Evaluation and Analysis of Environmental Vibration Caused by Heavy-haul Train

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***Abstract*-Based on Shuo-huang railway line, we use the direct method, filtering and spectral density methods to calculate and analyze the measured results. It is verified that the environmental vibration intensity caused by heavy-haul train decreases with increasing distance while increases in the axis orbit distance. When the horizontal vibration acceleration level is smaller than the vertical vibration acceleration level, though its effects on the human body can be ignored; the vibration acceleration level acquired by filtering method can fairly reflect the environment vibration influences which provide a reference for environmental vibration assessment, also provide isolation vibration reduction design of structures along the railway with rules.**

Keywords- Heavy-haul Train; Environment Vibration; The Vibration Acceleration; Evaluation Method

I. INTRODUCTION

Environmental vibration problem caused by trains has become increasingly critical, especially more severe caused by the heavy-haul train. The main methods of environmental vibration effects caused by the operation of train are analytical method, empirical prediction method and numerical simulation method, which analyze environmental vibration effects from different points. However, countries have no uniform evaluation criteria on environmental vibration, the same to evaluation methods.

For environmental vibration problem, this article is in the background of heavy-haul train of the Shuo-Huang line, where we arrange each measuring point in the vertical line and test the vibration acceleration time history. We use the direct method [1], filtering method [2] and spectral density method [3] to calculate and analyze the measured results and study the similarities and differences between various vibration evaluation methods. It provides a reference for environmental vibration assessment and isolation vibration reduction design of structures along the railway with rules.

II. EVALUATION OF ENVIRONMENTAL VIBRATION

A. Evaluation Criteria of Environmental Vibration

According to our country national standard "Residential Building Indoor Vibration Limit and Measurement Method Standards" (GB/T50355-2005), the expression of vibration acceleration level [4] is as follows:

$$La = 20\lg \frac{a}{a_0} \tag{1}$$

Where La = vibration acceleration level (dB); a = RMS of vibration acceleration ($\mathrm{m/s^2}$); a_0 = reference acceleration value $a_0 = 1\times 10^{-6}\,\mathrm{m/s^2}$.

B. Evaluation Method of Environmental Vibration

For the calculations of vibration acceleration RMS, different documents have different calculation methods. The following briefly describes the three algorithms of vibration acceleration RMS:

– Direct method

"Mechanical Vibration and Shock in the Comments about the Human Body to Withstand Vibration - General Requirements"(ISO 2631-1-1997) put forward the evaluation method that is "weighted acceleration RMS" as the basic evaluation method, which was expressed as follows:

$$a = \sqrt{\frac{\int_0^T a^2(t)dt}{T}} \tag{2}$$

Where $a(t)$ = measured acceleration time history ($\mathrm{m/s^2}$); T = acceleration duration.

– Filter method

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From the actually measured acceleration time history data, it is easier to observe the attenuation law of vibration by adopting the vibration acceleration level of one-third octave frequency [5]. “Residential building indoor vibration limit and its measurement method standards” (GB/T 50355-2005) show the limits which are corresponding to one-third octave within the range of 1-80 Hz. In order to calculate the acceleration vibration level corresponding to each frequency band and obtain the magnitude of each frequency band which is corresponding to the frequency domain, the actual measured acceleration time history should make use of discrete Fourier transform [6]. The algorithm is as follows:

$$C_k = \frac{1}{N}\sum_{m=0}^{N-1} x_m e^{-i(2\pi km/N)} \qquad k = 0,1,2,3\cdots,N-1 \tag{3}$$

Where C_k = Frequency domain corresponding to the amplitude ($\mathrm{m/s^2}$); x_m = measured acceleration time history ($\mathrm{m/s^2}$); N = number of x_m.

Inverse discrete Fourier transform of $C_n(j)$ in the n-th one-third octave frequency bands to obtain the acceleration time history $x_n(k)$ corresponding to the n-th one-third octave frequency bands:

$$x_n(k) = \sum_{j=0}^{M-1} C_n(j) e^{i(2\pi jk/M)} \qquad k = 0,1,2,3\cdots,N-1 \tag{4}$$

RMS of vibration acceleration corresponding to the n-th one-third octave frequency bands is:

$$a_n = \sqrt{\frac{1}{M}\sum_{k=0}^{M-1} x_n^2(k)} \tag{5}$$

Where M = number of the n-th frequency bands.

Repeat the equations (5) and (6), obtain all the RMS of vibration acceleration corresponding to the frequency domain, and substitut it into the equation (1) can be obtained for vibration acceleration level of each frequency band. Then substitute the RMS of vibration acceleration into the following equation, calculate the weighted RMS of vibration acceleration [7]:

$$a = \sqrt{\sum_{n=1}^{20} (a_n^2 c_n^2)} \tag{6}$$

Where c_n = weight factor corresponding to the frequency band (shown in Table 1).

TABLE 1 EACH ONE-THIRD OCTAVE FREQUENCY RANGE AND THE CORRECTION VALUE OF VIBRATION LEVEL

1/3 octave center frequency (Hz)	1/3 octave lower frequency (Hz)	1/3 octave upper frequency (Hz)	Level weighting factor (dB)	Vertical weighting factor (dB)
1.0	0.89	1.12	0dB (1.00)	-6dB (0.50)
1.25	1.12	1.41	0dB (1.00)	-5dB (0.56)
1.6	1.41	1.78	0dB (1.00)	-4dB (0.63)
2.0	1.78	2.24	0dB (1.00)	-3dB (0.71)
2.5	2.24	2.82	-2dB (0.80)	-2dB (0.80)
3.15	2.82	3.55	-4dB (0.63)	-1dB (0.90)
4.0	3.55	4.47	-6dB (0.50)	0dB (1.00)
5.0	4.47	5.62	-8dB (0.40)	0dB (1.00)
6.3	5.62	7.08	-10dB (0.315)	0dB (1.00)
8.0	7.08	8.91	-12dB (0.25)	0dB (1.00)
10.0	8.91	11.2	-14dB (0.20)	-2dB (0.80)
12.5	11.2	14.1	-16dB (0.16)	-4dB (0.63)
16	14.1	17.8	-18dB (0.125)	-6dB (0.50)
20.0	17.8	22.4	-20dB (0.10)	-8dB (0.40)
25.0	22.4	28.2	-22dB (0.08)	-10dB (0.315)
31.5	28.2	35.5	-24dB (0.083)	-12dB (0.25)
40.0	35.5	44.7	-26dB (0.05)	-14dB (0.20)
50.0	44.7	56.2	-28dB (0.04)	-16dB (0.16)
63.0	56.2	70.8	-30dB (0.0315)	-18dB (0.125)
80.0	70.8	89.1	-32dB (0.025)	-20dB (0.10)

Finally get the vibration acceleration level La by the equation (1).

– Spectral density method

According to the measured acceleration time history $a(t)$, get their power spectral density function $G(f)$:

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$$G(f) = 2\frac{|a(f)|^2}{T} \tag{7}$$

Where $a(f)$ = magnitude of the Fourier transform of acceleration time history ($\mathrm{m/s^2}$); T = sampling period of acceleration time history.

RMS of vibration acceleration corresponding to the n-th one-third octave frequency bands is:

$$a_n = \sqrt{\int_{f_1}^{f_2} G(f)df} \tag{8}$$

Where f_1, f_2 = lower and upper frequency of the 1/3 octave frequency bands (shown in Table 1).

Calculated for RMS of vibration acceleration a_n of all frequency bands, substituted into the equation (6) to get RMS of vibration-weighted acceleration a, then get vibration acceleration level La by the equation (1).

III. COMPARATIVE ANALYSIS OF THE VIBRATION ACCELERATION LEVEL BASED ON MEASUREMENT RESULTS

A. Comparative Analysis of the Vertical Vibration Acceleration Level

The test is in the background of heavy-haul train of the Shuo-Huang line, there is no other building, structure around the test sites, other traffic and construction and other vibration impact around. The speed of overloaded train is 100 km/h, and the axle load of overloaded train is 30 t, and we collect vibration data from 30 overloaded trains, the specific test point arrangement is shown in Fig. 1.

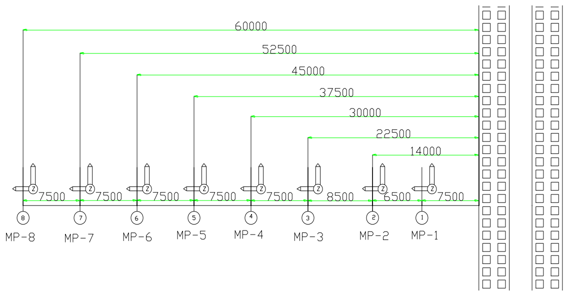

Fig. 1 Test point arrangement (Unit: mm)

The time history process of the measured vertical acceleration is calculated by the three different methods [8], and obtained the vertical vibrations acceleration level at different distances from the center line, as is shown in Fig. 2. In order not to disturb the work, study and rest of the surrounding residents, Chinese national standard "urban regional environmental vibration standard" (GB10070-88) provides regional rail trunk vertical vibration level on both sides of La standard value of 80 dB.

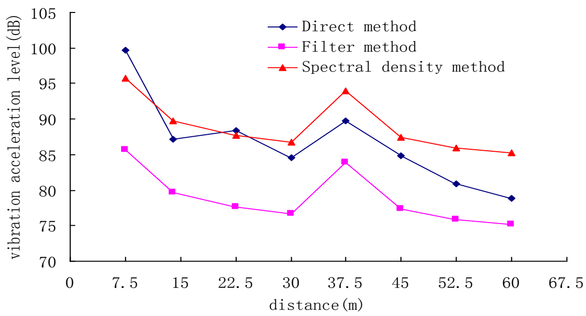

Fig. 2 Comparison of vertical vibration acceleration level algorithm

From Fig. 2: (1) The vertical vibration acceleration level decreases gradually with increasing distance. (2) There is a phenomenon that the vibration acceleration level has unexpected amplification at the distance of 37.5 m to the center line. (3) The vibration level calculated by filtering method is prevalently smaller than the vibration level calculated by direct method and spectral density method, while the vibration level calculated by filtering method is 10 dB smaller than that is calculated by spectral density method. (4) what is more the vibration levels calculated by direct method and spectral density method are more than bigger 80 dB, and the vibration levels calculated by filtering method at the distance of 14 m and 37.5 m are more than larger 80 dB respectively, above the vertical vibration level standard on both sides of railway lines area provisioned by "urban area environmental vibration control standard" (GB10070-88).

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B. *Comparative Analysis of the Horizontal Vibration Acceleration Level*

We test the lateral and longitudinal acceleration time-histories at the measuring point of the scene of the Shuo-Huang line. And we conduct 1/3 octave analysis to accelerate time-histories of each measuring point, use filter method and the spectral density method to calculate the horizontal weighted vibration acceleration level of different measuring points [9], as shown in Figs. 3 and 4.

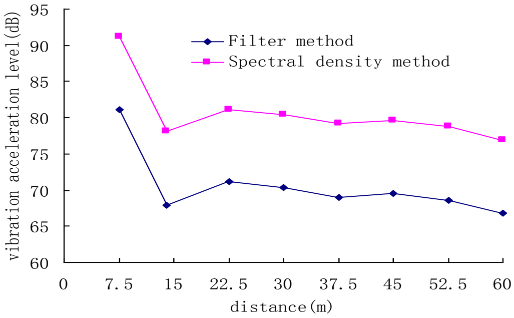

Fig. 3 Comparison of lateral vibration acceleration level algorithm

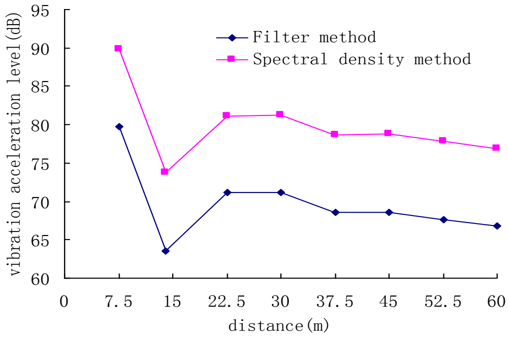

Fig. 4 Comparison of longitudinal vibration acceleration level algorithm

As it can be seen from the contrast of the horizontal and weighted vibration acceleration level by filter method and the spectral density method: Within the scope of 14m away from the measuring point, the weighted vibration acceleration level is very obvious, Otherwise it's unconspicuous; The vibration acceleration level of horizontal and vertical remains the same, whereas the vibration acceleration levels measured by the spectral density method which is 7.5 m, 22.5 m and 30 m away from the measuring point are over 80 dB, and that by filter method which is 7.5 m away from the measuring point are over 80 dB. Compared with the spectral density method, the horizontal vibration acceleration level calculated by filter method is lower 10 dB.

C. *Comparative Analysis of the Vertical Vibration Acceleration Level of Each One-third Octave Frequency Band*

The effects of vibration on the surrounding environment and on the human body are very complicated, especially when the vibration of vertical direction is a major factor affecting inhabitant activity and the reaction of human body is more sensitive to low frequency. Calculating each 1/3 octave frequency band corresponding to the vertical vibration acceleration level in the 1-80 Hz range is more accurate to reflect the impact of vibration on the human body. Moreover by calculating the acceleration time history to each measuring point by spectral density method and filtering method respectively, we can get the vertical vibration acceleration level corresponding to each 1/3 octave frequency band, as shown in Figs. 5 and 6. From the limiting value specified by China's national standard "Residential Building Indoor Vibration Limit and Measurement Method Standards" (GB/T 50355-2005), we take the second limit in the daytime.

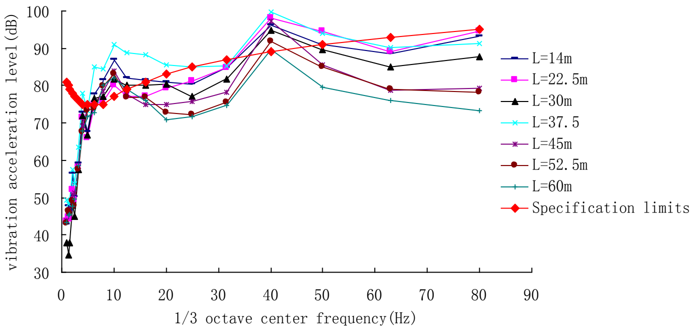

Fig. 5 Vertical vibration acceleration level of each frequency band (spectral density method)

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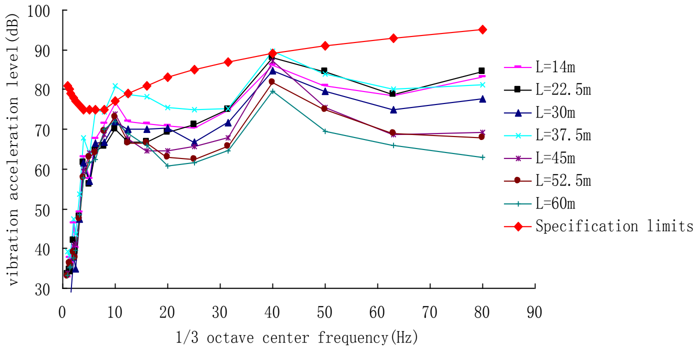

Fig. 6 Vertical vibration acceleration level of each frequency band (filter method)

As Fig. 5 shows, the vertical vibration acceleration level generally decreases with increasing distance, while increasing in the center frequency of 10 Hz and 40 Hz; The vibration acceleration level in frequency band of 6.3~20 Hz and 30~60 Hz is above the specification limit, so it’s necessary to take isolation measures. The vertical vibration acceleration level calculated by filtering method in Fig. 6 is obviously smaller than that in Fig. 5; The most magnitude is the specification limit in addition to that of 37.5 m away from the line, which meets the standard of the second limit in the daytime stipulated by the national standard.

IV. CONCLUSION

Doing the field test of the vibration of the along measuring points based on the running overloaded train with the Shuo-Huang line, calculating and analyzing the vibration level of acceleration time history based on filtering method, direct method and spectral density method, we draw conclusions as follows: (1) The vibration strength of the surrounding environment caused by the overloaded train of the Shuo-Huang line decreases gradually with increasing distance, whereas there is a phenomenon that the vibration acceleration level has a suddenly amplification at the distance of 37.5 m to the centerline. (2) The horizontal vibration acceleration level along the Shuo-Huang line is much smaller than the vertical vibration acceleration level, which meets the allowable vibration strength on both sides of the overload railway line stipulated by the national standard. The impact on human comfort is negligible. (3) With low-pass filtering to the data of the acceleration time history via filtering method, the vibration level calculated by filtering method is prevalently smaller than the vibration level calculated by direct method and spectral density method, which can truly reflect the influence of vibration caused by overload trains on the environment. (4) The influence of the vibration caused by the overload train on the environment is above the standard values on both sides of railway lines area provisioned by "urban area environmental vibration control standard" (GB10070-88), which needs to take appropriate isolation, damping measures to ensure the normal life of the residents along the railway line.

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