Research Status of Influencing Factors of Bridge Impact Coefficient

Shuang Wu, Songhui Li*, Ganglong Yu, Xianzuo Wang

School of Civil Engineering and Architecture, Shandong University of Science and Technology, Qingdao 266590, Shandong, China

*Corresponding Author Email: songhui.l@163.com

Abstract. With the continuous development of bridge transportation and long-span bridges in China, the coupling dynamic interaction between vehicles and bridges has become more and more complex, and has received more and more attention. This paper briefly summarizes the research on the influencing factors of bridge impact coefficient by domestic and foreign scholars, focusing on systematically sorting out and summarizing the three aspects of bridge structural parameters, vehicle parameters, and vehicle-bridge coupling, summarizing its main achievements, at the same time, it points out the differences and unsolved problems in the current research, and makes new discussions and prospects.

Key words: bridge, impact coefficient, influencing factors, review.

1. Introduction

In recent years, our country's transportation industry has developed rapidly. With the diversification of bridge structures in our country and the development of large-span and light-weight bridges, the coupling dynamic interaction between vehicles and bridges has become more and more complex. The bridge impact coefficient is the increase coefficient of the dynamic effect on the bridge structure when the vehicle crosses the bridge [1]., which can usually be studied or solved by using the code formula, field load test, vehicle-bridge coupling analysis and other methods. As an important index to evaluate the interaction between the vehicle and the bridge, it is often expressed by the dynamic impact coefficient μ (IM) or the dynamic amplification factor (DAF) to estimate the ultimate bearing capacity of the bridge. The dynamic impact coefficient μ (IM) is expressed as follows:

$$\mu = \frac{Y_{d\,max}}{Y_{j\,max}} - 1 \tag{1}$$

In the formula: μ is the impact coefficient under the vehicle load, $Y_{d\,max}$ is the maximum dynamic response value of the bridge deflection when the vehicle crosses the bridge, $Y_{j\,max}$ is the maximum static force of the bridge deflection when the vehicle crosses the bridge Response.

The dynamic amplification factor (DAF) is the ratio of the maximum dynamic value of deflection to the maximum static value of deflection, expressed as:

$$DAF = \frac{Y_{d\,max}}{Y_{j\,max}} \tag{2}$$

The factors affecting the impact coefficient of bridges can be roughly classified into three aspects: (1) the influence of bridge structural parameters, such as the flatness of the bridge deck, the type of bridge (section), etc.; (2) the influence of vehicle parameters, such as the number and spacing of vehicles, Driving speed, vehicle weight, etc.; (3) Influence of vehicle-bridge coupling, such as vehicle driving frequency and bridge frequency, relative stiffness of tires and bridge deck, etc. All of the above influencing factors will have an impact on the impact coefficient of the bridge, and the degree of influence varies.

So far, scholars at home and abroad have studied various bridge impact coefficients and their influence laws, and the conclusions drawn provide ideas for bridge structure inspection and reinforcement, and provide help for the transportation industry. Aiming at the many influencing factors involved in the current research, this paper systematically sorts out and summarizes the current research results from the three aspects mentioned above; at the same time, it focuses on the divergent conclusions and problems to be improved in the current research results. Conduct new discussions and prospects.

2. Research status at home and abroad

2.1 Bridge structural parameters

The flatness of the bridge deck is one of the important indicators to measure the quality of the bridge pavement. It is regarded as a Gaussian random process in the vehicle-bridge coupling theory and can be characterized by a power density function. There are currently two standards for the power spectral density function: the Chinese GB7031-2005 standard and the international ISO8608 standard.

China GB7031-2005 standard:

$$G_q(n) = G_q(n_0)\left|\frac{n}{n_0}\right|^{-w} \tag{3}$$

where:n——a certain spatial frequency, m^{-1};

n_0——reference spatial frequency, its value is $0.1m^{-1}$;

$G_q(n_0)$——The power spectral density of the road surface when the spatial frequency is n_0, and its value is related to the road surface grade;

w——frequency index, its value generally takes 2.

In my country, the road surface is divided into different grades according to GB7031-2005, as shown in Table 2.1.

Table 1. GB7031-2005 Standard Pavement Roughness Coefficient

road grade	Road Roughness Coefficient $G_q(n_0) \times 10^{-6}m^2/m^{-1}$		
	lower limit	geometric mean	Upper limit
A	8	16	32
B	32	64	128
C	128	256	512
D	512	1024	2048
E	2048	4096	8129
F	8129	16384	32768
G	32768	65536	131072
H	131072	262144	524288

International ISO8608 standard:

$$\begin{cases} S_q(\Omega) = S_q(\Omega_0)\left(\frac{\Omega_0}{\Omega}\right)^{w_1} & \Omega \le \Omega_0 \\ S_q(\Omega) = S_q(\Omega_0)\left(\frac{\Omega_0}{\Omega}\right)^{w_2} & \Omega \ge \Omega_0 \end{cases} \tag{4}$$

where:

Ω—— a certain spatial frequency;

Ω_0——Standard angular spatial frequency, the value is $\frac{1}{2\pi}$;

$S_q(\Omega_0)$——The power spectral density of the pavement whose angular spatial frequency is Ω_0, and the relevant values are shown in Table 2.2.

Table 2. ISO8608 standard road surface smoothness coefficient table

Pavement classification	$S_q(\Omega_0)$	$S_q(\Omega_0)$ mean	w_1	w_2
A	2~8	4	2	1.5
B	8~32	16	2	1.5
C	32~128	64	2	1.5
D	128~512	256	2	1.5
E	512~2048	1024	2	1.5

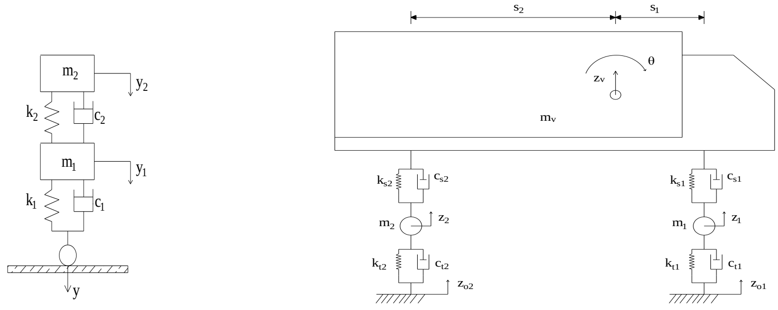
As an important excitation source affecting the impact coefficient of bridge structures, the flatness of the bridge deck has been studied extensively by scholars at home and abroad. In 2003, Yan Zhigang et al. [2] used the nonlinear finite element method to study and analyze the influence of the dynamic response of the vehicle-bridge system on the deck irregularity of the CFST arch bridge under the action of the moving vehicle load. In 2009, Wang Da et al. [3] studied and analyzed the dynamic response of long-span suspension bridges under different deck roughness based on the separation method, and found that the level of the deck flatness largely determines the magnitude of the structural impact coefficient. In the following years, many domestic scholars[4-6]studied and analyzed the impact of pavement flatness on the impact effect of various bridge components. In foreign countries, Saiji Fukada et al. [7] investigated the reasons for the large vibration of prestressed concrete bridges under vehicle loads, and found that the impact coefficient increased significantly with the worsening of the bridge deck unevenness. A. Rezaiguia et al. [8] studied and analyzed the dynamic interaction between the moving vehicle and the highway bridge deck, and found that the bridge deck roughness is one of the main excitations that affect the vibration response of the vehicle-bridge coupled system. However, since most of the previous studies usually used a single triangular series superposition method to simulate the unevenness of the bridge deck, ignoring the influence of its randomness on the impact coefficient, in 2015, Shen Ruili et al. [9] The dynamic response of the vehicle-axle coupling system is studied, and the influence of the road roughness factor on the impact coefficient is mainly studied. In recent years, the impact of bridge deck roughness on the impact coefficient has aroused active research and discussion by scholars[10-11].

To sum up, the existing studies all agree that the flatness of the bridge deck plays a crucial role in the impact coefficient of the bridge, and determines the impact coefficient to a certain extent. With the deterioration of the flatness of the bridge deck, the impact coefficient of the bridge increases significantly. big.

In addition, there are various types of bridges, including different types of bridges and bridge sections. Most of the bridge codes at home and abroad use the bridge span or fundamental frequency to calculate the dynamic impact coefficient. The impact cannot be ignored. In view of this, in the past ten years, scholars [12-14] have studied the influence of bridge type on the bridge impact coefficient. The analysis found that the section type will affect the dynamic response of the bridge, and the dynamic impact coefficient of bridges with the same span and different sections There are relative differences between the dynamic impact coefficients of bridges with the same fundamental frequency and different sections. Therefore, the influence of different bridge sections on the impact coefficient should be considered in the project.

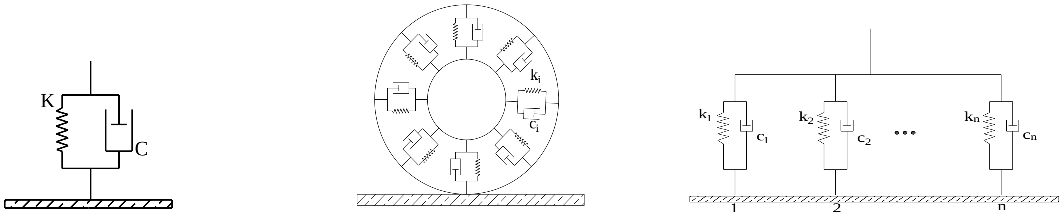
2.2 Vehicle parameters

The current vehicle models include analytical models (1/4 model, half-car model, whole vehicle model), tire contact model (single-point model, disc model, multi-point model) and simulated vehicle model, as shown in the figure below.



(a) 1/4 car model (b) Vehicle model

Figure 1. Vehicle Analysis Model



(a) Single point model (b) Disc model (c) Multipoint model

Figure 2. Tire contact model

According to the vehicle model, various factors affecting the coupled vibration response of the vehicle-axle can be analyzed, especially the impact of vehicle parameters on the bridge impact coefficient. Among them, the driving speed, as one of the factors that has a great influence on the bridge impact coefficient, has been repeatedly discussed by scholars at home and abroad.

In 2005, Huang et al. [15] studied the impact coefficient of the main beam of a mid-support CFST arch bridge under the action of expressway vehicles, and discussed and analyzed the impact of factors such as driving speed on the impact coefficient. In 2007, Ju et al. [16] used the 1/2 vehicle model for research, and developed a finite element method suitable for analyzing the dynamic response of the linear beam vehicle-axle coupling system under the action of a variable-speed vehicle. In 2008, Zhang He et al. [17] discussed the influence of factors such as driving speed on the impact coefficient of bridge structures through the method of vehicle-bridge coupled vibration analysis, and found that design parameters such as driving speed have an impact on the dynamic impact coefficient of the structure. Foreign H. Moghimi et al. [18] analyzed the influence of factors such as vehicle speed and vehicle weight on the impact coefficient of composite steel girder bridges by establishing a finite element model. In 2015, Deng et al. [19-20] established a three-dimensional vehicle-axle coupling model, and studied and analyzed the dynamic response and impact coefficient caused by vehicle braking, as well as the influence of vehicle braking position, vehicle speed and other factors on the impact coefficient. Li et al. [21] studied long-span railway bridges by establishing a vehicle-bridge coupling model, discussed and analyzed the impact coefficients of bridge structures such as main beams, stay cables, bearings and bridge towers under different vehicle speeds, and found that long-span railway cable-stayed Different components of the bridge have different impact coefficients. In 2016, Han Yan et al. [22] compiled a vehicle-axle coupling vibration program, studied and analyzed the response and impact coefficient of the coupling vibration of two-axle vehicles under driving speed and other factors, and found that the impact coefficient decreased first with the increase of vehicle speed. The trend of increasing after small. In 2017, Wang Jianqiang [23] used the ANSYS and UM co-simulation technology to study the sensitivity of the impact coefficient to the section form at different vehicle speeds. The study found that the impact coefficient does not increase monotonically with the increase of the driving speed, but peaks at the resonance speed. In the past two years, Liang Dong et al. [24-25]found that among various factors, vehicle speed had the most obvious impact on the impact coefficient, and fitted the calculation formula of the impact coefficient under the influence of various factors.

It can be seen from the above that scholars at home and abroad have not reached a consensus on the variation law of impact coefficient with vehicle speed. One of the viewpoints is that the impact coefficient increases with the increase of the vehicle speed, while some scholars believe that there is no obvious positive correlation between the impact coefficient and the vehicle speed. In fact, the influence of vehicle speed on the impact coefficient is often mixed with the interference of other factors. For example, when the road surface roughness level is different, even if the same vehicle crosses the bridge, the vehicle speed corresponding to the maximum impact coefficient is also different. In addition, differences in vehicle analysis models used in different studies may also have an impact on the analysis results.

In addition, most of the research on the coupled vibration response of highway bridges and bridges is limited to a single vehicle, and the coupled vibration response of multiple vehicles crossing the bridge is not considered, which is not rigorous. Some scholars [26-29] began to study the multi-vehicle load crossing bridge. The vehicle-axle coupled vibration response at . According to the existing research, it has a significant impact on the coupled vibration response when multiple vehicle loads cross the bridge. In the case of control variables, the bridge impact coefficient shows a downward trend as a whole with the increase of the number of loaded vehicles, but there are local fluctuations; the overall impact coefficient It decreases as the distance between vehicles increases, but some studies have pointed out that the impact coefficient will peak at a certain distance between vehicles and fluctuate in other ranges. This issue remains to be discussed and studied.

2.3 Vehicle-bridge coupling effect

When a car crosses a bridge, due to the interaction between the weight of the vehicle and the speed of the vehicle, the vibration of the bridge structure will be caused, and the vibration of the bridge will in turn affect the operation of the vehicle. This phenomenon is called vehicle-axle resonance. Vehicle-axle coupling vibration models include moving concentrated force model, moving mass model, moving sprung mass model, etc., as shown in the following figure.

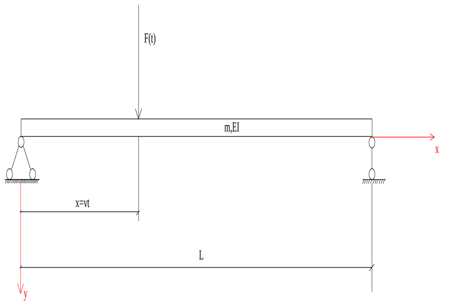


Figure 3. Moving Concentrated Force Model

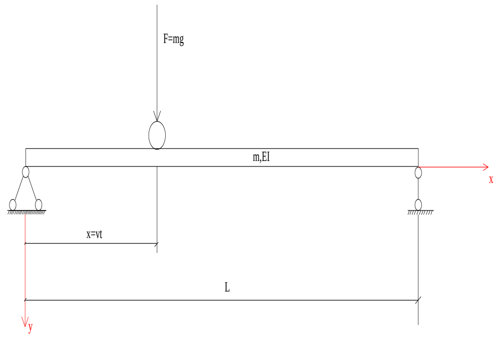


Figure 4. Moving mass model

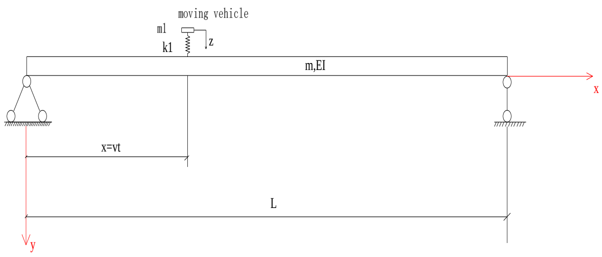


Figure 5. Moving sprung mass model

The vehicle-bridge coupling vibration has an unnegligible influence on the impact coefficient of the bridge, and scholars at home and abroad have done a lot of research on this factor. In 2006, Malm et al. [30] studied the vibration caused by trains through on-site measurements, and found that about 60% of the variable amplitude cyclic stress of the suspension rods of railway arch bridges originated from the vibration of the vehicle bridge. In 2007, Song Yifan et al. [31] studied and analyzed the influence of the natural frequency of the vehicle and the driving speed. The results showed that the vehicle dynamic load coefficient increased linearly with the increase of the vehicle speed, and increased nonlinearly with the variation of the road surface grade, and the road surface grade was the influence. The most significant factor in vehicle dynamics. Li Zhongxian et al. [32] established the beam lattice model of the curved box girder and the 7-DOF space vehicle model, analyzed the interaction between the vehicle and the bridge, and studied and analyzed the impact of the vehicle lateral position, vehicle speed, bridge deck unevenness and other factors on the bridge impact. the influence of coefficients. In 2010, Yin Xinfeng et al. [33] studied the vibration characteristics of the vehicle-pavement-bridge coupling system under the action of vehicle braking, focusing on the influence of vehicle braking on the bridge impact coefficient. In 2012, Huang Xiaomin et al. [34] used a three-girder model and a vehicle model with 12 degrees of freedom to study and analyze the influence of multiple vehicle loads and other factors on the vehicle-bridge coupled vibration of a concrete curved girder bridge. In 2015, Wang Guichun et al. [35] took the bridge deck irregularity as the excitation source, and analyzed the long-span cable-stayed bridge under different vehicle speeds, vehicle weights, and bridge deck irregularities by means of the coordination conditions of force and displacement between the vehicle and the bridge. Dynamic responses of different components in the case of smoothness. In 2016, Paolo et al. [36] studied the interaction between the bridge structure and moving loads of tied arch bridges, and further analyzed the effects of bridge structural stiffness and the mass and acceleration of moving train loads on the impact coefficient of bottom-bearing tied arch bridges. In recent years, many scholars[37-38] have successively studied the coupled response of the vehicle-axle and found that the vibration of the vehicle-axle is closely related to the vehicle frequency, the frequency of the vehicle-axle and the frequency caused by the vehicle motion.

3. Existing problems

After a brief review of the research results of scholars at home and abroad, the author found some problems to be solved, as follows:

1. The factors affecting the impact coefficient of bridges are complex and diverse, so it is not possible to analyze the impact of only one cause on the impact coefficient. Moreover, it can be seen that the influencing factors have a certain degree of randomness. For a factor with a greater degree of influence, the greater the dispersion, the greater the dispersion of the impact coefficient.

2. Researchers have different opinions on the changing law of the impact caused by vehicle speed. Some scholars believe that the impact coefficient increases with the increase of vehicle speed, while some scholars believe that the impact coefficient has no obvious positive correlation with the vehicle speed, but exists at the resonance speed. Peak, in fact, the vehicle speed may work with other factors to affect the vibration response of the bridge, which remains to be studied.

3. The research shows that the roughness of the bridge deck, the speed of vehicles, the number of vehicles, etc. are all important factors that affect the impact coefficient of the bridge, but these factors are not considered in the specification formula, so its reliability still needs to be studied.

4. Conclusion

This paper first briefly summarizes the classification of the influencing factors of the bridge impact coefficient, and then reviews the research on various factors by domestic and foreign scholars, focusing on the summary and analysis of factors such as bridge deck roughness, vehicle speed, and vehicle-bridge coupling, pointed out the existing problems, and provided ideas for further research and development.

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