EFFECTS OF THE TIRE-PAVEMENT CONTACT PRESSURE ON ASPHALT PAVEMENT

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Abstract: The interfacial pressure between tire and the pavement exhibits a highly non-uniform distribution over the contact area. It is different from the uniformly distributed vertical stress distributions traditionally used for pavement analysis. On the basis of abundant literature, simplified load models have been put forward according to the tire tread patterns. And the response of the pavement under the simplified load models has been obtained through finite element method. Studies have shown that the influence of different load models is remarkable near the contact area. There is a significant difference between the responses computed with the circular uniform and non-uniform contact pressure distributions. These results may be a possible explanation of near-surface pavement distress evolution in asphalt pavement.

Key words: tire; pavement; contact pressure; FEM

1. INTRODUCTION

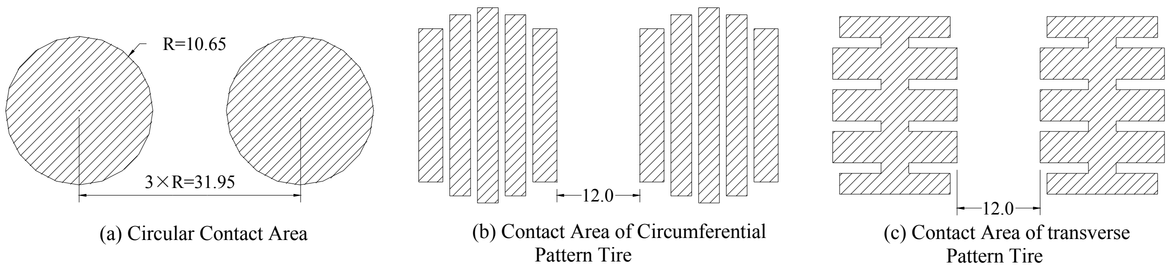
The interfacial pressure between tire and pavement exhibits a highly non-uniform distribution over the contact area. It is different from the uniformly distributed vertical stress distributions traditionally used for pavement analysis. In recent years the truck loads become much heavier with the increased traffic volume(Myers,1999;Gillespie,1993;Roque,2000). The wheel loads of trucks contribute to various forms of pavement distress. Of the various types of damages, fatigue crack and permanent deformation are of great importance. In order to better understand surface distress issues, models should be developed to describe the actual tire-pavement contact pressure.

The tire-pavement contact pressure distribution is significantly affected by tire inflation pressure, tire type, tire load and tire tread patterns. Many measuring systems have been developed to measure the tire-pavement contact pressure in the last decade. The measured data clearly reveal that the tire-pavement contact pressure distribution is noncircular, non-uniform and discontinuous(Tielking,1994;D.Beer,1999). In many recent pavement design procedures, circular uniform pressure was used to analyze the pavement response. The result cannot explain well some kinds of pavement distress. The primary objectives of this research study are to develop two simplified load models to analyze the asphalt pavement through the finite element method. Besides, the multi-layer elastic system theory is employed to analyze the pavement response under the circular uniform load.

2. COMPUTATIONAL MODEL

2.1 Simplified Load Models

This research study has presented two simplified tire footprint models according to the tire tread patterns. Figure 1 shows the three types of contact areas selected to compute the pavement response. The first case is the circular contact area with uniform contact pressure of 700kPa(Uniform). The second case represents the simplified tire footprint for the circumferential pattern tire (Nonuniform_C), and the third case is for the transverse pattern tire (Nonuniform_T). As shown, each tread is replaced by a rectangle. The contact pressure on each rectangle is assumed to be constant, which is illustrated in Figure 2.The load on each rectangular area sums to 25KN. In order to better compare the pavement response under the uniform loads with the pavement response under the non-uniform loads, the multi-layer elastic system theory is employed to analyze the pavement response under the uniform loads.

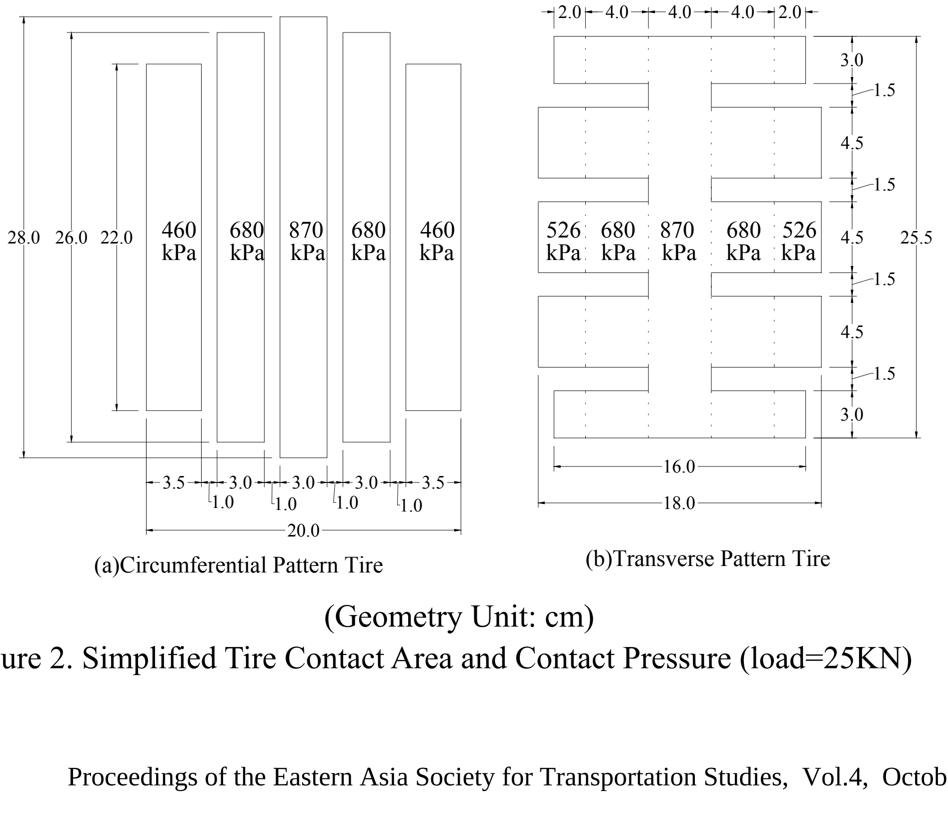


(a) Circular Contact Area

(b) Contact Area of Circumferential Pattern Tire

(c) Contact Area of transverse Pattern Tire

(Geometry Unit: cm)
Figure 1. Different Contact Areas of Dual Tire Configuration



(a)Circumferential Pattern Tire

(b)Transverse Pattern Tire

(Geometry Unit: cm)
Figure 2. Simplified Tire Contact Area and Contact Pressure (load=25KN)

2.2 Pavement Systems Used in the Analysis

The road pavement was modeled as a linear elastic multi-layer in three dimensions with finite boundaries. The size of the model was 6 meters long and 6 meters wide. In order to minimize the influence of the depth of subgrade, the models of 6 meters long and 6 meters wide with different depths were analyzed. When the depth of the subgrade is 6 meters, the pavement response converges quickly to a constant value. The boundary condition is fixed at the bottom of the subgrade. The interface contact conditions are assumed to be bonded. The pavement system and the material property used for the analysis in this research are shown in Figure 3. All the parameters are in consistence with the Specifications for Design of Highway Asphalt Pavement in China (IHPD,1997). The pavement structure model and coordinate used in the analysis is shown in Figure 4.

Surface	E_1 =1200MPa	μ_1=0.25	h_1=15cm
Base	E_2 =1400MPa	μ_2=0.25	h_2=20cm
Subbase	E_3=600MPa	μ_3=0.25	h_3=30cm
Subgrade	E_0=60MPa	μ_0=0.35	

Figure 3. Pavement Structure Used for Analysis

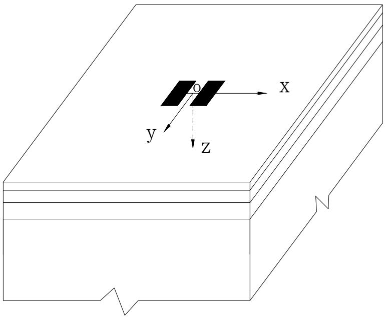


Figure 4. Finite Element Model of Pavement Structure

3.DISCUSSION OF NUMERICAL RESULTS

The finite element program MSC.NASTRAN was selected to analyze the response of pavement under two non-uniform modeling loads. The multi-layer elastic system theory is employed to analyze the response of pavement under the circular uniform loads.

3.1 Displacement Distribution

Figure 5 illustrates the displacement distribution along section XOZ under the uniform load and the non-uniform load. This figure shows that the displacements under circular uniform load are larger than those under the non-uniform load. It is also clear that there are some differences in displacement distribution near the region of contact area between the transverse pattern load model and circumferential pattern load model. The maximum magnitude of displacement for the circular uniform pressure is 0.404mm, but those in the case of non-uniform pressure of circumferential pattern and transverse pattern are 0.340mm and 0.351mm, respectively. This means that the assumption of the circular uniform load for pavement response gives a conservative result.

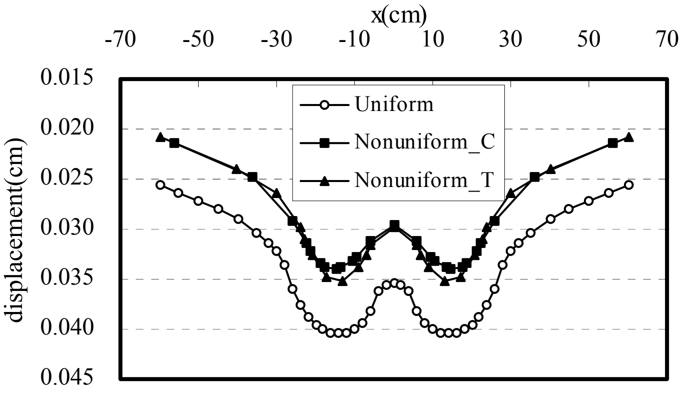


Figure 5. Displacement Distribution under the Different Pattern Load

3.2 Tensile Stresses in the Pavement Structure

The data shown in Table 1 indicate that the first principal stress at the bottom of base layer $\sigma_{1\ \mathrm{base}}$ and the first principal stress at the bottom of subbase layer $\sigma_{1\ \mathrm{subbase}}$ for the circular uniform pressure is larger than those in the case of non-uniform pressure of circumferential pattern and transverse pattern, respectively. The difference between the transverse pattern case and circumferential pattern case is as much as 3.9% for the first principal stress at the bottom of base layer, while it is much lower, at around 1.7%, for the first principal stress at the bottom of subbase layer.

Table 1. First Principal Stress at the Bottom of Base Layer and Subbase Layer for Three Different Load Models

Load Models	Nonuniform_C	Nonuniform_T	Uniform
$\sigma_{1\ \mathrm{base}}$（KPa）	83.09	86.35	96.30
$\sigma_{1\ \mathrm{subbase}}$（KPa）	64.09	65.17	69.50

3.3 Vertical Stress Distribution

Figure 6 shows the vertical stress distribution with depth. It can be seen that the vertical stress under both circular uniform pressure and non-uniform pressure dissipate rapidly with increased depth. In the top of 15cm of the pavement, there are some differences in the vertical stress among the three load models.

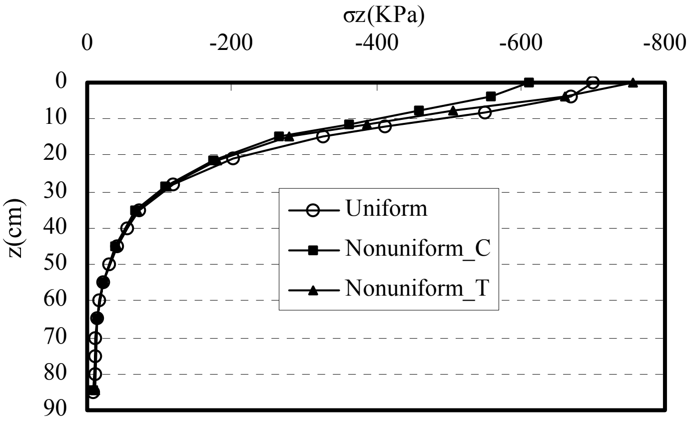


Figure 6. The Vertical Stress Distribution with Depth

3.4 Maximum Shear Stress Distribution

Figure 7 shows the maximum shear stress distribution in the depth of 3.75mm along x for the non-uniform load and circular uniform load. This figure indicates that in the region near the contact area, the maximum shear stress is much larger than the one of the region far away from the contact area. Figure 8 shows the variation of τ_{max} as a function of the depth for the non-uniform load and circular uniform load. Like the case of the σ_z response, τ_{max} under the three loads dissipate rapidly with increased depth. In the top of 3cm to 8cm of the pavement, the maximum shear stresses are much larger.

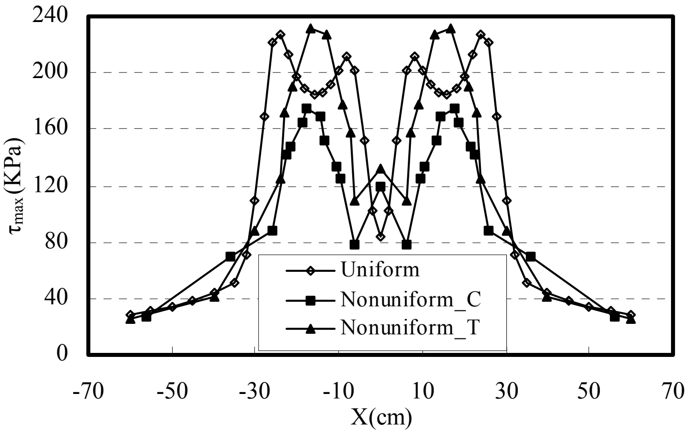


Figure 7. The Maximum Shear Stress in the Depth of 3.75mm along x

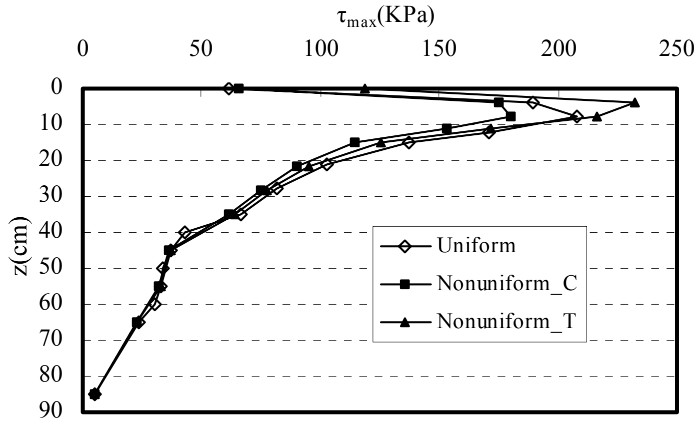


Figure 8. The Maximum Shear Stress Distribution with Depth

4. CONCLUSIONS

In this research two non-uniform distribution load models have been put forward according to the tire tread patterns. And the pavement response under the simplified load models has been obtained through finite element method. Also, the pavement response under the conventional load distribution (circular, uniform pressure) has been obtained through the multi-layer elastic system theory.

Several conclusions were reached based on the studies at this stage. They are summaried as follows:

1. There is a significant difference between the responses computed with the circular uniform and non-uniform contact pressure distributions.

2. Studies have shown that near the contact area the influence of different load models is very remarkable. In the region near contact area, the maximum shear stress is much larger than the one of the region far away from the contact area. These results may be a possible explanation of mechanics of near-surface distress evolution in asphalt pavement.

3.The magnitude of maximum shear stresses is much large within the top 50mm of surface layer, which can explain the recent prevalence of near-surface cracking and rutting in asphalt pavement.

4.It is shown that the magnitude of the maximum shear stresses that developed under the modelled transverse pattern tire load is higher than the ones that developed under the circumferential pattern tire load.

5.The displacement that developed under the modelled transverse pattern tire load is higher than the one developed under the circumferential pattern tire load near contact area, but in the region far away from the contact area, the displacement almost has no difference.

6.It is necessary to develop more practical mechanistic models for the improved prediction of pavement performance.

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