Asphalt Pavement Stress Intensity Analysis under Fluctuating Load

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Abstract. The finite element software ANSYS is used to build the asphalt pavement three-dimensional model and to carry through transient analysis. The stress intensity time-history curves of asphalt pavement under the fluctuating load are obtained. The curves reveal that the pavement structure stress intensity effect of dynamic load is complex. And the point stress intensity always reaches its peak value when the load reaches this point. After the load leaves, it decreases rapidly to zero. Pavement surface is most significantly affected by load. The deeper the pavement surface is, the smaller the impact is, but the influence law remains unchanged. These conclusions can provide reference for stress intensity condition of asphalt pavement under fluctuating load.

1. Introduction

Compared with other static loads structures, the loads on pavement structures are mobile[1-2]. At present, many scholars have carried out research on pavement structure dynamic response under dynamic load. For example, Chen Huaxin et [3] analyzed the impact of overload, braking and other horizontal loads on asphalt pavement by using finite element software ABAQUS to establish a three-dimensional model. Zou Jingrong et [4] studied the trunk road asphalt pavement failure mechanism by using BISAR software to establish a three-dimensional model. Zhou Zhengfeng et [5] analyzed the mechanical response laws of pavement structure and subgrade under different axle types and axle loads through several typical asphalt pavement structure combinations. Each of the above-mentioned authors has its own research emphasis. Based on vibration theory and structural dynamics, an asphalt pavement three-dimensional finite element model[6] is established by using ANSYS/APDL software in this paper. The stress intensity response laws under fluctuating load are analyzed in order to provide references for stress intensity conditions of asphalt pavement under dynamic loads.

2. Calculating parameters

2.1. Pavement structure combination

The modulus of elasticity, thickness, Poisson's ratio and density of surface and base in asphalt pavement structure combination are shown in Table 1. The pavement structure damping adopts Rayleigh damping. Referring to relevant references [6], the pavement structure damping ratio is $\zeta = 5\%$ , and $\alpha = 2.6907, \beta = 0.0009$.

Assuming: the pavement structural layers are continuous homogeneous and isotropic linear elastic materials; All pavement structural layers are completely continuous in vertical direction; Under the
traffic load, there will be no emptying between the layers; There is a complete continuous contact condition between asphalt surface and base.

| Structural layer   | Modulus/ MPa | thickness/cm | Poisson ratio | Density/ kg/m³ |
|---------------------|--------------|--------------|---------------|---------------|
| asphalt Surface     | 9000         | 20           | 0.25          | 2400          |
| granular base       | 300          | 40           | 0.35          | 2200          |
| subgrade            | 80           | —            | 0.40          | 1800          |

2.2. Finite element model establishment
The calculation model is shown in Figure 1. The pavement three-dimensional model dimension (X, Z, Y) is 6.0m×10.0m×0.6m. Four kinds of elements are used in the model: spring element for simulating soil foundation COMBIN14, and surface effect units SURF154, and plane elements for building two-dimensional solid structural model PLANE42, and equal parameter elements constituting three-dimensional solid structures SOLID45. Spring element is considered its axial performance only and its axial spring constant is $8 \times 10^7 \text{ N/m}$ and damping coefficient is $1 \times 10^5 \text{ N·S/m}$.

The boundary conditions: the driving Z direction is $U_Z = 0$; the width X direction is $U_X = 0$; the spring bottom is constrained completely. In engineering design, wheel load is simplified as equivalent circular uniform load, but considering that the imprint between tire and pavement is not circular, but closer to rectangle; so the loading area in this paper is calculated according to rectangle. The standard axle load is 100kN and the tire pressure is 0.7MPa. Considering the mesh size in the driving area, the rectangle length and width are as follows: width × length = 0.20m × 0.28m.

2.3. The fluctuating load application
The transient analysis in this paper adopts the FULL method. Using software programming language APDL, the load is moved from the starting position to the prescribed position at the same speed by compiling do and enddo cyclic statements. After each load step is solved, the load is deleted, and then applied to the next contact surface to continue solving, and then forward to end. In this paper, the half-wave sinusoidal load with uniform moving speed is used to simulate it with the following formula:

$$ P(t) = P_m \times \sin \left( \frac{\pi t}{T} \right) \quad (1) $$

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

In the formula: $P(t)$ for the distribution of load with time, $t$ is time; $P(m)$ is load amplitude, taking the static pressure of standard axle load 0.7MPa; $T$ is load cycle, s; $V$ is vehicle speed, m/s; $\delta$ is tire grounding area equivalent circle radius, 0.1065m.

In this paper, the designed speed is $V = 12.5m/s = 45km/h$. According to the above formula, as $V = 12.5m/s$, the period $T = 0.10224s$. 

In the formula: $P(t)$ for the distribution of load with time, $t$ is time; $P(m)$ is load amplitude, taking the static pressure of standard axle load 0.7MPa; $T$ is load cycle, s; $V$ is vehicle speed, m/s; $\delta$ is tire grounding area equivalent circle radius, 0.1065m.
3. Numerical simulation results analysis

As shown in Figure 2, the load moves in the Z positive direction. In order to clearly show the road structure different positions mechanical response under the fluctuating load, three nodes of the surface layer are selected: 1, 2, and 3. The three nodes at the bottom of the layer are 4, 5, and 6. The three nodes in the middle of the base are 7, 8, and 9. And the three nodes at the bottom of the base are 10, 11, and 12.

This paper mainly studies the stress intensity time-history curves of the above calculation points. This stress intensity is the equivalent strength of the classified stress at a given point according to the third strength theory. The analysis is concise and the concept is clear.

3.1. The surface and bottom nodes stress intensity time history curve analysis

Fig. 3 is the stress intensity time history curve at three points 1, 2, and 3 of the pavement surface. Table 2 shows the maximum stress intensity and corresponding time of each node. The curves in Figure 3 and the data in Table 2 show that when the vehicle starts to move, the stress intensity begins to appear almost at the same time at point 1 and 4. With the vehicle approaching gradually, the stress intensity of points 1 and 4 increase gradually. When the time is about 0.05 seconds, the stress intensity increases to a larger value, and then decreases rapidly with the load oscillation. Later, as the vehicle moves away from the boundary gradually, the constraint effect decreases. The stress intensity shows the maximum peak curve rapidly at points 1 and 4. When the time is 0.128s, the point 1 peak value is 458.48kPa. When the time is 0.124s, the point 4 peak value is 335.60 kPa. Then the load continues to move forward and the stress intensity here also tends to zero, and the peak time of point 4 is slightly ahead of point 1. The stress intensity of point 3 and 6 is similar to that of point 1 and point 4.
For points 2 and 5, the stress intensity at points 2 and 5 is zero when the vehicle moves from the starting point. Before the load approaches the point, a small peak curve appears at the point. Then at 0.348s, the curve peak value at point 2 reaches 656.12 kPa. At 0.356s, the curve peak value at point 5 reaches 664.19 kPa. Then the peak value decreases rapidly, and a small peak curve appears after the maximum peak curve due to the load fluctuation. With the load away from the points, the stress intensity at points 2 and 5 approaches zero. The peak time of point 5 is slightly behind that of point 2.

3.2. The nodes stress intensity time history curve analysis in the middle and bottom of base course

Fig. 4 is the stress intensity time history curve at three points 7, 8, 9 in the middle of base course and 10, 11, 12 in the bottom of base course. According to table 2 and Figure 4: when the vehicle starts to move, the stress intensity begins to appear almost at the same time at point 7 and 10. With the vehicle approaching gradually, the stress intensity of points 7 and 10 increase gradually. When the time is about 0.05 seconds, the stress intensity increases to a larger value, and then decreases rapidly with the load oscillation. Later, as the vehicle moves away from the boundary gradually, the boundary constraint effect decreases. Then at points 7 and 10, the stress intensity shows the maximum peak curve rapidly. When the time is 0.136s, the point 7 maximum value is 64.00 kPa, and the point 10 maximum value is 48.32 kPa. Then the vehicle load continues to move forward and gradually away from points 7 and 10, then the stress intensity here also tends to zero, and the peak time of point 7 is synchronous with point 10. The stress intensity of point 9 and point 12 is similar to that of point 7 and 10.

For points 8 and 11, the stress intensity is zero when the vehicle moves from the starting point. Before the load approaches the points, there is a small peak curve at each point. Then at 0.356s, the point 8 maximum value is 97.94 kPa, and the point 11 maximum value is 72.10 kPa. And then the peak value drops rapidly. Because of the load fluctuation, a small peak curve appears immediately after the maximum peak curve. With the load away from the point, the stress intensity at points 8 and 11 approaches zero.

Table 2 Maximum and minimum stress intensity and corresponding time

| node | max 10^3/pa | time /s | node | max 10^3/pa | time /s | node | max 10^3/pa | time /s | node | max 10^3/pa | time /s |
|------|-------------|---------|------|-------------|---------|------|-------------|---------|------|-------------|---------|
| 1    | 458.48      | 0.128   | 4    | 335.60      | 0.124   | 7    | 64.00       | 0.136   | 10   | 48.32       | 0.136   |
| 2    | 656.12      | 0.348   | 5    | 664.19      | 0.356   | 8    | 97.94       | 0.356   | 11   | 72.10       | 0.356   |
| 3    | 505.21      | 0.588   | 6    | 384.84      | 0.592   | 9    | 69.09       | 0.580   | 12   | 51.70       | 0.580   |

3.3. Different depths nodes stress intensity time history curves comparative analysis

Figure 5 shows the stress intensity time history curve of four nodes with different depths on the section with Z = 5m. The curves show the curve peak value between the surface and the bottom of the surface layer is similar. The decrease of stress intensity with depth is very small because the surface layer thickness is thin and its modulus is large. However, compared with the surface layer, the nodes stress intensity in the middle and bottom of the base decrease rapidly, mainly because the base layer is thick and its modulus is small relatively. It shows that the deeper the point is, the less the stress intensity is affected by the load. However, the four nodes curves at different depths are similar, which shows that the stress intensity changes at different depths are similar.

Fig. 6 shows the nodes stress intensity time history curves at different depths on the section with Z = 2m and z = 8m. There are obvious differences between Figure 6 and Figure 5. Each node curve shape is the peak between the small peaks on both sides in Figure 5. However, the node time history curve near the model boundary is a combination of a small peak and a large peak in Figure 6. And the small peak is always close to the boundary. The main reason is that these nodes are obviously affected by the boundary constraint effect. The maximum stress intensity of the surface and bottom nodes of the surface layer is relatively large and close. The nodes maximum stress intensity in the middle and bottom of the base course is much smaller than that of the surface course. In general, the nodes stress intensity at Z = 8m section is greater than that at Z = 2m section, which is mainly affected by the fluctuation of load.
Based on the above, it is concluded that no matter where the node is, the stress intensity time history curve fluctuates frequently under the fluctuating load. It shows that the dynamic load influence on the pavement structure dynamic response is complex. Always when the load reaches this point location, this point stress intensity reaches the maximum value. However, due to boundary constraints and load fluctuations, the nodes maximum stress intensity in the same depth is not the same. The fluctuating load influence on the road surface node is greater. The deeper the road surface is downward, the smaller the influence is, but the influence rule is the same.

Fig. 5 middle section nodes curve

Fig. 6 edge section nodes curve

4. conclusions
No matter where the node is, the stress intensity time history curve fluctuates frequently under the fluctuating load. It shows that the dynamic load influence on the pavement dynamic response is complex. The node stress intensity always reaches the peak value when the load reaches this point location. After the load leaves, it decreases rapidly to zero. The node on the surface is most obviously affected by the load. The deeper the surface is, the smaller the load effect is; however, no matter how deep, the influence rule is consistent.

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