Study on impact coefficient of simply supported hollow slab girder bridge

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Abstract: In this paper, the impact coefficient of small and medium span girder Bridges under different spans and vehicle speeds is studied with typical simple supported hollow slab girder Bridges. A multi-span bridge model is established in ANSYS by using numerical simulation method, and the actual load is simulated by combining space three-axis vehicle model. The influence of pavement grade, vehicle type and its parameters on the impact coefficient is studied and analyzed. It is found that the higher the pavement grade, the smaller the span or the higher the speed, the more significant the impact coefficient is affected by pavement. In addition, heavy vehicles have the greatest impact on the impact coefficient. Compared with the standard, the calculated results of the method in this paper are small, which indicates that the shock coefficient in the standard is too safe.

1. Introduction

As a key parameter in bridge design, impact coefficient plays an important role in ensuring the safety and durability of bridge structures[1]. After decades of research, although the calculation method of impact coefficient of simple bridge type has been relatively mature, the research results considering the comprehensive influence of many factors such as bridge deck pavement, span, bridge type and vehicle type are still limited[2]. Based on this background, this paper uses numerical analysis method to systematically study the impact coefficient of the simply-supported hollow slab girder bridge under different span, different speed, different deck pavement and different vehicle types. The aim is to provide a more scientific and reasonable value basis for bridge design and evaluation through comprehensive and in-depth research, so as to ensure the long-term safe use of bridge structure[3].

2. Numerical model analysis and parameters

2.1 Bridge model

In order to further study the relationship between impact coefficient and bridge span and vehicle speed, this paper takes a simple supported hollow slab girder bridge as the research object, and establishes several typical span hollow slab space girder models under ANSYS environment.

(1) Elevation layout

Suppose that a bridge on a highway has a superstructure span of 13m, 16m and 20m prestressed concrete simply supported hollow slab girder bridge.

(2) Cross-sectional layout

Bridge net width: 0.5m(guardrail)+11.00m(carriageway)+ 0.5m(guardrail), using 11 pieces of hollow plate composition, detailed dimensions see "Highway bridge and culvert general drawing (hollow plate)".

(3) Materials

Concrete: Precast hollow slab, hinge joint and cast-in-place layer of bridge floor adopt C50, elastic modulus Ec=3.45×104MPa, density 2500kg/ m3.

(4) Calculation model

Without considering the effect of pile soil and bridge substructure, the bridge structure is simulated by using the beam lattice method in ANSYS software. Each main beam is simulated by a series of beam elements, and the supports at both ends constrain Dx, Dy, Dz, Rx, Rz and Dy, Dz, Rx, Rz respectively to form a simple supported system.

2.2 Vehicle Model

In order to more truly reflect the dynamic effect of vehicles on the bridge structure, the spatial three-axis vehicle model that is closer to the actual situation is chosen here. The specific parameters of vehicles are based on reference [6], and the main parameters of vehicles are shown in Table 1

Table.1 Technical parameters of space three-axis vehicle

Vehicle model	axle	frame wheelset mass m/kg	vertical stiffness of one series $K_t/N\cdot m^{-1}$ $(\times10^6)$	vertical damping of one series $C_t/kg\cdot s^{-1}$ $(\times10^4)$	vertical stiffness of two series $K_s/N\cdot m^{-1}$ $(\times10^6)$	vertical damping of two series $C_s/kg\cdot s^{-1}$ $(\times10^4)$	Body mass M/kg $(\times10^4)$	longitudinal body nod stiffness($\times10^6$) $/kg\cdot m^2$	transverse body nod stiffness($\times10^6$) $/kg\cdot m^2$
axle, space vehicle model	front axle	2165	1.2675	9.8	2.14	4.9	2.15	1.376	0.688
		2165	1.2675	9.8	2.14	4.9			
	center axle	1082.5	0.63375	4.9	1.07	2.45			
		1082.5	0.63375	4.9	1.07	2.45			
	rear axle	1082.5	0.63375	4.9	1.07	2.45			
		1082.5	0.63375	4.9	1.07	2.45			

This paper studies the impact coefficient calculation of A-class bridge deck pavement. According to the effect of impact coefficient in the calculation of bridge internal force (that is, the impact effect under the maximum static load effect) combined with the layout of the bridge deck, only two vehicles on the bridge deck are considered to run side by side in the same direction, and the medium load form is adopted.

3. The impact of bridge deck pavement on the impact coefficient

3.1 Overview of bridge deck pavement types

In bridge engineering, bridge deck pavement, as the direct contact layer between vehicle and bridge structure, not only carries vehicle load, but also directly affects the dynamic response of bridge structure[4]. There are A variety of types of bridge pavement, according to materials, structure, performance and service life and other factors, usually can be divided into A, B, C and other different grades. Grade A pavement usually has high smoothness, wear resistance and durability, and is suitable for high-grade roads such as expressways; Class B pavement is second, suitable for general highways; Grade C paving is mostly used for low-grade roads or temporary Bridges. The material composition, thickness, stiffness and damping characteristics of bridge deck pavement of different grades are significantly different, which will directly affect the dynamic response of bridge under vehicle load, and then affect the calculation result of impact coefficient.

3.2 Calculation of impact coefficient under different paving

In order to deeply study the impact coefficient of bridge deck pavement, this paper establishes three different bridge models under the A-grade, B-grade and C-grade bridge deck pavement based on the original bridge model. In ANSYS software, bridge structures with different pavement types are simulated by adjusting the material properties (such as elastic modulus, density, damping ratio, etc.) and thickness parameters of pavement layers. Then, according to the working condition analysis method mentioned above, the dynamic response analysis of the bridge model under these three types of pavement is carried out, and the deflection time history curve and impact coefficient under each working condition are calculated and recorded[5].

3.3 Analysis of the impact coefficient of pavement type

Through the comparative analysis of the calculation results of the impact coefficient under the three paving types of A, B and C, the following rules can be found:

(1) The relationship between pavement grade and impact coefficient

Generally speaking, the higher the grade of pavement (such as grade A), the smaller the impact coefficient of the bridge; The lower the grade of pavement (such as grade C), the greater the impact coefficient. This is because the high-grade pavement has good flatness and damping characteristics, which can effectively absorb the vibration energy generated during the driving process of the vehicle, thereby reducing the dynamic response of the bridge structure.

(2) The interaction between span and pavement type

In Bridges with different spans, pavement type has different influence on impact coefficient. For small span Bridges (such as 13m span), pavement type has a significant impact on the impact coefficient. For long-span Bridges (such as 20m spans), the impact of pavement type is relatively small. This may be due to the large structural stiffness of long-span Bridges and their low sensitivity to external loads.

(3) The comprehensive effect of vehicle speed and pavement type

At different speed, the impact of pavement type on the impact coefficient also presents a certain difference. Generally speaking, at a lower speed (such as 5m/s), the pavement type has less influence on the impact coefficient; At higher speeds (such as 20m/s), the impact of pavement type is more significant. This may be because when the speed increases, the dynamic impact of the vehicle on the bridge structure is enhanced, which makes the damping and vibration absorption effect of the pavement layer more prominent.

3.4 Sensitivity analysis of pavement material parameters

In order to further explore the influence of pavement material parameters on impact coefficient, the sensitivity analysis of pavement material parameters is also carried out. By changing the elastic modulus, damping ratio and other key parameters of pavement layer, the influence of these parameters on the impact coefficient is observed. The analysis results show that:

The greater the elastic modulus of pavement layer, the smaller the impact coefficient of bridge. This is because the elastic modulus reflects the stiffness characteristics of the pavement layer. The higher the stiffness, the stronger the resistance of the pavement layer to the vehicle load, thus reducing the dynamic response of the bridge structure. The damping ratio of pavement layer is one of the important factors affecting the impact coefficient. The larger the damping ratio is, the stronger the pavement can absorb the vibration energy, and the smaller the impact coefficient of the bridge. Therefore, pavement materials should be selected reasonably in bridge design to increase the damping ratio of pavement layer and reduce the impact coefficient of bridge[6].

To sum up, the bridge deck pavement has a significant effect on the impact coefficient of the simply supported hollow slab girder bridge. In the process of bridge design, evaluation and maintenance, the type of bridge deck pavement, material parameters and their influence on the impact coefficient should be fully considered to ensure the safety and durability of the bridge structure.

4. Impact coefficient calculation

4.1 Working condition analysis

In order to explore the dynamic effects of hollow slab girder Bridges with different spans at different vehicle speeds, This paper defines the loading of vehicles with speed V of 5m/s(18km/h), 8m/s(28.8km/h), 10m/s(36km/h), 13m/s(46.8km/h), 15m/s(54km/h) and 20m/s(72km/h). For a simply supported hollow slab bridge with span L of 13m, 16m and 20m, 18 working conditions are formed at the corresponding six speeds, as shown in Table 2. In this section, 18 working conditions are analyzed in detail.

Table. 2 Analysis of working conditions

Condition number	bridge spanL(m)	vehicle speed V（m/s）
1	13	5
2	13	8
3	13	10
4	13	13
5	13	15
6	13	20
7	16	5
8	16	8
9	16	10
10	16	13
11	16	15
12	16	20
13	20	5
14	20	8
15	20	10
16	20	13
17	20	15
18	20	20

4.2 Impact coefficient of bridge deflection caused by moving vehicles

Because of the medium load form, the deflection of each hollow plate caused by the moving vehicle is symmetrical with respect to the center line of the bridge. Therefore, beam 1#-6# is taken as the research object here, and the mid-span deflection of bridge is selected as the observation point, and the time-history curve of deflection at the mid-span of each beam is obtained from the time when the vehicle enters the bridge, as shown in Figure 1.

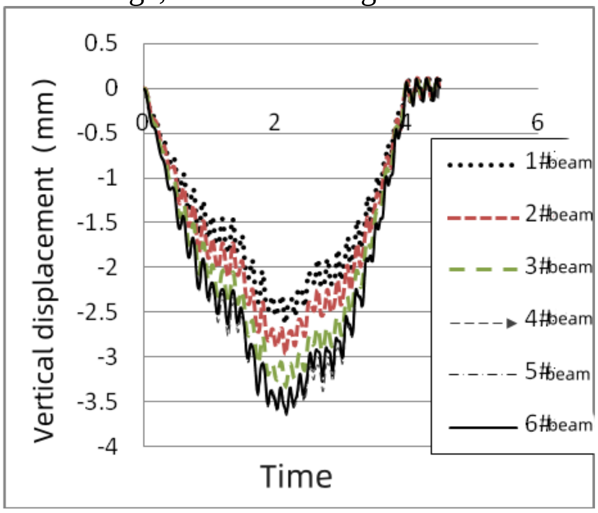

Fig. 1 Deflection time-history curve (L=13m, V=5m/s)

Through the dynamic deflection time history curve of the above working conditions, we can find the following rules:

(1) Under medium load conditions, the deflection of the middle beam of the bridge is larger than that of the side beam, but their vibration direction and frequency remain the same.

(2) Under the action of moving load, the maximum deflection of the bridge does not occur when the vehicle travels to the mid-span position, but there is a certain "delay". The position of maximum deflection of Bridges with the same span under vehicle load at different speeds is basically the same.

(3) When vehicle loads with different speeds pass through Bridges with the same span, the greater the speed, the greater the dynamic response, and the greater the subsequent amplitude caused by vehicles leaving the bridge deck.

(4) When the vehicle load with the same speed passes through the bridge with different spans, the larger the span, the greater the deflection response.

The deflection impact coefficient of each beam can be calculated from the deflection time-history curve, and compared with the Canadian Code for Bridge Design (DHBDC), the American Code for AASHTO Highway bridge Design, and the Chinese General Code for Highway bridge and culvert Design (Code 04).

From national norms can be known: The impact coefficient of the three kinds of Bridges corresponding to the Canadian code is 0.25, the corresponding American code is 0.33, and the corresponding Chinese code is 0.3651, 0.29415 and 0.21947 after calculation. The comparison results are shown in Figure 2- Figure 4 (in the figure, Canada, the United States and China respectively represent the impact coefficients calculated by the Canadian code, the United States code and the China 04 code). Each piece of beam with different spans shows different impact coefficients at different moving speeds. In this paper, the deflection impact coefficients at these 6 speeds are averaged and then compared with the norms of various countries, as shown in Figure 5.

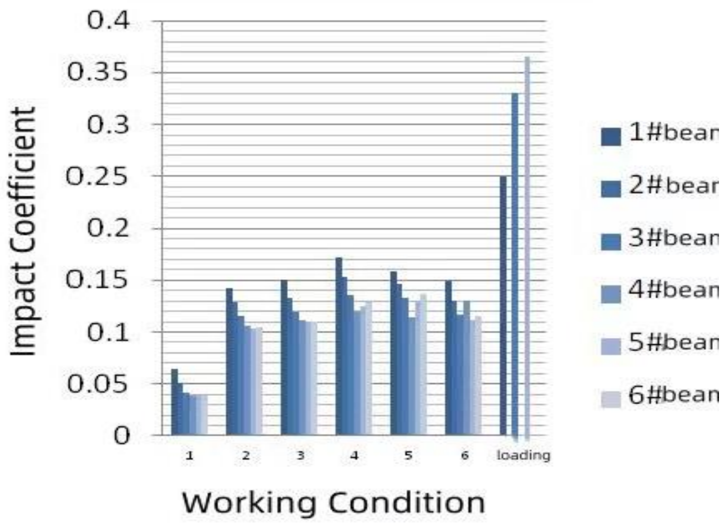

Fig 2 Deflection impact coefficient of 13-meter hollow plate

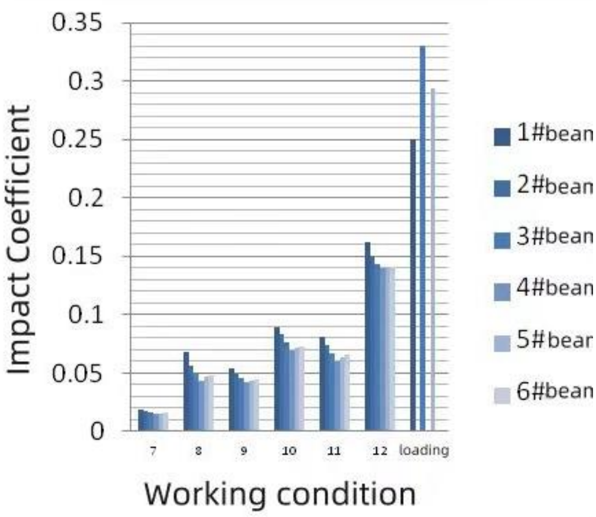

Fig 3 Deflection impact coefficient of 16-meter hollow plate

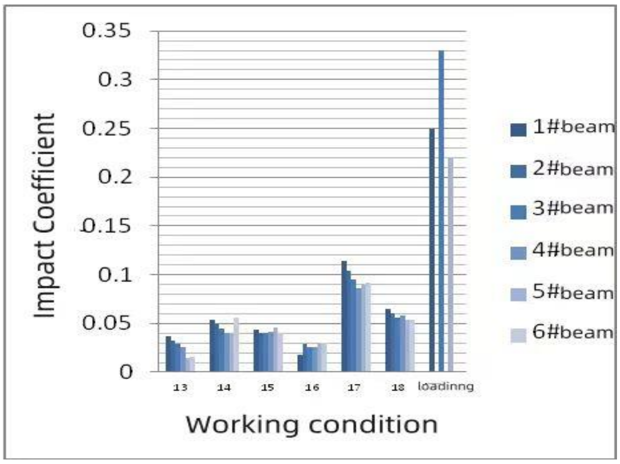

Fig 4 Deflection impact coefficient of 20-meter hollow plate

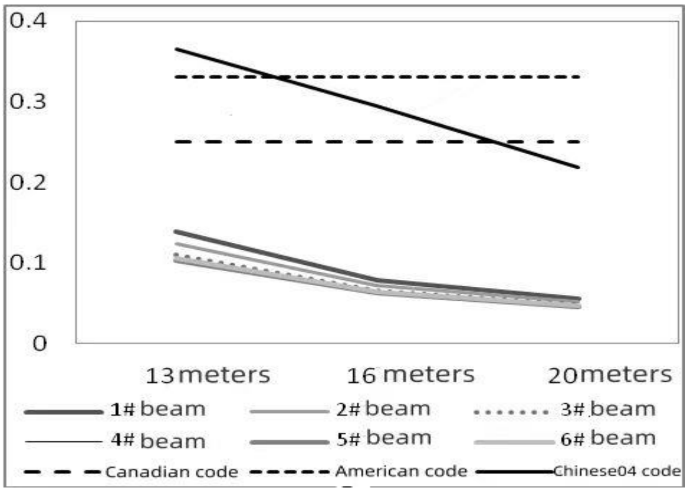

Fig 5 Comparison between deflection impact coefficient and standard impact coefficient

Some rules can be found from Figure 2- Figure 5:

(1) In each working condition, the deflection impact coefficient of the side beam is larger than that of the middle beam, and the smaller the span of the bridge, the more significant this law is. The impact coefficient of deflection of 13m hollow plate 1# beam is 31% larger than that of the 6# beam. Under normal circumstances, the impact effect of the side beam is the greatest. The deflection impact coefficients of 1# beam with span of 13m, 16m and 20m are 0.139, 0.079 and 0.055, respectively.

(2) Under moving loads at different speeds for Bridges with the same span, the deflection impact coefficient tends to increase with the increase of speed. The trend is not monotonically increasing, but rather undulating. It can be seen that the driving speed has a certain influence on the impact effect of the bridge.

(3) On the whole, the deflection impact coefficient of the bridge gradually decreases with the increase of span, which is consistent with the Chinese norms.

(4) The calculated results of deflection impact coefficient obtained by the method in this paper are smaller than the Canadian DHBDC, the American AASHTO and the Chinese 04 code, in which the deflection impact coefficient of 13m, 16m and 20m span Bridges is 0.251, 0.226 and 0.170 smaller than the Chinese 04 code, respectively. This shows that the impact coefficient stipulated by the code under the A-class bridge deck pavement is safe.

5. Influence of different vehicle types on impact coefficient

5.1 Overview of vehicle types

In bridge engineering, different types of vehicles have different dynamic effects on bridge structure because of their differences in mass, axle number, suspension system and driving characteristics. In order to understand and analyze the impact coefficient of the simply-supported hollow slab bridge more comprehensively, the influence of different vehicle types on the impact coefficient is further considered. Common vehicle types include trucks, buses, heavy vehicles, etc., which have their own unique characteristics and parameters.

The truck usually has a large total mass, a long body and multiple axles, and its impact on the bridge is relatively large. Passenger cars relatively light, but have a longer body and a softer suspension system, and may produce larger vibrations during operation; heavy vehicles such as heavy trucks or tractors, their mass and axle load are far beyond ordinary vehicles, and their impact on bridge structures is the most significant.

5.2 Calculation of impact coefficient under different vehicle types

In order to study the influence of different vehicle types on the impact coefficient, this paper further establishes vehicle models such as trucks, buses and heavy vehicles on the basis of the original spatial three-axis vehicle model. These models have been adjusted in terms of axle number, mass, suspension system, etc., to more truly reflect the characteristics of different vehicle types.

Specifically, the truck model considers multiple axles and large total mass, and sets reasonable suspension system parameters according to the actual situation. The passenger car model is relatively light, the body length is longer, and the suspension system is softer. Heavy vehicle models have higher total mass and axle load, and suspension systems may also vary depending on vehicle type and design requirements.

After the vehicle model is established, the impact coefficients of these vehicles at different speeds and spans are calculated. In the calculation process, the consistency of bridge model, calculation condition and loading mode is maintained to ensure the reliability and comparability of the results.

5.3 Analysis of the impact of vehicle type on impact coefficient

Through comparative analysis of the impact coefficient under different vehicle types, the following conclusions can be drawn:

(1) Vehicle type has a significant impact on the impact coefficient

Different types of vehicles have different dynamic effects on Bridges because of their different parameters such as mass, number of axles and suspension system. Therefore, the impact of vehicle type must be fully considered when calculating the impact coefficient.

(2) Heavy vehicles have the greatest impact on the impact coefficient

Because the total mass and axle load of heavy vehicles are far more than that of ordinary vehicles, their impact on the bridge structure is the most significant. Therefore, when designing and evaluating Bridges with heavy vehicles, special attention should be paid to the calculation and analysis of impact coefficient.

(3) The impact of trucks and buses on the impact coefficient is relatively small

Although trucks and buses will also have a certain impact on the bridge, the degree of impact is relatively small. This is mainly because the total mass and axle weight of trucks and buses are relatively light, and the suspension system is soft, which can alleviate the impact on the bridge to a certain extent.

5.4 Sensitivity analysis of vehicle parameters

In order to further explore the influence of vehicle parameters on the impact coefficient, the sensitivity analysis of vehicle parameters is also carried out in this paper. Specifically, this paper analyzes the impact coefficient of vehicle mass, axle load, suspension system and other parameters.

(1) The impact of vehicle quality

Vehicle mass is one of the important factors affecting the impact coefficient. With the increase of vehicle mass, its impact on the bridge will increase accordingly. Therefore, special attention should be paid to the calculation and analysis of the impact coefficient when designing and evaluating the bridge with large mass vehicles.

(2) Influence of axle load

Axle load is also an important factor affecting impact coefficient. The greater the axle weight, the greater the impact effect of a single axle on the bridge. The influence of axle load on impact coefficient should be fully considered when designing and evaluating Bridges with multi-axle vehicles.

(3) The impact of the suspension system

The impact of suspension system on shock coefficient is mainly reflected in its damping effect. The softer the suspension system is, the better its damping effect is, and the impact on the bridge will be reduced accordingly. When designing and evaluating Bridges for vehicular traffic, attention should be paid to the design and performance of vehicle suspension systems.

In summary, different vehicle types have significant effects on the impact coefficient of the simply-supported hollow slab bridge. In the design and evaluation of Bridges, the impact of vehicle type and its parameters must be fully considered to ensure the safety and durability of the bridge structure.

6. Conclusion

In this paper presents a comprehensive and in-depth study on the impact factor of simply supported hollow slab girder bridges, with a focus on the effects of deck paving, vehicle types, and their parameters on the impact factor. The research results indicate that the grade and material parameters of the bridge deck paving have a significant on the impact factor, with higher grade paving effectively reducing the impact factor and enhancing the safety and durability of the bridge structure. Additionally, different vehicle types, due their differences in mass, number of axles, suspension systems, etc., produce different dynamic effects on the bridge, with heavy vehicles having a particularly significant impact on impact factor.

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