Environment Vibration Evaluation of RC Slab under Equipment Vibration

Minfeng LI
Minhang power plant, Shanghai Electric Power CO., LTD, Shanghai, 200245, China

ABSTRACT: The environment vibration effect under equipment vibration was studied. Based on the international standards, vibration evaluation indicator and allowable value was applied to the vibration quantitative evaluation. Combined with the engineering project, using R.M.S (Root-Mean-Square) and VDV (Vibration Dose Value) vibration evaluation methods, the vibration evaluation of RC slab was carried out. The results show that vertical vibration was more than the allowable value of standard, while horizontal vibration was met the requirement, which agreed with the human feeling on site. Finally, both vibration machines and structure were suggested to consider the environment vibration effect when designed.
KEYWORD: Equipment vibration; Environment effect; Root-Mean-Square acceleration; Frequency weighting curve; Vibration dose value; Vibration evaluation; RC slab

1 INTRODUCTION

As the differential equipment used in the plant, such as coal pulverizers and suction fans in coal-fired power plant, the vibration of theses equipment may cause the discomfort to the operation workers. Also, the operation speed of equipment is fast. There are so many factors caused the environment vibration. Vehicles (air, land and water), machinery (for example, those used in industry and agriculture) and industrial activities (such as piling and blasting), expose people to periodic, random and transient mechanical vibration which can interfere with comfort, activities and health (Griffin, M.J. 1994). Also the vibration source intensity is big. Meanwhile, as the technical level improved, the requirements of the equipment are very high, and the vibration limit is very strict (EN-14253 2004). Therefore, great attention is attached on the human vibration comfortable issue for researchers from different countries (Kjellberg A. & Wikstrom B. O. 1985, HOWARTH H.V.C.& Griffin, M.J. 1987, Griffin, M.J. 2007).

Vibration impacts on the environment mainly in three aspects: effects on the comfort of human body, influence of precision instrument and equipment, and effects on buildings (ANSI S3.29 1983). Structural vibration in buildings can be detected by the occupants and can affect them in many ways; their quality of life can be reduced, as can their working efficiency (DIN 4150-2 1999). In accordance with the reinforced concrete slab vibration test data, combination with different vibration evaluation methods, the environment vibration evaluation of the RC slab is analyzed, and some suggestions are presented.

2 VIBRATION EVALUATION METHOD

2.1 *Vibration frequency weighting curves*

A new frequency weighting method is adopted in ISO 2631-1: 1997, including principal and additional frequency weighting curves in one-third octaves. It includes six frequency weighting factors W_k, W_d, W_f, W_c, W_e, W_j. The former three factors are used to calculate the R.M.S. acceleration, others are used for calculation the additional evaluation indicator. And the frequency weighting for principal and additional frequency weighting curves show as Figure 1 and Figure 2.

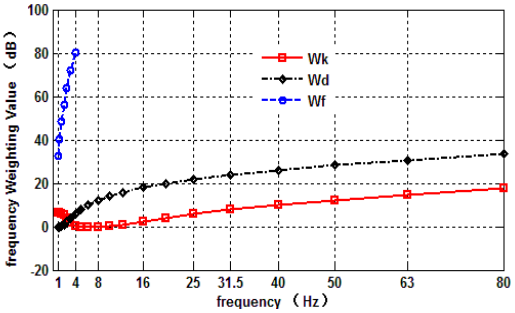

Figure 1 Principal frequency-weighting curves

© 2015. The authors - Published by Atlantis Press

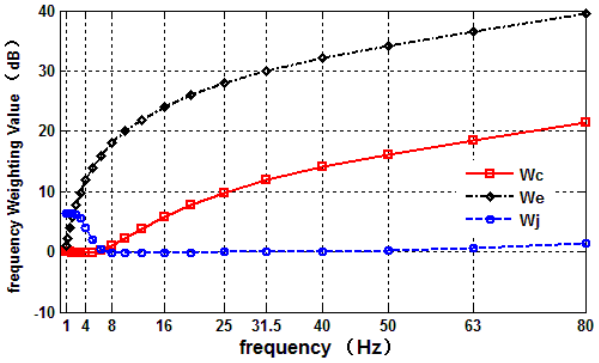

Figure 2 Additional frequency-weighting curves

The two Principal frequency-weightings W_k for the *z* direction and W_d for the *x* and *y* directions are related to health, comfort and perception, which are also used for the fourth power vibration dose value method (VDV method) in BS6472-1 2008. The frequency-weighting curves show as Fig. 3.

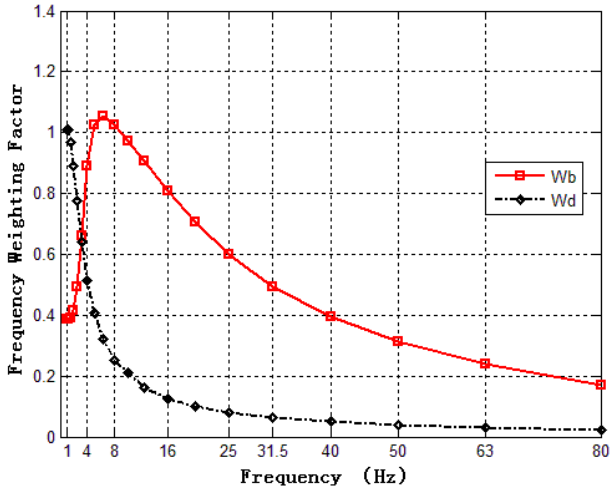

Figure 3 Frequency weighting curves of VDV method

2.2 *Vibration evaluation calculation*

The vibration evaluation indicators for human body are vibration acceleration, velocity, displacement. Most vibration evaluation methods use the acceleration indicator for evaluation.

2.2.1 *R.M.S method using weighted acceleration*

Weighted root-mean-square acceleration a_w is expressed in m/s^2 for translational vibration and rad/s^2 for rotational vibration. In ISO 2631-1: 1997 the weighted R.M.S. acceleration shall be calculated in accordance with the following equation

$$a_w = [\frac{1}{T}\int_0^T a_w^2(t)dt]^{\frac{1}{2}} \quad (1)$$

Where $a_w(t)$ is the weighted acceleration (translational or rotational) as a function of time history, in m/s^2 for translational vibration and rad/s^2, respectively; it reflects the combing vibration effect in time *T*. *T* is the duration of the measurement, in seconds.

For combing vibrations in more than one direction, the vibrations total value of weighted R.M.S. acceleration is calculated as follows,

$$a_w = (k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2)^{\frac{1}{2}} \quad (2)$$

Where a_{wx}, a_{wy}, a_wz are the weighted R.M.S. acceleration with respect to the orthogonal axes x, y, z respectively, k_x, k_y, k_z are multiplying factors to the orthogonal axes x, y, z respectively.

Using the R.M.S. method, the vibration of human body is indicated objectively, and it is applicable for most vibration. Therefore, this method is used widely by many countries and organizations.

2.2.2 *R.M.S method using weighted acceleration*

The Vibration Dose Value (VDV) defines a relationship that yields a consistent assessment of continuous, intermittent, occasional and impulsive vibration and correlates well with subjective response. The ISO standard used this VDV as the additional vibration indicator (in m.s$^{-1.75}$ or rad.s$^{-1.75}$). In BS6472-1 2008, the vibration dose value is defined in Equation 3.

$$VDV_{b/d,day/night} = \{\int_0^T [a_w(t)]^4 dt\}^{\frac{1}{4}} \quad (3)$$

Where $VDV_{b/d,\ day/night}$ is the vibration dose value (in m.s$^{-1.75}$); $a_w(t)$ is the frequency-weighted accelerationas a function of time history, in m/s^2. *T* is the total period of the day or night (in s) during which vibration can occur.

From the Eq.3, the VDV is given by the fourth root of the time integral of the fourth power of the acceleration after it has been frequency-weighted. And it is more sensitive to peaks than the R.M.S. method.

2.3 *Vibration limited*

For the regulations of the vibration limited, different countries and organizations have variable regulations, and do not develop an agreed standard. The BS standard BS 6472-1: 2008 uses the VDV as the vibration evaluation indicator. When the appropriately weighed vibration measurements or predictions have been used to drive the VDV for either 16 h (day-time) or 8 h (night-time) at the relevant places of interest, their significance in respect of human response for people in those places can be derived from Table 1.

For acceptable values of vibration magnitude for comfort depends on many factors which vary with each application. And there is no limit defined in ISO 2631-2. For perception, fifty percent of alert, fit persons can just detect a vibration with a peak magnitude of 0.015m/s^2. There is a large variation

for perceiving vibration between individuals. When the median perception threshold is approximately 0.015 m/s^2, the interquartile range of responses may extend from about 0.01 m/s^2 to 0.02m/s^2 peak.

Table 1 VDV ranges which might result in various adverse comments (BS6472-1 2008)

Place and time	Low probability of adverse comment m.s$^{-1.75}$	Adverse comment possible m.s$^{-1.75}$	Adverse comment probable m.s$^{-1.75}$
Residential buildings 16 h day	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Residential buildings 8 h night	0.1 to 0.2	0.2 to 0.4	0.4 to 0.8

Note: for office and workshops, multiplying factors of 2 and 4 respectively should be applied to above VDV ranges for a 16 hours day.

3 VIBRATION EVALUATION APPLICATION

In terms of the engineering vibration project, the vibration evaluation of RC slab under machine load is quantified. Using the test data, the R.M.S and VDV vibration evaluation methods are applied to evaluate the vibration of RC slab.

3.1 *Vibration test data*

The vibration test of a plant RC slab is proceed, in accordance with the maximum vibration acceleration time history curves of the tests nodes under the machines worked, the vibration acceleration the time history curves are tested as Figure 4

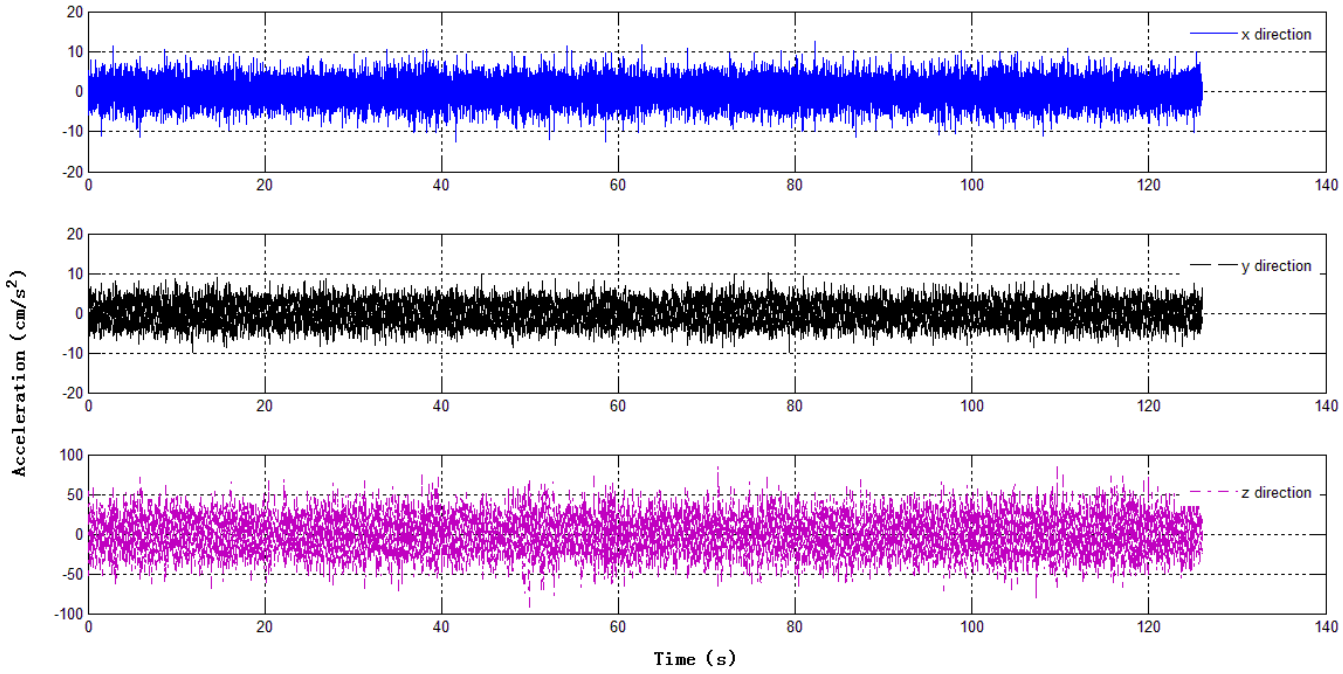

Figure 4 maximum acceleration time history curves

3.2 *Vibration evaluation for RC slab*

In line with the maximum vibration acceleration test data, the R.M.S and VDV vibration evaluation methods are applied to evaluate the vibration of RC slab.

Using the test data, the equivalent accelerations are calculated in one-third octaves. And distribute curves of the maximum vibration node are presented as Figure 5.

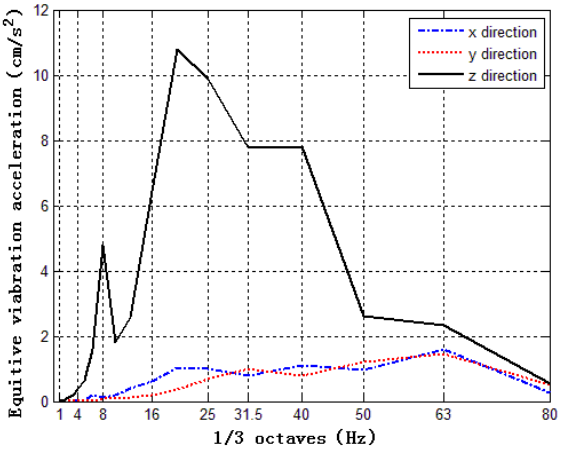

Figure 5 Equivalent acceleration distribute curves

3.2.1 *R.M.S method vibration evaluation*

According to the Fig 6, the vibration magnitude of Z direction is more than other directions. Therefore, the Z direction will be as the vibration axial for vibration evaluation.

The frequency-weighted vibration magnitude of Z direction is 12.265 cm/s^2, combing vibration of three directions for seated is 12.267 cm/s^2, and combing vibration of three directions for standing is 12.270 cm/s^2, which is much more than the standard reference perception limit value of 1 cm/s^2 to 2 cm/s^2 .

3.2.2 *VDV method Vibration evaluation*

Using the VDV method, considering the horizontal frequency-weighted W_d, with respect to Eq. 3, the vibration dose value of x direction is 0.1269 $m.s^{-1.75}$, the vibration dose value of x direction is 0.078$m.s^{-1.75}$; Considering the vertical frequency-weighted W_b, the vertical vibration dose value is 8.9118$m.s^{-1.75}$. For the workshop, according to the vibration limited value of Table 2, multiply the factor 4 to the adverse comment probable is from 3.2 $m.s^{-1.75}$ to 6.4 $m.s^{-1.75}$. Therefore, the vertical vibration dose value is more than the allowed limited value, this result is coincide with the human body feels discomfort, and some workers even feel adverse comment probable.

4 SUMMARY

The environment vibration effect is presented. With respect to the international standard of human exposed in the vibration environment, combination with vibration indicators and vibration limited value, the vibration could be quantified.

In accordance with the vibration test data of a plant's RC slab, using the R.M.S method and VDV method, the vibration of the RC slab is evaluated, the main results is as follows,

1. The test maximum vertical vibration is more than the vibration limited value, and the horizontal vibration is accord with the standards.

2. The calculation result of human comfort is coincided with the human body feeling.

3. The vibration equipment and the structure when designed may consider the environment vibration effect and human body comfort. The precision instrument and equipment when installed may consider the design of vibration damping.

REFERENCES

[1] Griffin, M.J. 1994. Handbook of Human Vibration. *Academic Press*, London

[2] EN-14253 2004. Mechanical vibration Measurement and evaluation of occupational exposure to whole-body vibration with reference to health - Practical guidance

[3] Kjellberg A., Wikstrom B. O. 1985. Subjective reaction to whole-body vibration of short duration. *Journal of Sound and Vibration*, 99(3): 415-424

[4] HOWARTH H.V.C., Griffin, M.J. 1987. The frequency dependence of subjective reaction to vertical and horizontal whole-body vibration at low magnitudes. *The Journal of the Acoustical Society of America*, 83(4): 1406-1413

[5] Griffin, M.J. 2007. Predicting the feeling of building vibration. *Proceedings of the Institute of Acoustics*, Vol.29. Pt.4

[6] ANSI S3.29 1983. Guide to the evaluation of human exposure to vibration in buildings

[7] DIN 4150-2 1999. Vibrations in buildings - Part 2: Effects on persons in buildingss. *Deutsches Institut for Normung*

[8] ISO 2631-1 1997. Mechanical vibration and shock: Evaluation of human exposure to whole-body. Part-1: General requirements

[9] BS6472-1 2008. Guide to evaluation of human exposure to vibration in buildings. Vibration sources other than blasting, *British Standard Institute*

[10] ISO 2631-2 2003. Mechanical vibration and shock: Evaluation of human exposure to whole-body. Part-2: Vibration in buildings(1~80Hz)