Effect of Vibration from Highway Vehicle Load on adjacent Buildings and Its Assessment

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Abstract: This paper studies the influence of highway vehicle loads on the vibration of nearby buildings, and both the vehicle induced vibration of ground and adjacent residential are analyzed. Firstly, testing points are arranged on both sides of a highway named Xiongchu Avenue to measure the ground vibration caused by vehicle loads. Secondly, the corresponding vibration response of a nearby residential building is measured. The natural frequency of this building is identified by NexT/ERA method. The results show that the influence of the traffic load on the frequency of the building is mainly between 8Hz to 20Hz. The acceleration level of each storey and influence of vibration on human comfort are calculated, and it is concluded that all the degree of vertical vibration are belong to the requirements in the Chinese code. This paper provides corresponding technical support for solving the problem of such traffic system.

1. Introduction

Accompany with the improvement of people’s living, the number and size of vehicles increased rapidly. The influence of noise and vibration induced by vehicle load are raising people’s attention. Firstly, the vehicles can cause the road or bridge vibration. Then vibration waves are outward by the surrounding ground, which induces the vibration of nearby structures. At last, safety of people living in the adjacent structures may be affected.

Analysis of traffic-induced ground vibration and adjacent structures are quite complicate since the problem involves a amount of unknown factors and many factors are stochastic[1]. A lot of researches have been done in the area of environmental vibration caused by vehicle load[2]. However, most of them are focus on subway or rail traffic induced vibration, especially acting on the ground vibration instead of adjacent buildings’ vibration. [3] analyzed the horizontal vibration responses of 5 frame structures with different heights under horizontal vibration acceleration of ground induced by road vehicle load. [4] studied the vibration response and environmental impact of a building of 54m under the influence of vehicle load. [5] studied the indoor environmental vibration induced of the adjacent buildings induced by rail traffic load, the influence of natural frequency and height of each floors on the vibration were discussed. Numerical and measurement results were also compared to explain some phenomenon. In [6] the vibration response of a long-span elevated railway station waiting room floor slab in the general speed field of heavy long truck line through different conditions was studied, a method of suppressing vibration of floor slab by TMD energy dissipation was proposed.
The aim of the paper is to study the ground and building vibrations caused by large-scale buses and trucks on adjacent road. In the second section, vertical acceleration of the ground near a highway is measured, the ground vibration character and its degree induced by vehicles are also studied. In the third section, the vertical acceleration time-history curve and spectrum of a residential building near the highway are also measured to identify the impact of vehicle load on it. Eigensystem Realization Algorithm (ERA) is also used to identify the modal of the building. In the forth section, the distribution of the vibration degree as well as 1/3 octave spectrum of each measure point in the building are analyzed. Finally, some suggestions are giving to this kind of buildings near the highway.

2. Vibration Measurement of Road Vehicles

2.1 Testing instrument and measuring points

DH5901 dynamic signal acquisition system and IEPE acceleration sensors (figure 1) are used in this test. Since vehicle induced load are mainly vertical, the acceleration response perpendicular to the ground is measured. No Frequency band-pass filter is adopted and all the measured data are original response signal.

The researched highway -Xiongchu Avenue in Wuhan, China is an important highway from Wuhan to many other cities with frequency of large and heavy vehicles. As shown in figure 2, six measuring points are arranged every five meters near one side of this highway.

2.2 Testing results

Only time-history curve of measuring point 1 and 5 are giving here due to the limited page. It can be concluded that the acceleration decreases with the increasing of the distance between measuring point and vibration source (the highway). Fourier transform can be used to obtain the Fourier spectra by calculating the time history data of each samples, and smoothing the Fourier spectra to obtain the predominance frequency band of signal. It can be seen in figure 4 that the area enclosed by Fourier spectrum decreases rapidly with the increase of the distance from measuring point to vibration source, which indicates that the energy of the signal decreased rapidly. What's more, the ground frequency induced by vehicle load is mainly concentrate between 8-20Hz. The amplitude decreases rapidly with the increasing of the distance between measuring points and vibration sources, maximum at 14Hz. However, the predominance frequency band corresponding to the response signal changes little. It can
be concluded that the all frequency distribution of response spectrum in the testing ground are similar, the decrease velocity of different frequency components are also approximately the same.

3. Measurement of a Nearby Building

Dynamic measurement of a residential building near the Xiongchu Avenue was conducted to study the influence of vehicle load. LanTing Ju is a 9-storey frame structure with a height of 28.5m. The first and second storey is respectively 3.9m, 3.6m and others are 3m. It is in the design area of seismic intensity degree of 7. 1 vertical and 2 horizontal vibration sensors were arranged in the same place on each floor. The testing data were canceled if it was not smooth in a length of 10min. The photo of the building and the layout of measuring points are shown in figure 5 and 6. Filtering measures are adopted before data processing to eliminate the interference such as noise or other high frequency.

3.1 Modal analysis of the building

Figure 4 Vertical acceleration time-history curve of measuring point (a)point 1 (b)point 5

Figure 5 Photo of the building

Figure 6 The position of the building and the layout of the measuring points

Figure 7 The time-history curve of the acceleration 1st storey (b) 9th storey
Figure 8 Spectrum of the building (a) Vertical (b) Horizontal

The time history curve of vertical acceleration and vertical spectrum is shown in figure 7 and 8 (just 1st and 9th storey considering the limit of page). It can be concluded that the acceleration remain nearly the same with the increasing of the building storey, but the spectrum amplitude increase obviously especially between 8 to 20Hz, which is the same with the spectrum of vehicles on the highway. These results also indicate that the influence of vehicles to the nearby buildings are mostly concentrate on 8 to 20 Hz. When comparing the vibration of vertical direction in figure 8(a) with horizontal direction in figure 8(b), there is apparent changes of frequency induced by vehicle in the direction of vertical while no obvious changes in the horizontal, hence the horizontal vibration will be no more expatiation here.

3.2 Modal identification by NExT/ERA

Table 1. Modal frequency of the test building

| Order | Testing results (Hz) | NExT/ERA identification results |
|-------|----------------------|---------------------------------|
| 1     | 0.9042               | 0.9242                          |
| 2     | 1.821                | 1.8204                          |
| 3     | 2.788                | 2.9438                          |
| 4     | 4.088                | 4.2772                          |
| 5     | 5.417                | 5.5137                          |
| 6     | 6.729                | 6.8739                          |
| 7     | 8.317                | 8.3245                          |
| 8     | 9.663                | 9.7369                          |
| 9     | 10.5                 | 10.8747                         |
| 10    | 11.81                | 12.2507                         |

Natural Excitation Technique (NExT) and Eigensystem Realization Algorithm (ERA) method are used to identify the modal parameter of the building. Firstly, the correlation between the 9 testing storeys with the ground storey is obtained by MATLAB. Then NExT is used to de-noise. At last, the obtained data are used as the input of ERA method. As shown in table 1, the frequency obtained by test and identification is quite similar. These indicate that the identification method is effective, it provides basic theoretical and practical for the later modal identification of large-scale structures.

4. Influence of vibration on human comfort

4.1 Vibration level

The peak of acceleration is used to evaluate the degree of environmental vibration. Since Code [7] and [8] in China stipulate that only the vertical vibration acceleration of the measured building should be evaluated, according to chapter 6 in [9], the degree of the vibration can be calculated as follows:

$$VAL_i = 20 \log \left( \frac{a_i}{a_0} \right)$$  (1)
where is $a$, the vertical valid acceleration, $a_0$ is the standard acceleration, the vibration weighting acceleration is shown in figure 9.

![Figure 9 Vibration degree of vertical acceleration](image)

It can be concluded that all the degree of vertical vibration haven’t exceed the limits 70dB in [7]. With the increase of the storey, the vibration degree of acceleration increases initially an then followed by decreases, but nearly always decrease rapidly with the increase of the distance.

### 4.2 Degree of 1/3 octave acceleration in the building

The 1/3 octave spectrum of the acceleration time history are calculated to study the main frequency band and the corresponding vibration. Considered the different frequency weight factor of whole-body vibration, the acceleration time history of testing points in the storey of 1st, 3rd, 6th, 9th and distance of 5m, 10m, 15m are chosen to calculated the 1/3 octave spectrum based on random signal analysis.

![Figure 10 1/3 octave center frequency of vertical acceleration](image)

It can be seen that all the frequency of the test building are low frequency and mainly concentrate in the range of 8-30Hz. The vertical vibration of different storey are nearly the same with each other, but the vibration of upper storey are larger than that of lower storey till the top storey being the largest one. What’s more, the decrement of the vibration acceleration along the horizontal distance in different frequency band are nearly the same while the attenuation gradient is larger in the closer places. The main frequencies are concentrate in the range of 5 to 30 Hz, which is similar to that of residential buildings, indicating that the vibration of residential is caused by vehicle loads.

### 5. Conclusion
(1) The ground frequency induced by vehicle loads is mainly concentrate between 8 to 20Hz. The amplitude decreases rapidly with the increasing of the distance between measuring points and the highway, maximum at 14Hz while the predominance frequency band changes little.

(2) The modal parameter identified by NExT/ERA method is found be valid after comparing with the testing results, which provides basic theoretical and practical for the later modal identification of large-scale structures.

(3) The main frequency of the testing building is concentrated between 8 to 30Hz, since it is belong to low frequency, the vibration responses of building decrease with the increase of load frequency.

(4) It can be concluded that buildings should be constructed reasonably, about more than 30m’s away from the edge of highways. As for some large-scale or heavy vehicles, the traffic should also be reasonably restricted. What’s more, facilities can be improved. For example, damping materials can be used in pavement to reduce the vibration of vehicles.

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