Experimental Study on The Influence of Precision Instruments Caused by Heavy Vehicles Vibration

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Abstract: In order to evaluate the influence of heavy vehicles vibration on precision instruments in a proposed experimental building, the three-dimensional environmental vibration induced by heavy vehicles was measured in a soft soil site. Combined with continuous wavelet transform and 1/3 octave frequency vibration level, the vibration transferring characteristics of the construction site were analyzed, and the Z vibration level of the site was tested. The results are as follows: (1) Vertical vibration is the main vibration; (2) The predominant frequency of soil layer is 4 Hz, and the excitation frequency of vehicles is 5 ~ 20 Hz; (3) With the increase of vibration source distance, the high frequency vibration is greatly attenuated, while the low frequency vibration is amplified; (4) The amplitude of heavy vehicles is about 3 ~ 5 times of the small cars; (5) The environmental vibration produced by the vehicles exceeds the vibration standard of the normal use of the instruments, necessary vibration reduction and isolation measures should be taken.

1. Introduction

In recent years, with the continuous development of China's industry and the expansion of urbanization, the environmental vibration of buildings caused by human production, life and various traffic loads has become more and more obvious. The environmental vibration of buildings will not only affect the comfort of nearby residents, but also have a negative impact on the normal use of precision instruments [1-2].

The vibration caused by road traffic is the vibration caused by a changing grounding pressure on the ground through the tire when the motor vehicle is driving. The vehicle model, load, road flatness and other factors will affect the vibration. Aiming at the problems of road load, scholars at home and abroad have carried out a series of studies. Mohannad et al [3] analyzed the vibration reduction caused by vehicles by combining numerical simulation with field measurement, and considered that the vibration reduction and isolation effect of heavy objects is better than that of ditches and vibration isolation walls; M. A. LAK [4] analyzed the relationship between pavement flatness and vibration; Ma Meng et al [5] compared the impact of subway and vehicles vibration on precision instruments; Qin
Lin et al [6] analyzed the attenuation law of vibration caused by bus with distance; Lou Menglin et al [7] measured the vibration caused by heavy trucks on site and analyzed its attenuation law; Zhang Bingqiang et al [8] established the analysis model and dynamic balance equation of vehicle-road coupled system to theoretically analyze the environmental vibration response caused by road traffic; Yue Jianyong et al [9] established a three-dimensional numerical model of soil structure, conducted transient analysis on the foundation slab vibration of medical ion center, and analyzed and evaluated the foundation vibration caused by traffic according to the international vibration VC standard.

In order to better reflect the vibration caused by vehicle load in real life, the complex road conditions of various vehicles with different models, loads and speeds are measured in this paper. In view of the surrounding environmental problems caused by vehicle driving, the surface vibration signal generated by heavy vehicle driving is measured on site by using the dynamic signal acquisition system, and the influence of vehicle vibration on the use of precision instruments is analyzed. The research results can provide a further reference for the vibration control of precision instruments on nearby roads.

2. Engineering background and vibration test

2.1. Project overview
The test is located near a provincial road in a soft soil site in Hangzhou, with busy traffic around. The west provincial road is dominated by heavy vehicles, and the straight-line distance between the central line of the road and the precision test area is only 145 meters. The strong environmental vibration induced by vehicles may have a great negative impact on the precision instruments in the precision test area. According to the field survey results, the soil layer within 20 m depths mainly includes cohesive soil and mucky soil, in which the mucky soil is continuously distributed, and the average shear wave velocity of the whole covering soil layer is 125 m/s, which is a typical soft soil site condition.

2.2. Layout of measuring points
In order to determine the influence of vehicle vibration on the use of precision instruments, measuring points 1 ~ 5 are arranged. Among them, measuring points 1 ~ 2 are located at the edge of the road, and measuring points 3 ~ 5 are located in the precision instruments placement area. The distance from the measuring points to the road edge are 5 m, 29 m, 68 m, 90 m and 120 m. The plan of the measuring points and the linear distance between measuring points and road edge are shown in figure 1.

![Figure 1. Layout of measuring points](image)

2.3. Test instruments and process
The photos of vibration test site are shown in figure 2. SVSA dynamic data acquisition instrument, DH5922 dynamic data acquisition instrument and several high-sensitivity piezoelectric acceleration sensors were used in this test, and the sampling frequency was set to 400 Hz. In order to reduce the
interference of on-site construction, the three-dimensional environmental vibration was tested at noon on a working day. The spectrum characteristics and attenuation law of environmental vibration are analyzed from four aspects: time domain, frequency domain, time-frequency domain and 1/3 octave frequency vibration level. The time-frequency domain analysis method mainly adopts Morlet continuous wavelet transform [10], and the 1/3 octave frequency vibration level is mainly based on the allowable vibration value at the center frequency of each 1/3 octave in the specification (GB 50868-2013). The vertical environmental vibration near the construction site was continuously tested for more than 20 minutes to analyze the Z vibration level of the construction site.

3. Three-dimensional vibration test
In order to evaluate the time-frequency domain characteristics of east-west, north-south and vertical environmental vibration caused by the same traffic flow, the three-dimensional traffic environmental vibration on the side of the provincial road close to the construction site was tested synchronously. The three-dimensional environmental vibration of measuring point 1 and measuring point 2 caused by 15 traffic flows were randomly tested.

The three-dimensional vibration of measuring point 1 caused by the first traffic flow is shown in figure 3, including time domain, frequency domain and time-frequency domain, and aligned with each other on the time axis and frequency axis, so as to understand its time-frequency domain variation characteristics. Among them, 20 ~ 35 s and 40 ~ 50 s vehicles are mainly heavy vehicles, and 35 ~ 40 s are small cars. Since the characteristics of three-dimensional vibration caused by other traffic flows in time domain, frequency domain and time-frequency domain are similar to those of the first traffic flow, it will not be repeated.

In terms of amplitude, the acceleration amplitude produced by heavy vehicles is about 3 ~ 5 times that of small cars; The amplitude of vertical and east-west vibration acceleration are large, and the amplitude of north-south vibration acceleration is small. From the perspective of frequency, the east-west direction belongs to broadband vibration, which is distributed in the range of 2 ~ 100 Hz. The north-south vibration is mainly 4 ~ 40 Hz, and the vertical vibration frequency is not higher than 30 Hz, mainly 4 Hz. In addition, when there is no vehicle passing in the vertical vibration, the 4 Hz vibration always exists. When the vehicles pass, the 4 Hz vibration amplitude is significantly strengthened. It shows that the predominant frequency of the soil layer is 4 Hz, and the vertical excitation frequency of the vehicles is 5 ~ 20 Hz.
The vibration acceleration time history, power spectrum and wavelet time spectrum of measuring point 2 caused by the traffic flow are shown in figure 4. The test results show that: ① After the east-west vibration is transmitted from measuring point 1 to measuring point 2, the high frequency vibration is completely attenuated. At this time, the frequency below 20 Hz is mainly about 4 Hz; ② The high frequency component of north-south vibration also attenuates greatly in the transmission process, mainly about 4 Hz; ③ The high frequency component of vertical vibration is also greatly attenuated, which greatly reduces the acceleration amplitude; ④ At the same time, the vertical vibration of about 4 Hz is significantly amplified relative to measuring point 1, which is mainly due to the cumulative effect of low frequency vibration transmission in deep soil layer from measuring point 1 to measuring point 2.

![Figure 4. Three-dimensional vibration of measuring point 2 caused by the first traffic flow](image)

Calculate the effective acceleration value of measuring point 1 and measuring point 2 caused by the traffic flow, as shown in figure 5, and the effective velocity value is shown in figure 6.

![Figure 5. Effective acceleration value caused by the first traffic flow](image)

![Figure 6. Effective velocity value caused by the first traffic flow](image)

The calculated value is compared with the allowable vibration value at the center frequency of each 1/3 octave in the specification(GB 50868-2013). According to the specification, the allowable
vibration value at the center frequency of each 1/3 octave in the frequency domain is shown in the table below.

| allowable acceleration vibration (mm/s²) | allowable velocity vibration (µm/s) | corresponding frequency (Hz) |
|------------------------------------------|-----------------------------------|-----------------------------|
| 0.30                                      | —                                 | 4~8                         |
| —                                        | 6.00                              | 8~100                       |

It can be seen from figure 5 and figure 6: ① The main vibration frequency of three-dimensional vibration is about 4 Hz; ② Vehicle environmental vibration mainly causes the vertical vibration of the ground; ③ Transmitted from measuring point 1 to measuring point 2, high frequency vibration attenuates obviously, mainly low frequency vibration of 4 Hz; ④ The effective values of vibration acceleration of measuring points 1 ~ 2 are much greater than the standard limit value of 0.3 mm/s² at the center frequency of 4 ~ 8 Hz, and the peak velocities of measuring points 1 ~ 2 at 8 ~ 100 Hz also exceed the standard limit value of 6 µm/s, further vibration reduction and isolation measures need to be taken.

4. Z vibration level Vlz10 test

In order to reduce the interference of other surrounding vibration, the vertical environmental vibration on the side of the provincial road close to the construction site was continuously tested for more than 20 minutes, the Z vibration level of the construction site is analyzed and compared with the limit value of the specification (GB 10070-88).

As the road environmental vibration belongs to random vibration, the cumulative percentage Z vibration level Vlz10 is taken as the evaluation quantity according to GB 10070-88, and the sampling interval is 1 s. The measured acceleration time history, power spectrum and Z vibration level of measuring points 3 and 5 are shown in figure 7, the Vlz10 of measuring points 1 ~ 5 are shown in table 2. The red solid line in the figure is the daytime standard limit of "both sides of the traffic trunk line", which is 75 dB, and the red dotted line is the nighttime standard limit, which is 72 dB.

![Figure 7. Acceleration time history, power spectrum and Z vibration level of points 3 and 5](image)

Table 2. Measured cumulative percentage Z vibration level Vlz10.

| Cumulative percentage Z vibration level Vlz10 (dB) |
|-----------------------------------------------|
| point 1                                       |
| 74.0                                          |
| point 2                                       |
| 74.5                                          |
| point 3                                       |
| 70.8                                          |
| point 4                                       |
| 67.3                                          |
| point 5                                       |
| 66.8                                          |

It can be seen from figure 7 and table 2: (1) With the increase of distance, the vertical vibration caused by the vehicles attenuates significantly; (2) The vehicle vibration is mainly low frequency vibration, and the main vibration frequency is about 4 Hz; (3) Vehicle vibration has a certain impact on the use of the instruments. If the standard limit value of "both sides of the traffic trunk line" is used, the Z vibration level of measuring points 1 ~ 2 on the site cannot meet the standard limit value at
night, and the Z vibration level of measuring points 3 ~ 5 in the precision instruments placement area is within the standard limit value.

5. Conclusions
The three-dimensional environmental vibration induced by heavy vehicles on a soft soil site is measured on site. Combined with continuous wavelet transform and 1/3 octave frequency vibration level, the vibration spectrum characteristics and transmission law of the construction site are analyzed, and the Z vibration level of the construction site is tested. The following conclusions are drawn:

1. Vehicle vibration is mainly vertical vibration.
2. The predominant frequency of the soil layer is 4 Hz, and the excitation frequency of the vehicles is 5 ~ 20 Hz.
3. With the increase of vibration source distance, high frequency vibration attenuates greatly, while low frequency vibration amplifies.
4. The vibration amplitude produced by heavy vehicles is about 3 ~ 5 times that of small cars.

According to the test, the vibration near the road edge exceeds the allowable limit, while the vibration in the instruments placement area is close to the allowable limit. In order to reduce the vibration generated by vehicles, further vibration reduction and isolation measures need to be taken. For example, barrier vibration reduction and isolation measures shall be adopted at the edge of the road, and three-dimensional vibration reduction and isolation platform shall be adopted in the building to ensure the normal use of the instruments.

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