

STRUCTURAL RESPONSE OF ASPHALT PAVEMENT UNDER DYNAMIC LOADINGS

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Abstract In this paper, the finite element software NASTRAL was employed to investigate the structural response of asphalt pavement under different types of excitation such as rectangular, triangle and sine types. The asphalt pavement was modeled by a multi-layer elastic system. Numerical results show that both the dynamic deflection and the dynamic stress oscillate with different phases after the remove of the dynamic loading. The pavement stress decays faster than the pavement deflection. The stresses reach a maximum after the remove of the dynamic loading. Furthermore, the stresses and deflection are closely related to the momentum of the excitation instead of the maximum dynamic loading. Real dynamic loading was obtained from field data of pavement unevenness by Quarter-truck vehicle model. Finally, The structural response of the pavement to the real dynamic loading was conducted.

Key Words: asphalt pavement, dynamic loading, structural response, NASTRAL

INTRODUCTION

The vehicle traveling on the road exerts a dynamic loading on the pavement. The dynamic loading is characterized by its speed, duration of loading, headways and traffic volume. The response of the pavement structure under the dynamic loading is totally different from that under static loading. Traditionally, highway engineering emphasizes more on road pavement design, materials used and the durability of the roads but traffic engineering focus more on the operation side, for instance, speed, capacity, acceleration/deceleration and headways. More research is needed to investigate the interaction between vehicles and road pavement in a dynamic environment. Most of the problems associated with the safety, economy, and overall quality of road transportation are affected by the characteristics of both roads and vehicles and by the manner in which these two dynamic systems interact. The research emphasis was usually placed either on roads or on vehicles, but rarely on both. Existing mechanistic pavement design methods use static wheel loads, which are assumed to be constant over the life of the pavement. Dynamic loads are only considered implicitly, their effect is introduced in the calibration factors applied to the computed stress and strain. In the "A Guide to the Structural Design of Road Pavements" (AUSTROADS, Sydney, 1992), it indicates that vehicle speed plays an important role in the road pavement design, but without further details. In engineering practice, the suspension performance, road surface profile, dynamic wheel

loads and the pavement response are closely related.

The structural response of pavements to dynamic loadings is too complex to be solved theoretically. The aim of this paper is to determine the structural response of pavements to different types of loading by making use of the finite element method. The study in this paper is a continuation of the “Simulations between Vehicles and Road Pavements”(Zheng, 2001), which will further deepen the understanding of the interaction between vehicles and roads, help regulate and improve vehicles to suit the road, and benefit the design and maintenance of the road pavements.

2. COMPUTATIONAL MODEL

The road pavement was modeled as a multi-layer linear elastic dynamic system in plane strain-state in this study. The multi-layer linear elastic system consists of a wearing course, a basecourse, a subbase and subgrade. The boundary condition is fixed at the bottom of the subgrade with two end sides fixed horizontally and one free side is acting upon by dynamic forces. The size of the model was 10.00 meters long and 9.48 meters in depth. The finite mesh has 360 elements with the smallest one of 5.325cm \times 2.5cm. The size of the model was chosen to minimize the influence of the boundaries. The size of the elements was denser near the loading area and sparsely spaced far from the loading position in order to increase the accuracy of the numerical results. The loading area is 21.3 cm wide and maximum loading magnitude is 117043.5Pa, which corresponds to a 100KN tandem axle on the road. All the results were calculated by NASTRAL software. The material property is listed in Table 1.

Table1. Material Properties

Elastic modulus of wearing course E_1 (MPa)	1000
Poisson ratio of wearing course μ_1	.25
Thickness of wearing course H_1 (m)	.12
Density of wearing course γ_1 (kg/m ³)	2400
Elastic modulus of basecourse E_2 (MPa)	1200
Poisson ratio of basecourse μ_2	.25
Thickness of the basecourse H_2 (m)	.2
Density of the basecourse γ_2 (kg/m ³)	2200
Elastic modulus of subbase E_3 (MPa)	500
Poisson ratio of subbase μ_3	.25
Thickness of subbase H_3 (m)	.2
Density of subbase γ_3 (kg/m ³)	1750
Elastic modulus of subgrade E_0 (MPa)	50
Poisson ratio of subgrade μ_0	.35
Density of the subgrade γ_0 (kg/m ³)	1400

From Table 1 it can be seen that the parameters chosen to conduct the modeling and calculation are in the range of highway engineering practice in China. The parameters include the properties of Wearing Course, Base Course, Sub-base Course and Sub-grade.

The computational accuracy was first checked statically by the solution of multi-layer elastic

half space. The horizontal direction is x direction, and vertical direction is y direction.

3. METHOD OF SIMULATION

The natural frequency is closely related to the dynamic responses. Numerical results show the frequency increases with the increase of the stiffness and decrease of the density. The Poisson ration has little influence on the pavement frequency. In addition, the smaller the mesh sizes, the smaller the frequency. Pavement frequencies tend to be stable when the mesh size is small enough as designed in this paper. The difference between the adjacent frequencies in lower modes is larger than that in high modes. Pavement dynamics involves the analysis of pavement subject to time-varying loads generated by road traffic. There are two main parameters required in the dynamic analysis: duration of the analysis and the minimum length of analysis. For transient response analysis, the duration of analysis should be greater than inverse of the lowest frequency. This ensures that all modes will oscillate at least once. Solution time increment should not exceed the inverse of the frequency of the highest mode of interest. Damping is a measure of a pavement structure's capacity to dissipate energy. Critically damping means when it returns to its equilibrium state without oscillation. The less damping in the pavement structure, the greater the response at a given frequency. Damping percentage of critical damping is assumed to be 15 in the analysis.

4. STRUCTURAL RESPONSE OF ASPHALT PAVEMENT TO DIFFERENT TYPES OF LOADING

4.1 Single Rectangular Loading

The road surface deflection under a single rectangular loading at different speeds is shown in the Figures 1. In the Figure 1, the load durations of 0.015s, 0.010s and 0.008s correspond to

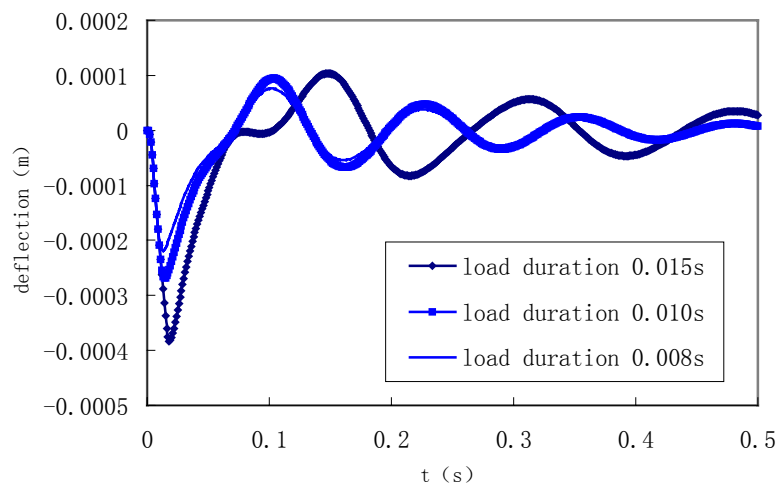


Figure 1. Surface Deflection versus Time

three speeds of 51.1km/h, 76.7km/h and 95.9km/h respectively. Figures 1 shows that there are about four cycles of the variations of displacement and then decays to zero. Each cycle period is approximately ten times of the duration. The faster the vehicles speed, the smaller the

surface deflection. The deflection under the speed of 95.9km/h is approximately one third of the deflection under static load as shown in Table 2.

Table 2. Maximum Road Surface Deflection

Load Duration(s)	Static Load	0.015	0.010	0.008
Max. Deflection (mm)	0.640	0.384	0.268	0.219

Figure 2 and Figure 3 are the horizontal stress and vertical stress variations with load duration of 0.015. It can be seen from Figure 2 and Figure 3 that the variation of stresses can be divided into three different phases: I forced vibration by the excitation; II mixed vibration and III free vibration. Phase I plays an dominate role in the pavement damage analysis, which lasts approximately 0.04s. The stress decreases with the increase of vehicle speed.

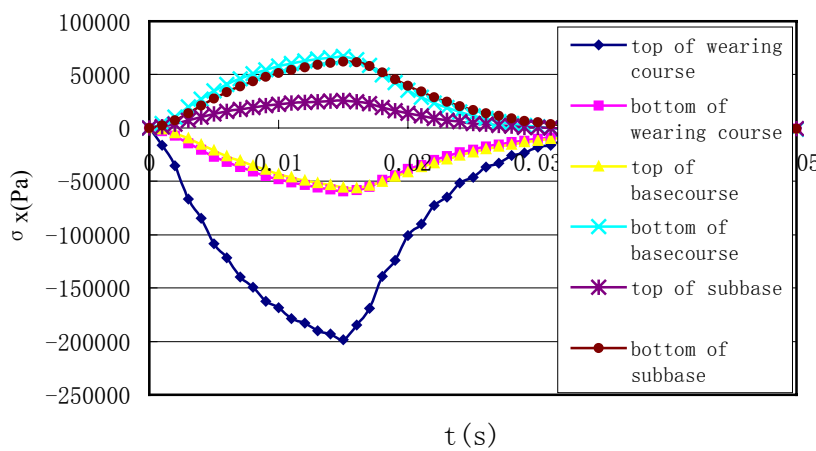


Figure 2. Horizontal Stresses versus Time (at Speed 51.1km/h)

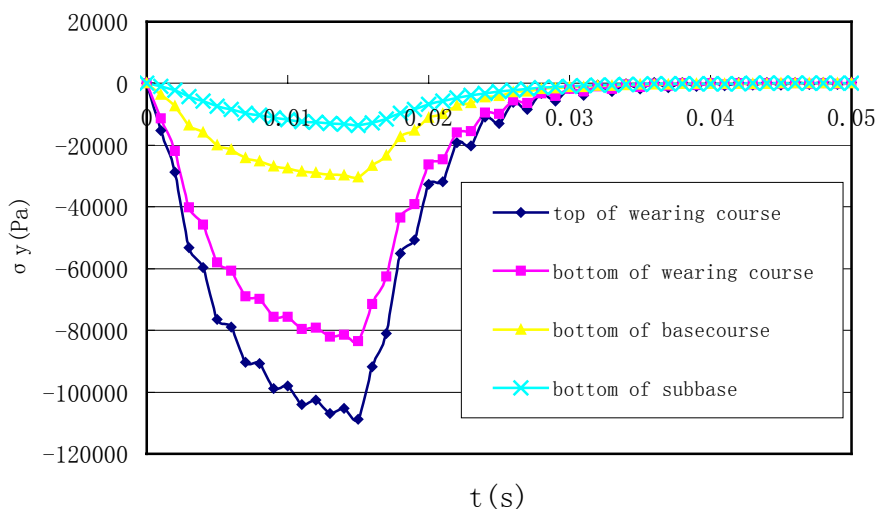


Figure 3. Vertical Stresses versus Time (at Speed 51.1km/h)

The stresses reach a maximum after the remove of the dynamic loading. Both the horizontal stress and the vertical stresses do not reach a maximum at the same time because of the stress wave propagation.

4.2 A Half Sine Loading

Structural responses of the pavement to a half sine or the triangular excitation are similar to that in the case of rectangular excitation as illustrated by Figure 4. Given the same loading duration and magnitude, the displacement under a half sine loading is smaller than that under rectangular loading by a magnitude of 37 percent. In addition, the period in the case of a half sine loading is longer than the period in the case of a rectangular loading.

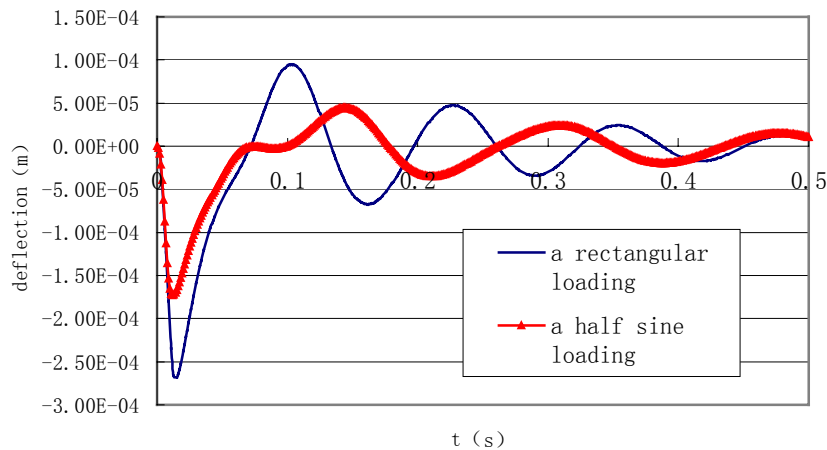


Figure 4. Deflections versus Time (at Speed 76.7km/h)

The stresses under the half sine loading are smaller than that under rectangular loading, but greater than that under the triangular loading. These results mean the structural response of the pavement is closely related to the momentum instead of the magnitude of the loading.

4.3 The Interaction of Two Rectangular Loadings

Figure 5(a) and Figure 5(b) are the surface deflections subject to two rectangular loadings

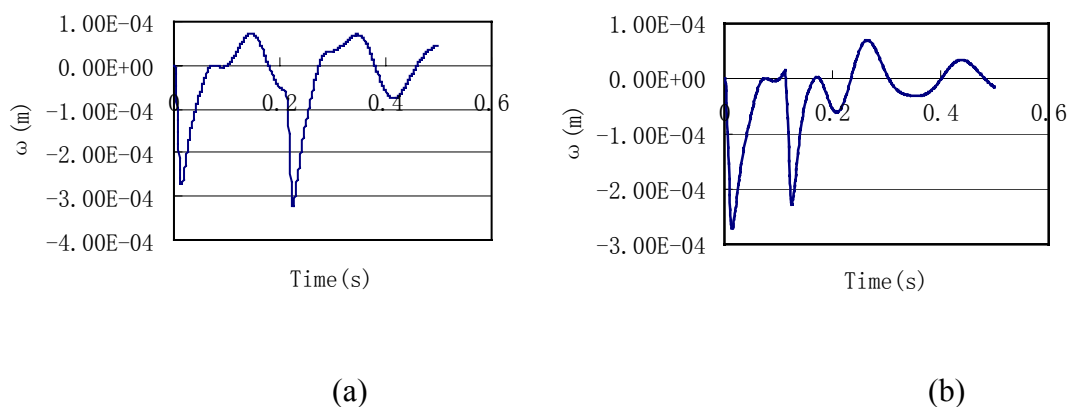


Figure 5. Displacement versus Time (at Speed 76.7km/h)

of the same magnitude with a load duration of 0.01s and a rest time of 0.10s and 0.20s. The rest time between the two rectangular loadings influence the interaction of the two loadings.

The interaction between the loadings results in accelerate as in Figure 5(a) or deceleration as in Figure 5(b) of the deflection. That is to say, the headways or axle distances have an important effect on the pavements. The pavement design is closely related to the vehicle design and the traffic flow conditions.

4.4 A Real Dynamic Loading

The real dynamic loading in Figure 6 was obtained from the field data of the pavement

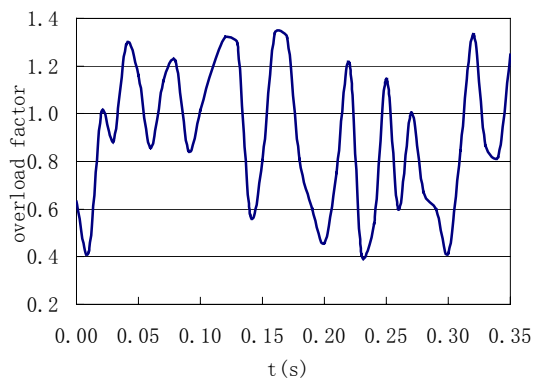


Figure 6. A Real Dynamic Loading

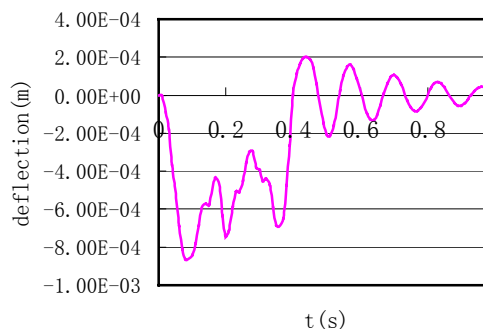


Figure 7. Deflection versus Time

unevenness by Quarter-Truck model. The smoother the pavement, the smaller the overload. The factor of real dynamic loading. The real dynamic loading is random in nature. The deflection of pavement induced by the random loading is also random as shown in Figure 7. So are the stresses illustrated in Figure 8. Because of the complex interaction of the random loading, the maximum deflections do not coincide with the maximum overload factors. The stresses exhibit a different variation. Further studies are needed in order to fully understand the nature of random loading of the pavement.

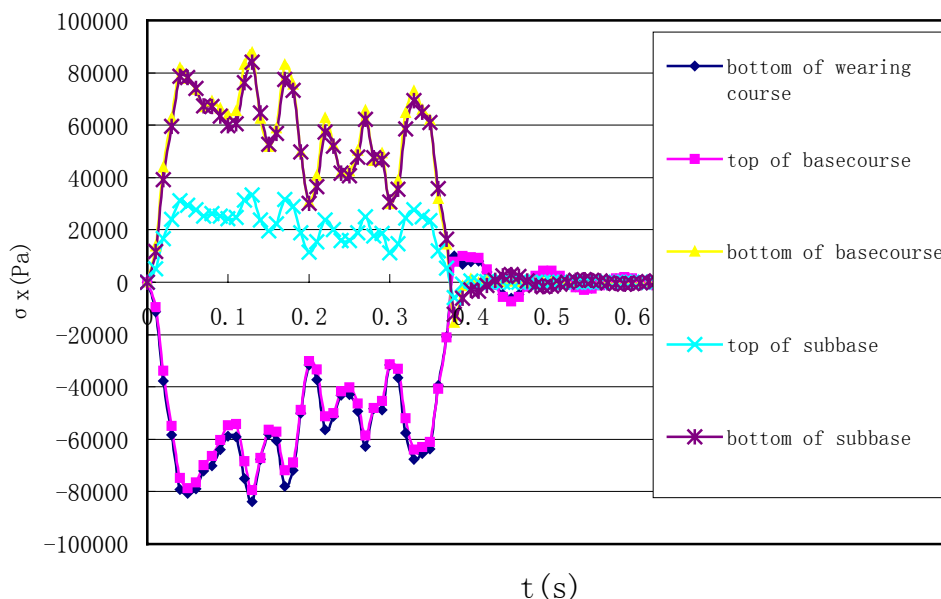


Figure 8. Horizontal Stresses versus Time (Random Loading)

4.5 The Effect of Pavement Material Properties

Pavement material properties also influence the stress and displacement variation under dynamic loading. Usually, the material properties are time dependent and temperature dependent. The faster the speed of vehicles, the stiffer the pavement materials. Both deflections and the periods decrease with increase of the subgrade modulus as shown by Figure 9.

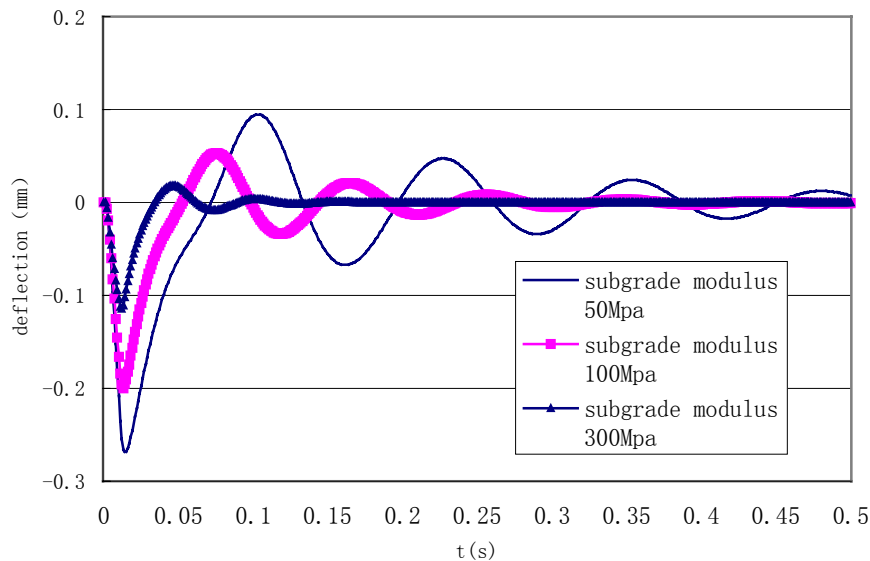


Figure 9. Deflections versus Time (at Speed 76.7km/h)

4.6 The Application and Limitation of the Analysis Presented.

Theoretically and numerically, this paper demonstrated the differences between the static loading and dynamic loading. In order to apply this analysis presented, many experiments must be carried out on the dynamic parameters, such as: dynamic modulus and strength of pavement materials and test of dynamic deflections. From the results obtained, it can be predicted that the pavement subject to a dynamic loading will fracture in a different way. For the same axle loading, the loading type and duration must be taken into consideration not only in pavement analysis but also in materials design.

In practice, asphalt concrete is a viscoelastic and plastic material, especially at high temperature and lower frequencies. The relaxation time can be used to characterize the effect of viscosity. Lower frequencies dominate the dynamic response of the pavement when the vehicle speed is very low. But at higher speed, the dynamic structural response of the pavements mainly depends on the higher frequencies. Therefore, the higher the speed of vehicles, the less the influence of viscoelastic effect on the response of asphalt pavements. The linear elastic model for the asphalt pavement in this paper must be modified in order to analyze the dynamic response in the case of low velocity.

5.CONCLUSIONS

This research employed NASTRAL software to investigate asphalt pavement structural response to several different types of loading. A few conclusions were reached based on the studies at this stage. These findings help to improve the design and the maintenance of asphalt pavements by considering the dynamic effect of the pavement. They are summarised as follows:

1. The dynamic structural response of pavement differs from the static case in that the former depends on the speed, headways, and distribution of the axles, as well as the time dependent nature of pavement materials.
2. Both the stresses and the displacement reach a maximum after the removal of the dynamic loading. The displacement decays slower than the stresses after the maximum.
3. The dynamic stresses and deflection depend mainly on the momentum of the excitation instead of the magnitude of dynamic loading.
4. The interaction of two rectangular loadings shows that the rest time between the rectangular loadings must be carefully considered in the analyses of pavement.
5. Primary study on real dynamic loading was conducted. Much more studies are needed in order to better understand the nature of random loading.

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