Estimation of dynamic response for highway CFST arch bridges

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ABSTRACT: The applications of concrete-filled steel tubular (CFST) arch bridges have been widely used in China. The comfort characteristic estimation under vehicle loads for CFST arch bridges is a observant problem in design. There are several estimation systems in different codes by the criterion of deflection limit or vibration parameters control. Three different type CFST arch bridges are taken as cases study to examine the existing estimation system in codes. Analytical results show that the limit of live-load deflection can be eliminated and it can be given as a founction of dynamic parameter in design to control the vibration performance of CFST arch bridge.

1 INTRODUCTION

The applications of concrete-filled steel tubular (CFST) arch bridges are widely in China. The dynamic response which is the main contain of the comfort characteristic estimation under vehicle loads for CFST arch bridges is a observant problem in design. But there is no design codes for this type bridges presently. In China, how to control comfort characteristics are mostly based on the design codes of JTJ022-85[1] or JTJ023-85[2] to check the live-load deflection limit. But corresponding items were eliminated in design code of JTG D62-2004[3] which was carried out in 2004. In design codes of others countries, estimation systems are based not only on deflection limit but also vibration parameters control. So three different types of CFST arch bridges are taken as cases study to examine the existing estimation system by difereent codes in this paper and the characteristic of diferent systems are discussed.

2 COMFORT ESTIMATION SYSTEMS

2.1 Live-load deflection criteria

The live-load deflection which was limited to control the vibration of bridges was originate from a report concerning to the bridge vibration in USA in 1930's. In the report, vibration of various types bridges which under automobile loads was investigated and the statistics analysis was carried on. This study concluded that structures having unacceptable vibrations determined by subjective human response had deflections that exceeded L/800(L is span of bridges)and this conclusion resulted in the L/800 deflection design limit[4].

In China, this method was adopted in design codes for highway bridges. For arch bridges under automobile loads, the caculation results of deflection (sum of plus and negative absolute value) of upper structure in one span must not exceed L/1000[1]. When the loads was acted on half of span, it should not exceed L/800[2].

2.2 Alternate live-load deflection serviceability criteria

A subsequent study investigated the rationality of the deflection limits. They reviewed literature on human response to vibration and on the effect of deflection and vibration on deck deterioration. These studies suggested that bridge deflections did not have a significant influence on structural performance, and that deflection limits alone were not a good method of controlling bridge vibrations or assuring human comfort[5].

   Research has shown that deflection and vibration criteria should be derived by considering human reaction to vibration rather than structural performance. The important parameters that effect human perception to vibration are the acceleration, deflection, and period (or frequency) of the response. Human reactions to vibrations are classified as either physiological or psychological. Psychological discomfort results from unexpected motion, but physiological discomfort results from a low frequency, high amplitude vibration[6].

   Canadian Standard (OHBDC1992）use a relationship between natural frequency and maximum superstructure static deflection to evaluate the acceptability of a bridge design for the anticipated degree of pedestrian use[7]. Figure 2 shows the plot of the first flexural frequency (Hz) versus static deflection (mm) at the edge of the bridge, which the natural frequency is calculated using Eqn. 1.

$$\begin{cases} f_{obs} = f_{cal} & f_{cal} \leq 2 \\ f_{obs} = 0.95 f_{cal} + 0.072 & 2 < f_{cal} < 7 \end{cases} \tag{1}$$

Where f_{obs} is the observed frequency(Hz)
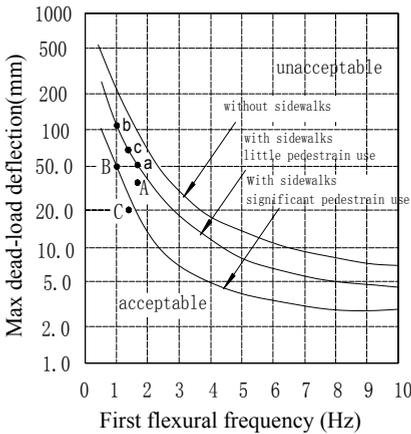 f_{cal} is the calculated frequency(Hz)

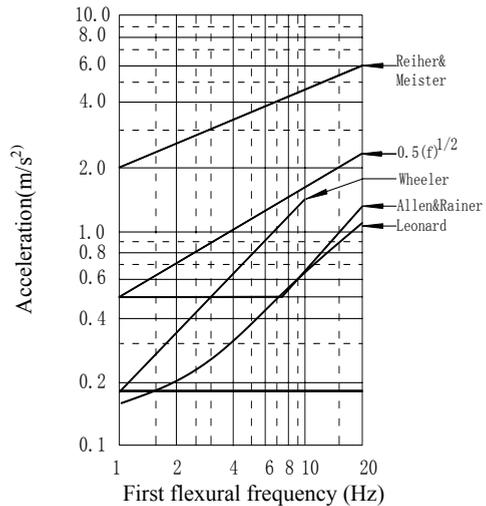Fig 1First flexural frequency versus static deflection[7]

Fig 2 Acceleration curves allowed[8]

   Three types of pedestrian use of highway bridge are considered for serviceability: very occasional use by pedestrians or maintenance personnel of bridges without sidewalks, infrequent pedestrian use (generally do not stop) of bridges with sidewalks, and frequent use by pedestrians who may be walking or standing on bridges with sidewalks[7].

   But the criteria is changed when this code was update in 1995 (OHBDC1995）in which dynamic parameters was adopted completely. The allowed acceleration curves were bring forward versus different vibration frequency, as shown in figure 2[8]. Different standards can be adopted according to the service of the bridge in desgin.

   A lot of tests in highway bridge vibration had been done by Kobori T and Kajikawa Y in

Japan. They believe that how the vibration affects human depended on psychological reactions. The comfort of highway bridge was classified by vibration feeling index which calculated by the max response velocity of the bridges. The vibration feeling index is calculated as follows [9]:

$$S = V_{max} / \sqrt{2} \tag{2}$$
$$VGL = 20\log_{10}(S/S_0) \tag{3}$$

Where S is the vibration stimulation (cm/s),
VGL is the vibration level value(dB), $S_0 = 1.4 \times 10^{-2}$(cm/s)
The vibration feeling index VG can be derive by Eqn. 3 according to different VGL:

$$\begin{cases} \log_{10} VG = 0.05(VGL - 40) & (as \qquad VGL \le 40\mathrm{d}B) \\ \log_{10} VG = 0.03(VGL - 40) & (as \qquad VGL \ge 40\mathrm{d}B) \end{cases} \tag{4}$$

The relations between the comfort of pedestrian and VG are listed on table 1.

Table 1.Comfort of pedestrian and standard value of VG

Comfort grade	Sort	VG
1	Vibration feeling slightly	0.32
2	Vibration feeling clearly	0.61
3	A little difficult to walk	1.12
4	Extremely difficult to walk	1.48

3 BRIDGE CASES AND FINITE ELEMENT MODEL

The comfort of three CFST arch bridges under automobile loads will be evaluated by different criterias forementioned. They are Fuding Xintongshan Bridge, Minqing Shitanxi River Bridge and Zhengzhou Yellow River Bridge. The main span of Xintongshan bridge which is three-span through rigid frame tied arch bridge is 75m. Shitanxi Bridge is a half through arch bridge with the span of 136m. Zhengzhou Yellow River Bridge is a Loser tied arch bridge with the span of 100m. The finite element models of three bridges (as seen in Fig3) were built by ANSYS and verified by the field testes. More detail informations can be found in references [10] to [12].

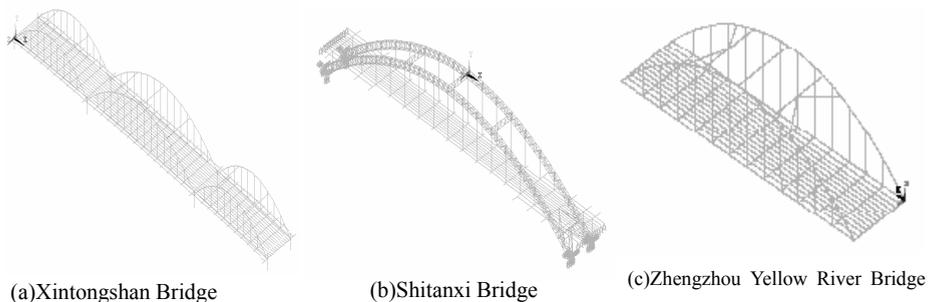(a)Xintongshan Bridge   (b)Shitanxi Bridge   (c)Zhengzhou Yellow River Bridge

Fig3. Finite element models of CFST arch bridge cases

In locale with traffic loadings, the sidewalkers will feel slightly vibration in Xintongshan bridge and Zhengzhou Yellow River Bridge but clearly in Shitanxi Bridge. It will be the estimation criterion for comfort estimation systems discussed as follow.

4 ESTIMATION OF COMFORT FOR BRIDGE CASES

4.1 Estimation by live-load deflection criteria

In order to get the maximum absolute value of deflection △ at L/4 and 3L/4 sections, the automobile loads were distributed by the deflection influence line of L/4 section. The calculative results of the most deflection of three bridge cases are shown in Table 2.

As seen from Table 2, because Zhengzhou Yellow River Highway Bridge is an Loser tied arch bridge which has greater stiffness of superstructure, its deflection is far less than the others. But all the deflection values of three bridges are far less than the deflections limits of L/1000 or L/800 required by JTJ022-85 and JTJ023-85. And the result of Xintongshan bridge is so closed to Shitanxi bridge. So the deflection limits could not reflect the actual vibration perception which is obviously different among three bridges.

Table 2.Results of bridges finite element method

Bridges	Deflection(mm)		/L	First vertical vibration frequency (Hz)
	L/4	3L/4		
Xintongshan Bridge	-20.1	8.2	1/2669	1.680
Shitanxi Bridge	-32.2	20.5	1/2580	1.048
Zhengzhou Yellow River Bridge	-14.3	5.6	1/5025	1.394

4.2 Estimation by OHBDC(1992)

The frequency calculated of three bridges cases were shown in Table 2. The frequency versus static deflection of three bridges were substituted into Fig2, where the points A, B, C for Xintongshan bridge, Shitanxi Bridge, and Zhengzhou Yellow River Highway Bridge and points a, b, c for the acceptable value of deflection respectively. It can see from Fig2 that the deflection of three bridges are also far less than the acceptable values. This results is similar with forementioned analysis by using JTJ022-85 and JTJ023-85 and it could not distinguish the comfort characteristics of three bridges either.
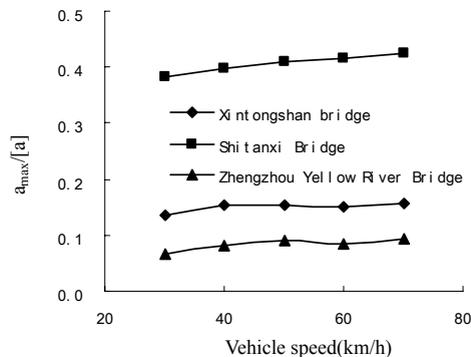

Fig 4 Peak value of acceleration response

4.3 Estimation by OHBDC(1995)

In the calculation of dynamic response of three bridges, the damping is set to 0.01 and the deck roughness is neglected. The vehicle effect was simulated by a pulse load. The velocity caculated is 30km/h, 40km/h, 50km/h, 60km/h and 70km/h respectively. The peak values of response in some sections were caculated and the maximum was selected as the peak value.

The allowable acceleration of three bridges deduced by OHBDC (1995)[8] with the limit of

[a]=0.5$f^{1/2}$ are shown in Fig4 in which the ordinate is the rate of the caculated acceleration to the allowable ones and the abscissa is different vehicle speeds.

The results shown that the peak acceleration of three bridges are all less than the allowable values. But by the estimation criterion of peak acceleration values, whit the condition of the same speed, the comfort characteristics of three bridges are that Shitanxi Bridge is the worst and the Zhengzhou Yellow River Bridge is the best. It accord with the physiological reactions of sidewalkers in locale. So this method may use to estimate the comfort characteristics of CFST bridges.

4.4 Estimation by vibration feeling index

The estimation results by using the method of vibration feeling index which brought forward by Kobori T and Kajikawa Y are shown in Figure 5.
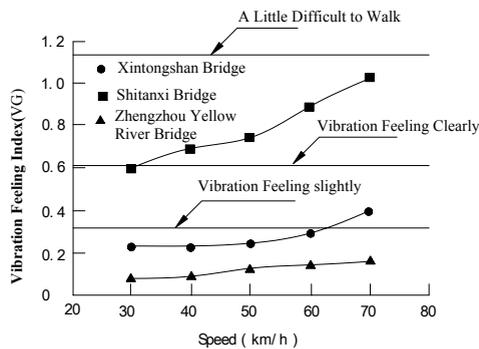

Fig5 Vibriation feeling index

This results shown that all the feeling index of three bridge do not exceed the criterion of a little difficult to walk. Obviously the index value of Shitanxi bridge are all between the criterion of a little difficult to walk and virbration feeling clearly when the speed is more than 30km/h. But the values of Xintongshan bridge and Zhenzhou yellow river bridge are below the criterion of virbration feeling slightly when the vehicle speed is less than 60km/h. It means that under traffic loadings, the comfort characteristics of Shitanxi bridge is the worse. The sidewalkers may feel vibration clearly in locale. And the comfort characteristics of Xintongshan bridge and Zhenzhou yellow river bridge is better. This conclusion is corresponded to the physiological reactions of sidewalkers and this method may use to estimate the comfort characteristics of CFST bridges, too.

5 CONCLUSIONS

The live-load deflection was limited to control the vibration of bridges in design usually. But the analytical results of three CFST arch bridges in this paper shown that this method could not reflect the actual vibration perception of sidewalkers.So the deflection limits were not a good method to estimate comfort characteristics of CFST bridges. But the conclusion of estimate comfort system which using the dynamic parameter is corresponded to physiological reactions in locale. So in the desgin of CFST arch briges, the defelection limit to estimate comfort characteristics could be eliminated, and the estimation system of dynamic parameter should be adapted.

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