Impacting Factor Caused by Highway Bridge Deck Roughness

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Summary

In order to analyse the interaction of highway bridge and vehicle, an analysis method of couple vibration between 1/2-four degree vehicle model and highway bridge is presented. According to the road power spectral density(PSD) function advised by GB/T 7031-1986(China Standard), the coefficients of different bridge deck roughness are obtained, which are taken as the inputting excitation of 1/2 vertical model for vehicle dynamics. The dynamic response of maximum moment and vertical displacement for the simply-supported beam and the continuous beam under different bridge deck roughness is analyzed by numerical simulation, and the variety rule of impacting factor is obtained. The result shows that the impacting factor increases non-linearly along with the grade of bridge deck roughness. The grade of bridge deck roughness is the most remarkable factor for the vehicle-bridge dynamic interaction.

Key Words: bridge engineering; bridge deck roughness; couple vibrations of vehicle-bridge; impacting factor; dynamic response

1. Introduction

In China, bridge deck condition is generally not very good, and the travelling condition is not optimistic. In the middle of 20th century, many countries carried out the research about the road surface power spectral density(PSD) to estimate the travelling quality and the automobile dynamic response. Some people argued that the bridge deck roughness was the steady Gauss stochastic process with zero mean, therefore, the vehicles-bridge coupling vibration under the effect of deck roughness was essentially a random vibration. The PSD function that advised by GB/T7031-1986 is cited in the paper, the value of bridge deck roughness is obtained, and roughness sequence is modelled as wheel displacement, which is put into the vehicle system, thus the vehicles' response is analyzed. According to the grade of road roughness in GB/T7031-1986, the influence of vehicle-bridge interaction due to bridge roughness is investigated; moreover, the impacting factor curve is presented under the condition of different bridge roughness grades.

2. Vehicle vibration model

Simplify the 1/2-four degrees vehicle model as double spring-damping-mass system, which is shown in Fig.1.

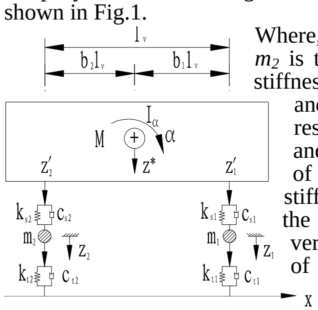

Fig.1:1/2 Vehicle Vibration Model

Where, M is the vehicle mass ;m_1 is the mass of front suspension and tire; m_2 is the mass of back suspension and tire ; k_{s1} and C_{s1} is the spring stiffness of front suspension and its damping coefficient ,respectively; k_{t1} and C_{t1} is the stiffness of front wheel tire and its damping coefficient, respectively; k_{s2} and C_{s2} is the spring stiffness of back suspension and its damping coefficient, respectively; k_{t2} and C_{t2} is the stiffness of back wheel tire and its damping coefficient, respectively; I_α is the stiffness of vehicle front body; b_1, b_2 is the proportional constant; lv is the distance from the front axle to the back axle of vehicle; $z*$ is the vertical displacement of centre of mass; α is the transverse rotation of centre of mass; z_1' is the vertical displacement of front suspension**,** z_2' is the vertical displacement back suspension; z_1 is the vertical displacement

https://doi.org/10.2749/222137908796293686

of front tire, z_2 is the vertical displacement of back tire; $y=\xi+w$, ξ is the bridge deck roughness value, w is the bridge corresponding dynamic deflection in the place of tire.
The vehicle system vibration differential equation is given by:

$$\begin{cases} m_1\ddot{z}_1+(c_{s1}+c_{t1})\dot{z}_1-c_{s1}\dot{z}_1'+(k_{s1}+k_{t1})z_1-k_{s1}z_1'=m_1g+k_{t1}y_1+c_{t1}\dot{y}_1 \\ m_2\ddot{z}_2+(c_{s2}+c_{t2})\dot{z}_2-c_{s2}\dot{z}_2'+(k_{s2}+k_{t2})z_2-k_{s2}z_2'=m_2g+k_{t2}y_2+c_{t2}\dot{y}_2 \\ (Mb_2^2+I_\alpha/l_v^{\ 2})\ddot{z}_1'+(Mb_1b_2-I_\alpha/l_v^{\ 2})\ddot{z}_2'-c_{s1}\dot{z}_1+c_{s1}\dot{z}_1'-k_{s1}z_1+k_{s1}z_1'=Mgb_2 \\ (Mb_1b_2-I_\alpha/l_v^{\ 2})\ddot{z}_1'+(Mb_1^2+I_\alpha/l_v^{\ 2})\ddot{z}_2'-c_{s2}\dot{z}_2+c_{s2}\dot{z}_2'-k_{s2}z_2+k_{s2}z_2'=Mgb_1 \end{cases} \quad (1)$$

Where $y_1=y(x_1)$、$y_2=y(x_2)$ is the deck roughness value in the place of front and back axle, respectively, $\dot{z}_i$、$\dot{z}_i'$、$\dot{y}_i(i=1,2)$ is the corresponding speed, $\ddot{z}_i$、$\ddot{z}_i'$、$\ddot{y}_i(i=1,2)$ is the corresponding acceleration, $\ddot{\alpha}$ is the angular acceleration, δ is the variation of virtual displacement.
Put the deck roughness sequence in the form of $\xi(x)$ into Eq. (1), and solve Eq. (1) using *Wilson* - θ method. Then, the vibration response of vehicle under the condition of different bridge deck grades and different vehicle speeds can be obtained.
The interaction force between vehicle and bridge can be expressed as follows:

$$p_i(t)=k_{i1}(z_{i1}-y_i)+c_{i1}(\dot{z}_{i1}-\dot{y}_i) \qquad (i=1,2) \qquad (2)$$

The bridge dynamic response can be solved by finite element method.

3. Dynamic response analysis of simply-supported beam and continuous beam

The parameters of simply-supported beam are listed as follows: its span L=32m, its unit length mass m=5.41×10^3$kg.m^{-1}$,its flexural rigidity EI = 3.5×10^{10}$N.m^2$.According to *JTG D60-2004*(General Code for Design of Highway Bridge and Culverts),the impacting factor of the beam is 1.2245.
The parameters of vehicle are listed as follows: M = 38500kg ; I_α = 2.446 x10^6$kg\ .\ m^2$; l_v = 8.4m ; $b_1=b_2$ = 0.5 ; $m_1=m_2$ = 4330kg ; $k_{s1}=k_{s2}$ = 2.535x10^6$N.m^{-1}$; $k_{t1}=k_{t2}$ = 4.28 x10^6$N.m^{-1}$; $c_{s1}=c_{s2}$ = 1.96 x10^5$kg.s^{-1}$; $c_{t1}=c_{t2}$ = 9.8 x10^4$kg.s^{-1}$.
The study shows that the impacting factor increases when the bridge deck become rougher. The impacting factor increases from 1.05 (the smooth bridge) to 2.28 (grade D bridge), it has increased 117.1％.
The parameters of continuous beam are listed as follows: L=3×25m, EI=3.2×10^{10}$N.m^2$, m = 9.375×10^3$kg.m^{-1}$.According to the code，the impacting factor is 1.2209.
The study shows that when the vehicle passes near the mid-span of first span, the maximum impacting factor of mid-span of second span happens. But the maximum impacting factor of mid-span of first span happens when the vehicle passes near the mid-span of second span. The impacting factor in mid-span of second span increases from 1.06 (smooth bridge) to 2.03 (grade D bridge), it increases 91.5%. The impacting factor in mid-span of first span increases from 1.08(smooth bridge) to 2.16 (grade D bridge), and it increases 100%. So, the condition of bridge deck is a very important factor affecting the vibration response of bridge.

4. Conclusion

According to the PSD function, the corresponding bridge roughness sequence is established. Using 1/2-four degree vehicle vibration model, the bridge response can be obtained with different bridge roughness. The conclusion can be drawn as follows:

(1) The deck roughness of bridge is a very important factor for vehicle-bridge interaction. As the bridge deck becomes worse, the vibration of bridge caused by vehicle increase rapidly. And it is more obvious for the simply-supported beam than that of continuous beam.
(2) The remarkable factor which affects bridge impacting factor is bridge deck grade. In the same vehicle speed, the value of impacting factor increases non-linearly when the grade of bridge deck roughness becomes worse.
(3) Generally speaking, the highway road spectrum is grade A,B and C in China, and the majority belong to the grade B and C. The impacting factor of grade B for simply-supported beam and grade C for continuous beam is greater than those obtained by the code. So, it is very important to pay more attention to the highway maintenance.