

Analysis of Local Vibration for High-Speed Railway Bridge Based on Finite Element Method

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Abstract: Based on the theory of vehicle track coupling dynamics, the local vibration of the high-speed railway box girder is analyzed by the Finite Element Method and the model is simulated with the solid elements. Through the study of vibration characteristics of the selected 6 sensitive points, the local vibrations in different parts of the box girder are figured out. It is compared the response of the time domain and frequency domain in different parts of the cross section on different train speeds. Furthermore, the influence of track irregularity of local vibration response is analyzed. The results show that the track irregularity is the main factor causing local vibration. At last, the effects of local vibration on the boundary conditions are discussed. The response of top panel, floor panel and web panel were different and the flange panel was similar between the simple supported beam and the fixed beam.

Keywords: Boundary conditions, bridge, local vibration, finite element method, track irregularity.

1. INTRODUCTION

The low frequency global vibration and the high frequency local vibration are producing due to high-speed trains passing on railway viaducts. The local vibration is the main source of structure-borne noise [1]. The researches of global vibration were shown clearly in many previous papers [2]. However, the researches of local vibration were focus on the fundamental propagating law and producing mechanism. In this study the local vibration of the high-speed railway box girder is analyzed by the FEM, based on the theory of vehicle track coupling dynamics.

2. COMPUTATIONAL MODEL

2.1. Finite Element Model

The viaduct is modeled with a simple supported box girder which is 32 m long and used in a high speed railway. The structure size is shown in the Fig. (1).

The box girder and the CRTSII track slab are simulated with solid45 element, the rail is simulated with beam188, the fastening and CA mortar is simulated with combine15, the finite element model is shown in Fig. (2). The bridge pier and some attached components are not considered, Table 1 show the relevant parameters.

2.1. Vehicle-Ballastless Track-Bridge Coupling System Model

The new Vehicle-Ballastless track-bridge coupling system is used in this paper [3], the vehicle is modeled to be

four driving wheel elements with a secondary suspension system. Car body, bogie and wheel set are considered to be rigid body, vertical motion is only concerned and the contact between wheel and rail is elastic. The analysis is divided in even track and uneven track. The vehicle is CRH3 and the speeds are considered from 230 to 410 km/h. We can get the wheel/rail forces in different conditions. When the track is even, the wheel/rail forces are unchanged with vehicle speed increasing. The stable value is floating in a small area near 69.7 KN [4].

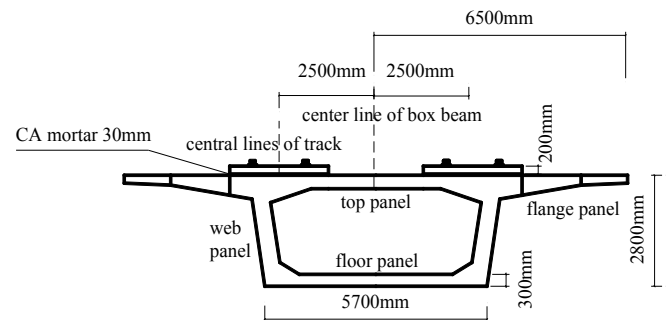


Fig. (1). Structure size.

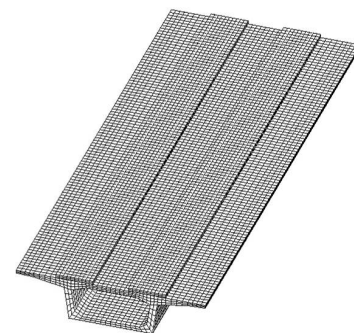


Fig. (2). Finite element model.

In the uneven track condition, the German high-speed low disturbance line is used to be the irregularity excitation. The irregularity sample is simulated in the method studied by Chen Guo [5]. The maximum wheel/rail forces in different speeds are listed in Table 2. It is shown that the forces are increasing with the speeds.

Table 1. The parameters of ballastless track and box girder.

Parameters	Value
Steel Rail density kg/m ³	7800
Track slab density kg/m ³	2500
Box girder density kg/m ³	2600
Stiffness of tie N/m	7.8e7
Damping of CA mortar N*s/m	8.3e4
Poisson ratio of slab	0.3
Poisson ratio of slab	0.176
Poisson ratio of girder	0.2
Stiffness of CA N/m	1.2e9
Young's modulus of rail GP	210
Young's modulus of slab GP	39
Damping of CA mortar GP	34.5
Damping of ties N*s/m	5e4

Then the forces were loaded them on the rail model based on the wheel position.

2.3. The Natural Analysis of Box Girder

By the modal analysis of the box girder, the natural vibration frequency bands before 500 can be computed, the frequency range from 0 to 401.2 Hz. The vibration frequency and modes before 10 are listed in Table 3.

It is shown that the first six modes are the global vibration and the remaining modes are all attributed to the local vibration. Thus the local vibration is high frequency vibration relatively.

3. THE INFLUENCE OF TRACK STATUS ON THE LOCAL VIBRATION

In the analysis of the transient dynamic behavior, 6 sensitive points at the mid-span section are selected. And the modal superposition method is used to calculate [6] based on the wheel position.

Table 2. Maximum of wheel/rail forces.

Speed (km/h)	Maximum of Wheel/Rail Forces (KN)	Speed (km/h)	Maximum of Wheel/Rail Forces (KN)
230	113.7	330	137.3
250	119.1	350	142.1
270	124.1	370	147.5
290	128.8	390	152.9
310	133.1	410	158.4

3.1. Even Track State

- (1) Through the analysis of the result, the maximum acceleration and Root Mean Square (RMS) of acceleration of all sensitive points in different velocities are shown in Fig. (5).

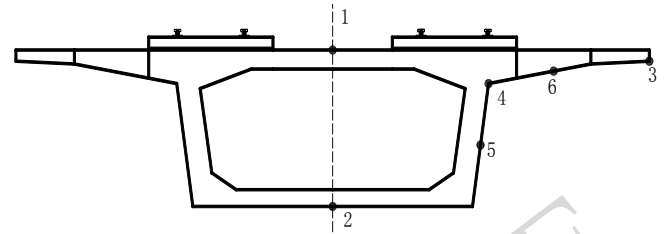


Fig. (4). The distribution of sensitive points.

The above figure shows that the maximums acceleration of all points are increasing gradually with the increasing of speeds. As known, the RMS of acceleration is an important indicator which can reflect the vibration very well. Fig. (5.1) show that all RMS are increasing with the speeds and the increasing rate of the six points are consistent. On the whole, an ascending order of the acceleration of the points at same speed is: point two, point one, point four, point five (four and five are similar), point six, point three.

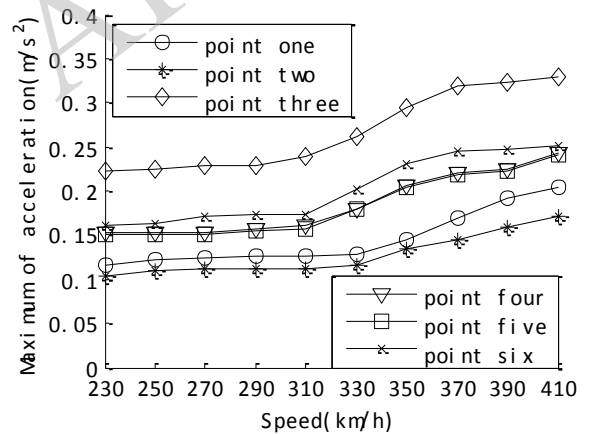


Fig. (5.1). The maximum acceleration.

- (2) The frequency analysis of the acceleration at the speed (230 km/h, 270 km/h, 310 km/h, 350 km/h, 390 km/h) is shown in Fig. (6).

The figures show that the dominant frequency of the points range from 0 to 189 Hz. When it is in the 0-22 Hz band, the vibration models in this frequency band belong to the global forced vibration. As it is more than 189 Hz, the amplitude is so small that the part can be neglected. At one

speed, the peaks of vibration of all points appear at the same frequencies. By contrast with the result of natural analysis, we can figure out that the frequencies of local vibration focus on 22-189 Hz.

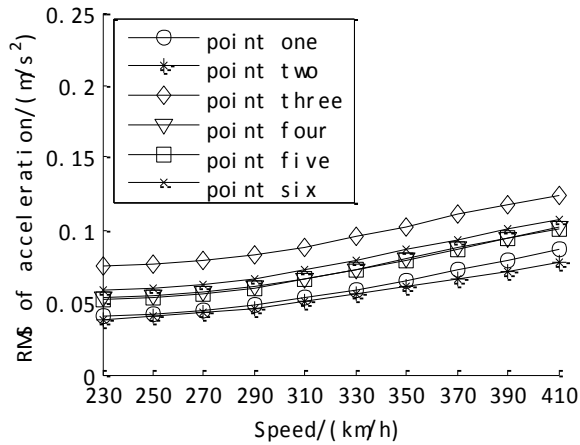
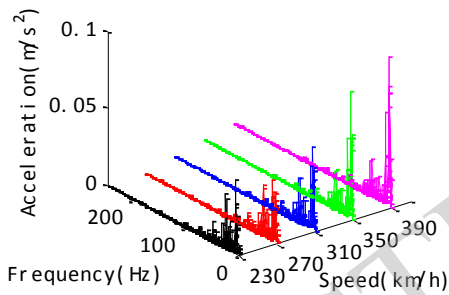


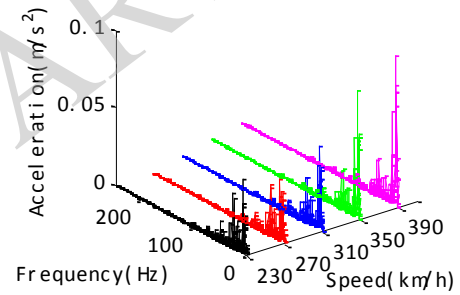
Fig. (5.2). Root Mean Square of acceleration.

Table 3. The first 10 order modal description.

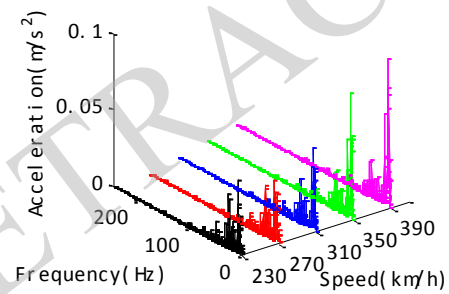
Modal Order	Natural Frequency/ Hz Frequency/Hz	Vibration Type Description
1	5.61	The first-order vertical bending
2	5.88	Dumping of box girder
3	10.58	The second-order vertical bending
4	12.67	The first-order torsion
5	14.71	The second-order torsion
6	17.54	Ant symmetric bending
7	22.81	Local vibration
8	24.60	Local vibration
9	26.35	Local vibration
10	26.91	Local vibration



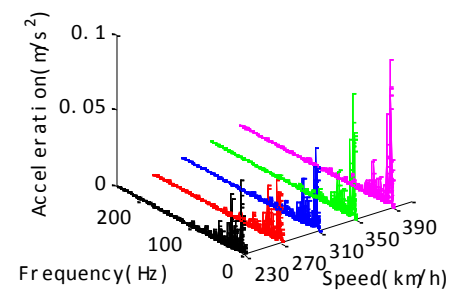
Point one



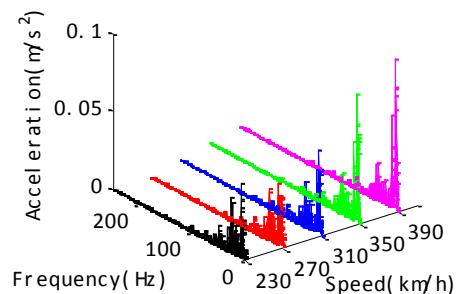
Point two



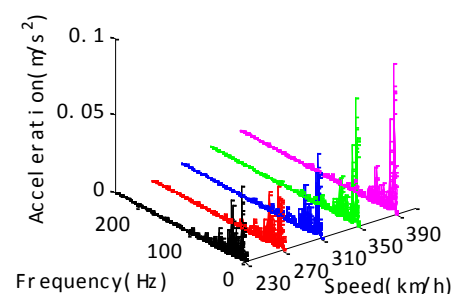
Point three



Point four



Point five



Point six

Fig. (6). The frequency spectrums of the points.

3.2. Track Irregularity State

In this state, the maximum acceleration and RMS acceleration of all sensitive points in different velocities is of shown in Fig. (7).

(2) Compared the Fig. (7.1) with the Fig. (7.2), the accelerations in track irregularity is 10 times that of them

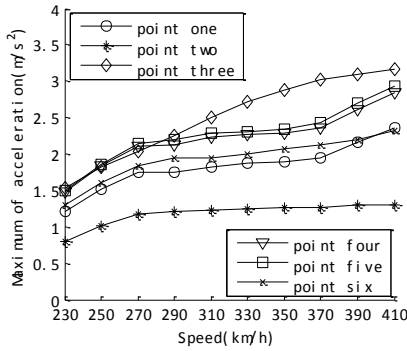


Fig. (7.1). The maximum acceleration.

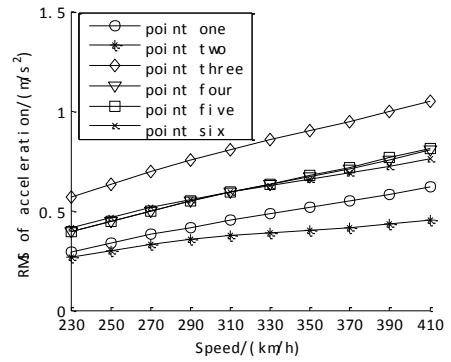
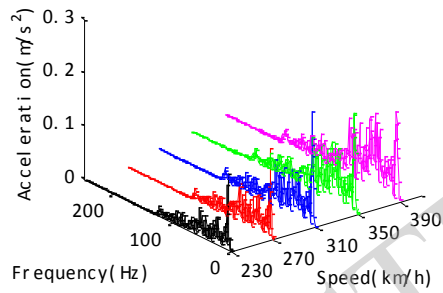


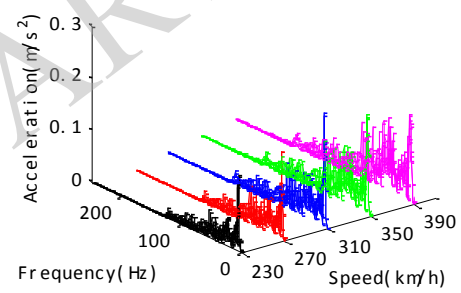
Fig. (7.2). Root Mean Square of acceleration.

in track even. It can figure out that track irregularity is the main factor caused the local vibration. When the speed is 410 km/h, the acceleration of point three is 3.37 m/s² and the acceleration of point two is 1.09 m/s². The values don't exceed the value of the standard-5 m/s².

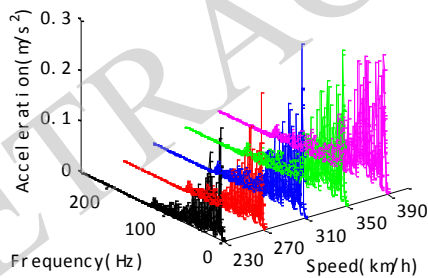
It is shown that the RMS of point three is larger significantly than other points. Thus as the high speed train load on the box girder, the flange panel of the girder vibrates



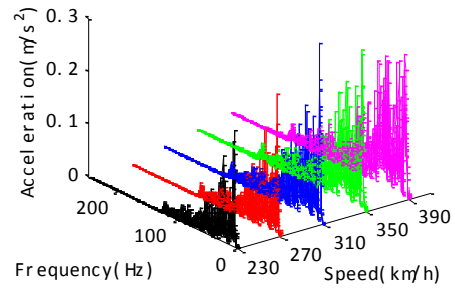
Point one



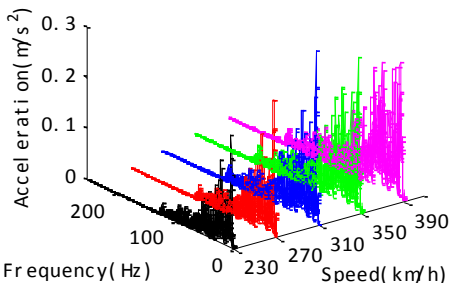
Point two



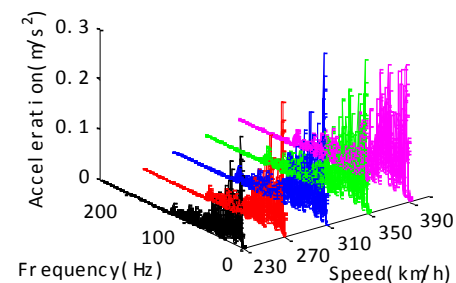
Point three



Point four



Point five



Point six

Fig. (8). The frequency spectrums of six sensitive points.

more strongly than other parts. The amplitude of point two is the least.

- (3) At this status, the frequency analysis of the acceleration at speed (230 km/h, 270 km/h, 310 km/h, 350 km/h, 390 km/h) is shown in Fig. (8).

The figures show that the dominant frequency of the points range from 0 to 199 Hz. From 0 to 22 Hz, the peaks appear the same as the forward status and it is the global forced vibration. Compared to the even track, the distribution intervals of local vibration extend a little. Table 4 lists the dominant frequency of local vibration between the irregularity track and even track.

Table 4. Frequency interval distribution.

Speed	Dominant Frequency of Local Vibration (Hz)	
	Even Status	Irregularity
230	22-108	22-120
250	22-117	22-128
270	22-126	22-136
290	24-135	24-148
310	24-144	24-156
330	24-153	24-167
350	26-162	26-176
370	26-171	26-184
390	28-180	28-191
410	28-189	28-199

4. INFLUENCE OF BOUNDARY CONDITION ON LOCAL VIBRATION

In this paper, two kinds of boundary condition—simple support condition and fixed condition—are compared. The fixed beam refer to a beam that the six degrees of freedom of the both ends are constrained. Table 5 lists the first ten natural frequencies. It is shown that the frequencies of the fixed boundary condition are larger than simple support condition.

Table 5. The natural frequencies of the first ten order.

Modal Order	The Natural Frequencies (Hz)	
	Simple Support	Fixed
1	5.61	6.43
2	5.87	6.97
3	10.58	12.69
4	12.67	13.26
5	14.7	14.77
6	17.54	19.68
7	22.81	23.05
8	23.6	24.61
9	25.35	26.48
10	26.9	27.96

Table 6 lists the maximum acceleration of all the points on the two conditions. As the table show, the behavior of fixed girder is weaker than the simple support girder overall. Based on the third row which shows the reducing percentage, we summed that the influence on the point three and six is not obvious. Therefore the fixed girder is valid to reduce the local vibration behavior of top panel, floor panel and web panel. And the effects on flange panel of both sides are not obvious.

Table 6. Maximum acceleration of the points.

Point Number	Maximum Acceleration (m/s ²)		Reducing Percentage (%)
	Simple Support	Fixed	
Point one	1.52	1.27	16.22
Point two	1.02	0.90	11.49
Point three	2.09	2.13	1.6
Point four	1.83	1.49	18.31
Point five	1.86	1.52	18.17
Point six	1.60	1.53	4.12

CONCLUSION

- (1) Through the analysis of local vibration on the finite element model, the vibration of flange panel is strongest and the floor panel is the weakest at the same speed and track status.
- (2) The dominant frequency interval of the local vibration is focus on 22-199 Hz. The interval will extend with the speed increasing.
- (3) Track irregularity is the main factor to cause the local vibration. It is great that the influence of the track irregularity on the local vibration.
- (4) The effects of local vibration on the boundary conditions are discussed. The response of top panel, floor panel and web panel were different and the flange panel was similar between the simple supported beam and the fixed beam.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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