SIMULATION OF INTERACTIONS BETWEEN VEHICLES AND ROAD PAVEMENTS

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Abstract: This paper employed finite element methods to simulate the interactions of vehicle speeds and headways on the road pavement. The vehicle speeds and headways are expressed in terms of duration and rest periods on the load spectrum. Duration for different speeds can be predicted based on the tyre/pavement contact area and speeds. The road pavement is modelled as a linear elastic mullet-layer dynamic system in plane strain-state. It was found that dynamic loading induces oscillation of the deflection and stresses. The decrease of the stiffness and increase of the thickness of the wearing course weak the stresses at the bottom of the wearing course. The suddenly applied constant loading was examined to provide some information for non-destructive pavement testing. The dynamic deflection is smaller than static deflection. Vertical and horizontal loading were compared. Single loading and tandem loading were investigated.

Key Words: vehicle speeds, pavements, dynamic response

1. INTRODUCTION

Traditionally, highway engineering emphasises 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. Little research has been conducted to investigate the interactions 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. It appears that the tensions between roads and loads have been in existence from the beginning. Carriers (i.e. commercial vehicles) have always had an incentive to carry larger loads and those responsible for building and repairing roads have always had an incentive to protect their facilities by regulating various features of the traffic using them. 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.

This research investigated responses of road pavement subject to dynamic loadings induced by vehicle speeds and headways. The aim is to determine which commercial vehicle characteristics have the strongest effect on road pavement damage and how the road pavement reacts to the dynamic loading induced by the vehicle suspension systems and responses of pavements to different vehicle speeds. The study of the dynamic responses of road pavements to traffic speed and headway distributions in this research will deepen the understanding of the interactions between vehicles and roads, help regulate and improve vehicles to suit the road, and change the design, construction and maintenance of the road pavements.

2. COPUTATIONAL MODEL

The road pavement was modelled as a multi-layer linear elastic dynamic system in plane strain-state in this study. The boundary condition is fixed at the bottom of the sub-grade with two end sides free and one side is acting upon by dynamic forces. The size of the model was 10.67 metres long and 4.9 metres in depth. The finite mesh has 6400 elements with the smallest one of 5.335cm × 2.5cm. The size of the model was chosen to minimise the influence of the boundaries. The size of the elements was designed to increase the accuracy of the numerical results. All the results were calculated by Algor software. The material property is listed in Table 1.

Table1 Material Properties

Elastic Modulus of Wearing Course E_1(MPa)	2800
Poisson Ratio of Wearing Course μ_1	0.4
Thickness of Wearing Course H_1(m)	0.1
Density of Wearing Course γ_1 (kg/m^3)	2200
Elastic Modulus of Base Course E_2(MPa)	2000
Poisson Ratio of Base Course μ_2	0.2
Thickness of the Base Course H_2(m)	0.2
Density of The Base Course γ_2(kg/m^3)	2000
Elastic Modulus of Sub-base Course E_3(MPa)	800
Poisson Ratio of Sub-base Course μ_3	0.35
Thickness of Sub-base Course H_3(m)	0.2
Density of Sub-base Course γ_3(kg/m^3)	1800
Elastic Modulus of Sub-grade E_0(MPa)	30
Poisson Ratio of Sub-grade μ_0	0.45
Density of The Sub-grade γ_0(kg/m^3)	1600

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

3. MODAL ANALYSIS

Modal analysis is the most important but simplest form of dynamic analysis (also called mode frequency and normal mode analysis). The objective of the modal analysis here is to determine the natural frequencies and corresponding mode shapes of the pavement structures. This is obtained from unmapped free harmonic vibration. Since there are no forces or damping, the frequencies are called fundamental frequencies. The modal shapes are required to solve more general dynamics problems such as transient response or response spectrum analysis. The calculated frequencies of the first five modals are shown in Table 2.

Table 2. Pavement Frequencies

Mode	First	Second	Third	Fourth	Fifth
Frequency(Hz)	3.6293	7.6812	8.0589	9.9652	11.182

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. Table 2 shows that difference between the adjacent frequencies in lower modes is larger than that in high modes.

4. DISCUSSION OF THE NUMERICAL RESULTS

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 1/First, the frequency of the lowest. This ensures that all modes will oscillate at least once. Solution time increment should not exceed 0.5/Fifth, the frequency of the highest mode of interest. Damping is a measure of a pavement structure's capacity to dissipate energy. It is not concerned in this modal analysis. 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 modal analysis. The loading is time-varying uniformly distributed along the contact area. The contact area is a circle with a radius of 10.67cm. The dynamic loadings are Heavyside functions with duration of 0.015 second or 0.007 second corresponding to the speeds of 50km/h or 110km/h respectively. The pressure of the contact area is 0.55MPa,which corresponds to a single axle of 80KN with dual tyres.

4.1 Vehicle Speeds

The stresses and displacements under a single dynamic loading at the speed of 110 km/h are shown in Figures 1 and 2 (in figures 2, 3, 4, and 6, the mesh points 6935, 6915, 6895, 6875

6855 and 6835 denote the different positions of the points away from the centre of the contact area). The letters "a", "b" and "c" in Figures 1 and 5 represent the points on the surface, at the bottom of the wearing course and the base course of the road pavement respectively.

From Figures 1 and 2, we can see that there are about six cycles of the variations of stresses and then decayed to zero. Each cycle period is approximately twenty times of the duration. It is clear that the stress on the surface can be tensile or compressive, which completely different to the static case. The dynamic deflection is smaller than the static deflection.

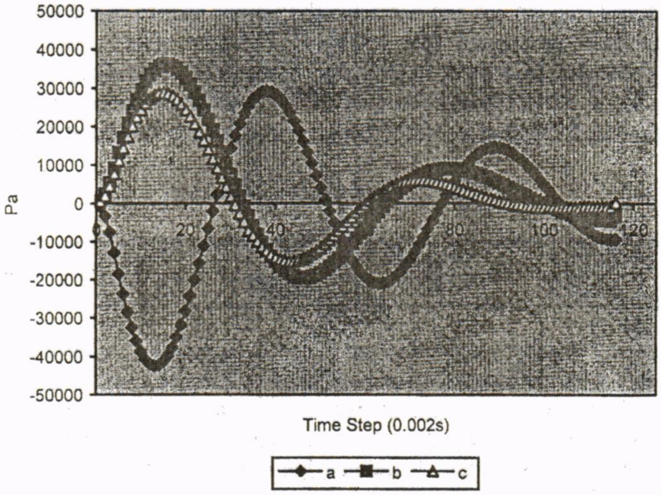

Figure1 Stresses versus Time (at 110 Km/h)

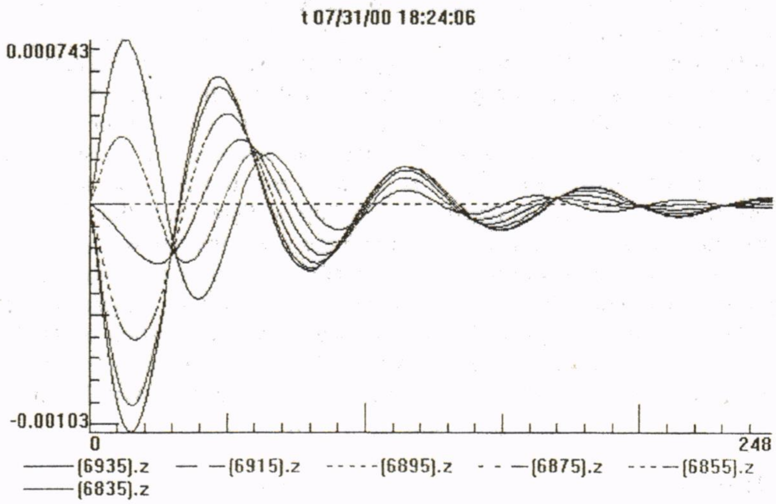

Figure 2 Displacement versus Time (at 110km/h)

The variation of the displacement versus time indicates that the wave propagation of the stress wave through the pavement. There are delays in the different positions on the pavement surface, which corresponding to the distance travelled through the elastic media as shown in Figure 3 which presents the details of part of the Figure 2 but at the speed of 50km/h.

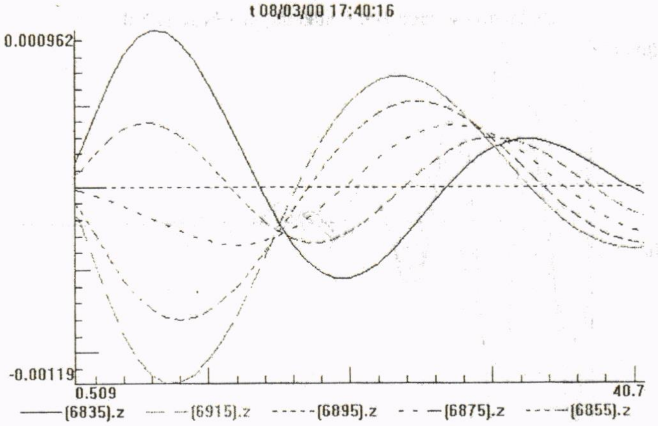

Figure 3 Displacement versus Time (at 50km/h)

4.2 The Interactions of Two Dynamic Loadings

Figures 4 and 5 present the stresses and the displacements of two dynamic loadings with a speed of 50km/h. The rest period between the two dynamic loadings is 0.1 second. Because of the interactions between the loadings, as a result, the two loadings will accelerate or decelerate the strength of the pavement stresses and the displacements.

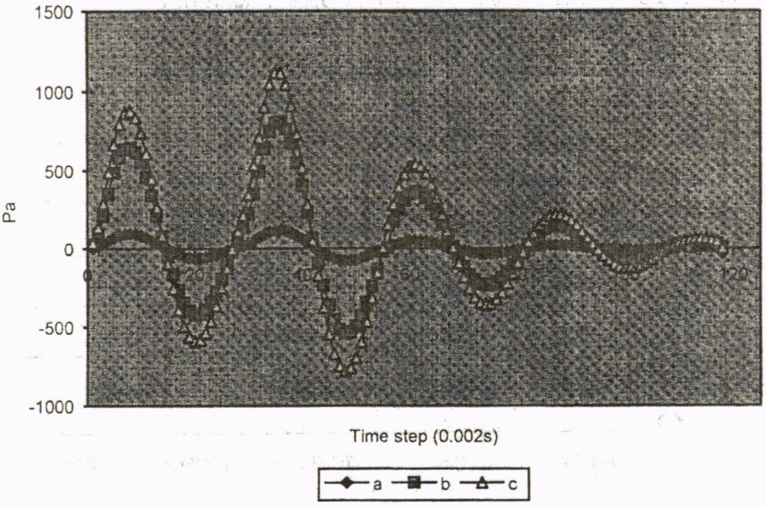

Figure 4 Stresses versus Time (at 50km/h)

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. The symbols for Figure 4 have the same meaning as mentioned in section 4.1.

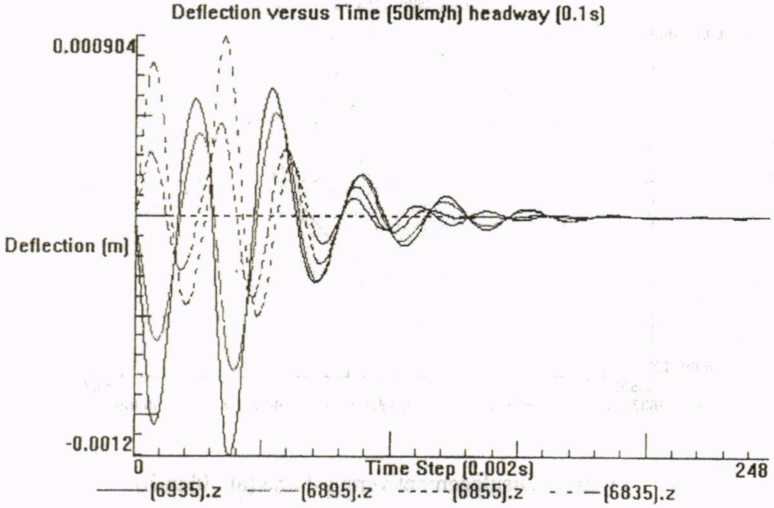

Figure 5 Displacement of Two Loadings (at 50km/h)

4.3 Suddenly Applied Loading

In another case for evaluating the interactions considering speed and pavement is suddenly applied loadings. In the airport pavement/runway design, suddenly applied loading induced by the landing gears must be considered when aeroplane lands down.

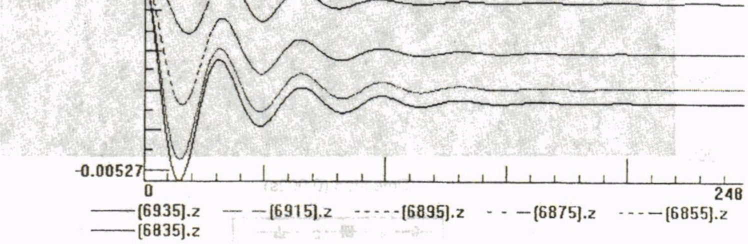

Figure 6 Displacement versus Time (suddenly)

In pavement/runway maintenance, Falling Weight Defectometer (FWD) is widely used to detect the dynamic deflection of the pavements/runways. Figure 6 is simulation the falling Weight Deflectometer. Together with the data produced by the FWD, the simulated results can be used to calculate the dynamic modulus of the pavements/runways.

5.CONCLUSIONS

This research employed finite element method to simulate vehicle speeds and headways on general road pavements. It attempted to evaluate the load conditions under different operation environments. Several conclusions were reached based on the studies at this stage, they are summarised as follows:

1. The preliminary numerical analysis demonstrated a dynamic process for deferent loading and speed conditions, which are completely different from a statical loading in distribution and magnitude.

2. The duration of loading generated five major periods of oscillations, each period is approximately twenty times the duration, which is important for prediction of pavement fatigue life.

3. The maximum tensile stress could be at the bottom of the layer or at the top of the surface, which explains that crack formation occurred at the top of the road pavement first.

4. The dynamic deflection was smaller than the static deflection. The fast the vehicle, the smaller the deflection.

5. Suddenly applied constant loading caused bigger stress compared to the static cases. The deflection is useful for non-destruction detection in pavement maintenance.

6. The interactions of two dynamic loadings showed that some strengthen the stresses and some weaken the situations. The pavement design is closely related to the vehicle design and traffic flow conditions.

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