Rutting prediction and regularity analysis of typical structures in Shandong Province

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Abstract. In order to further research the development law of rutting damage in Shandong Province, Shandong is divided into four regions based on different regional characteristics, and 2~4 typical structures are selected in each region to fit the rutting damage prediction model. The relevant parameters (traffic flow, thickness of asphalt layer, regional characteristics) of the rutting damage were selected, and the influence on the rutting depth of each parameter was analyzed. It is suggested that the pavement structure should be differentiated designed based on the different working conditions to balance the relationship between the development of rutting damage and the initial construction investment.

1. Introduction

Previous research on rutting caused by the rheological deformation of the asphalt mixture can only be based on empirical methods. Among these methods, the rutting test using fixed temperature and simplified load can be used to evaluate the high temperature deformation properties of asphalt concrete. The test results and the regression relationship of the actual conditions indicate the limited effect of the test [1] [2]; Or taking large accelerated loading equipment to simulate the deformation of asphalt pavement under several actual wheel loads, such as ALF (Accelerated Loading Facility) [3], HVS (Heavy Vehicle Simulator) [4] and so on. For road workers, since the environmental and load conditions of each road are different, the rutting estimate for each road is necessary for targeted maintenance measures. Many models have also been established at home and abroad [5-9]. According to the specific circumstance and the typical road sections of Shandong Province, this paper carried out a rutting prediction, and analyzed the relevant laws to provide some suggestions for the selection of maintenance measures and the analysis of the whole life-cycle cost of Shandong Province.

2. Selection of RD Estimation Model [10]

According to the research of Tang Wen, Sun Lijun and others, the uplift coefficient of the asphalt pavement, that is, the ratio of the uplift deformation to the permanent deformation, increases with the increase of the number of the loading times, but the increase amplitude decreases significantly with the increase of loading times. When the load times exceed 10 million times, the influence of increasing the number of load times on the uplift coefficient is not obvious. Therefore, it is feasible to directly convert the permanent deformation into the rutting prediction model by multiplying a coefficient in the permanent deformation prediction model, as shown in the following equation:
\[ Rd = \left( 1 + L_p \right) \sum_{i=1}^{n} \alpha T_i^\beta \left( V^N / V^T \right)^{\tau_i} \]  

(1)

In the formula:  

RD——Rutting depth, mm;  

L_p——The uplift coefficient, which is 0.505 for the semi-rigid base asphalt pavement and 0.330 for the flexible base asphalt pavement;  

T——Road surface temperature, °C;  

N——Number of times of wheel loading;  

\[ \tau_i \]——The represented value of shear stress of the i-th sub-layer;  

\[ \left[ \tau_i \right] \]——The shear strength of the material of the i-th sub-layer;

3. Selection of typical structure

According to the climate and topographical characteristics of Shandong, Shandong Province is divided into three zones: Jiaodong area, Luzhong mountainous area, and Luxi plain area. According to the difference of traffic flow and structure, each area selects 3~4 typical pavement structures, the total thickness of the structural layer ranges from 65cm to 91cm, and the thickness of the asphalt structural layer ranges from 17cm to 33cm. Among them, Jiaodong area chooses Yantai section of G1813 Weiqing Expressway, Yantai section of G18 Rongwu Expressway, Weifang section of G18 Rongwu Expressway, Yantai section of G15 Shenhai Expressway; Luzhong mountainous area chooses Zibo-Linyi section of G22 Qinglan Expressway, Laiwu section of S29 Binlai Expressway; Luxi plain area selected Binzhou section of the G18 Rongwu Expressway, Dezhou section of S12 Binde Expressway, Liaocheng section of S1 Jinan-Liaocheng Expressway; Lunan Plain District choose Jining section of G1511 Rilan Expressway, Linyi section of G1511 Rilan Expressway, Linyi section of G2 Beijing-Shanghai Expressway.

### Table 1. Typical Pavement Structure Table in Jiaodong Area

| Expressway | Weiqing Expressway (Yantai Section) | Rongwu Expressway (Yantai Section) | Rongwu Expressway (Weifang Section) | Shenhai Expressway (Yantai Section) |
|------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Stake Number | K163+900~K208+800 | K139+600~K153+800 | K352+300~K450+600 | K460+000~K500+100 |
| Opening Year | 2007 | 1998 | 2008 | 2000 |
| Maintenance Year | 2010 | 2010 | | |
| Traffic | 12000 | 11500 | 50000 | 22000 |
| Pavement Structure | | | | |
| SMA-13 | 4 cm | SMA-13 | 4 cm | SMA-13 | 4 cm |
| SBS AC-20 | 5 cm | SBS AC-20 | 6 cm | AC-20 | 4 cm |
| AC-25 | 6 cm | SBS AC-20 | 6 cm | AC-25 | 5 cm |
| LSPM-30 | 12 cm | LSPM-25 | 10 cm | LSPM-25 | 12 cm |
| Water-stabilized macadam | 30 cm | Water-stabilized macadam | 24 cm | Water-stabilized macadam | 36 cm |
| Water-stabilized macadam | 18 cm | Water-stabilized macadam | 30 cm | Water-stabilized macadam | 20 cm |
| Cement stabilized sand | 18 cm | Cement stabilized sand | 30 cm | Cement stabilized sand | 18 cm |

### Table 2. Typical Pavement Structure Table in Mountainous Area of central Shandong

| Expressway | Qinglan Expressway (Linyi and Zibo Section) | Binlai Expressway (Laiwu Section) | Beijing-Shanghai Expressway (Laiwu Section) |
|------------|-----------------------------------------------|----------------------------------|---------------------------------------------|
| Stake | K61+200~K266+700 | K108+600~K131+200 | K489+000~K507+506 |

2
Table 3. Typical Pavement Structure Table in Plain Area of Western Shandong

| Expressway                                   | Stake Number       | Opening Year | Maintenance Year | Traffic  |
|----------------------------------------------|--------------------|--------------|------------------|----------|
| Rongwu Expressway (Binzhou Section)         | K576+200~K619+100  | 2007         | 2012             | 50000    |
| Rongwu Expressway (Dezhou Section)          | K0+000~K142+000    | 2012         | 2000             | 11000    |
| Shenhai Expressway (Yantai Section)         | K78+500~K1116+300  | 2000         |                  | 45000    |

Pavement Structure

| Traffic          | SMA-13 | SBS AC-20 | AC-25 | Water-stabilized macadam | Cement stabilized sand |
|------------------|--------|-----------|-------|--------------------------|------------------------|
| SMA-13           | 4cm    | 6cm       | 8cm   | 36cm                     | 18cm                   |
| SBS AC-20        | 4cm    | 4cm       | 4cm   | 32cm                     | 19cm                   |
| AC-25            | 4cm    | 5cm       | 36cm  | Water-stabilized macadam | 20cm                   |
| LSPM-30          | 4cm    | 4cm       | 36cm  | 18cm                     | 20cm                   |

4. Typical road segment RD decay simulation results

At present, the road network of Shandong Province has been formed, and the traffic flow of each high speed tends to be stable. In order to reflect the correlation between the decay model and the maintenance period, Equation 1 is simplified to the relationship between the rutting depth and the service life, as shown below.

\[ RD = a \cdot Age^b \]  

According to the regular inspection data of road conditions in Shandong Province from 2014 to 2018, the RD performance decay of different typical sections in different areas is analyzed, and the RD decay models are shown in Table 4 and Figure 1.

Table 4. Rutting Depth Decay Model

| Expressway                                   | a    | b    |
|----------------------------------------------|------|------|
| Weiqing Expressway (Yantai Section)          | 1.654| 0.804|
| Rongwu Expressway (Yantai Section)           | 3.575| 0.553|
| Rongwu Expressway (Weifang Section)          | 2.641| 0.747|
| Shenhai Expressway (Yantai Section)          | 3.577| 0.621|
5. Analysis of influencing factors

According to the maintenance standards of Shandong Province, the 13mm rutting depth is taken as the maintenance standard. Based on the existing research results, the rutting damage of asphalt pavement is mainly caused by insufficient shear strength of asphalt surface layer, which mainly occurs in asphalt surface layer [1]. Therefore, this paper takes traffic flow, asphalt layer thickness and regional characteristics as factors affecting the depth of the rut, the analysis are as follows:

5.1. Impact of traffic flow

In the Jiaodong area, the thickness of the asphalt layer of Weiqing Expressway and Rongwu Expressway (Weifang Section) is roughly the same. The average daily traffic flow of Rongwu Expressway (Weifang Section) is 50000pcu, and the RD service life is 8 years. The average daily traffic flow of Weiqing Expressway is 12000pcu, its RD service life is 14 years, 6 years more than Rongwu Expressway (Weifang section); Rongwu Expressway (Yantai section) and Shenhai Expressway asphalt layer thickness is roughly the same, Shenhai Expressway average daily traffic flow is 22000pcu, which has a RD service life of 9 years. The average daily traffic flow of Rongwu Expressway (Yantai section) is 11500pcu, and its RD service life is 11 years, 2 years more than Shenhai Expressway.

Luzhong mountainous area, Qinglan Expressway (thickness 33cm, traffic flow 15000pcu) has a RD service life of 13 years, Binlai Expressway (thickness 17cm, traffic flow 32000pcu) has a RD service life of 8 years, Beijing-Shanghai Expressway (thickness 11cm, traffic flow 40000pcu). Because these thicknesses and traffic flows of three high-speed are inconsistent, quantitative judgment cannot be made, only a qualitative analysis could be carried out as a supplementary explanation.

| Expressway                        | RD (mm) | Thickness (cm) |
|----------------------------------|---------|----------------|
| Qinglan Expressway (Linyi and Zibo Section) | 2.617   | 33             |
| Binlai Expressway (Laiwu Section) | 3.006   | 17             |
| Beijing-Shanghai Expressway (Laiwu Section) | 2.848   | 11             |
| Rongwu Expressway (Binzhou Section) | 3.479   | 11             |
| Binde Expressway (Dezhou Section) | 2.529   | 11             |
| Rilan Expressway (Linyi Section)  | 4.586   | 33             |

![Figure 1. Rutting Depth Decay Map](image)
In the Luxi plain area, the thickness of the asphalt layer of Rongwu Expressway (Binzhou Section) and Binde Expressway is roughly the same. The average daily traffic flow of Rongwu Expressway is 50000pcu, the RD service life is 9 years, and the average daily traffic flow of Binde Expressway is 11000pcu, which has a RD service life of 15 years and is 6 years longer than the Rongwu Expressway (Binzhou Section).

Traffic flow has a significant impact on RD service life. The heavier the traffic flow, the shorter the RD service life.

5.2. Influence of asphalt layer thickness

Jiaodong area, Weiqing Expressway and Rongwu Expressway (Yantai section) traffic flow is roughly the same, Rongwu Expressway (Yantai section) asphalt layer thickness is 20cm, its RD service life is 11 years, Weiqing high-speed asphalt layer is 27cm, its RD service life is 14 years, three years longer than the Rongwu Expressway (Yantai section).

Luzhong mountainous area, Qinglan Expressway (thickness 33cm, traffic flow 15000pcu) has a RD service life of 14 years, Binlai Expressway (thickness 17cm, traffic flow 32000pcu) has a RD service life of 8 years, due to the thickness and traffic flow of these two high-speed asphalt layers are inconsistent, so quantitative judgments cannot be made, only a qualitative analysis can be draw as a supplementary explanation.

The thickness of the asphalt layer has a great influence on the RD service life. The thicker the thickness of the asphalt layer, the longer the RD service life.

5.3. Impact of regional characteristics

The thickness and the traffic flow (Binzhou Section 50000, Weifang Section 50000) of the pavement asphalt layer in the Rongwu Expressway (Weifang Section) in the Jiaodong area and the Rongwu Expressway (Binzhou Section) in the Luxi plain area (the Weifang Section 30cm, the Binzhou Section 33cm) are roughly equivalent. The RD service life of Binzhou section is 1 year longer than the Weifang section.

The Binlai Expressway in Luzhong mountainous area (thickness 17cm, traffic flow 32000pcu) is roughly equivalent to the structure and traffic flow of the Jining section of the Rilan Expressway (thickness 19cm, traffic flow 31000) in the Luxi plain area, while the RD service life of Jining section of the Rilan Expressway is 2 year longer than the Binhai Expressway.

The RD decay curve of Jiaodong area and Luzhong mountainous area showed no obvious change in the early stage and a sudden decline in the later stage. The RD decay curve in the Lubei Plain region, and Lunan Plain region was flat and showed uniform changes.

The RD service life of the coastal regions of Jiaodong area and Luzhong mountainous area is 1–2 years shorter than that of the Luxi plain area.

6. Conclusion

According to analysis of the factors affecting RD decay, the traffic flow has a significant impact on the RD service life. The thickness of the asphalt layer and the regional characteristics also have a great influence on the RD service life.

It is suggested that the pavement structure should be differentiated based on the working conditions (traffic flow and regional characteristics), and the relationship between the severity of the rutting damage and the initial construction investment fund should be balanced. In hot and humid regions, mountainous regions and regions with heavy traffic flow, it is necessary to increase the thickness of the asphalt layer to slow down deterioration of the rut and extend the service life of the road. For the hot and semi-humid regions, plain regions and small traffic flow regions, the asphalt layer can be appropriately thinner to reduce the initial construction investment.
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