A$ is the parameter of the pavement settlement.

### 3. ESTABLISHMENT OF CONTROLLING STANDARD

#### 3.1 Based on smoothness demand

Smoothness is one of two main service performances for highway pavement. Excellent smoothness could keep lots of car to drive rapidly, comfortably, economically and safely. According to *Technical Specifications of Asphalt Pavement Maintenance for Highway* and *Technical Specifications of Concrete Pavement Maintenance for Highway*, the maximum feeler gauge clearance should be 0.5cm for highway when the pavement surface maintains, that is $AD=0.5cm$ (as shown in Fig.1).

Chinese scholars analyzed lots of factors, which cause ground surface settlement during subway and tunnel construction, and did Statistical analyze with lots of measurement data in shallow buried tunnel project. They bring up empirical formula about settlement width. That is the longitudinal influenced width of the ground surface.

$$\beta = 2 \tan \left( 45^\circ - \frac{\phi}{2} \right) Z + D$$  \hspace{1cm} (2)

Where $\beta$ is settlement width (m); $\phi$ is the internal frictional angle of the ground; $Z$ is the distance from ground surface to tunnel midline (m); $D$ is tunnel diameter (m). Therefore, we could get $a_1=5.555e-6$ from the parabola Eq.(1) of the longitudinal settlement cross section, which is due to the permitted maximum feeler gauge clearance in the specifications. Substation the longitudinal influenced width from Eq.(2) into Eq.(1), then we get:

$$S_{\text{max}} = 5.555 \times 10^{-6} \left[ \tan \left( 45^\circ - \frac{\phi}{2} \right) + \frac{D}{2} \right]^2$$  \hspace{1cm} (3)
We can include that $S_{\text{max}}$ is the function of $\Phi$ and $D$ from Eq. (3). So we get the permitted maximum value of the settlement controlling standard which satisfies the pavement smoothness demand.

### 3.2 Based on driving comfort

Recently our freeway has developed rapidly, which provided more convenience to people's travel. As the vehicle driving flat, it should offer the more comfortable and economical traveling service under the driving safety. The comfortable performance consists of driving comfort, noise, air-conditioning and residential performance, where we usually use the driving comfort as the main evaluation Index of the vehicle comfort. The driving comfort is defined as that: passengers wouldn’t feel uncomfortable and tired by the vibration of the vehicle body during running, or it could keep the goods intact in the process of delivery. It is a functional settlement controlling standard only connecting with the calculation of the driving speed, without considering the structure form of the pavement.

Early 70’s, ISO had set up the international standard ISO2631 “Evaluation guideline of the capacity of whole-body vibration on human body”, based on lots of research and literature on the capability of whole-body vibration on human body. The influence of vibration on human body connects not only with frequency, intensity and direction of vibration, but also with acceleration especially. For calculated with root mean square of acceleration precisely and conveniently, through the hard work of our research staff, China has set up the limit value of the assessment index of vehicle comfort ability, which is suitable for our country. According to main performance of highway, we could get the rational acceleration $a_{\text{max}}$ which could be used as the upper limit value of acceleration in the process of vehicle driving in our country.

| Table 1. The limit value of vehicle comfort ability assessment index in our country. |
|-------------------------------|----------------|------|-------|------|
| Assessment index               | Large and medium bus | Light bus |       |       |
| Weighted root mean square of acceleration (m/s²) | tour | long distance | city | advanced | ordinary |
| ≤0.708                         | ≤1.024          | ≤1.122 | ≤0.683 | ≤0.812 |

In the design of highway cross section, vertical curve should satisfy a very important condition, which is mitigation of impact. When a vehicle runs in the vertical curve, radial centrifugal force will appear and the passenger would feel light or weight, and feel uncomfortable. So the radius of vertical curve should satisfy the equation (4).

$$ R = \frac{V^2}{a} \quad (4) $$

Where $a$ is centrifugal acceleration (m/s²); $V$ is travelling speed for calculation (m/s); $R$ is radius of vertical curve (m). According to the travelling speed standard of the highway in our country, we get the $R$ value.

The curvature of vertical curve in cross section should be greater or equal to the curvature of parabola. According to Eq.(1) and Eq.(4),we could get :

$$ k = \frac{1}{R} = \frac{|y'|}{\left(1+y'^2ight)^{\frac{3}{2}}} \quad (5) $$

From Eq. (1), Eq. (5) and the maximum centrifugal acceleration of the cross section of the longitudinal settlement, we could get the pavement settlement parameter $a_i$ and the parabola equation. Then according to the width $i$ of the ground surface settlement caused by tunnel excavation, we could get the permitted maximum value of settlement, which satisfies the vehicle and driving comfort.
3.3 Compare of two standards

The standards set up with smoothness only satisfy the non-maintain demand in specification. It’s a lower level demand. And it could be used when the demand of the pavement performance is lower. The standards set up with driving comfort have the more strict demand for settlement value and it puts the passenger on the primary position and pays attention to the passengers’ feeling much more. So when the highway has the higher level, it should use the driving comfort to decide the controlling standard of settlement.

4. ENGINEERING PROJECT

Zhengzhou-Xi’an passenger dedicated railway line is the very important part of Xuzhou-Lanzhou passenger dedicated railway line in “The Middle-long term planning for China’s railway networks”, which is being constructed positively. It lies in central place of loess region. Because of the high construction standard and straight line, the whole line has lots of loess tunnel with big cross section, about 70 km.

Lian-huo highway (045 national highway) cross the east, middle and west mainland, connecting Lianyungang in Jiangsu Province and Huoerguosi in Xinjiang Province, and the whole length is 4395 kilometers. It’s the longest and rapid land-Freeway corridor, which also is the main transverse freeway in china freeway networks.

The Minxiang tunnel of Zhengzhou-Xi’an passenger dedicated railway line excavate under the Lian-huo freeway. The span of tunnel is 15.5m and the range of under-cross is DK298+820~DK299+020. The intersection angles between the line and the existing freeway is 15.5°. The overburden of the roof is only 10m. Tunnel surrounding rock is Sandy loess $Q_3$. The internal frictional angle is 28.5°. By Eq.(2) and Eq.(1) We could get the parabola equation:

$$y = \frac{0.5}{300^2}x^2 = 0.000005555x^2$$

So $y=10.43cm$. We take $10cm$ as the settlement controlling standard of Minxiang tunnel under cross Lianhuo freeway, which satisfies the smoothness demand of pavement structure.

According to No.78 of “Implementation regulation of Road Traffic Safety Law of the People’s Republic of China”, the Highest Speed in freeway should not exceed 120km per hour ($V = 120km/h$). What’s more, it could take $\frac{a_{\text{max}}}{V} = 1.024 m/s^2$ with main performance of freeway (as shown in Table1).

Therefore the parabola equation is:

$$y = 0.0004576x^2$$

When $x = 13.7m$, we calculate and get the value, $y = S_{\text{max}} = 8.59cm$.

Taking driving in daily life into consideration, overspeed-driving often happens. So it could get the value of settlement controlling standard in other driving speed, which is similar to the above calculating process. There are many values of the settlement controlling standard under the different driving speed in table 2. We could choose the different value according to the actual situation.

<table>
<thead>
<tr>
<th>Calculation driving speed (km/h)</th>
<th>parameter $(a)$</th>
<th>Calculation settlement value (cm)</th>
<th>settlement standard value (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0.0001688</td>
<td>3.17</td>
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<tr>
<td>160</td>
<td>0.0002625</td>
<td>4.92</td>
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<tr>
<td>120</td>
<td>0.0004576</td>
<td>8.59</td>
<td>8</td>
</tr>
</tbody>
</table>
With the two results above, we could find that the comfort performance takes the higher demand for pavement settlement. Because Lianhuo freeway is the main transverse part of China freeway networks, we suggest that Minxiang tunnel should take 3cm as the settlement controlling standard when it under cross Lianhuo freeway.

5. CONCLUSION

1. It uses quadratic parabola to simulate the form of settlement section, which made the calculating process simply and convenient.
2. From the perspective of pavement driving performance, it set up the value of the settlement controlling standard respectively from the two aspects of the driving smoothness and passengers’ comfort.
3. Through the result of calculation from engineering project, we could find it’s the higher level of demand for satisfying the passengers’ comfort. So it has the smaller settlement value than the one permitted by smoothness.
4. It could be the reference to similar projects later. And the controlling standard of settlement should be suit the highway grade, purpose and the real driving condition.

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