Research on Heavy Truck Dynamic Load Coefficient and Influence Factors

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Abstract. In order to research the vehicle dynamic load coefficient(DLC) and influence factors, high class and low class pavement roughness is tested in fields, 2 degree of freedom vehicle model is built, DLC computing formula is given. Heavy truck is taken as an example, the relationship among DLC and traffic speed, vibrating frequency, loading mass are analyzed. The results show that resonation frequency of heavy truck is about 1HZ and 12HZ, the DLC increases with the increase of traffic speed while decreases with the increase of the loading. The relationship between DLC and travel speed(V) can be described as DLC=0.0047V0.5 for high class road and DLC=0.0102V0.5 for low class road

1 Introduction

Vehicle load is a kind of dynamic load which varies in size and frequency. When the pavement is applied with dynamic load, its response is different from static load. Some failure types are caused by dynamic load, such as fatigue cracking, rutting, etc. It is necessary to study the characters of dynamic load which is related with vehicle structure, loading and traffic speed.

In China the dynamic load mainly focus on theory of size, frequency. Huang[1](1993),Sun and Deng[2] from Southeast of China carried out the research of relationship between pavement roughness and dynamic load. From then on more scholars started to carry out the research of dynamic load characters, Zhang(2005), Song(2007), Yao(2008) and Zheng(2009) [3-6] have built multi degree of freedom vehicle model to research vehicle-pavement interaction force. In others countries the research started earlier, Dodds and Roson take pavement roughness as a function of vehicle departing off flat pavement and power spectral density (PSD) is employed to calculate dynamic load [7]. Todd（1987）[8]analyzed dynamic load by quarter truck model and half truck model. Hunt(1991)[9]gave calculating model of pavement vibrating PSD. With the development of research, Watts（1992）[10] started to calculate the vehicle vibrating characters when vehicle travel across pavement distress, such as pavement depression, rutting, pot holes. By means of a three-dimensional truck model, Javier(2013) [11] found that the vertical dynamic load applied by a tyre to the pavement depends not only on the profile under that wheel but also on the profile under the other wheels, mainly under the one on the same axle.Dae-Wook [12] formulated a continuous or distributed model using a two-dimensional (2D) half-truck finite element model. Using the 2D half-truck finite element model, numerical simulations were performed to obtain the dynamic loads using various parameters such as the road roughness, vehicle speed, suspension stiffness and damping in order to evaluate their individual effects on the dynamic axle load response.All these researches have supplied basic theories for dynamic load characters

In this research high class and low class pavement roughness is tested in field, relationship of pavement roughness indexes among variance(σ), international roughness index(IRI) and PSD is analyzed. Heavy truck is taken as example, DLC is calculated and influence factors are analyzed.

2 Pavement roughness and testing results in field

2.1 PSD of pavement roughness

According to the standard (GB/T 7031-2005)[13], PSD of pavement roughness can be described with formula(1) listed below:

$$G_x(n) = G_x(n_0)[\frac{n}{n_0}]^{-w} \tag{1}$$

where: n is space frequency, it is used to denote wave numbers within 1 meter equaling to reciprocal of wave length; n0 is referenced space frequency and equals to 0.1m-1； Gx(n0) is PSD of pavement roughness in condition that n0 is o.1m, which is determined by pavement class listed in Table 1. w is frequency exponent, which determines structure of PSD and equals to 2.

Table 1. PSD of pavement roughness Gx(n0)

Pavement class	$G_x(n_0)\times 10^{-6} m^2/m^{-1}, n_0 = 0.1m^{-1}$	
	Lower limit	Average	Upper limit
A	8	16	32
B	32	64	128
C	128	256	512
D	512	1024	2048

2.2 PSD formula expressed in time frequency

When the vehicle travels across the pavement with space frequency of n（m^{-1}） with the speed of v（m/s）,time frequency f（s-1）equals to v*n, then PSD formula expressed in time frequency:

$$G_x(f) = \frac{1}{v} G_x(n_0)(\frac{n}{n_0})^{-2} = G_x(n_0) {n_0}^2 \frac{v}{f^2} \quad (2)$$

2.3 Testing result for pavement roughness in field

2.3.1 Pavement roughness testing in field

Changxiao road is chosen as a low class testing road and Jinan belt expressway is chosen as a high class testing road. Changxiao road is a newly built low class road, asphalt pavement, single carriage with two lanes. Jinan belt expressway is a high class road, asphalt pavement, dual carriage with two lanes in each direction. Pavement roughness testing on Changxiao road is shown in figure 1.The testing results: variance of Chang-xiao road is 1.8, International Roughness Index (IRI) of Jinan belt expressway is 1.40m/km.

2.3.2 Relationship among international roughness indexes

Some scholars have studied the relationship among international roughness indexes of IRI, σ and PSD, the conclusions are almost the same. In this article we assume[14,15]:

$$IRI = 0.6\sqrt{S_q(n_0)}$$

$$\sigma = 0.6 IRI$$

According to the two formulas and testing results in fields, $G_x(n_0)$ of high class road equals to 5.4, low class road $G_x(n_0)$ equals to 25.

3 Two degrees of freedom vehicle vibration model and DLC

3.1 Two degrees of freedom vehicle vibration model

Two degrees of freedom vehicle vibration model is employed here, it also named quarter vibration model shown in Fig. 2.

Figure 1. Pavement roughness testing in field

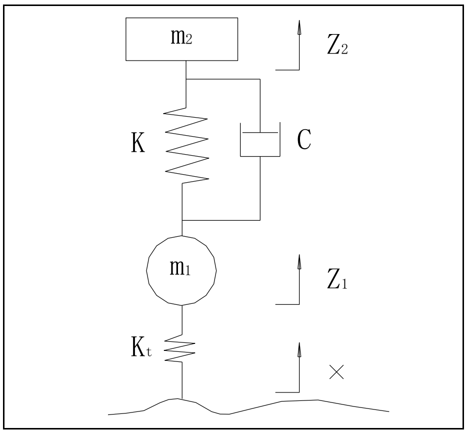

Figure 2. Quarter vehicle model

where: m1 is tire mass, m2 is mass on spring, K is suspension rigidity, Kt is tire rigidity, C is suspension damping, Z_2 is vertical displacement of m_2, Z1 is vertical displacement of m1, x is pavement roughness distance. According to Newton's laws of motion，formula(3) and (4) are obtained:

$$\mu_2 \ddot{Z}_2 + X(\dot{Z}_2 - \dot{Z}_1) + K(Z_2 - Z_1) = 0 \quad (3)$$

$$\mu_1 \ddot{Z}_1 + X(\dot{Z}_1 - \dot{Z}_2) + K(Z_1 - Z_2) + K_\tau(Z_1 - \xi) = 0 \quad (4)$$

3.2 Amplitude-frequency solutions for dynamic load

According to stochastic process theory, for a linear time invariant system, if the input is stationary process, the output process is also stationary. When this system is applied to a stimulation $x_0 e^{i\omega t}$ with amplitude x0 and frequency ω, after a transient lag, the output is produced which has the same form with the simulation. The output can be expressed as:

$$Z_1 = Z_{10} e^{i(\omega t + \phi)}$$

$$Z_2 = Z_{20} e^{i(\omega t + \phi)}$$

Z_{10} and Z_{20} are output amplitude.

Then:

$$\dot{Z}_1 = i\omega Z_1,\ \ddot{Z}_1 = -\omega^2 Z_1$$

$$\dot{Z}_2 = i\omega Z_2,\ \ddot{Z}_2 = -\omega^2 Z_2$$

Formula(3) and(4) can be transformed into (5) and (6):

$$Z_2(-\omega^2 m_2 + i\omega C + K) = Z_1(i\omega C + K) \quad (5)$$

$$Z_1(\omega^2 m_1 + i\omega C + K + K_t) = Z_2(i\omega C + K) + xK_t \quad (6)$$

From formula (5), we can get:

$$Z_2 = \frac{i\omega C + K}{-\omega^2 m_2 + K + i\omega C} Z_1 \quad (7)$$

Take formula (7) into formula(6), frequency -response function of Z_1-x can be obtained:

$$H(\omega) = \frac{Z_1}{x} = \frac{A_2 k_t}{A_3 A_2 - A_1^2} \quad (8)$$

where: $A_1 = i\omega C + K$,

$$A_2 = -\omega^2 m_2 + K + i\omega C,$$

$$A_3 = -\omega^2 m_1 + K + K_t + i\omega C$$

3.3 Dynamic load coefficient computing

Vehicle static load $G = (m_1 + m_2)g$, dynamic load $F_d = K_t(Z_1 - x)$, dynamic load coefficient: DLC=Fd/G. The frequency-response function of DLC is:

$$H(\omega)_{F_d - x} = \frac{F_d}{Gx} = \frac{K_t(Z_1 - x)}{Gx} = \left(\frac{A_2 k_t}{A_3 A_2 - A_1^2} - 1\right)\frac{K_t}{(m_1 + m_2)g} \quad (9)$$

PSD of dynamic load coefficient can be obtained [16]:

$$G_{F_d/G}(f) = \left|H(\omega)_{Fd-x}\right|^2 G_x(f) \quad (10)$$

As the probability of negative and positive dynamic load occurs, average dynamic load becomes zero, average DLC is also zero, so variance of DLC is the same with mean square value.

$$\sigma_{Fd/G}^2 = \int_0^\infty G_{F_d/G}(f)df = \int_0^\infty \left|H(\omega)_{F_d-x}\right|^2 G_x(f)df = \mu^2_{F_d/G} \quad (11)$$

Take formula (9) into (11), we can get:

$$\mu^2_{F_d/G} = \int_0^\infty \left|H(\omega)_{F_d-x}\right|^2 G_x(f)df = \int_0^\infty \left|\left(\frac{A_2 k_t}{A_3 A_2 - A_1^2} - 1\right)\frac{K_t}{(m_1 + m_2)g}\right|^2 G_x(n_0)n_0^2 \frac{v}{f^2} df \quad (12)$$

By formula (12), a program is developed in MATLAB which is used to compute DLC.

4 Example of heavy truck

The parameters of a heavy truck: tire mass m1 is 1000kg, mass on spring m2 is 9200kg, suspension stiffness K is 500000N/m, tire stiffness kt is 5000000N/m, suspension damping c2 is 15000Ns/m.

4.1 Relationship between PSD of DLC and vibration frequency

After computing by the program, the relationship between PSD of DLC and vibration frequency for the high class road is shown in Fig. 3 and Fig. 4. For the low class road it is shown is Fig. 5 and Fig. 6.

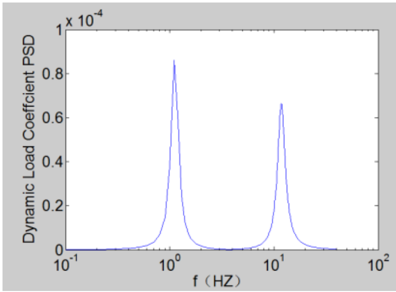

Figure 3. Relationship between PSD of DLC and vibration frequency（V=120km/h）

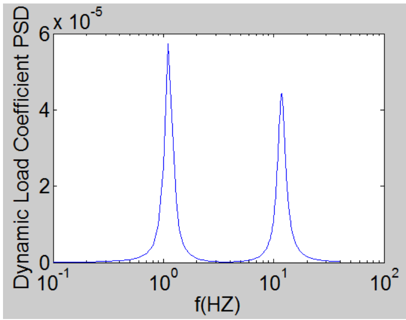

Figure 4. Relationship between PSD of DLC and vibration frequency (V=80km/h)

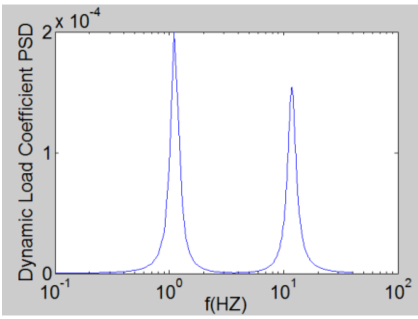

Figure 5. Relationship between PSD of DLC and vibration frequency（V=60km/h）

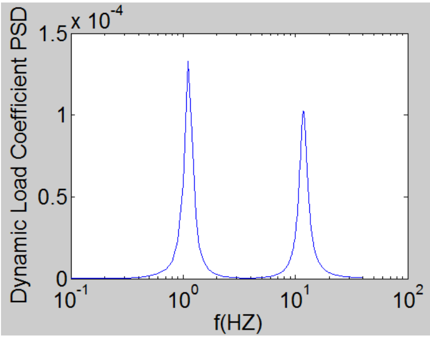

Figure 6. Relationship between PSD of DLC and vibration frequency（V=40km/h）

From the four figures, we can see that both in high class road and low class road vehicle tire will resonate at the frequency of 1HZ and 12HZ.

4.2 Relationship between DLC and travel speed

Dynamic coefficients are computed when the truck travels in different speeds and they are listed in Table 2.

Table 2. DLC in different travel speed

High class road		Low class road	
Speed(km/h)	DLC	Speed km/h	DLC
120	0.0522	80	0.0916
100	0.0467	60	0.0795
80	0.0426	40	0.0648
60	0.0369	20	0.0458

From the results in table 2, we can know that: (1)DLC is much lower on high class road than low class road; (2)DLC increases with the increase of travel speed, by regression analysis the relationship between DLC and travel speed(V) can be described as $DLC=0.0047V^{0.5}$ for high class road and $DLC=0.0102V^{0.5}$ for low class road .

4.3 Relationship between DLC and loading mass

As m2 is related with loading mass directly, it is taken as 12000kg, 8000kg and 4000kg individually, travel speed is 100km/h for high class road and 60km/h for low class road, and then DLC is calculated. The results are shown in table 3.

Table 3. Dynamic load and coefficients for different loading mass

Road class		Speed km/h	m2 /（kg）		
			12000	8000	4000
High class road	DLC	100	0.0372	0.0526	0.0921
	Dynamic load(N)	100	4464	4208	3684
Low class road	DLC	60	0.0801	0.1131	0.1981
	Dynamic load(N)	60	9612	9048	7924

From Table 3 we can know that DLC increases with the decrease of loading mass. But computing results also manifests that dynamic load decreases a little because the loading mass decreases.

5 Conclusions

PSD of pavement roughness is given according to testing results in high class and low class road, DLC computing program is developed. By analyzing DLC of heavy truck, conclusions are included:

(1) Resonation frequency of heavy truck is 1HZ and 12HZ;

(2) The relationship between DLC and travel speed (V) can be described as $DLC=0.0047V^{0.5}$ for high class road and $DLC=0.0102V^{0.5}$ for low class road .

(3)DLC decreases while dynamic load increases slightly with the increase of the loading.

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