Coupling Vibration Research on Vehicle-Bridge System

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Abstract. Take vehicle running through a long-span cable-stayed bridge as an example to study the vibration rule of vehicle and bridge in the process of vehicles running on the large span bridge. Vehicle-bridge coupling numerical analysis model is established to study the changing rule of vertical displacement of the vehicle, vehicle wheel vertical contact force, the vertical displacement of the bridge and the impact coefficients of bridge while different quality of vehicles running on the bridge. The results show that, the heavier the vehicle, the greater and the more obvious wave of the vertical displacement change of bridge main-span across. The heavier the vehicles, the more obvious the change of the vertical displacement and torsion angle of cable-stayed bridge main-span across.

1. Introduction
The coupling vibration of vehicle-bridge system while vehicle running on the bridge will generate a relative influence on the driving safety, running comfort, and the safety of bridge structure itself. Especially for the large coupling vibration of vehicle-bridge system, it will cause the serious consequences while vehicle running. Most of the earliest analyses are on the basis of the differential equation of the whole system for the vehicle-bridge coupling vibration, and then apply the analytic method to solve.

The high-speed vehicle will generate certain impact on structure, which will affect the structure working status and service life. Meanwhile, the vibration generated in the process of vehicle running will affect the comfort and security of the vehicle. With the more and more large span bridge being constructed, the structure inclines to more and more soft with the characteristics of stiffness and lower damping. So, it is more sensitive of the influence between the large span bridge and vehicle. This paper mainly researches the vehicle-bridge system coupling vibration respectively considering the driving speed, vehicle quality.

2. Analysis model
The vehicle is being under the action of irregular track and external load in the process of running. The interaction of force and displacement will generate between the components of vehicle model system. So, the reasonable vehicle model established can properly reflect the vibration characteristics of vehicle system. The model in this paper simplify the dynamic vehicle model as the car body, vehicle frame, vehicle wheel. The components of vehicle are all be counted as rigid bode and connect with elastic and damping elements between components. Meanwhile, adopting damping system arrange between vehicle wheel, car body, and road surface.

Where, the numerical vehicle model is simplified as rigid car body, elastic and damping synthesis device, and four rigid wheels. This paper adopts biaxial seven degree of freedom model for numerical
vehicle model. Based on a large-span cable stayed bridge, this paper considers the structure geometric nonlinearity as following for the finite element numerical simulation of the bridge structure. The cable appears sag effect because of curve form as the results of the influence of gravity of cable and pretension of cable. The main tower and main girder anchorage cable are considered by equivalent modulus of elasticity.

3. Analysis method
The vehicle-bridge coupling system are studied with numerical simulations. This paper does not consider the influence of the deck roughness on vehicle-bridge system coupling vibration. Where the entity cell was used to imitate the main girder of cable stayed bridge, cable cell was used to imitate the cable, COMBIN14 cell was used to imitate the spring and damping of vehicle, the contact element CONTA174 and target element TRAGE170 were used to imitate the contact between the vehicle wheel and bridge deck. The established analysis finite element numerical model diagram is shown in Figure 1.

4. Results and discussion
To study the effect of the vehicle quality on the vehicle-bridge vibration response, respectively taking a car lateral located in the second lane, two car lateral respective located in the first and second lane position at the same time, set up the vehicle speed 100 km/h and the quality of the vehicle respectively 12t and 24t to study the vertical displacement variation rule of vehicle and bridge.

4.1 Dynamic response of vehicle
Car body vertical displacement and vertical wheel contact force are as shown in figure 2. Where, the side of the L tire vertical contact force on behalf of the average car body front and rear wheel contact force near the bridge centerline, the side of the R tire vertical contact force on behalf of the average car body front and rear wheel contact force near the bridge side. Car body vertical displacement on behalf of vertical displacement of Car body shape heart.

Car body vertical deformation increases with the quality of car body, and its volatility range increases with the quality of car body. One 24t vehicles produced vertical deformation is big than two 12t vehicles producing vertical deformation. This is because the vertical deformation of the 24t vehicle
weight itself is larger than the vertical deformation of 12t vehicle weight itself. At the same time, as it can be seen, vertical displacement of two 12t car bodies is larger than that of one 12t car body because although the body's own weight is same but the former generates the vertical deformation of the bridge is larger than the latter.

![Figure 3. Contact force of left side tire](image_url)

![Figure 4. Contact force of right side tire](image_url)

The greater the quality of the vehicle, the larger are the vertical contact force of the vehicle tires. The change rule of the wheel contact forces is basically identical for four kinds of working conditions in the process of vehicle running. Vehicle vibration of vehicle-bridge coupling system cause small-scope fluctuation of vehicle vertical contact force in the process of vehicle running. The tire vertical contact force is basically the same between the one 12t vehicle and two 12t vehicles. The tire vertical contact force is basically the same between the one 24t vehicle and two 24t vehicles. At the same time, tire vertical contact force of lateral tire is slightly bigger than tire vertical contact force of inside tire.

### 4.2 Dynamic response of bridge and impact factor

The temporal change of the vertical displacement of side-span, second side-span and 1/4 of main-span for cable-stayed bridge and the torsion angle of the main-span of the bridge are shown in figure below.

![Figure 5. Displacement in the middle of side-span](image_url)
Figure 6. Displacement in the middle of second side-span

It can be seen that, the heavier the vehicle quality is in the process of vehicles running on the bridge, the greater and more obvious fluctuations of the vertical displacement in the side span across and second side span cross are. From the figure, it shows that the vertical deformation produced by one 24t vehicle is the same with that vertical deformation produced by two 12t vehicles, which is also accord with the actual.

Figure 7. Displacement in the 1/4 of main-span

Figure 8. Displacement in the middle of entire bridge
Figure 9. Torsion angle in the middle of entire bridge

It can be seen that the difference is more obvious between the vertical displacement of $1/4$ span and main-span of entire bridge as the greater weight of vehicle in the process of vehicle running on bridge. The vertical displacement of bridge produced by one 24t vehicle and two 12t vehicles are basically the same. The value of torsion angle changes greater and fluctuate more obviously as the heavier of vehicle weight. But the torsion angle value is not the same between one 24t vehicle and two 12t vehicles. The former torsion angle is relatively large, which conform to reality because the 24t vehicle is locate in the second lane, and two 12t vehicles respectively locate on the first and second lanes.

While one car body quality respectively is 12t and 24t, two car body quality respectively is 12t and 24t, the vehicle running through bridge at speed of 100 km/h, the impact coefficients of each cross-section of the cable-stayed bridge is shown in table.

Table 1. Main-span impact coefficients under different vehicle weight

| Condition       | One Vehicle (12T) | One Vehicle (24T) | Two Vehicles (12T) | Two Vehicles (24T) |
|-----------------|-------------------|-------------------|-------------------|-------------------|
| 1/8 main-span   | 1.110             | 1.120             | 1.120             | 1.145             |
| 2/8 main-span   | 1.082             | 1.107             | 1.107             | 1.085             |
| 3/8 main-span   | 1.020             | 1.021             | 1.021             | 1.040             |
| 4/8 main-span   | 1.020             | 1.040             | 1.040             | 1.050             |
| 5/8 main-span   | 1.041             | 1.043             | 1.043             | 1.041             |
| 6/8 main-span   | 1.120             | 1.100             | 1.100             | 1.061             |
| 7/8 main-span   | 1.133             | 1.173             | 1.173             | 1.177             |

From the table it can see that, the impact coefficients of main-span cross of entire bridge is relative maximum when 24t vehicle driving through the bridge for the different quality vehicle driving through the bridge. It can be seen by the data in the table, the impact coefficients are basically same when one 24t weight vehicle and two 12t weight vehicles driving on the bridge and the impact coefficients of the bridge cross section near tower is relatively large.

5. Conclusion
The heavier the vehicle weight are, the more obvious the change of vertical displacement and torsion angle for the cable-stayed bridge main-span cross section is. The vertical displacement of bridge produced is basically same for one 24t weight vehicle and two 12t weight vehicles. But, the torsion angle produced by one 24t weight vehicle is larger than the torsion angle produced by two 12t weight vehicles.

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