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Vijay K. Puri

Southern Illinois University, Carbondale, IL

Braja M. Das

California State University, Sacramento, CA

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Vijay K. Puri
Professor
Dept. of Civil Engineering
Southern Illinois University Carbondale
Carbondale, IL 62901-6603

Braja M. Das
Dean
College of Engineering and Computer Science
California State University
Sacramento, CA 95819

ABSTRACT

Steady state vertical vibration tests were conducted on test blocks measuring 1.5m x 0.75m x 0.7 m and 3m x 1.5m x 0.7m resting on ground surface. The amplitudes of vibration the blocks were measured at different frequencies. Dynamic shear modulus of the soil at site was also determined by conducting in-situ tests. The natural frequencies and amplitudes of vibration were calculated by (i) elastic half space method and (ii) impedance function method. A comparison was then made of the observed and the computed values natural frequencies and the vibration amplitudes. The data obtained shows that for this case the natural frequencies could be reasonably predicted by either of these methods. The observed and computed amplitude however showed a wide scatter. Further details are given in the paper.

KEYWORDS

Vibration, vertical, blocks, comparison, response

INTRODUCTION

Block foundations are commonly used for supporting machines. The criteria for design of machine foundations requires that the natural frequency of the foundations should not coincide with the operational frequency of the machine; and the vibration amplitude should not exceed a given value. The design of a machine foundation is generally made by the elastic half space method (Richart, Hall and Woods, 1970; Prakash and Puri, 1988; Das, 1992; Puri and Das, 1993). Recently, a new method has been proposed which utilizes the impedance-compliance functions for obtaining the stiffness and damping values for the foundation soil system (Dobry and Gazettas, 1986), Dobry, Gazettas and Stokes, 1986), (Gazettas, 1991), and Gazettas and Stokes, 1991). The information on computed and predicted response of a machine foundation is in general very limited. This paper presents a comparison of the computed and monitored response of two test blocks resting on ground surface and excited into vertical vibrations. The dynamic soil properties were determined by conducting in-situ tests and oscillatory shear tests in the laboratory. The response of the two test blocks was then computed by the (i) elastic half space method and (ii) the impedance function approach. A comparison was made of the observed and calculated response of the test blocks.

TESTS PERFORMED

Vertical Vibration Tests

The vertical vibration tests were conducted on two rigid concrete blocks. The sizes of the test blocks were 3.0m x 1.5m x 0.7m and 1.5m x 0.75m x 0.7 m. The blocks were subjected to vertical excitation with a speed controlled mechanical vibrator. The vibrations were monitored with acceleration transducers. Records were obtained for different excitation frequencies and for different values of 'θ', the angle of setting of eccentric masses. From the vibration test data, the natural frequencies and corresponding amplitudes were determined (Table 1 and 2).

Tests for Dynamic Soil Properties

Dynamic soil properties used for computing the response of the blocks were determined from in-situ and laboratory tests. These properties are affected by a number of factors which must be accounted for when selecting the design values of shear modulus and damping. The most important factors which affect these properties are (1) the mean effective confining pressure, (2) the shear strain

Table 1. Comparison of Observed and Computed Response of 1.5m x 0.75m x 0.7m Block.

Angle of Eccentricity θ	Observed Data		Shear Strain γ_θ	Shear Modulus G kN/m^2	Computed Data			
					Elastic Half Space Analog Method		Impedance Function Method	
	Natural Frequency Hz	Amplitude Az mm			Natural Frequency Hz	Damped Amplitude Az mm	Natural Frequency Hz	Damped Amplitude Az mm
25	38.5	0.031	4.13×10^{-5}	35,500	41.4	0.127	55.6	0.0761
50	37.5	0.069	9.2×10^{-5}	29,000	37.1	0.27	49.4	0.170
75	37.0	0.0975	1.3×10^{-4}	26,000	35.2	0.406	46.3	0.248
125	36.7	0.182	2.43×10^{-4}	22,100	33.1	0.531	42.6	0.250
180	35.0	0.240	3.3×10^{-4}	18,100	29.3	0.720	37.4	1.00

Table 2. Comparison of Observed and Computed Response of 3.0m x 1.5m x 0.7m Block.

Angle of Eccentricity θ	Observed Data		Shear Strain γ_θ	Shear Modulus G kN/m^2	Computed Data			
					Elastic Half Space Analog Method		Impedance Function Method	
	Natural Frequency Hz	Amplitude Az mm			Natural Frequency Hz	Damped Amplitude Az mm	Natural Frequency Hz	Damped Amplitude Az Mm
25	36.0	0.006	4×10^{-6}	70,000	42.0	0.0261	29.5	0.021
50	34.5	0.012	8×10^{-6}	67,500	41.3	0.0478	29.4	0.0381
75	37.0	0.018	1.2×10^{-5}	66,000	40.7	0.0852	29.05	0.051
100	37.0	0.024	1.6×10^{-5}	65,000	40.4	0.109	28.8	0.050
125	35.0	0.030	2.0×10^{-5}	61,000	39.2	0.119	27.9	0.0423
150	34.5	0.036	2.4×10^{-5}	60,000	28.8	0.127	27.7	0.025
180	33.5	0.053	3.5×10^{-7}	56,000	37.5	0.133	26.7	0.102

Note: The vibration amplitudes were calculated at the observed natural frequency of the block.

amplitude, and (3) density of the soil. A good discussion the effect of these parameters and how to correct for their effects has been presented by Prakash and Puri (1977,1981 and 1988), Nandakumaran et al. (1977) and Das (1992).

In-situ soil tests consisted of (1) wave propagation tests, (2) cyclic plate load tests and (3) standard penetration tests.

Using the data obtained from these tests, the values of dynamic shear modulus "G" were computed. From the uncorrected standard penetration (N) values shear wave velocity V_s at a particular depth was determined from equation (1), Imai (1977) and dynamic shear modulus "G" was computed from equation (2).

$$V_s = 91.0\ N^{0.337} \quad (1)$$

$$G = V_s^{\ 2} \times \rho \quad (2)$$

in which $\rho = \gamma/g$ = mass density of soil.

The laboratory investigation consisted of oscillatory shear tests conducted on undisturbed representative samples. The tests were conducted using several different combinations of normal and shear loads. The values of dynamic shear modulus were calculated.

PREDICTED RESPONSE OF THE TEST BLOCKS

The methods commonly used for the analysis and design of foundations for machines are (1) the elastic half space method and (2) the impedance function method. In the elastic half space approach the vibrating footing is treated as resting on the surface of an elastic, semi-infinite, homogenous, isotropic half space (Richart, 1962). The elasticity of the soil and the energy carried into the half space by waves traveling away from the vibrating footing (geometric damping) are thus accounted for and the response of such a system may be predicted using a mass-spring-dashpot model known as the half space analog (Richart and Whitman (1967) and Richart, Hall and Woods (1970)). The impedance function method (Gazettas, 1991) gives an approach for calculating soil spring and damping values which are frequency dependent.

The dynamic response of the foundation was computed using the above methods of analysis. The values of dynamic shear modulus were selected depending on the effective overburden pressure and the shear strain induced in the soil by the vibrating block. The pertinent values of dynamic shear modulus were obtained from the in-situ and laboratory test data following the approach suggested by Prakash and Puri (1988).

Elastic Half Space Method

The natural frequency of the foundation in vertical vibrations ω_{nz} is computed by equation (3).

$$\omega_{nz} = \sqrt{\frac{k_z}{m}} \quad (3)$$

m = mass of the foundation and machine

k_z = stiffness of vertical soil spring

The soil spring is computed as follows (Prakash and Puri, (1988) and Richart, Hall and Woods (1970):

$$k_z = \frac{4Gr_0}{1-\nu} \quad (4)$$

in which, r_0 = equivalent radius of the foundation and is obtained as follows: For vertical vibrations or sliding:

$$r_0 = \sqrt{A/\pi} \quad (5)$$

The damped amplitude of vertical vibrations is given by

$$A = \frac{P_z}{k_z\left\{\left[1-(\omega/\omega_{nz})^2\right]^2 + (2\xi_z\omega/\omega_{nz})^2\right\}^{1/2}} \quad (6)$$

Where,

ξ_z = Damping ratio

$$= \frac{0.425}{\sqrt{B_z}} \quad (7)$$

and

B_z = Modified mass ratio

$$= \frac{(1-\nu)m}{4\rho r_0^{\ 3}} \quad (8)$$

The computed values of undamped natural frequencies and damped amplitudes of vibration obtained from the elastic half space method for the two test blocks are given in Tables 1 and 2.

Impedance Function Method

The soil spring for surface foundations undergoing vibrations in the vertical direction is calculated from equation (9) (Gazettas, 1991):

$$k_z = K_z \times k^*_z \quad (9)$$

in which, K_z = static stiffness, and k^*_z = dynamic stiffness coefficient.

Static stiffness K_z is obtained as:

$$K_z = \left[\frac{2GL}{1-\nu}\right](0.73 + 1.54x^{0.75}) \quad (10)$$

in which, L = Length of the foundation and

$$x = \frac{A_b}{4L^2} \quad (11)$$

where, A_b = Area of the foundation base.

The values of dynamic stiffness coefficient k^*_z depend on the L/B ratio, Poisson's ratio ν and the dimensionless frequency factor 'a'$_o$. The dimensionless frequency factor is given by:

$$a_o = \frac{B\omega}{V_s} \quad (12)$$

The values of k^*_z were obtained from Gazettas (1991). The radiation damping coefficient C_{z1} is obtained from equation (13).

$$C_{z1} = (\rho V_{La} A_b)\overline{C_z} \quad (13)$$

in which,

$$V_{La} = \frac{3.4V_s}{\pi(1-\nu)} \quad (14)$$

and $\overline{C_z}$ = Dynamic damping coefficient.

The values of $\overline{C_z}$ were given as a function of the dimensionless frequency factor a_o by Gazettas (1991) and were obtained from there.

The total damping C_z in the system may then be obtained from equation (15).

$$C_z = C_{z1} + \frac{2k_z}{\omega}\beta \qquad (15)$$

The values of 'β' depend on the type of soil. Using the values of dynamic stiffness k_z, the dynamic response is calculated using the theory of vibrations. The calculated values of natural frequencies and damped amplitudes are given in Tables 1 and 2.

CONCLUSIONS AND DISCUSSION

1. It is observed from tables 1and 2, that the natural frequencies of vertical vibrations for the two test blocks calculated by using stiffness values from the elastic half space analog and from the impedance function approach are generally different from the observed natural frequencies. The natural frequencies of vertical vibration computed by the elastic half space analog, in this case , are some what higher than the observed natural frequencies. The natural frequencies of vertical vibration computed by using the stiffness values obtained form the impedance function approach are higher compared to the observed frequencies for the 1.5m x 0.75m x 0.7m block (table 1) and they are lower than the observed values for the 3.0 m x 1.5 m x 0.7m block. In this particular case the natural frequencies of vertical vibration computed by the elastic half space analog are generally within about 15 % of the observed values .

2. The damped amplitudes of vibration calculated by using the elastic half space analog are higher than the corresponding observed values for both the test blocks. (tables 1and 2).

3. The damped amplitudes of vibration predicted by using the impedance function approach are also higher than the corresponding observed values given in tables 1 and 2. However , the vibration amplitudes predicted by using the impedance function approach in this case show a more reasonable agreement with the observed values compared to those predicted by using the elastic half space analog.

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