Attenuation of environment vibration from rail traffic in urban areas

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Abstract

The vibration and noise from rail traffic is an important impediment to traffic development in urban areas. In order to deal with the engineering measures needed to reduce environmental vibration, the attenuation of vibration caused by rail traffic along the segment between Huoying to Huilongguan of Beijing line 13 is observed and studied, and the result is reported in this paper. It shows that vertical components of the vibrations are much stronger than those of horizontal ones; the average peak acceleration of the vibration decreases gradually with the increasing from distance the railway. An attenuation equation of the average peak acceleration is presented in this paper by statistical analysis. However, there is no vibration attenuation at the distance from 50m to 60m, although there is a small amount from the wave guide effect caused by refraction and reflection at the buried rock surface. The high frequency vibration decreases fast and the low frequency vibration decreases relatively slower, so that the vibration near the railway is predominated by the high frequency component and the vibration in the far field is then predominated by the low frequency component. The effect of background vibration is not so large and mainly in the frequency range below 8 Hz. Finally, a new ground vibration level attenuation law is presented.

Keywords: environmental vibration, urban rail transit, attenuation.

1 Introduction

Environmental vibration from rail traffic is an important impediment to traffic development in urban areas. There were many studies on this issue worldwide, such as Lang [3], Urgar [7], Kurzweil [2] and Kurze [1]. To deal with the vibration from rail traffic in urban areas in China, an array observation was

WIT Transactions on The Built Environment, Vol 107, © 2009 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/UT090411

carried out in Beijing, and the results are reported in this paper. Attenuation equations of the average peak acceleration and ground vibration level are presented.

2 Instrumentation of the array

The array was laid out along a line perpendicular to the railway between Huilongguan to Huoying of Beijing line 13, as shown in figure 1. It consisted of 5 measuring points with distances 10m, 20m, 40m, 50m and 60m. An ETNA geophone of ALTUSTM and a notebook computer were fixed at each point. There was a GPS receiver in each geophone and all time systems were set to exactly Greenwich standard time so that the data could be acquired simultaneously. The sampling rate was 200Hz to guarantee the Nequist frequency being larger than 80Hz.

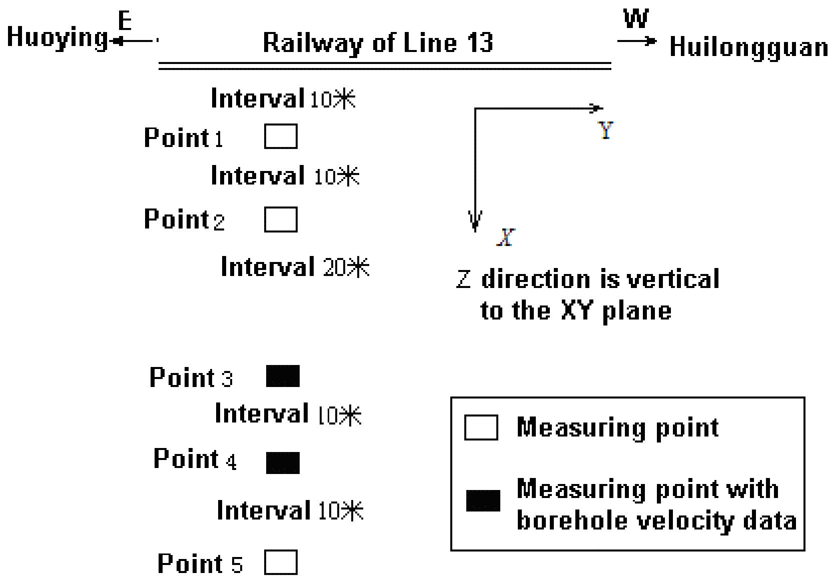

Figure 1: The lay out map of the measurement.

There were four carriages in each train; the interval between the trains was about 5 minutes, up and down in turn. The duration of each record was 60 seconds and totally 435 segments of time history at the five points were recorded for 29 trains. Figure 2 shows the equipment and the field work. Shear wave velocity data were measured from bore holes at four points in the array.

3 Attenuation of the vibration amplitude

As an example, the acceleration time histories along three directions at the five points are shown in figure 3. From it one find that the vertical amplitudes are obviously larger than those along horizontal directions at the points within 50 meters from the rail line, and the amplitudes attenuate quite fast with distance.

According to the state standard for environment vibration measurement in urban area, the mean of peak values of 20 time histories observed along the same direction and at the same point is calculated. The values of the mean peak accelerations at the five points are listed in table 1.

Figure 2: Pictures of the equipment and the field work.

Table 1: Mean values of pack acceleration at the five points.

r (m)	Z direction ($m \cdot s^{-2}$)	X direction ($m \cdot s^{-2}$)	Y direction ($m \cdot s^{-2}$)
10	0.2168	0.1071	0.0894
20	0.1400	0.0972	0.0749
40	0.0504	0.0300	0.0303
50	0.0262	0.0195	0.0180
60	0.0299	0.0241	0.0258

The attenuation curves for the three directions then are developed from the data in the above table, as shown in figure 4. From the figure, one can clearly see the fact that the vibration along Z direction is stronger than those along X or Y directions. The attenuation rate of vertical component is obviously larger than those along horizontal directions within 20 m. The rates are similar in the distance range from 20 m to 50 m. The amplitudes do not decrease, but also increase appreciably from 50 m to 60 m.

Attenuation law of peak acceleration is fitted by a formula with the following form

$$A = x_0 r^{-x_1} e^{-x_2 r} \tag{1}$$

where x_0 is for peak acceleration amplitude at the railway, x_1 is the coefficient for geometric attenuation, x_2 is that for damping attenuation.

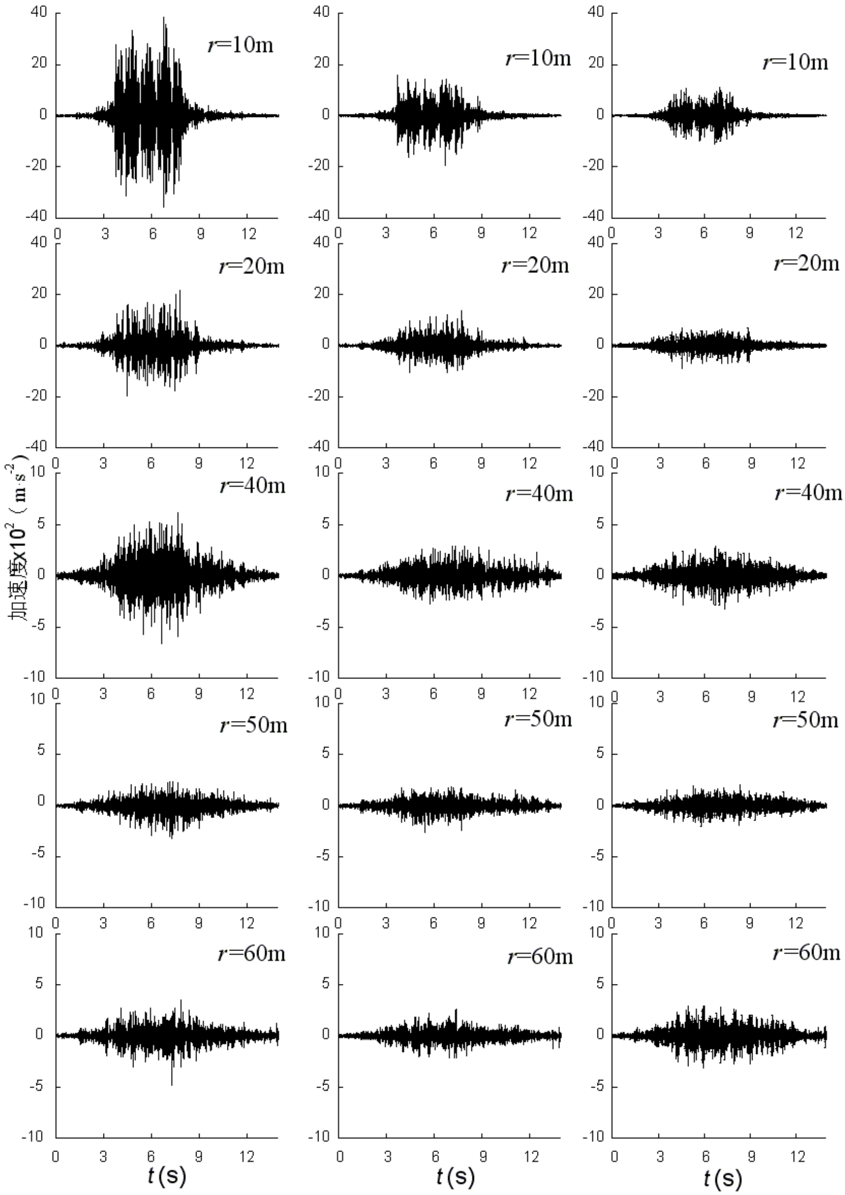

Figure 3: Samples of three component acceleration time histories.

From the peak values of accelerations at all five points in 20 measurements, the resulted attenuation formula is fitted as

$$A = 0.0564 r^{-0.3126} e^{-0.0285 r} \tag{2}$$

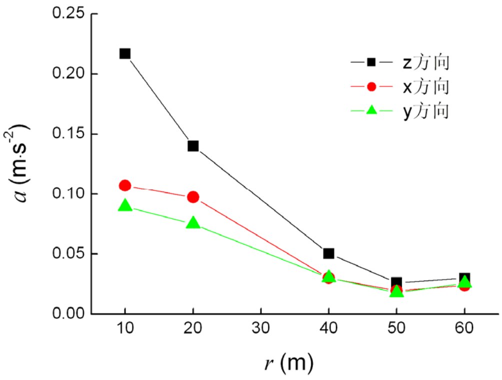

Figure 4: Attenuation of mean pack acceleration with distance.

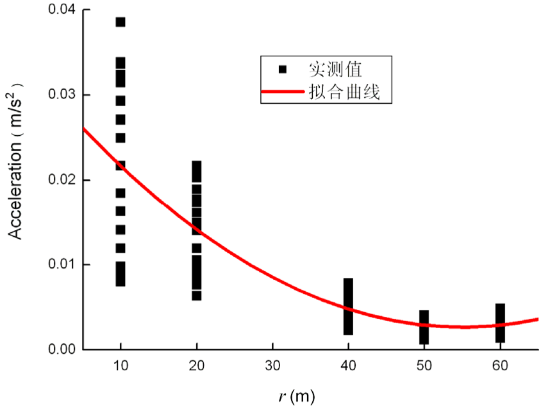

Figure 5: The resulting attenuation curve of peak acceleration.

The attenuation curves are shown in figure 5. One can see from the figure that the attenuation rate at the near field is much bigger than that in further field.

4 Attenuation of the vibration level and the frequency contents

In order to consider the fact that environment vibration caused by rail traffic is quite complicated vibration with many frequency components, the acceleration vibration level VL (in dB) is adopted in the analysis, which is defined as

$$VL = 20\log\frac{a_\omega}{a_0} \tag{3}$$

where a_ω is the weighted acceleration, m/s^2; a_0 is the benchmark acceleration 10^{-6}m/s^2.

$$a_\omega = \sqrt{\sum_{i=1}^{n}\left(a_{ri}^2 c_i\right)} \qquad \left(i = 1, 2, \cdots, n\right) \tag{4}$$

where c_i is the weighting factor for the i[th] frequency band, a_{ri} is the virtual value of acceleration at the center frequency of the i[th] frequency band that can be calculated from the following equation

$$a_{ri} = \sqrt{\int_{f_1}^{f_2} G\left(f\right) \mathrm{d}f} \tag{5}$$

where f_1 and f_2 are the lower and upper bound frequencies respectively; in Hz; $G\left(f\right)$ is the spectral density function of the measured vibration.

In a detail analysis, the measured vibration consists of not only those caused by rail traffic, but also by other traffic, microtremors, machines in near factories and construction sites, and so on. The latter inherent environment vibrations are summarized as back ground vibration, and can be separated the former.

For a narrow band vibration, its power is in proportion to the virtual acceleration,

$$W \propto a_r^2 \tag{6}$$

and the total power is the sum of those in all frequency bands.

$$W = W_1 + W_2 + \cdots + W_n \tag{7}$$

So,

$$a_r^2 = a_{r1}^2 + a_{r2}^2 + \cdots + a_{rn}^2 \tag{8}$$

and

$$VL = 20 \cdot \log\left(\frac{a_r}{a_0}\right) = 10 \cdot \log\left(\frac{a_r}{a_0}\right)^2 = 10 \cdot \log\left(\frac{a_{r1}^2 + a_{r2}^2 + \cdots + a_{rn}^2}{a_0^2}\right) \tag{9}$$

Therefore,

$$VL = 10 \cdot \log\left(10^{\frac{VL_1}{10}} + 10^{\frac{VL_2}{10}} + \cdots + 10^{\frac{VL_n}{10}}\right) \tag{10}$$

Let VL_A for the total vibration level, and VL_B for the back ground vibration level, then the level from rail traffic is

$$VL = 10 \cdot \log\left(\frac{a_{rA}^2 - a_{rB}^2}{a_0^2}\right) = 10 \cdot \log\left(10^{\frac{VL_A}{10}} - 10^{\frac{VL_B}{10}}\right) \tag{11}$$

where VL_B is determined from the measurement without pass of any train.

The attenuation law of the vibration level, is fitted from the measurements with the following equation form

$$VL = VL_0 - \left(\Delta VL / \log_{10} 2\right) \times \log_{10}\left(\frac{r}{10}\right) \tag{12}$$

where r is for distance to the railway, m; ΔVL is for the attenuation at the point with double distance, dB; VL_0 is the referenced vibration level, dB.

A sample of the measured acceleration time histories at the five points and the results of spectral analysis and vibration levels are shown in figure 6. From the Fourier spectra in figure (b), one can see the fact that the predominate frequency is in the range between 50 to 60 Hz at distance 10 m; then 35 to 45 Hz at 20 m, and the spectral amplitudes are attenuated obviously; the amplitudes and the predominate frequency both decrease with distance further, the former is quite small and the letter is in the range between 25 to 30 Hz at 50 m. It means that the high frequency components of vibration caused by rail traffic attenuate with distance very fast, mainly from 10 to 30 m, while the low frequency components decrease not so much. Figure (c) shows the vibration levels in all frequency range at the five points. It is clear that the maximum value of the levels decreases with distance, and the effect of the back ground vibration is mainly on the frequency range 1 to 8 Hz, nothing on the higher frequency part.

The attenuation law fitted from vibration levels of 20 measurements at the five points is

$$VL = 74.6778 - \left(7.31 / \log_{10} 2\right) \times \log_{10}\left(\frac{r}{10}\right) \tag{13}$$

The resulted attenuation curve of the level is shown if figure 7. From the figure, one can find that the vibration from rail traffic within 15 m exceeds the upper bound of requirement in the state standard of China, for urban residence, cultural and education areas, 70 dB, but is OK for the areas further than 20 m. The bounds for the areas near to road and railway in the state standard are 75 dB and 80 dB, respectively.

5 Conclusions

A measurement of vibration from rail traffic in urban area of Beijing is reported in this paper. The measuring array consists of five points on a line perpendicular to the railway with distances 10, 20, 40, 50 and 60 m. Total 435 acceleration time history components were recorded for 29 passes of train. The result of analysis shows that:

(1) The amplitude of vertical component is obviously larger than those of horizontal.

(2) Vertical vibration amplitude decreases with distance very fast within 20 m. The attenuation rates are similar in the distance range from 20 m to 50 m. The amplitudes do not decrease, but also increase appreciably from 50 m to 60 m; reason may be the wave guide effect and will be analyzed in the next paper.

(3) High frequency vibration attenuates much faster than those in low frequency range, so that the relative frequency component of the vibration

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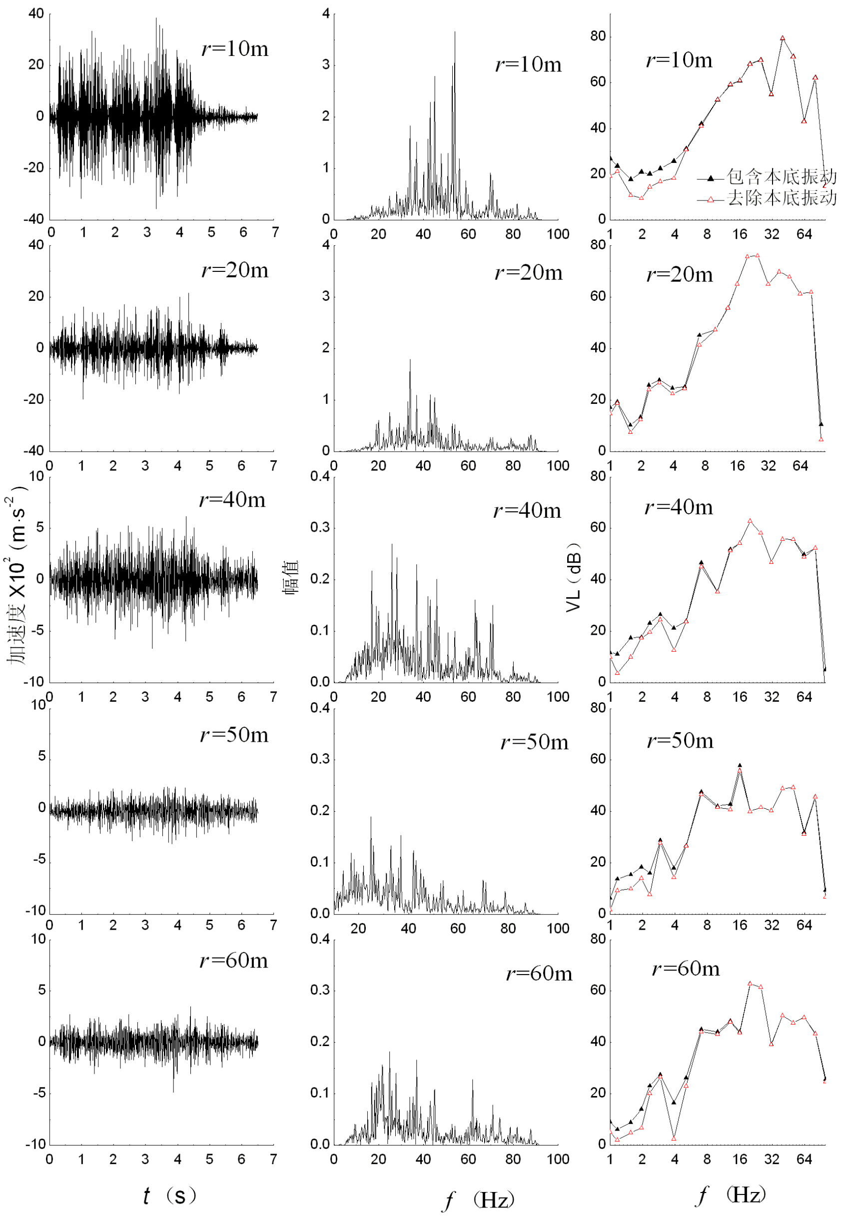

Figure 6: An example of the observed acceleration time histories (a), Fourier spectra (b) and vibration levels (c) at the five points.

changes also with distance. The predominate frequency decreases from 50-60 Hz at 10 m to 25-30 Hz at 50 m. The effect of back ground vibration is mainly on the range of 1 to 8 Hz.

(4) An attenuation law is worked out for vibration level. The result shows that the vibration from rail traffic within 15 m exceeds 70 dB, the upper bound of requirement in the state standard of China, for urban residence, cultural and education areas, but that in the areas further than 20 m is less than the bound for the area near to road, 75 dB, or near to railway 80 dB.

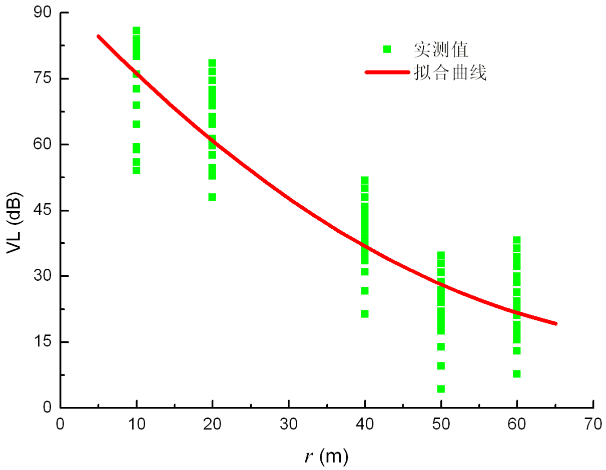

Figure 7: Fitted attenuation curve of vibration level from rail traffic in Beijing.

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