Applied Mechanics and Materials Vol. 534 (2014) pp 105-110
Online available since 2014/Feb/27 at www.scientific.net
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doi:10.4028/www.scientific.net/AMM.534.105

Predicting Truck Load Variation Using Q-Truck Model

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Keywords: Primary response, dynamic loads, Q-truck, truck load variation, suspension and damping stiffness

Abstract. The study of heavy vehicle forces on pavement is important for both vehicle and pavement. Indeed it was identified several factors such as environment, materials and design consideration affects pavement damage over time with traffic loads playing a key role in deterioration. Therefore, this paper presents dynamically varying tire pavement interaction load, thus enable to assess the strain response of pavements influenced by road roughness, truck suspension system, variation of axle loading and vehicle speed. A 100m pavement with good evenness was simulated to check the sensitivity of the dynamic loads and heavy truck vertical motions to the roughness. The most important performance indicators that are required in pavement distress evaluation are radial strain at the bottom of the asphalt concrete and vertical strain at the subgrade surface was predicted using peak influence function approach. The results show that truck speed is the most important variables that interact with truck suspension system and thus effect of loading time are extremely important when calculating the critical.

Introduction

Irregularities in the pavement profile excite a vehicle as it travels along a road, causing a continually changing tyre force. The variation in tire force about its mean is the dynamic wheel loads (DWLs). These loads are caused by variety of static and dynamic processes, and are responsible for pavement deterioration. Heavy good vehicles (HGVs) are the major consumers of the pavement network, applying higher wheel loads than the nominal axle loads and perhaps induced the heaviest loads to the pavement through various combinations of axle configurations depending on its type. Meanwhile, the dynamic component of heavy vehicle tyre forces may a significant factor contributing to road damage.

The increased in dynamic loads with speed can increase theoretical road damage significantly [1]. However at high speed, road damage may decrease somewhat because of the reduction in road response with speed. It is compensated for by the shorter duration of an applied axle load. In specific, as the speed increases, the peak strain under a constant moving load diminishes in amplitude and occurs behind the point of applications of the load. In addition, high speed motions lead to significant vehicle vibrations that not only reduce the ride quality of passenger, but also generate additional inertia forces. Otherwise, at low speed vehicle vibration is slight.

A study by several researchers concluded that the soft suspension springs and tyres of low vertical stiffness are desirable for minimising dynamic loads [2-3]. Later in the study to examine Root Mean Square (RMS) dynamic wheel loads for various suspension results tyre and operating conditions generally have broadly similar conclusions about the effect of suspensions and tyre types on dynamic wheel load [4-5]. They concluded that, dynamic wheel loads were found by all studies to increase with speed and road roughness. Other than that, the study on the quantitative influence of surface roughness, speed and vehicle parameter resulted that vehicle speed has a significant effect on power spectral density (PSD) of loads and getting worst for the rougher surface [6].

Method of predicting truck forces

The simple quarter truck model can be efficiently used with personal computers to predict pavement loading [7-9]. In order to achieve the bold objective to investigate the vehicle and loading condition factors influence on critical response the following loading aspects are to be considered including; axle loads, types of suspensions and vehicle speed. In order to simulate the axle loading, the quarter truck (Q-truck) model is simulated by the sprung mass supported by a spring and a dashpot on top of an unsprung that contacts road surfaces via the vehicle tire. The Q-truck parameters are largely based on the results from validated articulated vehicle simulations developed by Cole and Cebon [10]. The Q-truck model parameters are given in Table 1 the road profile as illustrates in Fig. 1 (refer [11] for further detail). Considering the reality of traffic loading condition will contain a distribution of axles load between unladen and fully laden, the study was further to take into account realistic axle load variation. To achieve this adjustment, the sprung mass was divided into three other weight bands of 1/3, 2/3 of fully laden and overloading. The maximum axle load for single axle is based on Weight restriction (Federal Road) [Amendment] Order 2003, Ministry of Transportation Malaysia. The maximum weight for single tyre was calculated 3000kg for steer single axle with steel suspension (STEER), tractor drive axle with steel or air suspension (SINS, SINA) at fully loading condition respectively and multiply with 1/3, 2/3 and 4/3 to get the required axle weight.

Table 1: Q-truck Axle model

		Suspension type		
Parameters		**STEER**	**SINS**	**SINA**
Body mass	(kg)	X	X	X
Wheel mass	(kg)	400	600	600
Suspension damping	(Ns/m)	1.5E+03	6.5E+03	1.3E+04
Wheel damping	(Ns/m)	1.0E+03	2.0E+03	2.0E+03
Suspension stiffness	(N/m)	2.3E+05	8.6E+05	5.0E+05
Wheel stiffness	(N/m)	1.0E+06	2.0E+06	2.0E+06

*** X = 1/3, 2/3, fully lading or overloading from maximum gross weight

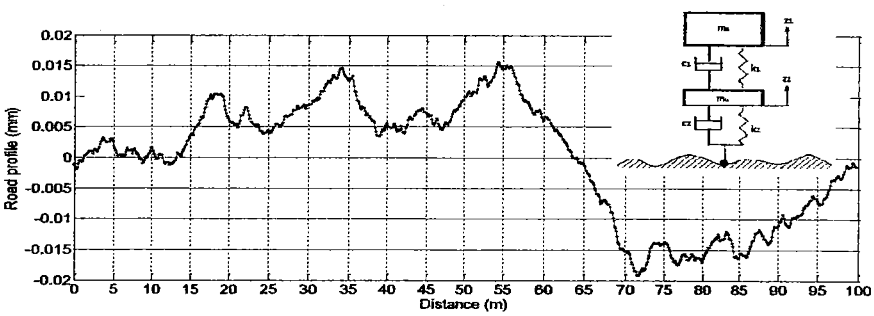


Figure 1 Road Profile

Result and Discussion

Dynamic Wheel loads

The dynamic force exerted on the road surface by traffic dependent on the characteristic of the road profile in addition to the vehicle characteristics. In this task the measured dynamic wheel loads generated by particular Q-truck axle model are assessed in term of varies loading condition and truck speeds. Fig. 2 shows the simulated dynamic tyre forces generated by single axle of steel suspension with varies loading condition in response of road displacement at truck speed 20m/s.

Dynamic load typically tend to concentrate at points along intervals of 8-9 metres. The figure also shows, at lower loads the impact forces are smaller and vice versa. However, for certain nodes along the pavement, the impact from 1/3 of fully laden are more aggressive which give a high peaks with the maximum increasing greater than 150 percent more than the mean average loads. This phenomena is due to uncertainties body bounce generated by the truck which strongly dependent to the surface irregularities. The percentage increasing of forces for truck with 2/3 of fully laden conditions are lesser that 45 percentage and the value decreasing with increasing the truck static loading. As been expected, the dynamic tyre forces generated by the steel suspension gives the higher peaks compare with the forces generated by the air-sprung suspension, with their amplitudes quickly increasing at certain location due to the body bounce modes through immediate goes up/down level of road surface [please refer Fig. 3].

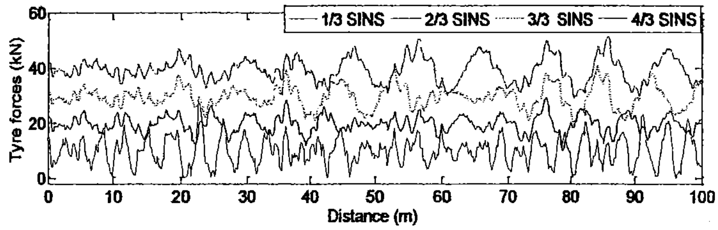


Figure 2: Comparison of wheel forces by 1/3, 2/3 and fully laden single tyre of steel suspension

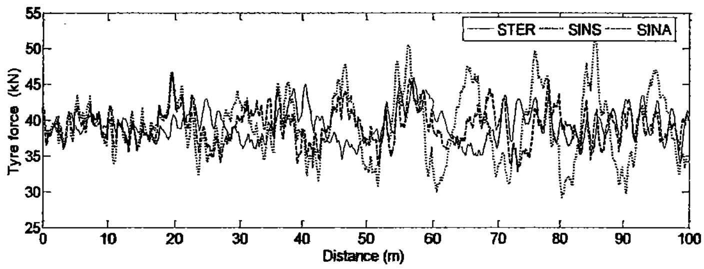


Figure 3: Comparison of wheel forces by single tyre of steel and air suspension over loading

Fig. 4 shows the dynamic wheel loads for fully laden truck with steel suspension travelling at speed 20m/s generate maximum dynamic wheel load 41 kN, which is 14 percent higher than vehicle with speed 10m/s for along the path. It can be clearly seen that the standard deviation for 10m/s and 20m/s is almost double the number which is about 1.9 kN. It can further noticed that, by comparing with the static loading (29.6 kN), the maximum dynamic loading for vehicle travelling 10m/s and 20m/s are clearly higher with approximately 22 percent and 39 percent..

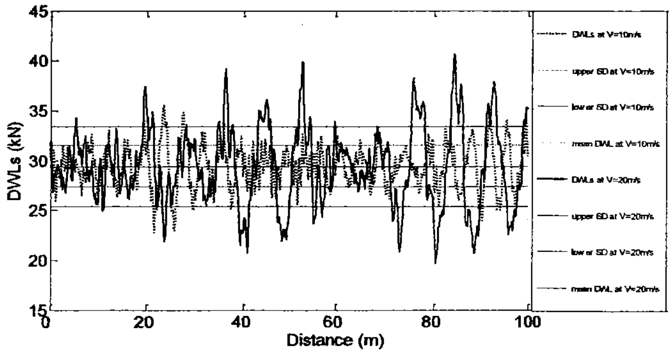


Figure 4: DWLs with the Mean and Standard Deviation

To ensure that the dynamic force levels generated by the axle group models were realistic, a level of dynamic variation of a tyre force history is a dynamic load Goefficient (DLC), defined as the ratio of standard deviation to mean of the tyre force. Previous research found the strong dependency of Dynamic Wheel Loads (DLCs) with vehicle speed, suspension design and road roughness. In Gillispie et al reported that under normal operating condition DLC's value typically in the range of 0.1- 0.3. As a point of reference, all axle of a truck moving over a perfectly smooth road would theoretically have DLC values close to zero [12]. DLC values of less than 8% indicate moderately smooth pavements, DLC values greater than 10% are considered to indicate moderately rough pavement, and DLC value higher than 15% indicate very rough pavement surfaces. Fig. 5 shows the DLCs changes with speed (loading time) for particular truck axles with varies loading conditions. It is observed from Figure 5 that, the result separated into two different parts, high and low degree of effects. As can be seen, the DLCs are relatively insensitive to the truck speed used when the truck loading with 1/3 of the fully laden for both steel and air suspension but not for steer axle. The reason for the phenomena is the effect of immediate goes up/down level of road surface on body bounce modes. Apart from that, for other loading condition the effect of the truck speed are insignificant due to the lesser truck vibration than the vibration of lighter loading.

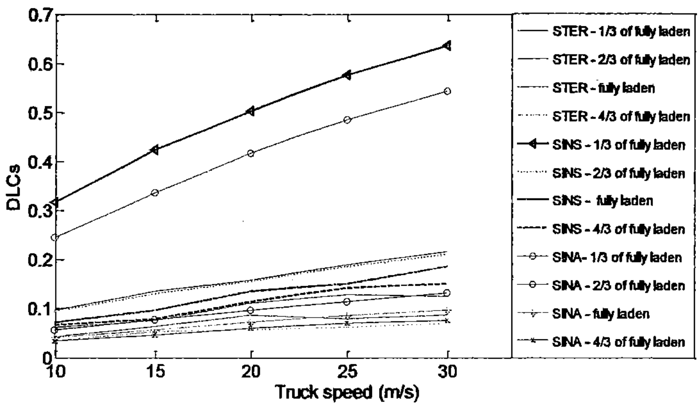


Figure 5: DLCs for varies truck speed

Critical responses in the pavement layer

The applied load to a flexible pavement comprising, generally, non-linear and viscoelastic materials set up a system of stresses, strains and permanent deflection in the pavement. This system referred as the response of the pavement to the load. The changes in the system as the magnitude and frequency of the load applied load changes because response parameters influence the nature and thus the rate of deterioration for the pavement. The normal strain in the longitudinal direction, ε_x at the bottom of the AC layer is the critical input in the evaluation of fatigue life of AC pavements. Current analytical (or semi-analytical) pavement design procedures relate fatigue damage and rutting to the horizontal tensile strain at the bottom of a bound layers and the vertical compressive strain at the top of the subgrade layer respectively which are typically calculated using a layered elastic model. The linear elastic system is usually assumed, allowing for the superposition of multiple wheels. Alternatively, in this study, Odemark's Method of Equivalent Thicknesses (MET) used to transform a layered system into a half-space and Bousinesq's equations used calculate stresses, strains and displacements [13].

In this tasks, the pavement structure modeled are characterized by Young's modulus of elasticity and Poisson's ratio, consisting of three layers; 0.2m of asphalt surface layer, 0.2m of granular base layer and semi-infinite of soil layer. Poisson's ratio was taken to be 0.35 for the asphaltic layer and 0.4 for the unbound layers. Bituminous material is characterized by viscoelastic behavior The loads acting vertically on the surface are assumed to be uniformly distributed over one circular area. The radius of the contact area is 0.15m and bitumen Penetration and its percentage are 40 and 8% respectively.

As a results, Fig. 6 shows the radial strain at base of asphaltic layer and vertical strain on top of the subgrade soil as a function of distance for pavement with the layer properties anad loading conditions as shown above. The strain distribution is dependent on the degree of dynamic excitation in response of the road roughness. It shows that the tensile strain at the bottom of the asphalt layer is smaller than compressive strain at the top of the subgrade with the mean value 144 μstrain and 391 μstrain respectively. Hence it might be conclude that fatigue damage is less critical than permanent deformation.

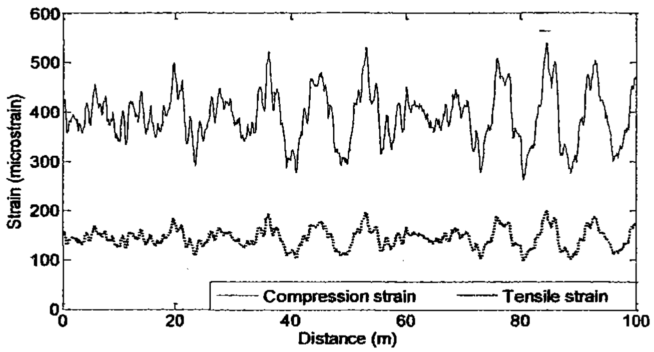
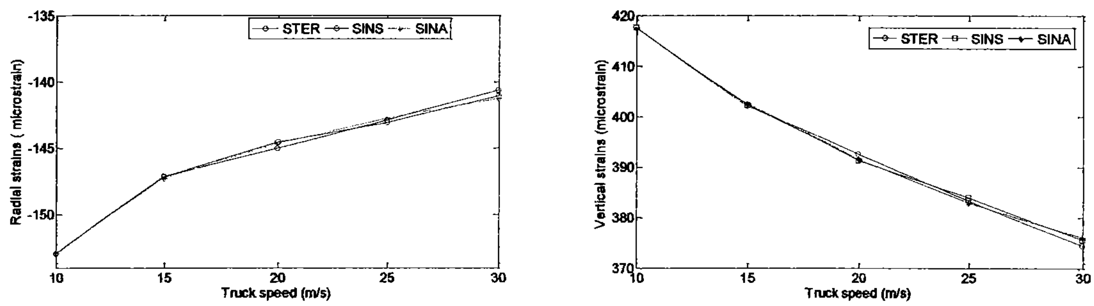


Figure 6: Critical strain in the pavement

Fig. 7 shows the effect of changes in truck speed (loading time) on critical strain in the asphaltic layer for different truck suspensions. Generally, at low speed vehicle vibration is slight, but high speed motions lead to significant vehicle vibrations that not only reduce the ride quality of passenger, but also generate additional inertia forces. It is clearly shown the critical strains are sensitive on the truck speed with the mean vertical and radial strains decrease around 10% with increasing truck speed from 10 m/s to 30m/s. This result agreed with some concluded in previous section that strain decrease with increasing speeds due to shorter loading time.



(a) (b)

Figure 7: Mean strain of axle with fully laden for varies speeds; (a) Tensile; (b) Compression

Summary and Conclusion

It can be concluded from the above result that:

- Apart of truck loads, truck speed is one of the most important variable that interact with truck suspension system and pavement roughness.

- The effect of loading time are extremely important when calculating the critical strains that is the strain in the-longitudinal direction, ε_x at the bottom of the AC layer and the vertical compressive strain at the top of the subgrade layer respectively which are typically calculated using a layered elastic model. In accordance, Odemark's Method of Equivalent Thicknesses (MET) used to transform a layered system into a half-space and Bousinesq's equations are used.
- The magnitude of the dynamic loads exerted at certain nodes on pavements by heavy goods vehicles may vary up to an extreme of 150% than the mean average. It was experience by applying the trucks with 1/3 laden.
- Axle with steel suspension exerted higher forces than axle with air suspension. It is inline with the previous findings that soft suspension springs of low vertical stiffness are desirable for minimising dynamic loads.
- The base strains indicating tension and directly proportional to the applied load, that is increasing the applied load at each point will instantaneously result increases of tension strain and vice versa.

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