

Dynamic Response Analysis of Liaocheng Guangyue Tower Under the Ground Traffic Load

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Abstract. This paper takes liaocheng Guangyue Tower for study, it uses the 1/4 vehicle model of zhongtong bus LCK6105HGC, and it makes dynamic response analyses when ancient timber structure's speed is 20km/h and 40km/h. The results show that when the vehicle speed is 40km/h, horizontal vibration velocity of the top column is 1.03 times than when vehicle speed is 20km/h. According to Technical specifications for protection of historic buildings against man-made vibration, horizontal vibration velocity of the top column is 0.156mm/s, and it is less than the limited one which is 0.196 mm/s.

Introduction

Guangyue tower is located in center of Liaocheng city. It's founded in 1374, which is composed of two parts of the high pedestal and the upper timber structure. The high pedestal is four prism. The length of the bottom edge is 34.43m and on the bottom side is 31.62m respectively. The height of this historic timber structure is 9.38m. On the wall of the four directions, there is one semicylinder arch in each wall, the center of the cross is the intersection of the arch form. The width of each arch is 5.76m and the vertical height is 2.88m. The upper timber structure is located in the central of high stylobate, which have four layers and 24 meters high. It is shown in Fig.1.



Fig.1 The panorama of Guangyue tower

Material parameters and section sizes

The material parameters and beam-column section sizes of the timber structure are shown in Table 1 and Table 2.

Table.1 material parameters.

Materia	Elastic Modulus(MPa)	Density(kg/m ³)	Poisson's Ratio
Wood	8307	410	0.25
Stylobate	129	1780	0.175
Soil	20	1800	0.35

Table.2 section of beam

Name	first and second column	third and fourth column	first beams	second beams	third and fourth column
Diameter(m)	0.6	0.4	0.3*0.3	0.21*0.37	0.35*0.45

Finite element model

The upper beam and column are simulated by beam188 element. The high pedestal and soil used SOLID45 element simulation. The beam-column mortise and tenon connection node are simulated by spring element COMBIN14. The stiffness of mortise and tenon are $K_x=K_z=1.71 \times 10^7 \text{N/m}$, $K_y=2.08 \times 10^8 \text{N/m}$. The rotational stiffness are $6.244 \times 10^8 \text{N/m}$ [1]. The finite element model of Guangyue tower is shown in Fig.2.

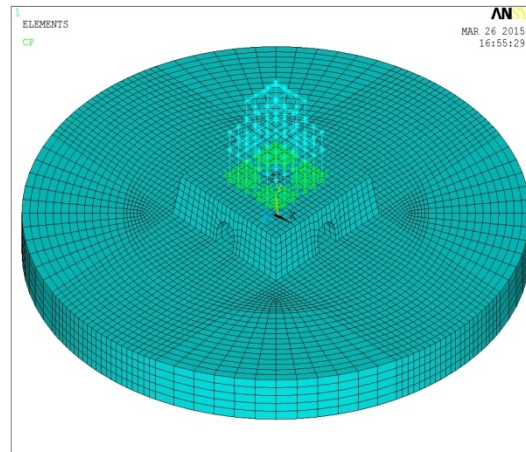


Fig.2 The whole finite element model

The dynamic response of Guangyue tower

At present, there are mainly three kinds of vehicle models: 1/4 vehicle model[2], 1/2 vehicle model model[3]and the whole vehicle model, which is widely used as the vehicle model and the quarter vehicle model. A lot of experimental analysis shows that the 1/4 vehicle model can accurately predict the vertical vibration of the vehicle. Therefore, this paper uses 1/4 vehicle model. The vehicle load expression[4] is as follows:

$$F(T) = P_0 + P \sin(\omega t) \quad (1)$$

In the formula: P_0 —static load of the wheel; P — the amplitude of the vibration load, $P = M_0 a w^2$, M_0 represents a spring mass, a is the geometric irregularity rise, which reflect the condition of the road; w is the vibration circle frequency, n is the vehicle running speed, L is the geometric curve (car length) pavement wavelength.

This paper select the representative of Zhongtong bus in the Liaocheng city with the LCK6105HGC simulation of ground traffic load, the whole vehicle quality 16000kg, rated capacity of 78 people. Taking the per person as 60kg, the total quality of the bus is 20680kg. For the specific

parameters of the vehicle: single side static wheel weight $P_0 = 51.7\text{KN}$, spring quality $M_0 = 120\text{N} \cdot \text{S}^2/\text{m}$, $a = 2\text{mm}$, $L = 10.5\text{m}$.

This paper select the speed of 20 km/h and 40 km/h as excitation and take each of them into the equation (1) respectively:

$$F(t) = 51700 + 2.61\sin(3.3t) \quad (2)$$

$$F(t) = 51700 + 10.5\sin(6.6t) \quad (3)$$

Using the equation (2) and (3), the load-time history and frequency spectrum can be obtained under different speed though Matlab software programming. It is shown in Fig.3~Fig.4.

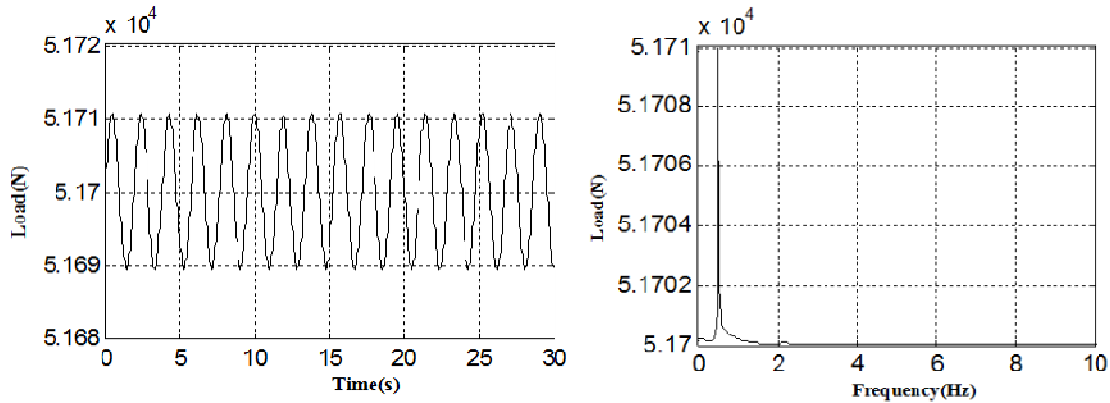


Fig.3 Load-time history and frequency spectrum ($v=20\text{km/h}$)

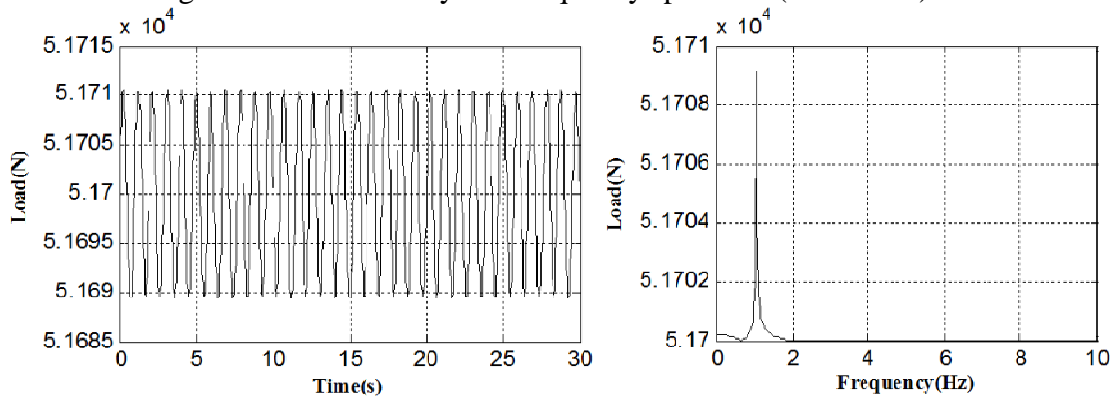


Fig. 4 Load-time history and frequency spectrum ($v=40\text{km/h}$)

To predict the traffic conditions in the rotary road of Guangyue Tower, this paper assume that the safety distance between two travelling vehicles is 40 meters. Meanwhile, according to length of the bus is 10.5m, it can calculated that the rotary road can accommodate up five buses at the same time. Taking the load to the finite element model and the load mode is shown in Fig.5.

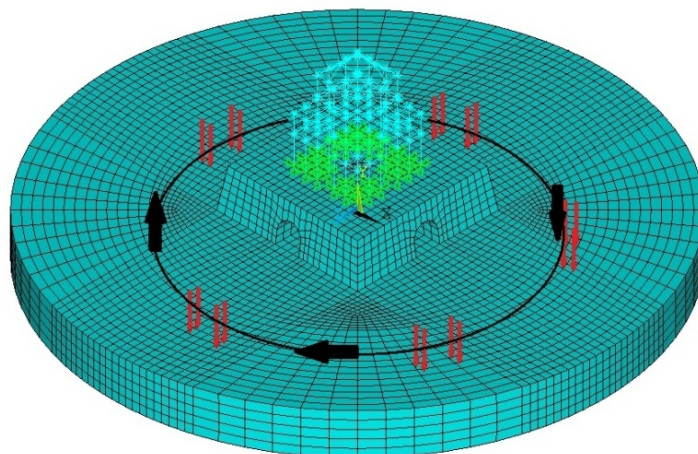


Fig.5 vehicle load mode

Analysis of calculation results

To analyze the vibration of corner post and stele in Guangyue Tower every layer, this paper select eight vibration points. It is shown in Fig.6, the dynamic model divided eight vibration points into four groups. Each of them include two points which represent the top node of corner column and stele in Guangyue Tower each layer. Horizontal velocity amplitudes of every vibration points can be shown in Fig.7.

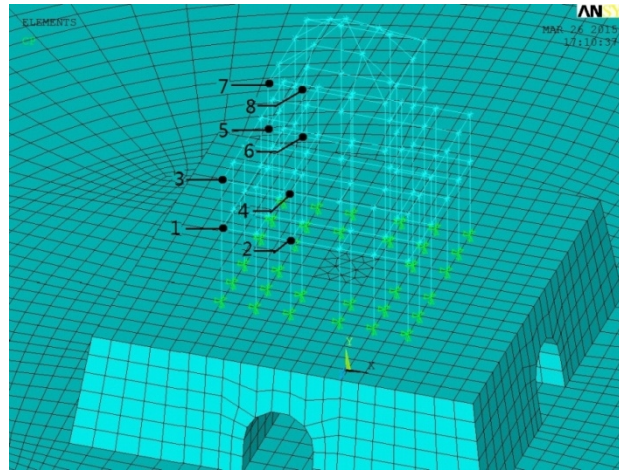


Fig.6 Schematic diagram of eight vibration points

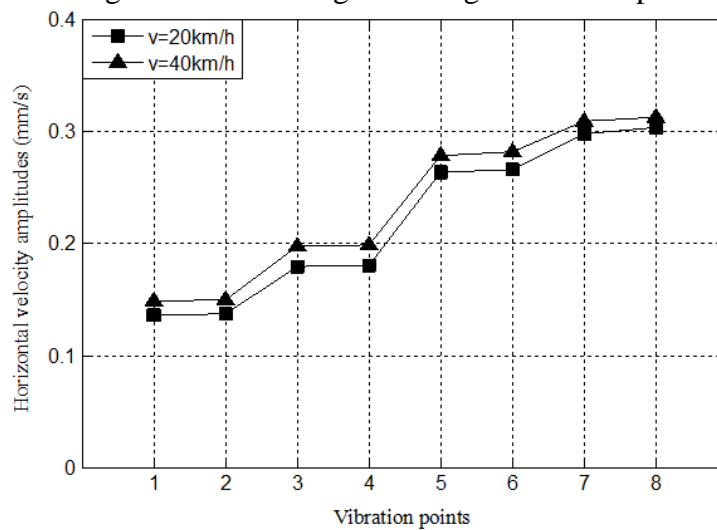


Fig.7 Horizontal velocity amplitudes of every vibration points

It is shown in Fig.7, the horizontal vibration velocity of stele in every layer is bigger than corner column slightly. Therefore, horizontal vibration velocity of the top of the column should be used to make traffic safety assessment; When the speed of travelling vehicles running at 40km/h, the maximum horizontal vibration velocity of stele in each layers were 0.1497 mm/s, 0.1993 mm/s, 0.2817 mm/s, 0.3125 mm/s, which is more than the one when driving at a speed of 20 km/h whose maximum horizontal vibration velocity were 0.1378 mm/s, 0.1806 mm/s, 0.2664 mm/s, 0.3042 mm/s.

Safety Assessment

According to *Technical specifications for protection of historic buildings against man-made vibration*[5], the historic timber structures vibration velocity limits is shown in Table. 3.

Table 3 The permitted oscillatory velocity of historic timber structure

Protection rank	Position of controlled point	Direction of controlled point	The permitted vibration velocity [mm/s]		
			<4600	4600—5600	>5600
The key places of historic sites under State Protection	Column top	Horizontal	0.18	0.18~0.22	0.2
The key places of historic sites under Province Protection	Column top	Horizontal	0.25	0.25~0.30	0.3
The key places of historic sites under City or county Protection	Column top	Horizontal	0.29	0.29~0.35	0.35

Note: Using the insertion method when the V_p is between the 4600-5600m/s .

Guangyue tower belongs to the national key cultural relics protection units. The wood elastic wave velocity is among 4600m/s and 5600m/s and the mean is 5011m/s. According to the standard, horizontal vibration velocity limit is 0.196 mm/s. Then, make safety assessment of Guangyue tower basis on the standard.

Horizontal vibration velocity amplitude of column cap in the five top columns is shown in Table 4.

Table.4 Horizontal vibration velocity of the top columns

Number	Column 1	Column 2	Column 3	Column 4	Column 5	Average	Final Value
Peak	0.312	0.313	0.312	0.312	0.313	0.313	0.156

It can be seen from table 3, half of the horizontal speed of top of column cap the average peak value is 0.156mm/s, which is less than the standard provisions of 0.196mm/s. It is conclude that the Guangyue tower is in a safe state under traffic excitation.

Conclusions

This paper using 1/4 vehicle mode to make vibration response analysis of Guangyue tower when vehicle speed were taken 20km/h and 40km/h. The results show that horizontal vibration velocity amplitude of column cap when vehicle speed in 40 km/h is 1.03 times of 20km/h. The measured horizontal vibration velocity is 0.156mm/s which less than the standard 0.196mm/s limit value. Therefore, It is conclude that the Guangyue tower is in a safe state under traffic excitation.

Acknowledgements

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