TELKOMNIKA, Vol.11, No.3, March 2013, pp. 1383 ~ 1392
ISSN: 2302-4046

Vibration Characteristics of the Platform in high-speed Railway Elevated Station

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Abstract

Aiming at a large number construction of high-speed railway and elevated railway passenger station, make a dynamics simulation study on the law of platform vibration characteristics on the situation of high-speed train passing through. First, make a brief introduction on the theory of the interaction of the vehicle-elevated station structure in vertical and transverse directions. Secondly, on the background of the actual elevated station structure form, selecting relevant model parameters, establish the train-elevated station coupling dynamics simulation analysis model and calculate it. Finally, based on the calculation results, make an analysis of vibration characteristics of the platform structure, and obtain relevant study conclusions.

Keywords: *high-speed railway, elevated railway station, platform structure, vibration characteristics*

1. Introduction

With the rapid development of high-speed railway, a large number of elevated railway passenger stations will be put into building and using. The high speed of train will generates dynamic impact effect on the elevated station when it passes through, which will not only affect the life of elevated station and its work status, but also the health and mood of the travelers in the station [1]. The security of elevated station and the comfortableness of travelers make it receive increasing attention to the vibration effects of the elevated station structure causing by train dynamic load, and many scholars began to study structural vibration characteristics of the elevated railway passenger station. In 2001, Wen Yuping put forward "two-step analysis method" which is applicable to the dynamic analysis of building-bridge combination elevated railway station, however, the deficiencies of this method is not consider the coupling interaction between the bridge and the framework [2]. Liu Feng, in his master's degree thesis, studied up on the noise and vibration of elevated station in the urban rail traffic [3]. Zhou Tao, in his master's degree thesis, studied up on the vibration response of the elevated station on the situation of high-speed train passing through. It is not only take the coupling effect between vehicle and structure into consideration, but also raise a kind of feasible and effective calculating method [4]. Qiao Xiaolin, in her master's degree thesis, used the method of equivalent spring stiffness, and take the impact of station structure causing by train's driving force and braking force into consideration [5]. But the study of vibration characteristics is mainly concentrated in the station house of the elevated passenger station; the study of vibration characteristics on the platform of elevated station is relatively few.

Therefore, this article based on the structural form of an actual elevated passenger station, start from introducing the theory of vehicle-structure interaction. And then make a simulation calculation for the train passing through an elevated station by using LS-DYNA a software of dynamic finite element analysis. Using the calculation results, analyze the vibration regulation of the platform when the train passes through the elevated station and the affection on the vibration regulation of the platform caused by train's speed.

2. Structure Form of the Elevated Passenger Station's in this Article

The elevated station in this article is a typical Two-lane railway elevated passenger station. The ballastless track model is based on the CRTSI flatbed ballastless track structure

Received October 13, 2012; Revised January 15, 2013; Accepted January 26, 2013

used in intercity high-speed railway. The ballastless track is composed of rail, fastening system, track plate, CA mortar and concrete base. The main structure of this elevated station has 5 bridge spans, and both track beam and platform beam are continuous beams. Track beam is in the form of two-hole box beam structure and the platform beam is in the form of single-hole box beam. The bridge pier's type of the elevated station is in the form of letter "m". The overall rendering picture of the station is shown in Figure 1, and the sectional structure design picture of the station is shown in Figure 2.

Figure 1. The overall rendering picture of the station

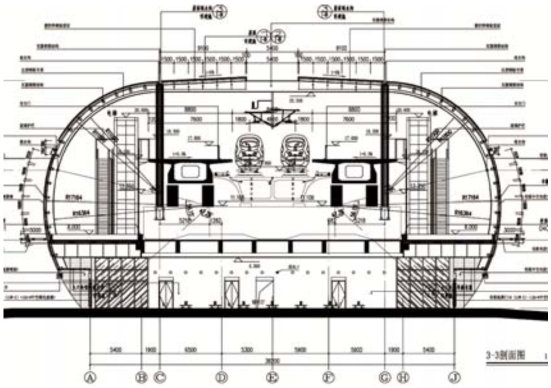

Figure 2. The sectional structure design picture of the station

3. Vehicles-Station Structure Interaction

3.1. The Dynamic Equation of Vehicles Model

In this article, vehicle model adopt the typical four-axis vehicle model. The vehicle is composed of body, bogie, wheel, the primary suspension and secondary suspension. Vehicle body, bogie and wheel are considered as rigid body, and vehicle body and bogie are only considered the degree of freedom in *Y, Z*, R_X, R_Y and R_Z five directions. The typical four-axis vehicle model is shown as the Figure 3 [6].

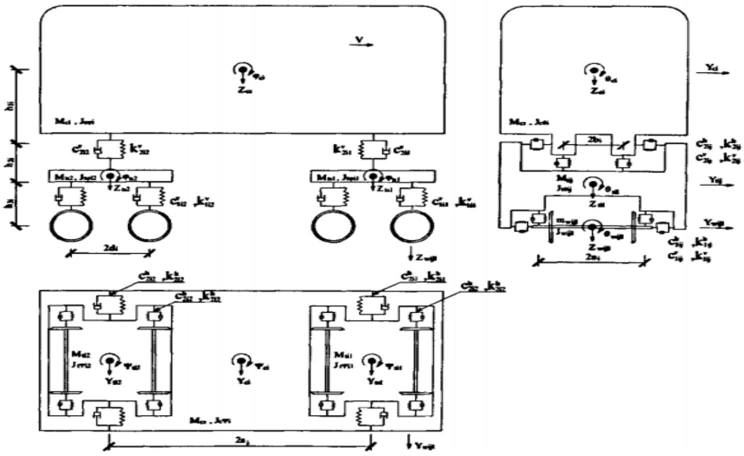

Figure 3. The typical four-axis vehicle model

Based on the assumption of the vehicle and the vehicle model shown in Figure 3, this paper establish the vehicle's equations of motion by Lagrange method. The vehicle's equations of motion shown as follows:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_k}\right)-\frac{\partial T}{\partial q_k}+\frac{\partial V}{\partial q_k}+\frac{\partial Q}{\partial \dot{q}_k}=0 \quad (1)$$

In the formula above, T is the total kinetic energy of the vehicle system movement, V is the total elastic potential energy, and Q is the total damping dissipated energy. T, V and Q can be linearly represented by the displacement, velocity and acceleration of vehicle body, bogie and wheel.

According to the above formula, the typical dynamic equation of vehicle subsystem can be established:

$$M_V \ddot{X}_V + C_V \dot{X}_V + K_V X_V = F_V \quad (2)$$

In the formula: M_V - the overall mass matrix of the vehicle subsystem
C_V - the overall damping matrix of the vehicle subsystem
K_V -the overall stiffness matrix of the vehicle subsystem
F_V - the overall external force matrix of the vehicle subsystem

3.2. The Dynamic Equation of Station Structure Model

The station structure subsystem is a linear system. In the course of study, the overall mass matrix, the overall damping matrix and the overall stiffness matrix of the station structure subsystem are all constants. Only considering the force on station structure subsystem given by vehicle subsystem in Y, Z and R_X directions, establish the dynamic equation of station structure subsystem:

$$M_B \ddot{X}_B + C_B \dot{X}_B + K_B X_B = F_B \quad (3)$$

In the formula: M_B - the overall mass matrix of the station structure subsystem
C_B - the overall damping matrix of the station structure subsystem
K_B - the overall stiffness matrix of the station structure subsystem
F_B - the overall external force matrix of the station structure subsystem

3.3. The Dynamic Balance Equations Set of Vehicles-Structure System

The relationship of the interaction between vehicle and structure is shown as the Figure 4, and calculate the external force F_V of vehicle subsystem and the external force F_B of station structure subsystem, by the relationship shown in Figure 4 [7]. Through the dynamic equations of the two subsystems, establish the vehicle-structural dynamic balancing equation set and solve it. Then research the vibration characteristics of the station platform on the situation of train passing through. The simultaneous equation set make up by formula (2) and formula (3) shown as follows:

$$\begin{cases} M_V \ddot{X}_V + C_V \dot{X}_V + K_V X_V = F_V \\ M_B \ddot{X}_B + C_B \dot{X}_B + K_B X_B = F_B \end{cases} \quad (4)$$

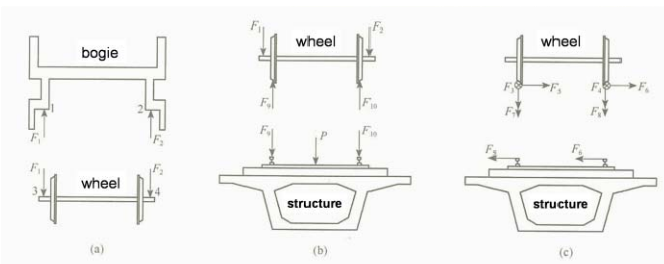

Figure 4. The relationship of the interaction between vehicle and structure

4. Establishment of Finite Element Simulation Model
4.1. Selection of the Model Element Type
This article uses the LS-DYNA, a finite element software to establish the model of train-elevated station system.

SOLID164 entity unit of LS-DYNA is used for rail, track plate, CA mortar layer, concrete base, track beam, m-type pier, platform beam, vehicle body, bogie and wheel; and the COMBI165 spring-damper unit is used for fastening systems, beam bearings , primary suspension and secondary suspension of the vehicle.

4.2. Parameters of the Model
The selection of the high-speed train's parameter refers to the CRH2 vehicle which the axle load is 12t, wheelbase is 2.5m and the length between vehicle bogie centers is 18m. Parameters of elevated line and elevated station are shown as the Table 1 [8].

Table 1. Parameters of elevated line and station

parameter	value
Rail elastic modulus/ (N/m^2)	2.06×10^{11}
Rail Poisson's ratio	0.3
Fastener vertical stiffness/ (N/m)	6.0×10^{7}
Fastener vertical damping/ ($N\cdot s/m$)	7.5×10^{4}
Fastener transverse stiffness/ (N/m)	3.0×10^{7}
Fastener transverse damping/ ($N\cdot s/m$)	6.0×10^{4}
Fastener distance/ (m)	0.6
Track plate elastic modulus/ (N/m^2)	3.5×10^{10}
Track plate Poisson's ratio	0.167
CA mortar elastic modulus/ (N/m^2)	3.0×10^{8}
CA mortar Poisson's ratio	0.4
Concrete base elastic modulus/ (N/m^2)	2.4×10^{10}
Concrete base Poisson's ratio	0.2
Beam elastic modulus/ (N/m^2)	3.5×10^{10}
Beam Poisson's ratio	0.167
Track beam height/ (m)	3
Track beam roof plate width/ (m)	12.2
Track beam bottom plate width/ (m)	6.328
Track beam bearing stiffness/ (N/m)	8.0×10^{8}
Track beam bearing damping/ ($N\cdot s/m$)	6.8×10^{6}
Platform beam height/ (m)	2.7
Platform beam roof plate width/ (m)	9.2
Platform beam bottom plate width/ (m)	4
Platform beam bearing stiffness/ (N/m)	6.3×10^{8}
Platform beam bearing damping/ ($N\cdot s/m$)	2.04×10^{5}
Pier elastic modulus/ (N/m^2)	3.55×10^{10}
Pier Poisson's ratio	0.3
Pier height/ (m)	13.5

4.3. Establishment of the Simulation Model
In the model of train-elevated station system, train is composed of 3 vehicles. Single vehicle's finite element model is shown in Figure 5 [9], and the elevated station model is shown in Figure 6. By setting the contacted relationship between wheel and rail, assemble the train and the elevated station together [10]. The train-elevated station system dynamic simulation analysis model is shown in the Figure 7.

5. Calculation of the Finite Element Simulation Model and the Analysis of Results
5.1. The Conditions of the Calculation and the Contents of the Analysis
Due to it is the study about the vibration of platform causing by high-speed train in this article. Choosing the speeds of the train are 250km/h, 280km/h, 300km/h, 320km/h and 350km/h as the five conditions of the calculation. After the calculation, the results of calculation will be analyzed. There are three parts of the analysis. First, study about the law of vibration

acceleration and deformation in the mid-span of the platform beam when the train passes through the station in the speed of 250km/h. The calculation points in the mid-span of the platform are shown in Figure 8. Second, selecting the calculation points at the centre of each span on the driving side platform, study the vibration law of the whole five span continuous platform beam structure when the high-speed train passes through the station in the speed of 250km/h. Third, take a comparative analysis of the vibration characteristic of the platform in five kinds of calculation conditions, and then, get the influence on the vibration of platform causing by different speeds of the train.

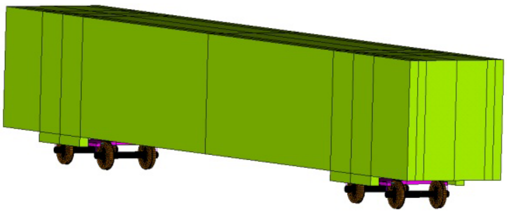

Figure 5. Vehicle finite element model

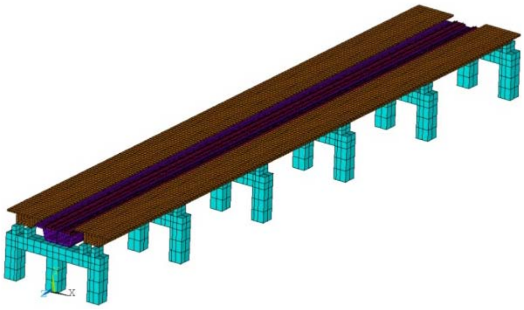

Figure 6. Elevated station finite element model

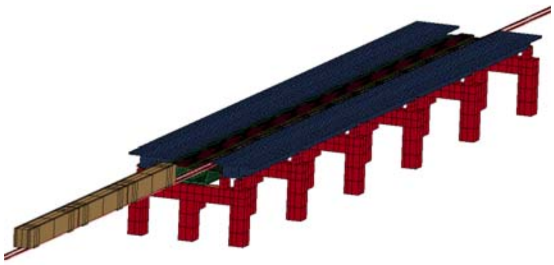

Figure 7. Train-elevated station finite element model

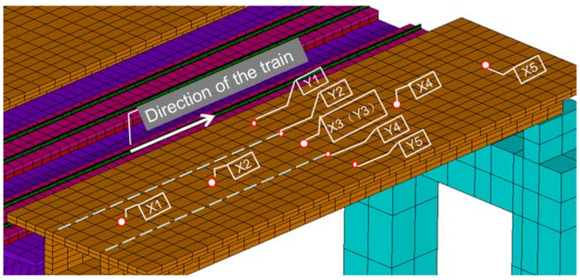

Figure 8. the calculation points in the mid-span of the platform beam

5.2. Results of the Simulation Calculation

Making use of the simulation calculation model which has established above to calculate the five different conditions and get the calculation results. The force in the longitudinal direction causing by the train is not taken into consideration in this article. Vertical acceleration time-history curve of the calculation point X3 in the centre of the platform beam's mid-span when the train passes through the station in the speed of 250km/h is shown in the Figure 9. Vertical displacement time-history curve is shown as the Figure 10. Transverse acceleration time-history curve is shown as the Figure 11. Transverse displacement time-history curve is shown as the Figure 12. The vibration characteristic's summit values of the calculation points in the mid-span of the platform beam are shown in Table 2 and Table 3. The summit values of vibration characteristics in the centre of each span are shown in Table 4. The summit values of the centre of the mid-span of the platform beam in five kinds of calculation conditions are shown in Table 5.

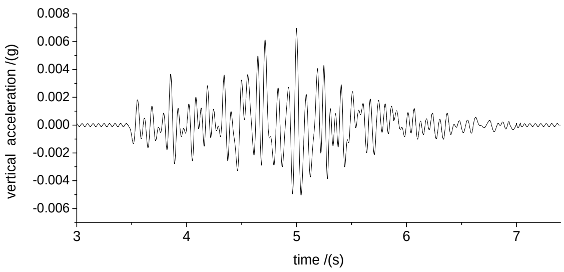

Figure 9. the vertical acceleration time-history curve of point X3

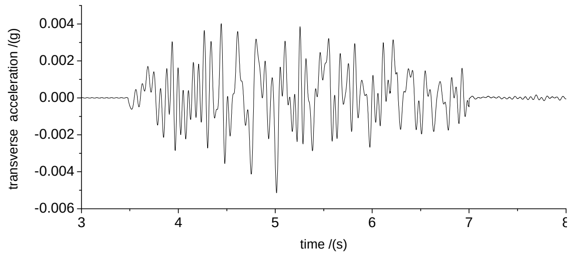

Figure 11. the transverse acceleration time-history curve of point X3

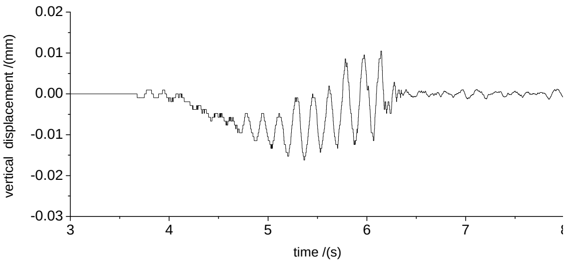

Figure 10. the vertical displacement time-history curve of point X3

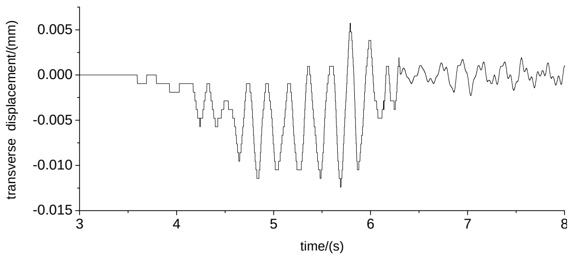

Figure 12. the transverse displacement time-history curve of point X3

Table 2. The summit values of vibration characteristics from X1 to X5

	X1	X2	X3	X4	X5
vertical acceleration/(g)	0.00840	0.00783	0.00696	0.00743	0.00883
vertical displacement/(mm)	0.01335	0.01431	0.01621	0.01444	0.01240
transverse acceleration/(g)	0.00749	0.0070	0.00514	0.00653	0.00809
transverse displacement/(mm)	0.01049	0.010798	0.0124	0.01084	0.010398

Table 3. The summit values of vibration characteristics from Y1 to Y5

	Y1	Y2	Y3	Y4	Y5
vertical acceleration/(g)	0.00672	0.00870	0.00696	0.00852	0.0064
vertical displacement/(mm)	-0.0248	-0.01907	-0.01621	-0.01526	0.01621
transverse acceleration/(g)	0.00539	0.00716	0.00514	0.00695	0.00519
transverse displacement/(mm)	0.01192	0.01192	0.0124	0.0124	0.0124

Table 4. The summit values of vibration characteristics in the centre of each span

	centre of 1 span	centre of 2 span	centre of 3 span	centre of 4 span	centre of 5 span
vertical acceleration (g)	0.0045	0.0056	0.00696	0.00583	0.00429
vertical displacement (mm)	0.01435	0.012398	0.01621	0.014305	0.016212
transverse acceleration (g)	0.007	0.00778	0.00514	0.00752	0.00758
transverse displacement (mm)	0.0095	0.0124	0.0124	0.01335	0.0114

Table 5. The summit values of vibration characteristics in the centre of mid-span of the five conditions

	250km/h	280km/h	300km/h	330km/h	350km/h
vertical acceleration （g）	0.00696	0.00607	0.00645	0.00868	0.01191
vertical displacement（mm）	0.01621	0.016212	0.01812	0.018659	0.01935
transverse acceleration（g）	0.00514	0.005063	0.00576	0.00767	0.00769
transverse displacement（mm）	0.0124	0.01144	0.01526	0.01533	0.01536

5.3. The Analysis of the Results

First, the variation of vibration characteristic in the mid-span of platform is going to be analyzed. In order to describe the vibration characteristic along the line’s longitudinal direction clearly, illustrate the data of table 2 and get Figure 13 - Figure 16.

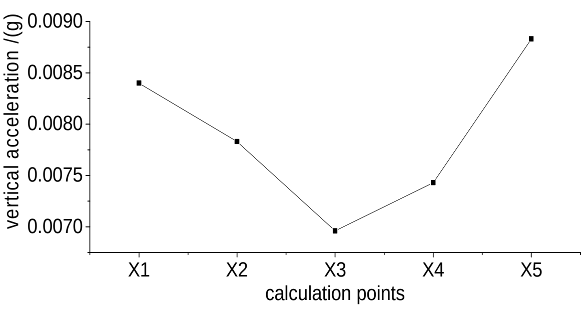

Figure 13. summit value of vertical acceleration of calculation points X1 to X5

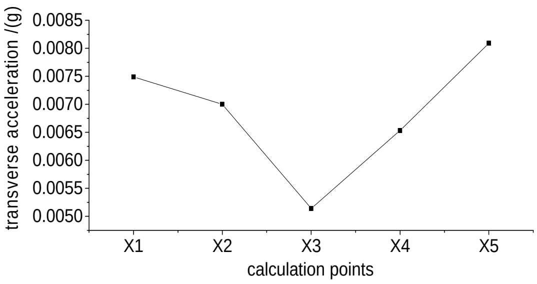

Figure 15. summit value of transverse acceleration of calculation points X1 to X5

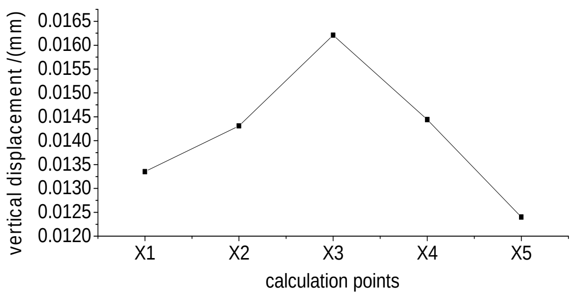

Figure 14. summit value of vertical displacement of calculation points X1 to X5

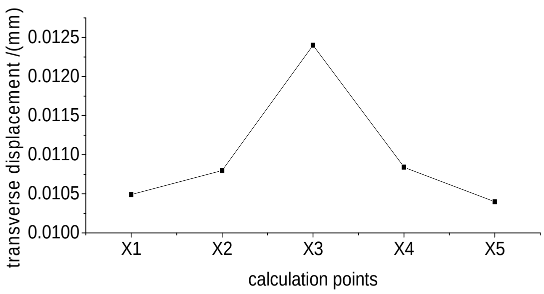

Figure 16. summit value of transverse displacement of calculation points X1 to X5

It can be noticed form Figure 13 and Figure 15 that the acceleration value of point X3 comes to the summit. On the contrary, the displacement value of point X3 is lower than other points known from Figure 14 and Figure 16. The reason of this phenomenon is that the stiffness at the centre of the span is relatively weak, but strong at the junction between beam and pier. And the variation of the vibration characteristics is substantially symmetrical because of the symmetrical of the structure.

The vertical displacement variation of calculation point Y1 to Y5 will be analyzed in this part. There is a clearly envelopment relationship among vertical displacement time-history curves shown in Figure 17. A negative displacement mainly appears on the point Y1 which near the track, but a positive displacement mainly appears on the point Y5. So it can be concluded that the platform not only have a settlement deformation but also a torsion deformation to the track direction.

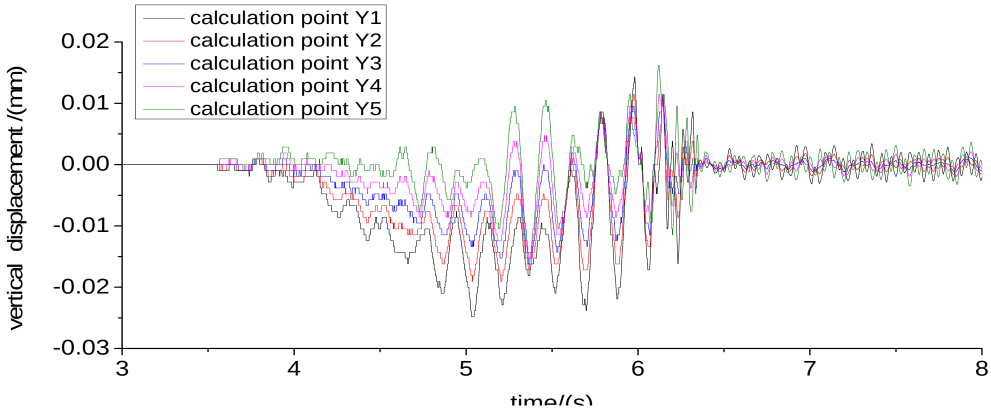

Figure 17. The vertical displacement time-history curves of the calculation points Y1 toY5

Second, make an analysis of the vibration characteristics variation of whole five-span continuous platform beam. Based on the data in Table 4, illustrate the variation of vibration characteristic in Figure 18 - Figure 21.

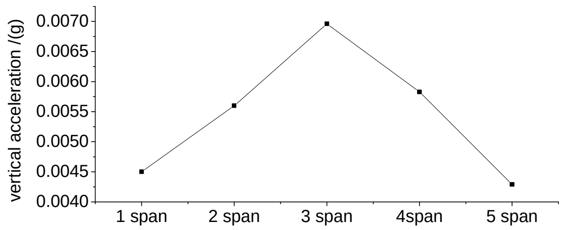

Figure 18. summit value of vertical acceleration in the centre of each span of the platform

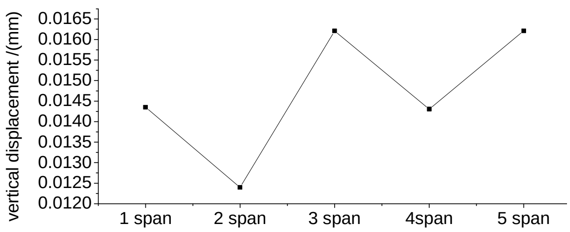

Figure 19. summit value of vertical displacement in the centre of each span of the platform

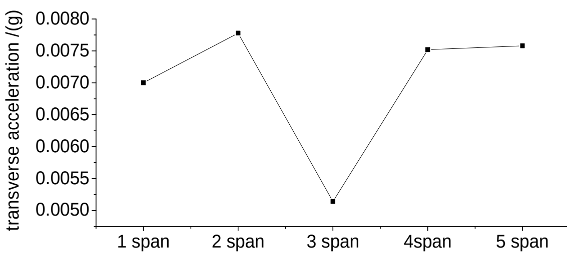

Figure 20. summit value of transverse acceleration in the centre of each span of the platform

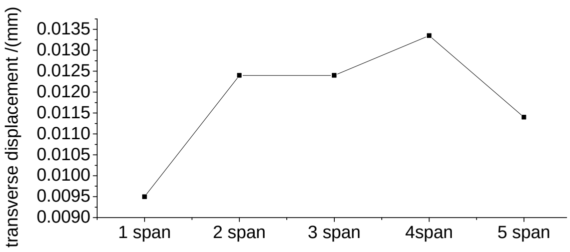

Figure 21. summit value of transverse displacement in the centre of each span of the platform

It can be concluded that the summit values of vertical acceleration and transverse acceleration will not appear at the same time. In the aspect of displacement, the vertical displacement is bigger than the transverse displacement and their variations are different.

Third, analyze the influence on vibration of platform causing by the speed of train. Via the Table 5, the change law of vibration characteristic is shown in Figure 22 - Figure 25.

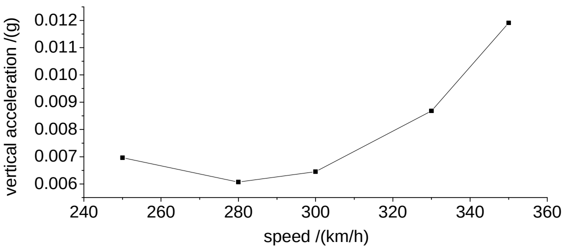

Figure 22. the variation of vertical acceleration in five conditions

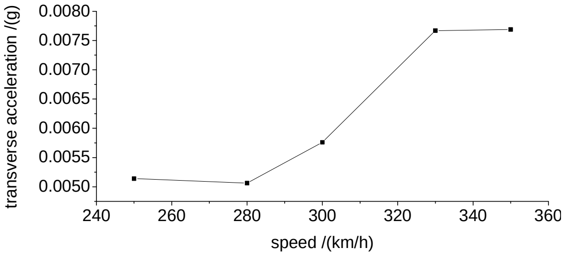

Figure 24. the variation of transverse acceleration in five conditions

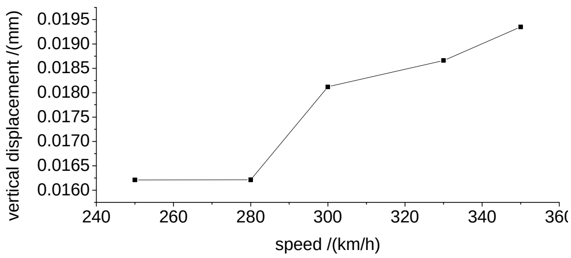

Figure 23. the variation of vertical displacement in five conditions

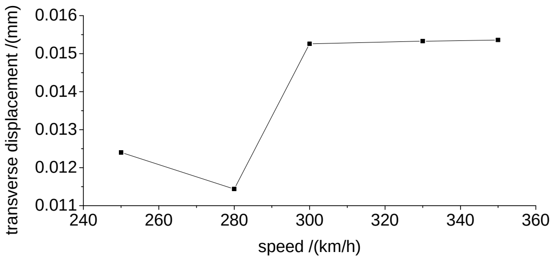

Figure 25. the variation of transverse displacement in five conditions

As is shown in the Figures, the vibration characteristics of the platform will increase with the improving of train's speed. Especially from 300 km/h to 330 km/h, the acceleration of both vertical and transverse have an obvious increase, and the displacement in vertical and transverse directions have an obvious increase when the train's speed improve from 280 km/h to 300 km/h.

6. Conclusion

After the analysis of the platform's vibration characteristics under the situation of the train passing through, this article gets the conclusion as follows:

(1) This article Figures out vibration form of the platform by the vibration time-history curves.
(2) The acceleration at the centre of one span is smaller than it at the both ends of the span in platform beam, but the displacement is just the opposite. There are settlement deformation and torsion deformation to the track two parts of the platform's displacement from the cross section.
(3) It can be known that the summit value of vertical vibration and summit value of transverse vibration will not appear at the same position of the platform when the train passes through the station.
(4) The acceleration has a obvious increase when the speed of train improve from 300 km/h to 330 km/h, and the displacement has a obvious increase when the speed of train improve from 280 km/h to 300 km/h. So it is suggested that the speed of the train should be under 300 km/h when the train passes through the station.

At last, this article emphasis on the theoretical study of the vibration of platform. If have the opportunity to test on the practical engineering will be better to provide advice to the engineering construction.

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