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Modeling and Vibration Analysis of Tire-curved Bridge Coupling System

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Abstract

In recent years, with the rapid development of transportation in our country, the study of curved bridges has become more advanced. The static analysis of curved bridges has been almost perfected, but research on the dynamic effects is still immature. In this paper, a five-span continuous curved box girder bridge is used as the subject. The ABAQUS finite element software is utilized to construct the bridge model, while the three-dimensional representation of the tire is created using SolidWorks software. The effects of vehicle speeds, loads, and eccentricity on the dynamic response of a curved bridge deck are studied using a tire model. The research shows that the maximum dynamic deflection in a bridge span increases gradually with the increase of vehicle speeds, but it does not increase in a linear manner. Additionally, the dynamic deflection of the bridge in the mid-span is greater with larger vehicle loads. Furthermore, the dynamic deflection, cross-section moment, and strain response of each span increase as the vehicle eccentricity increases.

Keywords

Tire model, finite element method, vehicle-bridge coupling, response regularity

Introduction

The dynamic response of bridge structures is an important topic in the study of bridges. With the rapid development of traffic, further research on the interaction between vehicles and bridges has increasingly captured people's attention. In the past, highway bridges were often designed with a focus on static analysis, while dynamic research was not given much attention. The static analysis of curved bridges has been significantly improved, with more emphasis now placed on the initial coupling effect between vehicles and bridges [1].

Based on a 5-span continuous curved box girder bridge as the background, a three-dimensional CAD model of a tire was created using SolidWorks software. The CAD model was then imported into ABAQUS to establish a finite element model of the tire. Material properties were defined using the Yeoh constitutive model, which is suitable for accurately representing the super elastic properties of rubber. Additionally, a simulation of the rubber-cord composite material was conducted to enhance the accuracy of the tire's structural parameters and mechanical characteristics [2]. The simulation of the finite element model on the curved bridge will assess the impact of various factors, such as vehicle speed, vehicle load, and vehicle eccentric driving conditions, on the dynamic response of the bridge.

1. The basic architecture of the tire

The geometry of the tire structure is complex, mainly composed of the tread, sidewall, cord fabric layer, belt of the beam, and bead [3]. This article uses the Dongfeng (DFL1250A9) heavy-duty truck tire model. Tyres are a very important part of a vehicle, and their main functions include: supporting the entire vehicle, buffering road unevenness caused by vibrations, and transferring longitudinal force to enable vehicle acceleration and braking. Transfer lateral force to provide vehicle steering. With the PAC2002 tire model of 10.00 R2.

2. Tire finite element model

Due to the complex structure and material properties of the tire, the tire model is divided into different areas in order to improve the meshing quality and precision of the finite element calculation. These areas are then further divided based on different levels of precision. With the assistance of SolidWorks software, the three-dimensional graph of the tire is drawn based on its geometric features. This is primarily done to prevent excessive deformation in the finite element mesh unit and to create smooth grooves and chamfers on the tire, thereby improving the mesh quality.

During the analysis process, the geometric structure of the tire, loading conditions, and the approximate incompressibility of rubber materials are taken into consideration. The convergence factors are calculated, such as the tire's approximate global dimensions of 0.05 m and a total of 1,728 units. The entire tire model is divided into boxes, with the unit type being C3D8R linear (Linear 8 node hexahedron reduced integral unit).

In this paper, the tire model makes the following basic assumptions:

(1) Tire rolling process, the rim as a rigid body, regardless of the deformation in the process of car body in vibration;

(2) The quality of the car body concentrated in the center of the axle reference point;

(3) Tires driving process, keep the wheel contact with the deck;

(4) Vehicle parts in their respective do tiny vibrations near the equilibrium position.

3. The curve bridge finite element model

ABAQUS is used to create the model for a curved box girder bridge. The bridge span is 125.6 m, with an average span of 25.1 m (5 across). The radius of curvature is 160 m, which imposes constraints on the radial displacement and vertical displacement of the girders. The width of the box girder roof is 8.35 m with an average thickness of 0.2 m. The slab width has a thickness of 5.55 m and 0.25 m. The flange plate has a cantilever length of 1.4 m.

The unit type adopted is the linear C3D8R, which is an 8-node hexahedron reduced integral unit. This unit type requires less calculation time and provides accurate displacement results. It also has good applicability for distortions. The bridge consists of a total of 50,000 units and 80,661 nodes.

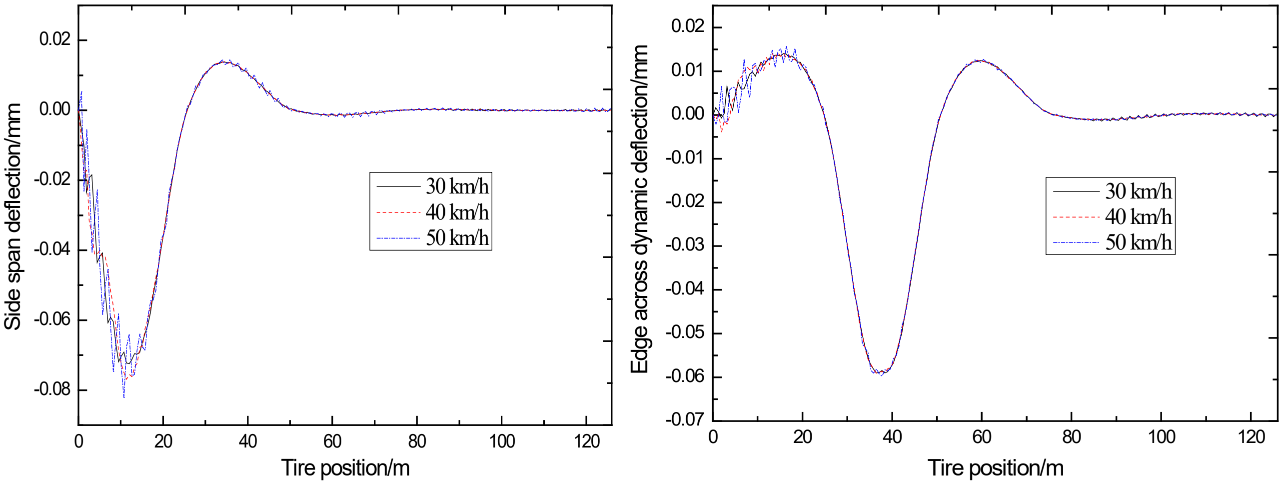
4. Car-curve box girder bridge coupled vibration influence parameter analysis

Vehicle and bridge structure interaction involves the roughness of the bridge deck, vibrations in the vehicle system, and the coupling relationship between the vehicle and the bridge [4]. The dynamic response curve of the bridge is influenced by factors such as vehicle speed, vehicle load, vehicle location, and many others. The analysis aims to determine the impact of these parameters on the vibration curve of the bridge.

4.1 The influence of vehicle speed on bridge vibration

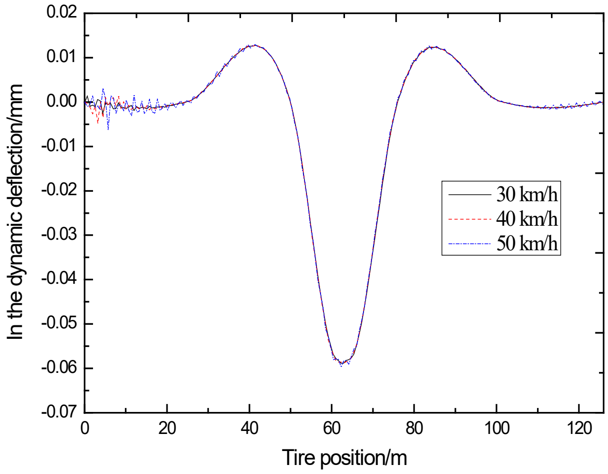
In this paper, we aim to investigate the impact of car speed on the dynamic response of curved bridges. To isolate this factor, we conducted simulations while keeping all other variables constant, except for the car speed.

Tire load position refers to the placement of the tires along the deck centerline. With all other parameters held constant, the load on a single tire is 2.5 t. Solving the dynamic response curve at the bottom of the box girder bridge for spans across at speeds of 30 km/h, 40 km/h, and 50 km/h [5]. Figure 1 shows the extraction of the curve bridge across the side span and middle span, based on the dynamic deflection curve.



(a) Deflection Response of Bridge Side Span

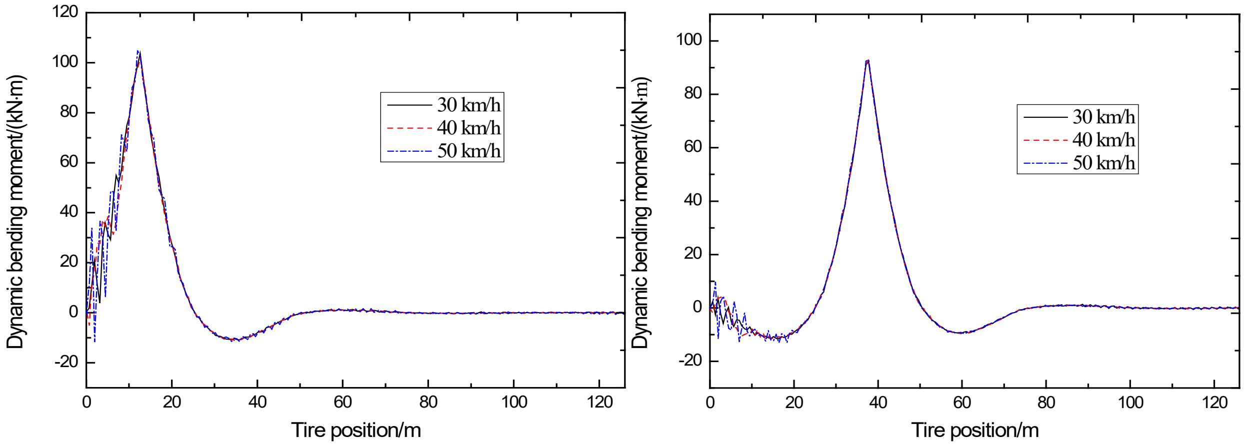
(b) Deflection response of bridge secondary Span



(c) Deflection response of mid-span Bridge

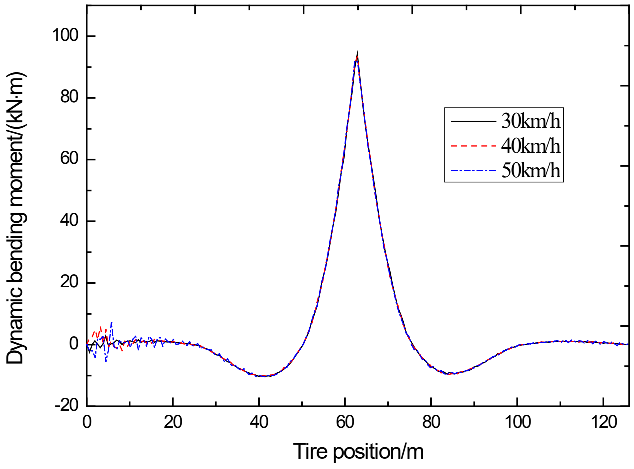
Fig. 1. The influence of vehicle speed on mid-span dynamic deflection of each span.

In Figure 2, the dynamic bending moment response curve is shown for each cross section of the box girder bridge at speeds of 30 km/h, 40 km/h, and 50 km/h.



(a) Dynamic moment response of mid-section of side span of bridge

(b) Dynamic moment response of middle section of bridge secondary span



(c) Dynamic bending moment response of mid-span section of bridge

Fig. 2. Effect of vehicle speed on dynamic bending moment of mid-span section.

Bridge can be seen in Figure 2, spanning across the maximum bending moment and showing a slow increase with the increase in speed. The maximum dynamic bending moment does not occur just after each span across the tire, but rather before and after the tire crosses the bridge [6]. The edge also experiences a different maximum dynamic bending moment compared to the other two spans.

The biggest counteracting force increases with the increase in speed and slows down due to the larger vehicle vibration during the initial startup. Therefore, the counteracting force curve shows substantial fluctuations at zero initial moment [7].

4.2 The influence of vehicle load of bridge vibration

We select the speeds of 40 km/h, 0.7 t, 1.5 t, and 2.5 t for curved bridge conditions and calculate the vertical cross-dynamic deflection and vertical bearing reaction force for different loads on the curved box girder bridge [8].

(1) When the speed and vehicle quality are the same, there is a significant increasing trend in the dynamic deflection of the bridge.

(2) The time span on the side and middle spans for the maximum dynamic deflection value are essentially the same.

(3) Vehicle. The vehicle load system is very sensitive, so larger vehicles need to limit their speed when passing a bridge to ensure appropriate load distribution.

4.3 The influence of the eccentric vehicles driving on the bridge vibration

At present, in order to accommodate traffic demands, most bridges are designed with wide lanes and decks to allow for increased car flow [9]. In this paper, the influence of vehicle-bridge coupling vibration caused by eccentric vehicles driving on curved bridges is studied, taking into consideration the different mechanical characteristics of curved bridges compared to straight line bridges [10]. Mainly, various cross-sections are analyzed for vertical dynamic deflection, bending moment, and strain analysis of the dynamic response. Eccentric driving under three load conditions is as follows:

Load one: Take eccentricity $e = -2$ m;

Load two: Take eccentricity $e = 0$ m;

Load three: Take eccentricity $e = 2$ m;

$e > 0$ said vehicles driving on the outside of the curve bridge, namely surface deviates from the center of the circle on that side. $e = 0$ means vehicles running along the center line, $e < 0$ vehicle on the inside of the curve bridge, namely the side closer to the center of the circle.

The working conditions for the three types of access mentioned above are the same. This means that a single driving tire is used on the bridge deck, and the road level is at the same level as the road surface irregularities [11].

Figure 3 illustrates the dynamic deflection of the vertical and cross sections of a curved bridge, as well as the dynamic bending moment and strain response. It also depicts the relationship between the eccentric position.

As can be seen from Figure 3(a), the dynamic deflection response of the vertical edge across different side spans increases with the increase of vehicle eccentric trends [12]. It can be seen from Figure 3(b) that all across the cross section in dynamic response, the increase of vehicle eccentric bending moment tends to slightly increase. The side span across the dynamic bending moment value is slightly larger than the other two spans across the cross. In the design of a bridge, one should avoid the occurrence of the lateral eccentric driving bridge rollover phenomenon. It can be seen from Figure 3(c) in the cross of strain that the increase of partial load position has an obvious increasing trend [13].

5. Conclusion

With the assistance of SolidWorks software for three-dimensional graph drawing, ABAQUS software for selecting the Yeoh constitutive model to fit the superelastic properties of rubber, and high-precision grid differentiation for the tire model, accurate characterization of tire material mechanics characteristics can be achieved. A finite element model of a curved bridge is established to simulate the entire process of a vehicle driving and the tire rolling on the deck of the bridge. The study examined the impact of vehicle speed, vehicle load, and vehicle eccentric driving on the dynamic response of the bridge. This research shows that:

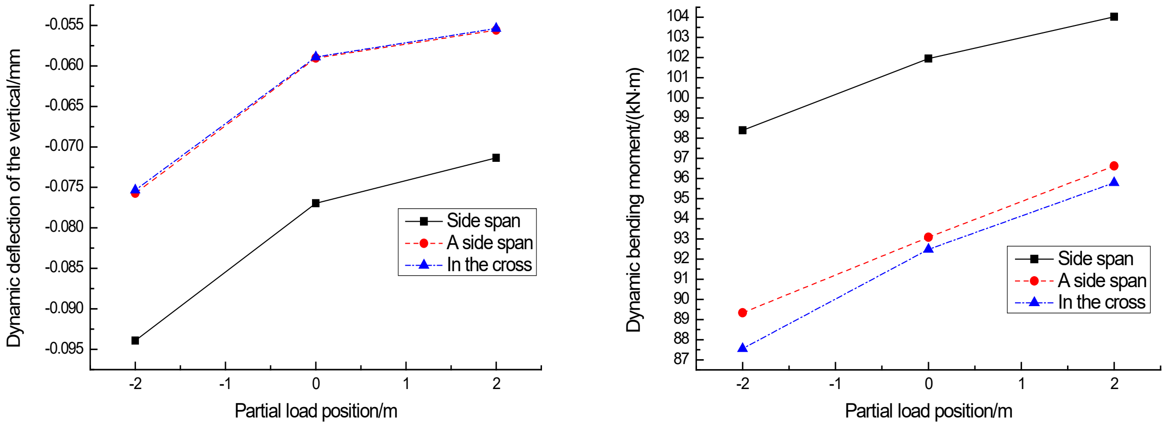
(1) Bridges across the maximum dynamic deflection and slowly increase with the increase of the speed of the car, but it is not linear; Bridge when the speed reaches a certain value, the maximum dynamic deflection value is less than the corresponding deflection value of the speed, thus caused by the speed of the car axle structure resonance point to consider.

(2) The side span across the maximum dynamic deflection value is smaller than the other two across, but the growth trend than the time side span and middle span.

(3) When the speed phase at the same time, the vehicle load, the greater the dynamic deflection of a bridge across a significant increasing trend. Vehicle. the system of vehicle load is very sensitive, so the load of the larger vehicles limits the appropriate speed when passing a bridge;

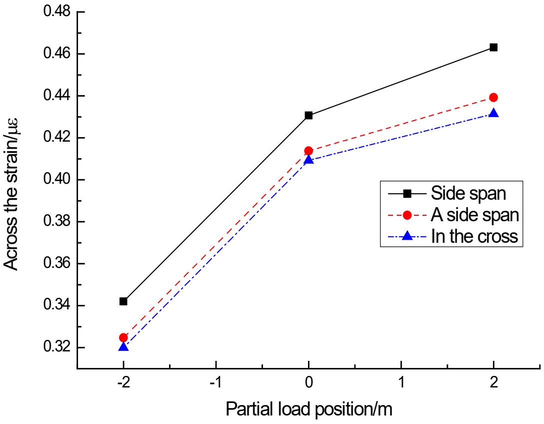
(4) All across the cross section in dynamic response, with the increase of vehicle eccentric bending moment tends to

slightly increase. Side span across the cross-section bending response value is slightly larger than the other two across a cross.



(a) The relationship between vertical displacement and offset load position

(b) The relationship between mid-span bending moment and offset load position



(c) The relationship between mid-span strain and offset load position

Fig. 3. Effect of eccentric driving on the response of mid-span section.

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