A field study of terrain effect for periodic vibrating-taking the ground vibration induced by road roller as an example

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Abstract. Taking vibration wave induced by road roller as a research object, terrain effect characteristics in propagation of periodic vibration wave were studied through the ground vibration monitoring. Data analysis results show that, vibration distance, frequency and terrain condition were the main factors affecting the attenuation speed of the ground vibration. On the flat terrain, the ground vibration velocity attenuated in negative exponential function form with distance; In complex terrain condition, the attenuation characteristic changed. Vibration velocity was obviously amplified when the location of the measuring point is higher than the source, and decreased more rapidly at the lower place. The increase of vibration frequency enhanced the topographic effect, the amplification of ground vibration caused by higher frequency vibration was more pronounced. The mathematical model of periodic vibration wave attenuation was proposed according to the characteristics of vibration velocity. The model provided an effective reference for the calculation of the safety distance which took the frequency, the height difference and the distance into account.

1. Introduction

Ground vibration induced by the traffic engineering construction propagates outward through the soil in the form of elastic wave, which could cause the damage to ground and underground buildings. Vibratory roller is the important machine in road construction. With the construction of a lot of traffic engineering, vibratory roller is widely used in highway, railway, airport runway and other large engineering foundation compaction work, however, the problem is the impact of sustained vibration on buildings. The attenuation rules and vibration range of vibratory roller are analyzed through the field vibration monitoring test by Yang, K.[1] and Yao, W. B.[2], Kuai, X. C. [3], Jiang, Y. L.[4] analyzed the dynamic response characteristics of ground buildings based on the finite element model of vibration source-medium-building. It was concluded that the vibration attenuation speed was related to the elastic model, vibration velocity decreased as a whole with the distance between measuring point and vibration source, but the attenuation characteristic was complex. On the basis of dimensional analysis, Zhang, Z. F. [5,6] concluded that ground vibration attenuation rule was negative power function.

Ground vibration attenuation formula, magnitude calculation formula and surface vibration attenuation experience formula were used to analyze the vibration data and predict the vibration safe distance[7-10]. Pan, L. S. pointed out that the vibration attenuation was associated with the vibration frequency, and the vibration frequency affected the vibration attenuation speed, the lower the
frequency was, the slower the vibration decayed. Yang, K. introduced the terrain factor, he pointed out that under the condition of complex topography, changing rules of the peak vibration velocity presented a series of complicated nonlinear feature.

Unlike natural earthquakes and artificial blasting earthquakes, the vibration of roller was on the surface of earth, and the periodic seismic wave was induced by the vertical excitation. The vibration attenuation laws were related to vibration frequency and terrain conditions, however, as above, there was no quantitative analysis. Taking vibration frequency and height difference as the research objects, topographic effect of the periodic vibration wave induced by the vibratory roller was studied in this paper based on the monitoring. Research results provided effective reference for engineering safety construction and vibration safe distance calculation.

2. Vibration monitoring

2.1. The test system
Vibration instrumentation was TC-4850, its main body was made up of acquisition equipment and three vector speed sensors. The main technical indicators: the frequency range was X/Y: 1~300Hz, Z: 1~500Hz, the sensitivity was 28 V/m/s, the harmonic distortion ≤0.1%. The vibration frequency = 33/28Hz.

2.2. Monitoring site and the station layout
Three measuring lines were selected for vibration monitoring and the monitoring points are shown in figure 1.

![Figure 1. Plan sketch of measuring point and vibration source.](image)

Table 1. Vibration monitoring results.

| Measuring line | The first vibration | The second vibration |
|----------------|---------------------|----------------------|
|                | Monitor point       | Distance             | Altitude difference | Vertical peak velocity | Monitor point | Distance | Altitude difference | Vertical peak velocity |
| I              | MP1                 | 7.3                  | -5.0                | 0.362                 | MP1           | 12.2     | -5.0                | 0.232                 |
Two vibration measurements were performed in each measuring line, as shown in figure 1, the location of the measuring points remained unchanged. The second source location was relatively far away from the road border. The vertical vibration velocities of measuring points were shown in table 1.

![Figure 2. Attenuation law between vertical PPV and distance.](image)

The attenuation characteristics of velocity could be seen in figure 2, attenuation law in general accorded with negative exponential function model. The curves, in the same area and under different terrain conditions, showed that the vibration attenuation speed was different. The local terrain elevation difference changed vibration amplitude. It can be seen as flat terrain because of the same height of measuring points and vibration source in measuring Line III. The topographic condition of Line I is negative elevation, and the further the distance was, the higher the difference was; The topographic condition of Line II was converted from a negative elevation to a positive height. As shown in figure 2, the curve of measuring Line II was rapidly attenuated at the initial phase, after entering the positive height, the attenuation speed was slower than before. The positive difference amplified the speed of the vibration at the same distance.
Vibration velocities were affected by terrain elevation in Line I and II. The position of measuring points remained unchanged in the two vibration tests of each line, but the vibration source was away from the measuring points, in other words, when the distance was equal, the elevation difference was higher in the second vibration. In figure 3 (a) the curves showed that the higher the difference was, the faster the attenuation of vibration velocity decayed. In figure 3 (b), at negative elevation stage, the negative difference was smaller and the vibration velocity was larger in the second vibration. After entering the positive height, velocity was smaller when the distance was same. The greater the positive height was, the larger the velocity vibrated.

The vibrational curve showed that the positive height had a magnifying effect on the vibration velocity, under the condition of the same distance, the positive height slowed down the rate of vibration decay. The negative height had the effect of strengthening the attenuation, the smaller the negative elevation was, the larger the vibration velocity vibrated. The terrain condition has a noticeable amplification and strengthening attenuation effect on the particle vibration velocity.

In the first vibration test of line II, the roller compacted the ground with different frequency of 28Hz and 33Hz respectively. In the near area of vibration source, the vibrational wave decayed rapidly. After entering the remote area, vibration amplitude excited by the low-frequency vibration was smaller than the high-frequency. The high-frequency vibration could enhance the terrain effect. Potentiation was associated with terrain elevation difference and vibration frequency. Due to the lack of monitoring data, the effect of frequency on the vibration topographic effect needed to be further studied.

4. Prediction model of periodic vibration
Zhang Z. F. and Lv S. R. proposed the negative exponential function, such as , where R is the distance between vibration source and the measuring point, alpha and beta are the correlation coefficients. Ground vibration attenuation formula was given in Dynamic Machine Foundation Design(GB 50040-96):

\[
V_r = V_0 \left[ \frac{f_0}{r} \epsilon_0 + \frac{f_0}{r} \left( 1 - \epsilon_0 \right) \right] e^{-f_0a_0(r-r_0)}
\]

Where \(V_r\) is vibration velocity at the monitoring point, \(V_0\) is vibration velocity at the vibration source, \(f_0\) is the frequency, \(r_0\) is the equivalent radius of the vibrational basis, \(\epsilon_0\), \(\alpha_0\) are the correlation index. Formula (1) also failed to consider the effect of topographic change on vibration wave propagation. The vibration data of measuring Line I was calculated and compared with the measured data. It can be seen from figure 4 that when the terrain elevation was present, the calculation values were less than the measured values, the formula (1) did not apply to the prediction of the vibration velocity under the condition of high difference terrain.
Based on the existing research results and the measured vibration curves, attenuation model was proposed with considering the height difference:

\[ V = K \cdot r^{-\alpha} \times e^{-\beta \cdot f \cdot H} \]  

(2)

Where \( r \) is distance between the vibration source and the measuring points, \( f \) = the frequency, \( H \) = the height difference, and \( K, \alpha, \beta \) are the factors that are related to the vibration source and topography. The vibration frequency and initial amplitude of roller could artificially be controlled, and \( f \) could be considered as constant value, the model was simplified to:

\[ H \ln V - \ln r - V \ln \gamma = \ln K \]

When \( H = 0 \), the fitting result was shown in figure 5(a), \( \alpha = 2.16, K = 186.8 \).

\[ y = -2.1608x + 5.2301 \]  

\[ R^2 = 0.9725 \]

\[ \ln r \quad \ln V \]

(a) Fitting result (H=0)

\[ y = -0.8768x + 0.533 \]  

\( R^2 = 0.2639 \)

\[ \ln r \quad \ln V \]

(b) Fitting result (H\neq 0)

When \( H \neq 0 \), the fitting correlation was low without considering the height difference, as shown in figure 5(b). Taking the height difference into consideration, fitting result was \( V = 12.06 \cdot r^{-1.61} \times e^{0.227 \cdot H} \), the correlation coefficient of \( R^2 = 0.7303 \). Comparing to the result in figure 5(b), accuracy of the mathematical model was improved significantly.

5. Conclusions

The roller excited periodic vibration waves, its propagation law in general accorded with negative power function form. The positive difference had obvious amplification effect on vibration speed, the negative difference accelerated the attenuation of vibration.

The vibration frequency had an enhanced effect on the topographic effect. The increase of vibration frequency enhanced the effects of terrain features. Terrain amplification effect induced by a higher frequency vibration was more obvious.

Ground vibration velocity excited by the roller was related with distance, vibration frequency and terrain elevation, its propagation rule could be predicted by model \( V = K \cdot r^{-\alpha} \times e^{-\beta / f \cdot H} \), whose calculation accuracy was significantly improved.
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