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# Numerical Analysis of Semi-rigid Asphalt Pavement Deflection under Dynamic Traffic Load

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**Abstract.** In order to detect dynamic deflection rapidly and continuously, a dynamic model under traffic load of asphalt pavement finite element was built, dynamic deflection with different traffic speeds and different point were studied; the dynamic deflection with different thickness of pavement layers and different dynamic modulus were also studied. Results show that the dynamic deflection is different with different traffic, the higher the speed the smaller the deflection, and the maximum deflection lags the peak traffic loads; road pavement thickness increased significantly reduced dynamic deflection, the order of thickness impact dynamic deflection was the surface layer, the base and subbase; the layers modulus increases the dynamic deflection reduced. Findings contribute to developing continuous and rapid dynamic deflection testing equipment based on dynamic deflection characteristics of the road surface.

## 1. Introduction

Pavement deflection detection and analysis is the basis for the evaluation of the overall bearing capacity of pavement, and it is one of the control indicators for asphalt pavement design. It is not only critical to the quality of inspection and control engineering, but also determines the scientific level of road network maintenance decision-making, directly affecting the rationality of maintenance fund allocation and old road reconstruction design. At present, the deflection testing equipment used at home and abroad is mainly Beckman beam, automatic deflection vehicle and FWD testing equipment. The detection method is gradually developed from static single-point test to dynamic multi-point test under pulse load and dynamic continuous deflection test, and gradually approaching the actual driving load mode.

Many scholars have calculated the dynamic deflection of pavement under dynamic loading. Zheng Yuanxun<sup>[1]</sup> established the dynamic characteristics model of asphalt pavement by finite element method, and studied the influence of pavement thickness, modulus and loading speed on the dynamic deflection of pavement under the action of FWD. The thickness, modulus and loading time of each layer of the road are important factors affecting the deflection of the road surface. Sun Shuqin<sup>[2]</sup> established a viscoelastic finite element model of asphalt pavement under non-uniform



loading. When the speed of heavy-duty vehicles is between 10~32km/h, the dynamic deflection value of the pavement is significantly larger than the static deflection value. Qiu Xin<sup>[3]</sup> simplified the FWD test impact load to static load, and analyzed the distribution law of the road surface deflection basin under the dynamic and static test load. The results show that the distribution law of the road surface deflection basin under the FWD dynamic and static load is obviously different, the same road surface. There are also obvious differences in the distribution of roads and bends between different layers. Xing Yaozhong<sup>[4]</sup> derived the analytical solution of the dynamic deflection of the elastic layered system on the Winkler foundation and compared it with the numerical results, laying the foundation for the dynamic analysis and parameter identification of the concrete pavement structure under this model. Dong Zezheng<sup>[5]</sup> established the three-dimensional finite element model of transient dynamic analysis of asphalt pavement under non-uniform moving loads, and gave the spatial distribution and time history of dynamic response of asphalt pavement under non-uniform moving loads.

Studies by the above researchers have shown, Dynamic deflection is more reflective of the true stress state of the road surface than static deflection. Therefore, the evaluation of pavement carrying capacity by dynamic deflection is the main direction of future research.

## 2. Model and parameters

### 2.1. Model parameters of the traffic load

In order to simplify calculations, simplified rectangular uniform load model is used by many researchers at home and abroad. This article refers to the relevant simplified model. Determine the grounding area of the tire according to the design parameters of the Yellow River JN150. The size of each rectangle is 16cm × 24cm, load area is 384cm<sup>2</sup>, and the distance between the two rectangular load centers is 24cm. Adopt standard double axle load, grounding pressure 0.7MPa.

Combining research results at home and abroad, In the three-dimensional finite element model of dynamic deflection of semi-rigid base asphalt pavement, the loading method is in the form of uniform load, and the vertical load is described by the half-wave sine function. The amplitude of the half-wave sinusoidal load is obtained by the equivalent conversion of the measured uniform load on site. Define the peak value of the uniform load as  $Q$ , load duration is  $T$ , the entire analysis period is  $T_a$ , so the uniform stress at any moment follows:

$$\begin{cases} q = Q \sin \left| \frac{\pi t}{T} \right| & 0 \leq t \leq T \\ q = 0 & T < t \leq T_a \end{cases} \quad (1)$$

$$T = \frac{12R}{V} \quad (2)$$

Where  $R$  represents the radius of the equivalent wheel of a single wheel pressure transfer surface, and  $V$  is the speed of the vehicle.

In this paper, the dynamic deflection values of roads at different vehicle speeds are calculated. The action time corresponding to different vehicle speeds is listed in Table 1.

Table 1. Load response time corresponding to the detection speed.

| Speed /km·h <sup>-1</sup> | 40   | 60    | 80    | 100   | 120   |
|---------------------------|------|-------|-------|-------|-------|
| Load time /s              | 0.11 | 0.076 | 0.057 | 0.046 | 0.038 |

First, as a preliminary analysis condition, the vehicle travel speed  $V$  is taken as 40km/h, the load action time  $T$  is taken as 0.115s, the entire analysis period  $T_a$  is 0.5s, the uniform load peak  $Q$  is taken as 0.7MPa.

### 2.2. Geometric model

This study uses the common semi-rigid base pavement form in China. The surface layer consists of a 4cm fine grain asphalt concrete upper layer, a 6cm medium granular asphalt concrete middle layer and an 8cm coarse grain asphalt gravel lower layer. The base layer is 36cm cement stabilized macadam,

and the base layer is 20cm two-ash stabilized soil. When the model is built, the size of the entire model is  $4.5\text{m} \times 4.5\text{m} \times 3.74\text{m}$ . According to the actual stress situation of asphalt concrete pavement, it is assumed that the bottom surface has no displacement and fixed constraints. Left and right ends, no displacement in the Y direction, no X-direction displacement at the front and rear ends. In the dynamic analysis, the explicit ABAQUS is selected, and the material model selects the quadrilateral linear reduction integral unit C3DR8.

After several trials and comparisons and adjustments, the finite element model calculates convergence and meets the accuracy requirements in a short calculation time.

### 2.3. Material parameters

The model used in this project is a linear elastic constitutive model. Density, modulus of resilience, Poisson's ratio and damping parameters of the material are to be determined during the calculation of deflection. Due to the analysis of semi-rigid base asphalt pavement under dynamic conditions, dynamic material parameters are required for calculation. The survey found that the literature believes that the dynamic modulus of pavement materials is about 2 to 3 times that of static modulus; In literature, the dynamic and static modulus ratio of the semi-rigid basement is 3:1, the dynamic modulus is between 2200 and 4500 MPa, and the mean value of the dynamic modulus of the soil at all sections is 100.4 MPa; In literature, when analyzing the dynamic response of pavement structure, the material dynamic modulus values of different vehicle moving speeds are analyzed. This project combines the relevant literature results, and the proposed material parameters are shown in Table 2.

Table 2. Test section structure and material parameters.

| Structural layer | Thickness /m | Elastic Modulus /MPa |         | Poisson's ratio | Density / $\text{kg}\cdot\text{m}^{-3}$ | Damping ratio |
|------------------|--------------|----------------------|---------|-----------------|-----------------------------------------|---------------|
|                  |              | Static               | dynamic |                 |                                         |               |
| Surface layer    | 0.04         | 1500                 | 4000    | 0.3             | 2400                                    | 0.05          |
| Middle layer     | 0.06         | 1300                 | 3500    | 0.35            | 2400                                    |               |
| Lower layer      | 0.08         | 1000                 | 3000    | 0.35            | 2400                                    |               |
| Base             | 0.36         | 1600                 | 4000    | 0.25            | 2200                                    |               |
| Subbase          | 0.20         | 700                  | 2500    | 0.3             | 1600                                    |               |
| Subgrand         | 3.00         | 40                   | 100     | 0.4             | 1900                                    |               |

## 3. Calculation results and analysis

### 3.1. Influence of driving speed on dynamic deflection of road surface

In the calculation process, the center of the wheel train is taken as the dynamic deflection analysis point to analyze the dynamic deflection at different driving speeds. By studying the calculation of deflection under different speeds, it shows that with the gradual increase of the speed of the vehicle, the time of the tire acting on the road is getting shorter and shorter, and the dynamic deflection at the center of the wheel train is gradually decreasing. When the vehicle speed is increased from 40km/h to 120km/h, the dynamic deflection is reduced from 34.3 (0.01mm) to 30.3 (0.01mm), which is reduced by 12%. The corresponding relationship between driving speed and deflection is shown in Table 3.

Table 3. Correspondence between driving speed and dynamic deflection.

| Detection speed ( $\text{km}\cdot\text{h}^{-1}$ ) | 40   | 60   | 80   | 100  | 120  |
|---------------------------------------------------|------|------|------|------|------|
| Deflection /0.01mm                                | 34.3 | 32.8 | 32.3 | 31.5 | 30.3 |

The process of driving load on the road surface is approximately half-wave sinusoidal load. Analysis of the curve of the deflection time at a certain speed can give the same wave law as the load. As the load changes, the deflection gradually increases and then decreases. The time history curve of the deflection is shown in Figure 3. Analysis of the deflection time-history curve also shows that the maximum value of the dynamic deflection is slightly behind the maximum time of the load, and as the speed of the detection vehicle increases, the lag time increases. When the vehicle speed is 40km/h,

60km/h, 80km/h, 100km/h, 120km/h. The maximum delay time of the deflection is 0, 3.16ms, 5.54ms, 6.8ms and 6.9ms respectively. It is thus known that when using a precision instrument for dynamic deflection detection, the true value of the dynamic deflection should be calculated according to the speed of the vehicle.

### 3.2. Dynamic deflection at different locations

In order to achieve the automatic continuous detection of the deflection, it is necessary to arrange the probes in the driving direction at the center of the two rear wheels to detect the shape of the deflection basin, thereby determining the dynamic deflection of the road surface. The author calculated the dynamic deflection value at different positions of the wheel center along the driving direction. The calculation results are shown in Figure 1.

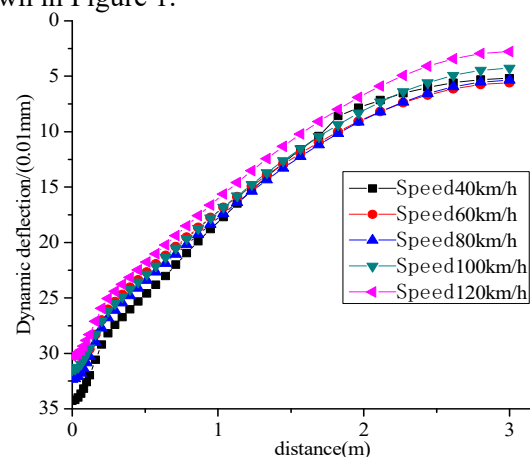


Figure 1. Dynamic deflection at different positions in the center of the wheel train at different speeds.

The calculation in Figure 1 shows that the deflection at the center of the wheel train is the largest. As the distance from the center of the wheel train increases, the deflection gradually decreases. The shape of deflection curve differs greatly at different speeds. The lower the speed, the greater the deflection radius is affected by the load. Under the condition of each speed, about 3.6m away from the center of the wheel train, the deflection value is less than 2 (0.01mm), so it can be used as the reference point for dynamic deflection detection at 3.6m from the center of the train.

### 3.3. Influence of structural layer thickness on dynamic deflection

In order to study the influence of different pavement layer thickness on the dynamic deflection response of the pavement, the thickness of the surface layer, the base layer and the subbase layer are respectively changed. The thickness of the pavement structure is shown in Table 4.

Table 4. The thickness of pavement structure.

| Pavement structure | Surface layers (upper layer + middle layer + lower layer) |          |           |           |           | Base           | Subbase        |
|--------------------|-----------------------------------------------------------|----------|-----------|-----------|-----------|----------------|----------------|
| Thickness / cm     | 18=4+6+8                                                  | 21=7+6+8 | 24=6+8+10 | 27=4+8+15 | 32=4+8+20 | 36、40、45、53、60 | 20、25、30、35、40 |

Based on Table 4. Each time a parameter is changed separately, the influence of the thickness of each structural layer on the dynamic deflection is calculated. The effect of the thickness of the pavement layer on the dynamic deflection of the pavement is shown in Figure 2.

The calculation results in Figure 2 show that the thickness of the surface layer, the base layer or the subbase layer can reduce the dynamic deflection of the road surface. With the increase of the center position of the wheel train, the increase of the thickness of the surface layer tends to decrease the deflection of the road surface. As the thickness of the base layer increases, the trend of decreasing the maximum deflection value tends to be flat, indicating that the semi-rigid base layer is not as thick as

possible. When it reaches a certain level, increasing the thickness will not significantly improve the road carrying capacity. The thickness of each layer contributes to the dynamic deflection of the road surface from large to small: surface layer, base layer and sub-base layer. In terms of the overall trend, the change in the thickness of the pavement structure does not change the shape of the dynamic deflection basin.

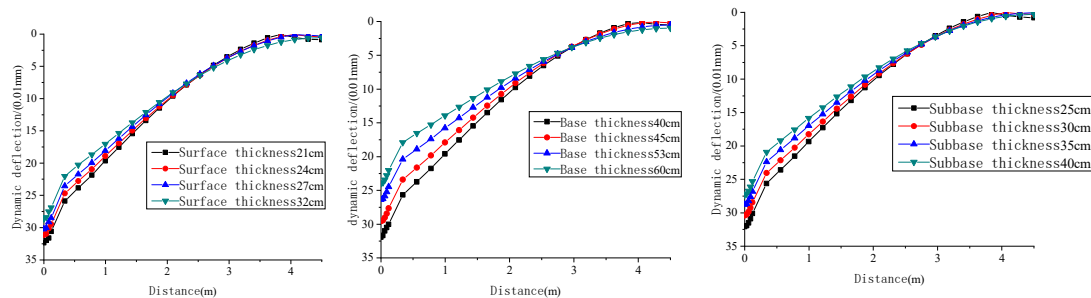


Figure 2. Influence of thickness of pavement structure layer on dynamic deflection of pavement.

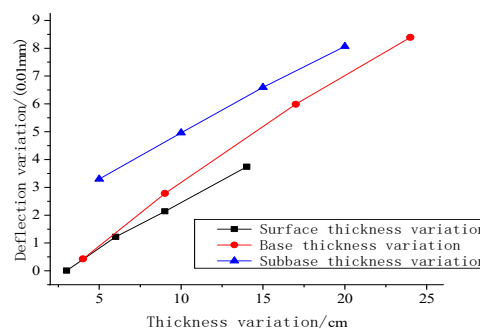


Figure 3. Influence of thickness variation of each layer on dynamic deflection of wheel center.

### 3.4. Influence of structural layer modulus on dynamic deflection

In order to study the influence of the pavement structure layer modulus on the dynamic deflection response of the pavement, the modulus of the surface layer, the base layer and the subbase layer were changed respectively, and the influence of the modulus on the dynamic response of the pavement was studied. The modulus of each structural layer of the pavement changes as shown in Table 5.

Table 5. Pavement structure layer modulus.

| Pavement structure | Modulus change /MPa      |
|--------------------|--------------------------|
| Surface layer      | 3000、3500、4500、5000、5500 |
| Base               | 2500、3000、4000、5000      |
| Subbase            | 1500、1800、2000、3000、3500 |

Based on the variation of the modulus of the pavement structure in Table 5, the influence of the modulus of each structural layer on the dynamic deflection is calculated by the finite element method. The calculation results are shown in Figure 4.

Figure 4 shows that the increase in the modulus of the asphalt surface layer and the base layer can significantly reduce the dynamic deflection of the road surface. Since the modulus of the asphalt road surface is closely related to the road surface temperature, it should be combined with the road surface temperature condition during the inspection. The increase of the surface modulus has a significant influence on the road surface deflection. As the distance from the center point of the wheel system increases, the increase of the base layer modulus has a weak influence on the road surface deflection.

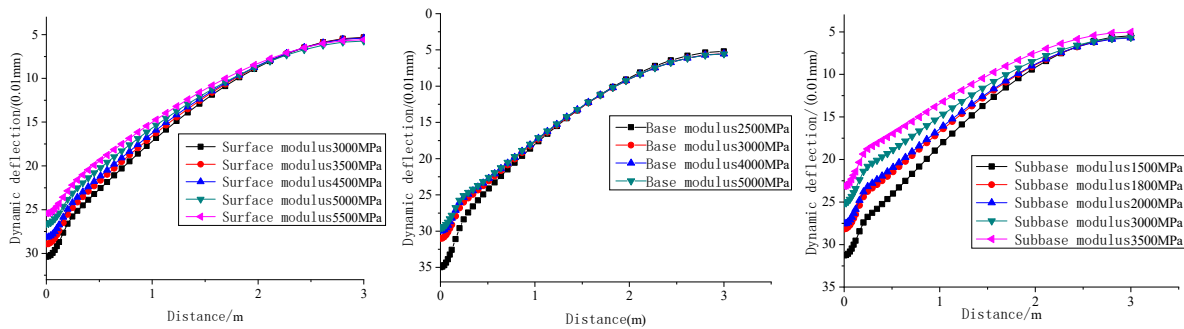


Figure 4. Effect of pavement layer modulus on dynamic deflection of pavement.

#### 4. Conclusion

(1) By establishing the finite element dynamic analysis model, it is concluded that the dynamic deflection value and the deflection value of the road surface will be delayed compared with the load action time under different driving speed conditions. The shape law of the dynamic deflection basin of the road under different driving speeds is obtained.

(2) Under the same condition, the center of the wheel train is different, the deflection is different, and the center position of the wheel gap is the largest. As the center position of the wheel train increases, the deflection decreases.

(3) The increase of thickness or modulus of each structural layer of the pavement will lead to the reduction of dynamic deflection of the road surface. The change of temperature conditions should be paid attention to during the inspection to correct the test results.

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#### References

- [1] Zheng,y.x., Xiong,x.l., Huang,j.q.(2012)Numerical Analysis of Dynamic Deflection of Asphalt Pavement under FWD. Journal of Zhengzhou University(Science edition), 44(2):120-124.
- [2] Sun,s.q.(2011)Finite Element Analysis of Viscoelasticity of Asphalt Pavement under Non-uniformly Distributed Loads. Transportation technology, 12(3):79-82.
- [3] Qiu,x.,Yang,q., You,q.l.(2013)Study on Damping Characteristic Parameters of Asphalt Pavement and Distribution Characteristics of Dynamic Deflection Basin of Road Surface. Highway transportation technology,30(7):1-6,17.
- [4] Xing,y.z., Liu,h.b.(2010)Calculation of dynamic deflection of elastic layered system on Winkler foundation. Journal of Guangdong Vocational College of Communications,09(2):1-4.
- [5] Dong,z.j., Tan,y.q., Ou,j.p.(2013)Dynamic response analysis of asphalt pavement under three-way non-uniform moving loads. Journal of Civil Engineering, 46(06):122-130.