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Dynamic Characteristics of a Beam in an Existing Brick-concrete Structure

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

With heavy hammer hammering method and road roller vibrating fixed-point method, field tests on dynamic characteristics were conducted for the brick-concrete structure beam of a teaching building. The experiment results of heavy hammer hammering method show that the horizontal and vertical natural frequencies of the heavy hammer are respectively concentrated in 2.726 ~ 5.313 Hz and 3.596 ~ 9.104 Hz, horizontal and vertical peak acceleration values are respectively 489.56 ~ 532.05 m/s^2 and 248.77 ~ 494.61 m/s^2; the natural frequency of the beam in horizontal direction is close to the vertical, first and second order natural frequencies are around 76.2 Hz and 125.2 Hz, horizontal and vertical peak acceleration values of each measuring point are respectively 1.58 ~ 4.02 m/s^2 and 6.10 ~11.82 m/s^2, and the peak acceleration follows the law of exponential decay. The experiment results of road roller vibrating fixed-point method show that the natural frequency of each measuring point in horizontal direction and the vertical is consistent, the first three order natural frequencies are 11.63 Hz, 39.94 Hz and 60.54 Hz in turn, and corresponding damping ratios are 0.010, 0.011 and 0.006; the peak acceleration in horizontal and vertical is respectively 0.4486 m/s^2 and 0.1731 m/s^2. The calculated frequency compared with test results, the first order natural frequency is basically the same, the second order and third order calculated frequencies are respectively larger 10.9% and 64.6% than test results.

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1. INTRODUCTION

In engineering practice, the vibration is a widespread natural phenomenon, such as vibration problem of high-rise structures and large bridge under the wind load, the vibration of building structures under seismic loading. In general, the structure design and analysis of the static problem is primary, but sometimes the failure caused by dynamic load also not allow to ignore, it is the main cause of structure destruction, such as the 2008 when chuan earthquake. In bridge structures, due to its long-term dynamic load, so the research on the dynamic characteristics of the bridge is more. However, for building structures, only considering the influences of wind and earthquake when designing process, and effect probability of other dynamic loads is very small during the using period, but the beam as an important component can inherit and pass loads, in engineering structure design and safety evaluation, analysis of structural dynamic characteristics has very important significance.

Weifeng Sun [1] analyzed and calculated the reinforced concrete simply supported beam using the bar structure finite element dynamics principles, established the additional load beam dynamic analysis model, and then conducted excitation test with fast relaxation method, analyzed the dynamic characteristics of concrete beam. Xin Shang [2] taken reinforced concrete beam as the research object, based on the Euler Bernoulli beam theory and structural dynamics theory, through the numerical simulation, got the natural frequencies of different damage location and damage degree under the beam single damage cases and studied the change law of natural frequency for vibration response. Jinlv Tan [3] on the background of structural damage detection, conducted the dynamic test for unbounded-pre-stressed and self-compacting concrete model beams based on the modal vibration analysis theory, explored the change law of the stiffness and damping ratio of the pre-stressed beam. Long Liu [4] simplified the crowd to elastic quality model of uniform distribution, investigated the influence on the dynamic performance of the simply supported beam under the cases of the elastic quality model without damping and with damping, acquired the qualitative law of the crowd for structure dynamic influence. Li chao Zhou [5] tested the seismic performance for the whole pre-stressed slab (beam) column system by the use of maul and sweep method, analyzed the collected data use the spectrum analysis technology, and got the natural frequency and modal of the whole pre-stressed slab (beam) column structure, to establish structural dynamic model for and analysis seismic response provide reliable basis. Changpao Zhang [6] conducted the dynamic test on simple supported pre-stressed concrete beam, through analyzed the natural frequency data of pre-stressed concrete beams under various states, the dynamic characteristics of pre-stressed concrete beam and its main influencing factor of the low frequency were detailed researched. Fushou Liu [7] took a 30 m long span concrete simply supported T beam bridge and a biaxial load truck as an example, calculated the dynamic response of bridges under vehicle excitation, and frequency spectrum analysis was carried out. The results showed that bridge frequency take bridge vibration as the main form of vehicle - bridge system. Xiaoyan Sun [8] conducted repeated overload test on reinforced concrete simply supported beam, To evaluate structural damage adopted structural dynamic parameters provide a theoretical basis. Jianqing bu [9], in order to explore change law of natural frequencies and modal damping ratio on the reinforced concrete beam under different conditions, taped the beam top, took natural frequencies and corresponding modal damping ratio.

The different methods were used respectively to research dynamic characteristics of simple supported beam model under different conditions. This article selects a beam in the brick structure as the research object, decorates acceleration sensor reasonably in the beam, connects data analysis system, studies dynamic characteristics of the beam under different incentive effect with heavy hammer hammering excitation method and road roller vibrating fixed-point method, such as natural frequency and damping characteristics, provides a reference for similar dynamic characteristics test.

2 DYNAMIC TEST METHOD ON BRICK-CONCRETE BEAM

2.1 The Introduce of Engineering

As shown in Fig. 1 is a five layer brick-concrete structure, covered area is 5157 m^2, plan view size is 54 × 20 m, and height is 19.6 m above the ground. This building was built in1967, which is a teaching building. According to relevant regulations of local seismological bureau, the project is of 7 seismic intensity protection, seismic load and wind load were considered in design. Through the real-time online monitoring, data of building deformation and subsidence is obtained, the using state of the building is evaluated, and then to remote real-time on-line monitoring to provide reference for similar projects.

2.2 Monitoring Point Arrangement

In a beam of the brick-concrete building as shown in Fig. 1 arranging the acceleration sensors as shown in Fig. 2. The Fig. 3 shows acceleration sensors and heavy hammer hammering locations. Beam component is simplified as uniform section beam under the action of uniformly distributed load. Net span of beam component is 6 m, height of cross section is 0.6 m, and width is 0.25 m, uniformly distributed load is 21.67 kN/m. Fig. 4 is the heavy hammer used in the test, the LWH of heavy hammer is about 5 × 5 × 15cm, and the weight is 2.72 kg.

2.3 The Dynamic Action Applied Way

As shown in Fig. 3, 13 hammering points are evenly arranged on the side of the beam, each hammering point strikes once. In order to compare the corresponding relation of excitation and response, paste the number 924 sensors on the surface of heavy hammer using super glue, at the same time in order to reduce the secondary effect of heavy hammer and beam, paste a rubber mat on one side of the hammer contacted with the beam.

Figs. 5 and 6 show that the road roller acts dynamic load on the building. First, along the building moving and then micro vibrate and earthquake on a fixed position for a period of time. Road roller moved along A-B-C-D-C-B-A, and then it vibrates 40s in point A, the total time of vibration is about 4000s.

Fig. 1. Five layer brick-concrete structure

Fig. 2. The arrangement of acceleration sensor

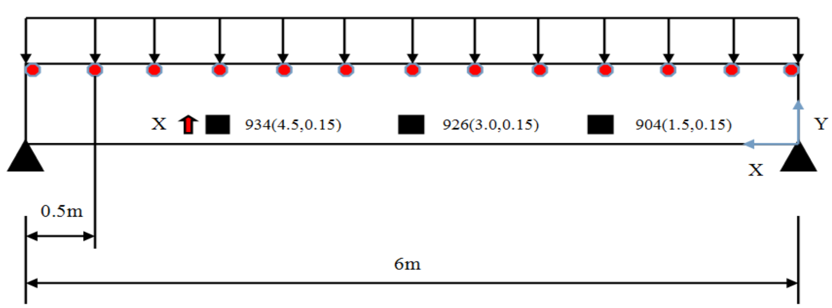

Fig. 3. The arrangement of acceleration sensors and hammering locations of the heavy hammer

Fig. 4. Heavy hammer under test fixed-point vibrating

Fig. 5. Diagram of the road roller

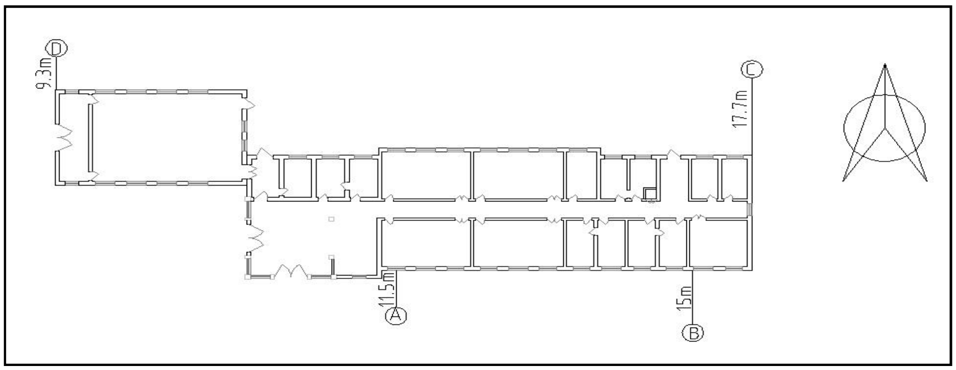

Fig. 6. Walk road map of road roller

3. THE NATURAL FREQUENCY OF SIMPLY SUPPORTED BEAM

Act uniformly distributed load on the simply supported beam, the uniformly distributed load according to the equivalent mass add to the simply supported beam, the equivalent mass is $m_{eq} = qL/g$, g is the acceleration of gravity. Natural frequencies of the bending beam is:

$$\omega_n = n^2\pi^2\sqrt{\frac{EI}{(m+m_{eq})L^4}} \quad (1)$$

$$f_n = \frac{\omega_n}{2\pi} \quad (2)$$

$$m = \frac{m_{\mathrm{con}}V_{\mathrm{con}} + m_{\mathrm{st}}V_{\mathrm{st}}}{V_{\mathrm{con}} + V_{\mathrm{st}}} = \frac{m_{\mathrm{con}}A_{\mathrm{con}} + m_{\mathrm{st}}A_{\mathrm{st}}}{A_{\mathrm{con}} + A_{\mathrm{st}}} \quad (3)$$

$$E = \frac{E_{\mathrm{con}}V_{\mathrm{con}} + E_{\mathrm{st}}V_{\mathrm{st}}}{V_{\mathrm{con}} + V_{\mathrm{st}}} = \frac{E_{\mathrm{con}}A_{\mathrm{con}} + E_{\mathrm{st}}A_{\mathrm{st}}}{A_{\mathrm{con}} + A_{\mathrm{st}}} \quad (4)$$

In which, ω_n is the n order circular frequency; m is the quality of beam. E is the beam elasticity modulus; I is the moment of inertia of beam section; L is the beam span; V_{con} and A_{con} is respectively the volume and the area of concrete in steel-concrete beam; V_{st} and A_{st} is respectively the volume and the area of steel in steel-concrete beam; E_{con} and E_{st} is respectively elastic modulus of concrete and steel in the steel-concrete beam.

In formula (1), elastic modulus of concrete is 32.5 GPa in steel-concrete beam, the steel is 207 GPa, the density of concrete and steel is respectively 2500 kg/m^3 and 7781kg/m^3. From formula (1), the first three order natural frequencies are 11.07 Hz, 44.30 Hz and 99.67 Hz.

4. THE RESULTS ANALYSIS OF DYNAMIC TEST

4.1 The Results Analysis of Heavy Hammer Hammering Method

4.1.1 Peak acceleration

Figs. 7 and 8 are respectively peak acceleration curves of heavy hammer and beam mid-span. Fig. 7 shows that the vibration time is around

0.05s, and each measuring point on beam is around 0.1s. The horizontal and vertical maximum peak acceleration of heavy hammer are respectively 489.56~532.05 m/s^2 and 248.77~494.61m/s^2, the average is 509.00 m/s^2 and 449.55 m/s^2.

Fig. 9 is peak acceleration changing curves of the mid-span point with the hammering location. Fig. 10 is the ratio changing curves with the hammering location of peak acceleration of the beam mid-span point and the heavy hammer point. From Figs. 9 and 10, the horizontal and vertical maximum peak acceleration of beam are respectively 1.58~4.02 m/s^{2}and 6.10~11.82m/s^2; the horizontal and vertical maximum peak acceleration ratio of beam mid-span and heavy hammer are respectively 0.00323 ~0.00789 and 0.01314~0.02679.

Figs. 11 and 12 are respectively the horizontal and vertical peak acceleration fitted curve of x=1.5m on beam when hammering point is x=0.0m:

The peak acceleration fitted curve meets:

$$y = A_1 \cdot \exp(-\frac{x}{t_1}) + y_0 \tag{5}$$

In which, y represents the peak acceleration of the measuring point; t represents time A_1, t_1 and y_0 are fitting constants.

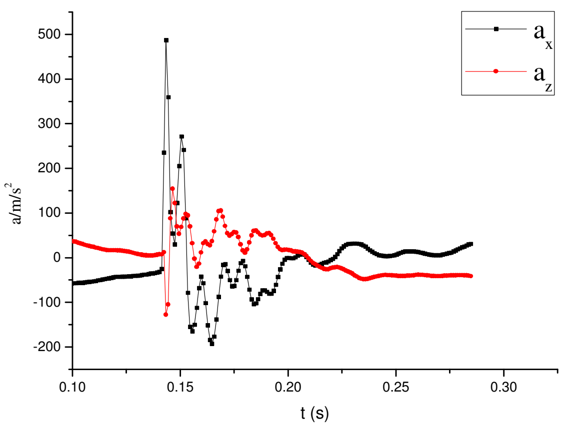

Fig. 7. Peak acceleration curves of heavy h ammer

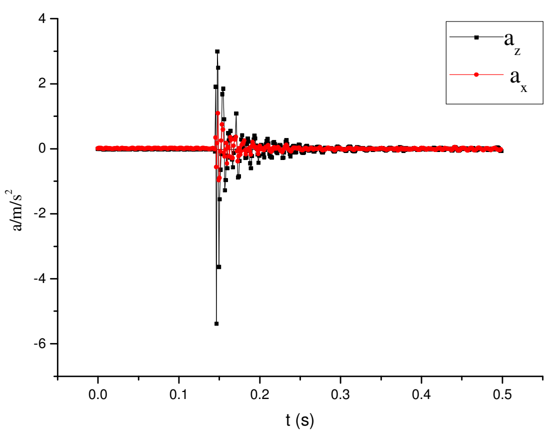

Fig. 8. Peak acceleration curves of beam mid-span

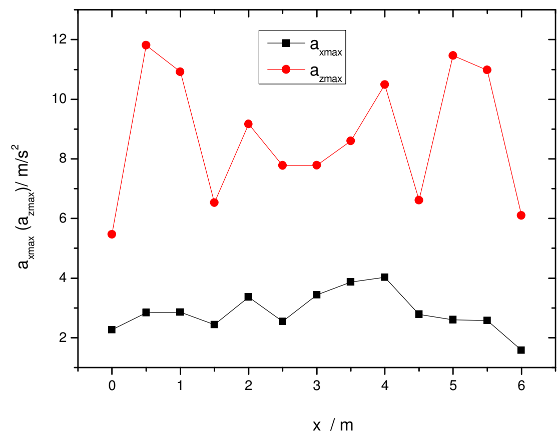

Fig. 9. $a_{x\max}(a_{z\max}) \sim x$ **curves of beam mid-span**

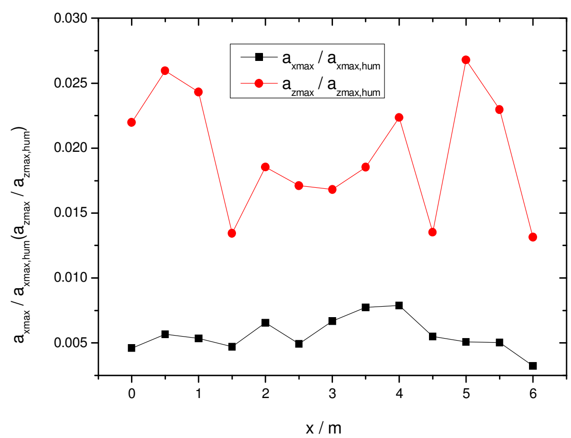

Fig. 10. $a_{x\max}/a_{x\max,\text{hum}}(a_{z\max}/a_{z\max,\text{hum}}) \sim x$ **curves of beam mid-span**

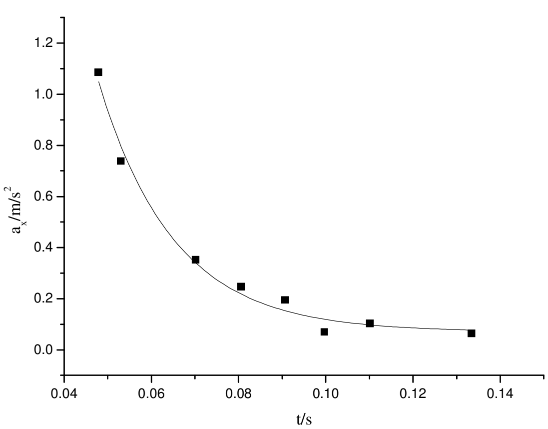

Fig. 11. Horizontal peak acceleration fitted curve when x=1.5

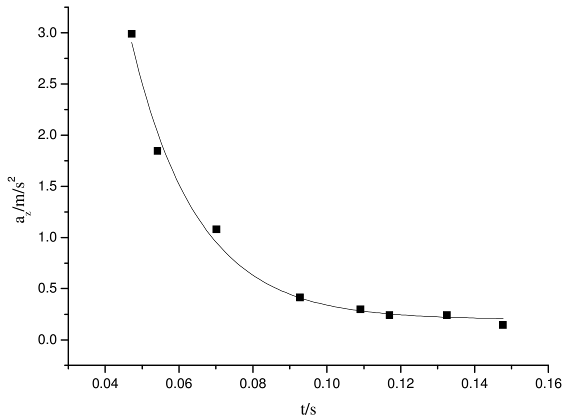

Fig. 12. Vertical peak acceleration fitted curve when x=1.5

Table 1 is the coefficient of peak acceleration fitted curve and first order damping ratio by fitted curve. The values of X column are horizontal frequencies, and the values of Z column are vertical frequencies in Table 1. From Figs. 11, 12 and Table 1, the peak acceleration of hammering point follows the law of exponential decay. From the fitted curve $y_{\max} = A_1 + y_0$, the maximum value of $y_0 / y_{\max}$ is 3.4%, therefore the peak acceleration fitted curve takes:

$$y = A_1 \cdot \exp(-\frac{x}{t_1}) \quad (6)$$

The decay curve of structure with damping is $y = \rho e^{-\xi \omega_n t}$, compared with the above type, the damping ratio takes $\xi = 1/(\omega_n t_1)$. The types of frequencies used to calculate these values are average frequencies.

4.1.2 The analysis of frequency

The horizontal and vertical natural frequencies when heavy hammer hammering are respectively 2.726~5.313 Hz and 3.596~9.104 Hz, the average value is 4.068 Hz and 5.80 Hz. The natural frequency of the beam in horizontal direction is close to the vertical, first and second order natural frequencies are around 76.2 Hz and 125.2 Hz.

4.2 The Results Analysis of Road Roller Vibrating Fixed-point Method

4.2.1 Peak acceleration

Figs. 13 and 14 are respectively peak acceleration curves of acceleration sensor 904 in beam (1.5,0.15) and 926 in beam (3.0,0.15) when road roller vibrate in fixed point A. From Figs. 13 and 14, the horizontal maximum peak acceleration is 0.4486 m/s^2 and 0.5101 m/s^2, the vertical is 0.1731m/s^2 and 0.2375 m/s^2.

4.2.2 The analysis of frequency

From Figs. 13 and 14, the maximum peak acceleration of beam is 0.69 m/s^2, the first three order natural frequencies are respectively 11.63 Hz, 39.94 Hz and 60.54 Hz, and corresponding damping ratios are 0.010, 0.011 and 0.006. The calculated frequency compared with test results, the first order natural frequency is basically the same, the second order and third order calculated frequency are respectively larger 10.9% and 64.6% than test results. The main reason of difference is the calculated results without considering the influence of the beam axis vibration.

5. DISCUSSION OF ANALYSIS RESULTS

The purpose of this paper is to research the dynamic characteristics of a beam in an existing brick-concrete structure with heavy hammer hammering method and road roller vibrating fixed-point method. The experimental results show that high older frequencies only can be got when using heavy hammer hammering method, then we can obtain low frequencies by road roller vibrating fixed-point method. In heavy hammer hammering method, peak acceleration changing curves of the mid-span point conform to the distribution of attenuation. In road roller vibrating fixed-point method, when road roller moved along the building, peak acceleration time history

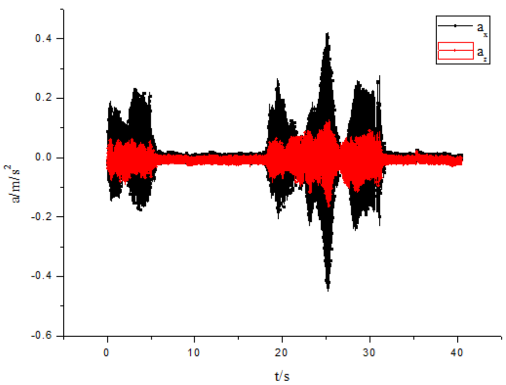

Fig. 13. The peak acceleration curve in beam(1.5, 0.15)

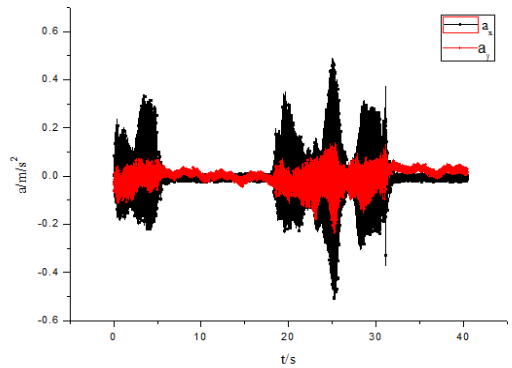

Fig. 14. The peak acceleration curve in beam(3.0, 0.15)

Table 1. The coefficient of peak acceleration fitted curve

Measure point coefficient	x=1.5		x=3.0		x=4.5	
	X	Z	X	Z	X	Z
y_0	0.07073	0.19804	0.04454	0.17013	0.0045	0.0064
A_1	15.63778	37.7012	7.72778	15.48717	0.1260	0.3637
t_1	0.01728	0.01791	0.01893	0.01987	0.0289	0.0284
y_0 / y_{max} /%	0. 45	0.52	0.57	1.1	3.4	1.7
ξ	0.0722	0.0696	0.0446	0.1042	0.0287	0.0440

curves of measuring point on the beam in zero up and down; when road roller vibrated in point A, time history curve appeared peak acceleration, Analyzing of data with FFT obtained the frequencies and damping ratio of beam components.

6. CONCLUSION

(1) When using heavy hammer hammering method, the peak acceleration on heavy hammer is obviously bigger than the peak acceleration on the beam, the reason is that heavy hammer is incentive, and beam is the corresponding response. The peak acceleration on the beam follows the law of exponential decay. From the law of exponential decay, each order damping ratio can be determined. The average horizontal and vertical natural frequency when heavy hammer hammering is 4.068 Hz and 5.80 Hz. The natural frequency of the beam in horizontal direction is close to the vertical, first order and second order natural frequencies is around 76.2 Hz and 125.2 Hz.

(2) The natural frequencies in horizontal and vertical directions in beam is approximate when using the road roller vibrating fixed-point method. The peak acceleration in horizontal and vertical is 0.4486 m/s^2 and 0.1731m/s^2, the first three order natural frequencies is 11.63 Hz, 39.94 Hz and 60.54 Hz in turn, and corresponding damping ratios are 0.010, 0.011 and 0.006. The calculated frequency compared with test results, the first order natural frequency is basically the same, the second order and third order calculated frequency is respectively larger 10.9% and 64.6% than test results.

(3) In heavy hammer hammering method and the road roller vibrating fixed-point method, the peak acceleration and frequency on the beam by using the method of heavy hammer hammering method are greater than its by using the road roller vibrating fixed-point method, the main reason maybe is that the road roller vibrating fixed-point method gets the dynamic characteristic results of all the building, not the beam.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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