

A Comparison of Damping Ratio Analysis for Dynamic Foundation Vibration

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ABSTRACT :

Damping ration measurement method of a foundation was studied theoretically and experimentally based on the corresponding Chinese testing and design Codes. It shows that there is a relatively large difference between numerical results of Codes, approximate formulae of elastic half-space analytical solution, and the practical testing result. Therefore, six-degree-freedom time histories of the center of mass of a foundation are calculated from three-component vibration curves of some points on the foundation surface to be selected as the time-history of damping ratio calculating of subsoil. And also, to reduce the difference mentioned above, influence of window function on the subsoil damping ratio of a massive concrete foundation is analyzed based on logrithmic decrement method in the time domain and point-peak method in the frequency domain. It shows that damping ratio decreases as the smoothing times increases in the time domain, and on the contrary in the frequency domain.

KEYWORDS: Subsoil damping ratio, motion of center of mass, time-domain, frequency-domain, window function

1. INTRODUCTION

Design requirements of dynamic machine foundations are presented in the Chinese Code for Dynamic Machine Foundation Design (GB50040-96) as rightly selecting corresponding dynamic parameters and foundation types with advanced technology, economical cost and high safety. The dynamic parameters include compressive stiffness, shear stiffness, torsional stiffness and rotational stiffness, damping ratio and mass of vibration of subsoil, where damping ratio selection can change the foundation dynamic response especially the resonance amplitude and the resonance frequency. That is, a right damping ratio selection is important to foundation design and response calculation. And the it is suggested a right damping ratio be determined based on in-situ test firstly in another Chinese Code for Measurement Method of Dynamic Properties of Subsoil (GB/T50269-97). The following vertical damping ration calculation formulae are proposed when there is no experimental condition and has previous foundation building experience:

Clay:
$$\xi_z = \frac{0.16}{\sqrt{m}}$$
 (1.1)

Sand and silt:
$$\xi_z = \frac{0.11}{\sqrt{m}}$$
 (1.2)

Where $\overline{m} = \frac{m}{\rho A \sqrt{A}}$ is dimensionless mass ratio, ρ is subsoil density (t/m³) and A, the bottom area of the

foundation (m²). The damping ratio of horizontal and rotational coupling vibration:

$$\zeta_{x\varphi 1} = 0.5\zeta_z \qquad \zeta_{x\varphi 2} = \zeta_z \qquad \zeta_{\psi} = \zeta_{x\varphi 1} \tag{1.3}$$

 $\zeta_{x\varphi_1}$, $\zeta_{x\varphi_2}$ are damping ratio of the first and second mode of coupling vibration and ζ_{ψ} , the torsional damping ratio. Wang Xikang(2007) presented detailed beginning and subsequent development of the damping ratio calculation method.



As a comparison, parameters' approximate calculating formulae for a mass-spring-damper model to represent a circular foundation on the elastic half-space are listed in Table 1.1, which were presented by Richard, Whitman and Lysmer and so on (1967). The formulae have been obtained based on the frequency-dependant analytical solutions of the problem and have deep and lasting significance in dynamic machine foundation design. Even for some non-circular foundations such as rectangular foundation, stiffness formulae also have been adopted as an equivalent bottom area of the circular foundation in some engineering practice.

In any case, approximate damping ratio formulae of (1.1)-(1.3) have the same form as what the elastic half-space ones as Table 1 shows. And basically, damping ratio value of the Code is less than these of Table 1. Some scholars in China have studied the damping ratio testing and calculating both in numerical calculating and experimental fields and drawn some conclusions. Han Yingcai (1986) demonstrated that the radiation damping ratio should be taken larger to reduce the foundation vibration efficiently but not by the way of increasing the foundation mass after calculating and testing dynamic response of a 5m×5m foundation of an earthquake simulation table. Wang Zhenyu etc. (2002) argued that if neglecting the radiation damping ratio of a large dynamic machine foundation will introduce a large calculating error using mass-spring-damper model, that is, a damping ratio larger than the Code should be taken to analyze the foundation dynamic response correctly. The conclusion was drawn after theoretical and experimental study on microvibration response calculation based on finite-element method of a large dynamic machine foundation. Chen Jiong (2002) calculated the vertical resonant damping ratio of a foundation based on distribution of base pressure of rigid and flexible foundation and different Poisson's ratio. He pointed out that value of the damping ratio is nearly the same as half-space theory's result and larger than the Code's.

		on elastic nan-space		
	Vertical	Horizontal	Rotational	Tosional
Stiffness	$4GR/(1-\upsilon)$	$8GR/(2-\upsilon)$	$8GR^3/3(1-\upsilon)$	$16GR^{3}/3$
Mass ratio \overline{m}	$\frac{m(1-\upsilon)}{4\rho R^3}$	$\frac{m(2-\upsilon)}{8\rho R^3}$	$\frac{3I_x(1-\upsilon)}{8\rho R^5}$	$\frac{I_z}{\rho R^5}$
Damping ratio	$\frac{0.425}{\overline{m}^{1/2}}$	$\frac{0.29}{\overline{m}^{1/2}}$	$\frac{0.15}{(1+\overline{m})\overline{m}^{1/2}}$	$\frac{0.50}{1+2\overline{m}}$

Table 1.1 Approximate formulae of equivalent mass-spring-damper model parameters of a circular foundation based on elastic half-space

m is mass of the rigid foundation, I_x and I_z are rotational inertia of the foundation around x- and z- axis

In this paper, a dynamic machine foundation was tested and damping ratio calculation method is studied. Damping ratio, soil-mass participating in vibration and compressive stiffness are important dynamic parameters in rigid foundation vibration analysis. Generally, measurement of these parameters and data processing depend upon some direct time-histories of vibration sensors installed on the foundation surface. Damping ratio testing and data processing method written in Chinese *Code for Dynamic Machine Foundation Design* (GB50040-96) include time-domain method and frequency-domain method. The former mainly is used free damping vibration sensors (such as a velocity sensor) are installed on the two ends of the axial line of a rectangular foundation surface. Imposing a steady-state force or an impacting load on the foundation and measuring the vibration time-histories to calculate the amplitude-frequency curves through Fourier transform to obtain the resonant frequency (f_m) and amplitude value (A_m), and at least three amplitude values (A_i) and frequencies (f_i) under 0.85 f_m . The frequency-domain damping ratio can be calculated as,

$$\xi_z = \frac{\sum_{i=1}^n \xi_{zi}}{n}$$
(1.4)



$$\xi_{zi} = \left[\frac{1}{2} \left(1 - \sqrt{\frac{\beta_i^2 - 1}{\alpha_i^4 - 2\alpha_i^2 + \beta_i^2}}\right)\right]^{1/2}$$
(1.5)

$$\alpha_i = \frac{f_m}{f_i}, \ \beta_i = \frac{A_m}{A_i}$$
(1.6)

In the time domain, logarithmic decrement method often be taken to calculate the damping ratio,

$$\xi_{z} = \frac{1}{2\pi} \frac{1}{n} \ln \frac{A_{1}}{A_{n+1}}$$
(1.7)

Where A_1 (m) is the amplitude of the first period and A_{n+1} (m), amplitude of the n+1*th* period.

2. MOTION OF CENTER OF FOUNDATION

A comparison method presented in this paper with the Code is a method of calculating six-degree-of-freedom motion vector (three translational and three rotational components) of center of mass of a rigid foundation based on four three-component vibration records. Figure 1 is an example of mass foundation with four groups of three-component time-histories is analyzed and compared both in the time domain and frequency domain. Four group of three-component vibration sensors are installed on the surface of the foundation.

To obtain the six-degree-of-freedom motion vector of center of mass of a rigid foundation, the following suppositions are introduced,

1 The foundation is rigid and has no deformation;

2 Motion of the foundation can be described totally by the six-degree-system as shown in Figure 1, three translational motions and three rotational motions. That is, the foundation motion state can be described by the motion vector of the mass center of the foundation and its shape,

$$\mathbf{U}(t) = \{ u_x(t), \ u_y(t), u_z(t), \phi_x(t), \phi_y(t), \phi_z(t) \}^T$$
(2.1)

3 Three-component vibration time-histories of point A, B, C, and D can be written as

$$\mathbf{U}_{A}(t) = \left\{ u_{xA}(t), \ u_{yA}(t), \ u_{zA}(t) \right\}^{T}$$
(2.2)

$$\mathbf{U}_{R}(t) = \left\{ u_{R}(t), \ u_{R}(t), \ u_{R}(t) \right\}^{T}$$
(2.3)

$$U_{C}(t) = \left\{ u_{xC}(t), \ u_{yC}(t), \ u_{zC}(t) \right\}^{T}$$
(2.4)

$$\mathbf{U}_{D}(t) = \left\{ u_{xD}(t), \ u_{yD}(t), \ u_{zD}(t) \right\}^{T}$$
(2.5)



Figure 1 Degree-of -freedom of a massive foundation vibration



Therefore, the mass center motion with the motions of the four points can be related as the following formula

$$\mathbf{U}_{i}(t) = \mathbf{T}_{i}\mathbf{U}(t) \quad (i=A, B, C, D)$$
(2.6)

Where T_i is a transform matrix of motions between mass center and four points' time-history measured by the installed vibration sensors,

$$\mathbf{T}_{\mathcal{A}} = \begin{bmatrix} 1 & 0 & 0 & 0 & -l_{1} \cos \theta_{1} & 0 \\ 0 & 1 & 0 & a/2 & 0 & -a/2 \\ 0 & 0 & 1 & 0 & 0 & l_{1} \sin \theta_{1} \end{bmatrix}$$
(2.7)

$$\mathbf{T}_{\mathcal{B}} = \begin{bmatrix} 1 & 0 & 0 & 0 & -h/2 & -b/2 \\ 0 & 1 & 0 & l_2 \cos \theta_2 & 0 & 0 \\ 0 & 0 & 1 & l_2 \sin \theta_2 & 0 & 0 \end{bmatrix}$$
(2.8)

$$\mathbf{T}_{C} = \begin{vmatrix} 1 & 0 & 0 & 0 & l_{1} \cos \theta_{1} & 0 \\ 0 & 1 & 0 & -a/2 & 0 & a/2 \\ 0 & 0 & 1 & 0 & 0 & -l_{1} \sin \theta_{1} \end{vmatrix}$$
(2.9)

$$\mathbf{T}_{D} = \begin{bmatrix} 1 & 0 & 0 & 0 & h/2 & b/2 \\ 0 & 1 & 0 & -l_{2} \cos \theta_{2} & 0 & 0 \\ 0 & 0 & 1 & -l_{2} \sin \theta_{2} & 0 & 0 \end{bmatrix}$$
(2.10)

And,

$$l_{1} = \sqrt{\left(\frac{h}{2}\right)^{2} + \left(\frac{a}{2}\right)^{2}}, \quad \sin \theta_{1} = \frac{a}{\sqrt{a^{2} + h^{2}}}, \quad \cos \theta_{1} = \frac{h}{\sqrt{a^{2} + h^{2}}}$$
(2.11)

$$l_{2} = \sqrt{\left(\frac{h}{2}\right)^{2} + \left(\frac{b}{2}\right)^{2}}, \quad \sin \theta_{2} = \frac{b}{\sqrt{b^{2} + h^{2}}}, \quad \cos \theta_{2} = \frac{h}{\sqrt{b^{2} + h^{2}}}$$
(2.12)

Equations (2.6)- (2.12) are 12 linear functions, only 6 unknown variables which can be solved by the least-square method as follows

$$\mathbf{DU}(t) = \mathbf{w}(t) \tag{2.13}$$

$$\mathbf{D} = \begin{bmatrix} 4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 4 & 0 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{a^2}{2} + 2l_2^2 & 0 & -\frac{a^2}{2} \\ 0 & 0 & 0 & 0 & \frac{h^2}{2} + 2(l_1 \cos \theta_1)^2 & \frac{bh}{2} \\ 0 & 0 & 0 & -\frac{a^2}{2} & \frac{bh}{2} & \frac{a^2}{2} + 2(l_1 \sin \theta_1)^2 + \frac{b^2}{2} \end{bmatrix}$$
(2.14)

And,



$$\mathbf{w}(t) = \begin{cases} x_1 + x_2 + x_3 + x_4 \\ y_1 + y_2 + y_3 + y_4 \\ z_1 + z_2 + z_3 + z_4 \end{cases}$$

$$\mathbf{w}(t) = \begin{cases} \frac{a}{2}y_1 + l_2 \cos\theta_2 y_2 - \frac{a}{2}y_3 - l_2 \cos\theta_2 y_4 + l_2 \sin\theta_2 z_2 - l_2 \sin\theta_2 z_4 \\ -l_1 \cos\theta_1 x_1 - \frac{h}{2}x_2 + l_1 \cos\theta_1 x_3 + \frac{h}{2}x_4 \\ -\frac{b}{2}x_2 + \frac{b}{2}x_4 - \frac{a}{2}y_1 + \frac{a}{2}y_3 + l_1 \sin\theta_1 z_1 - l_1 \sin\theta_1 z_3 \end{cases}$$

$$(2.15)$$

Where $\mathbf{w}(t)$ is recorded by the installed sensors.

3 COMPARISON OF VERTICAL DAMPING RATIO CALCULATING METHOD

3.1. Vertical damping ratio

Forced and decrement vibrations of a massive concrete foundation was measured to calculate the damping ratio of different methods above. The foundation is 8.0 meters long, 4.0 meters wide and 2.0 meters deep, about 155 tons (Figure2). The subsoil consists of no more than 1 meter miscellaneous fills and silty clay layer. The bottom of the foundation lies on silty clay. Some soil static and dynamic experiments have been done with water content is 14.7%, density is 1.95t/m³ and void ratio is 0.78 of a sample at 2.0 meters' deep from the ground surface.



Figure 2 Foundation appearance



Figure 4 Time-history (Forcing vibration)



Figure3 Input system of forcing vibration



Figure 5 Vertical free vibration of foundation



Besides the 12 sensors as shown in Figure1, a group of three-dimensional sensors also are installed at the machine pedestal to record velocity time-histories of the vibration resource. The sampling frequency is 1024 times per second, which satisfies sampling theorem. Type of the exciting pneumatic equipment is QJQ3-80, with gas resource is a potable air compression (Figure3). Totally 24 group of steady-state exciting, 12 group of decrement, and 3 group of tremor experiments have been tested. Time-histories of an exciting and a decrement test are shown in Figure 4 and Figure 5. Damping ratio results using *Code for Measurement Method of Dynamic Properties of Subsoil*(GB/T50269-97) and method of section 2 are listed in Table 2. For the former, n is take as 2 and data smoothing is introduced as the Code requires in equation (1.7).

	The Code method	Approximate formulae (Ta	The code method	The code method	Method of Section 2 (2.1)-(2.15)	
	(Eq. 1.1)	ble 1.1)	(1.4)-(1.6)	Eq. (1.7)	Steady- state force	Impact force
Forced No. 1	0.241	0.641	0.008		0.015	
Forced No. 2	0.241	0.641	0.008		0.008	
Forced No. 3	0.241	0.641	0.010		0.015	
Decrement No. 1	0.241	0.641		0.174		0.179
Decrement No. 2	0.241	0.641		0.177		0.197
Decrement No. 3	0.241	0.641		0.170		0.166

Table 2.1 Comparison of vertical damping ration of subsoil

From Table 2.1, the damping ratio is only about 0.179 using decrement force experimental results in the time domain and also, only about 0.01 using steady-state vibrations in the frequency domain, which if far less than that of the approximate formulae method based on the Chinese *Code for Dynamic Machine Foundation Design* (GB50040-96) (0.241) of Eq. (1.1)-(1.3) and half-space approximate formulae result of Table 1.1(0.641). Using method of section 2, the results is a little larger.

It should be mentioned that the foundation size of this paper is larger than that of the Code requirement $(2.0 \text{m} \times 1.5 \text{m} \times 1.0 \text{m})$, but another foundation's $(1.4 \text{m} \times 1.4 \text{m} \times 0.8 \text{m})$ calculating results shown the same results as Table 2.1 lists.

3.2. An advantage of using motions of center of mass

Figure 6 is a direct record of a vertical sensor in an impacting experiment. It is difficult to determine number of decrement period and calculate the damping ratio using Eq. (1.7). However, based on method of Eq.(2.1)-(2.15), the time history of the same test is very suitable for calculating damping ratio in the time domain.





Figure 6 Time-history of free vibration of original record

Figure 7 Time-history of center of mass



4 COMPARISION OF DIFFERENT WINDOW FUNCTIONS ON DAMPING RATIO

4.1. Window functions

Chinese *Code for Measurement Method of Dynamic Properties of Subsoil* (GB/T50269-97) also has prescribed that the time-histories should be smoothed before calculating the damping ratio of the foundation by correctly selecting suitable window function and smoothing times. Window function is a kind of smoothing technique in the frequency-domain. Some times, both the time-histories and their frequency-amplitude curves have many burrs which make the amplitude and frequency f_m or the other frequencies are difficult to be determined. Using a smoothing technique can make curves smoother and even improve the damping ratio calculating precision without losing the vibration information.

Supposing G(f) is the power spectrum of a time-history, multiplying a frequency-dependant function W(f), the following convolution $\overline{G}(f)$ is called smoothing power spectrum of G(f).

$$\overline{G}(f) = \int_{-\infty}^{\infty} G(g) W(f - g) dg$$
(4.1)

W(f) is called window function. A window function has invariable area and is an even function, that is

$$\int_{-\infty}^{\infty} W(f) df = 1$$
(4.2)

$$W(f) = W(-f) \tag{4.3}$$

Generally, the window function includes rectangular window, Bartlett window, Parzen window, Hanning window, Hamming window and so on. A window function only allows some frequency component to pass, just like a bandpass filter. So, a correct smoothing method will improve the precision of the subsoil damping ratio. Definitions of the three kind of window function (rectangular window, Bartlett window, Parzen window) are,

$$W(f) = 2u \left(\frac{\sin 2\pi u f}{2\pi u f} \right)$$
(4.4)

$$W(f) = u \left(\frac{\sin \pi u f}{\pi u f}\right)^2 \tag{4.5}$$

$$W(f) = \frac{3}{4}u \left(\frac{\sin\frac{\pi uf}{2}}{\frac{\pi uf}{2}}\right)^{*}$$
(4.6)

Where u is a constant. There are two important parameters of a window function, bias and leakage. Bias is difference of the original spectrum and the smoothed spectrum. A larger side-lobe means the smoothing will effect amplitude of farer frequencies, the phenomena is leakage. Because the side-lobe of the rectangular window is far larger than that of the Parzen window, the rectangular window has large leakage but the Parzen window has nearly no leakage. For a

window function with the form of
$$\left(\frac{\sin \frac{2\pi uf}{n}}{\frac{2\pi uf}{n}}\right)^n$$
, a smaller n will take less bias and larger leakage, otherwise, large

leakage and less bias. So, the bias and leakage's choice, or a window function choice, should depend upon special engineering requirements.

Take a point on the velocity time-history as the center and the average value of all the velocities of the original timehistory in fixed time as the velocity of the center, then move forward the center and calculate the average value as its new velocity, keep the fixed time without changing. This kind of smoothing method is called moving average method. In the fixed time, all of the points of the original curves have the same weighting value to new value of the center. Bu



t, some other kind of window functions, such as Hanning window and Hamming window, have different weighting values at different points,

$$\overline{G_k} = 0.25G_{k-1} + 0.5G_k + 0.25G_{k+1}$$
(4.7)

$$\overline{G_k} = 0.23G_{k-1} + 0.54G_k + 0.23G_{k+1}$$
(4.8)

Where, $\overline{G_k}$ is the *k*th spectrum value, and G_{k-1} , G_k and G_{k+1} are the (*k*-1)th, *k*th and (*k*+1)th original spectrum values.

4.2 Comparison of the subsoil damping ratio with different window function

A concrete foundation with size of $1.4m \times 1.4m \times 0.6m$ is about 2.822 tons weight. Also again, four groups of the three-component sensors are installed on its surface at the center of each side. Both steady-state-force and transient force are imposed on the center of the foundation to record the horizontal and vertical vibrating velocity. Figure 8 is the vertical decrement time-histories and Figure 9 is a amplitude-frequency curve of a steady-state-response.



Figure 8 Foundation vertical decrement time-history Figure 9 Amplitu

Figure 9 Amplitude-frequency curve of vertical vibration

	n=1	n=2	n=3	n=4	average
Original curve	0.117	0.087	0.065	0.065	0.084
Average value of neighboring 3 point	0.116	0.087	0.065	0.065	0.083
Hanning window	0.116	0.087	0.065	0.065	0.083
Hamming window	0.116	0.087	0.065	0.065	0.083

Table 4.1 Comparison of damping rations in the time domain

From Table 4.1, one can see that the three smoothing method, three neighboring points' average method, Hanning window and Hamming window have the same results of the damping ratio values and nearly have no difference with the original curves' results.

Table 4.2 Comparison of vertical damping ration in the frequency domain

f _i (Hz)	20.5	21.0	21.5	22.0	22.5	average
Original curve	0.149	0.148	0.099	0.055	0.062	0.103
Average value of neighboring 3 point	0.142	0.136	0.119	0.080	0.055	0.106
Hanning window	0.136	0.133	0.119	0.078	0.049	0.103
Hamming window	0.135	0.132	0.120	0.078	0.048	0.102



From Table 4.2, the three smoothing methods also have nearly the same results of the damping ratio values in the frequency domain.

To illustrate the influence of smoothing times on the subsoil damping ratio measurement in the time domain, Table 4.3 shows the results after some times' smoothing. Take the free vibration periods as 2, 3, 4, 5 respectively. There is little difference on the damping ratio with the times of the smoothing processing.

	Number of periods	Original curve	Averaging of neighboring three points	Hanning window	Hamming window
	n=1	0.117	0.115	0.116	0.115
2 times	n=2	0.087	0.092	0.087	0.087
2 times	n=3	0.065	0.065	0.065	0.065
	n=4	0.065	0.065	0.065	0.065
	n=1	0.117	0.115	0.115	0.115
2.1	n=2	0.087	0.087	0.087	0.087
5 times	n=3	0.065	0.065	0.065	0.065
	n=4	0.065	0.063	0.065	0.065
	n=1	0.117	0.113	0.115	0.115
1 times	n=2	0.087	0.086	0.087	0.087
4 times	n=3	0.065	0.065	0.065	0.065
	n=4	0.065	0.066	0.065	0.065
5 times	n=1	0.117	0.113	0.114	0.114
	n=2	0.087	0.086	0.086	0.087
	n=3	0.065	0.065	0.065	0.065
	n=4	0.065	0.066	0.066	0.065

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To illustrate the influence of smoothing times on the subsoil damping ratio measurement in the frequency domain, Table 4.4 shows the result after some times' smoothing. The damping ratio becomes larger and larger with the increasing of smoothing times.

From Table 4.1-4.4, the following conclusions can be drawn: a smoothing method (neighboring three points) has little done with damping ratio value. However, smoothing times can change it. The damping ratio becomes smaller and smaller with the smoothing times in the time domain although it is not remarkable. On the contrary, in the frequency domain, the damping ratio gets larger and larger.

According to the *Code for Dynamic Machine Foundation Design* (GB50040-96) the damping ratio of the foundation is about 0.25, and to the half-space theory, it is about 0.65. In the frequency domain, do 18 times of Hamming window smoothing on the amplitude-frequency curve, the damping ratio is about 0.28. Thus, to get an equivalent damping ratio to the Code, it needs about 18 times of smoothing.

From above analysis, in the fact, a window function in the time domain or frequency domain likes a filter. Thus, how to select a window function and the smoothing times, in some ways, is how to select a filter schedule to the original curves. So, basically, a correct selection of a window function should depend upon the foundation and subsoil information as well as the real damping ratio of the subsoil. It has been mentioned that the foundation damping ratio is about 0.65 according to the half-space theory and about 0.25 according to the corresponding Chinese Code. And in some works, it has been calculated that the damping ratio of vertical vibration of a PHC pile is about 0.2 (Shi Zhenming etc., 2004). Another opinion believes it should be about 0.1 (Zhang Gaihui, 2002). There are not many practical resting values of damping ratio for dynamic machine foundation. Some structural natural characteristics anal



ysis have verified that the damping ratio identification seems more difficult than the other natural properties such as natural frequency (Hu Yuxian, 2006). From this, it should be known that furthermore research should be taken on testing method and theoretical calculation of damping ratio.

	f _i (Hz)	Original curves	Averaging of neighboring three points	Hanning window	Hamming window
	20.5	0.149	0.151	0.143	0.142
	21.0	0.148	0.128	0.124	0.123
2 times	21.5	0.099	0.098	0.088	0.086
2 times	22.0	0.055	0.071	0.061	0.059
	22.5	0.062	0.056	0.046	0.042
	Average	0.103	0.108	0.092	0.091
	20.5	0.149	0.154	0.149	0.148
	21.0	0.148	0.136	0.130	0.128
2 times	21.5	0.099	0.108	0.098	0.095
3 times	22.0	0.055	0.086	0.072	0.069
	22.5	0.062	0.067	0.055	0.052
	Average	0.103	0.112	0.100	0.098
	20.5	0.149	0.160	0.154	0.152
	21.0	0.148	0.144	0.135	0.134
1 times	21.5	0.099	0.123	0.108	0.104
4 times	22.0	0.055	0.102	0.083	0.079
	22.5	0.062	0.087	0.065	0.061
	Average	0.103	0.123	0.109	0.106
	20.5	0.149	0.165	0.158	0.157
-	21.0	0.148	0.153	0.142	0.139
	21.5	0.099	0.135	0.117	0.113
5 times	22.0	0.055	0.120	0.095	0.090
-	22.5	0.062	0.108	0.077	0.071
	Average	0.103	0.136	0.118	0.114

Table 4.4 Influence of smoothing times on the vertical damping ration in the frequency domain

5 CONCLUSIONS

Vertical damping ratio testing method of a dynamic machine foundation is studied theoretically and experimentally based on the Chinese *Code for Dynamic Machine Foundation Design* (GB50040-96) and *Code for Measurement Method of Dynamic Properties of Subsoil* (GB/T50269-97). The damping ratio value of Code method, both in the time domain method and the frequency domain, is far from that of the approximate formulae and elastic half-space analytical method.

A method of calculating six-degree-of-freedom motion vector (three translational and three rotational components) of center of mass of a rigid foundation based on four three-component vibration records is presented. The method is verified to be suitable for damping ratio analysis.

Damping ratio, soil-mass participating in vibration, and compressive stiffness (rotational, torsional and shear stiffness) are important dynamic parameters in rigid foundation vibration analysis. Generally, me



asurement of these parameters and data processing depend upon some direct time-histories of vibration sensors installed on the foundation surface. It also should be recommended that vibration sensors be pre-embedded in some proper positions of bottom surface of the foundation to improve the precision of subsoil dynamic parameters measurement.

Influence of some often-used smoothing methods on the damping ratio testing methods, including logrithmic decrement method in the time domain and point-peak method in the frequency domain, is presented in this paper based on practical testing of a massive concrete foundation. Three methods, moving average of neighboring three points, Hanning window and Hamming window, nearly have no difference on damping ratio values. And also, the smoothing times seems having little done with the damping ratio in the time-domain. In the time domain, the more of smoothing times, the less of the damping ratio. On the contrary in the frequency domain, the larger of the damping ratio. 18 times repetition smoothing on an original curve, the damping ratio value in the time domain is about equal to the Code result in the frequency domain. Furthermore theoretical and experimental research on damping ratio should be carried out to really resolve the problem of selecting a reasonable smoothing schedule to test and calculate subsoil damping ratio correctly.

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