Short Communication

Natural Frequency of Block Foundations Under Free and Forced Vibrations

by

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Introduction

MACHINE foundations carry dynamic loads in addition to static weight of the machine and its foundation. The natural frequency of the machine-foundation soil system needs be determined to ensure that resonance may not occur.

The natural frequency is affected appreciably by the magnitude of the unbalanced force. Table I shows that in case of machines for which block foundations are used, the usual range of variation of dynamic force is from 1 to 10 percent the weight of the foundation and machine, Puri (1969).

The present study was undertaken to establish a relation between (*i*) natural frequency of forced vibrations, (*ii*) natural frequency of free vibrations, (*iii*) dynamic force level and (*iv*) static weight of the foundation. With the help of this relation, the natural frequency at any force level can be found out from a knowledge of the natural frequency of free vibrations which is relatively easy to determine in the field. Both the horizonal and vertical modes of vibration have been considered. Two blocks of nearly equal areas (1 sq m and 1.125 sq m) but of different shapes were selected for this study. Both the blocks rested on the surface of a medium sandy soil.

The validity of the frequency relation obtained was checked by analysing the field test.

Test Set-up and Test Procedure

The vertical and horizontal vibration tests were performed on two blocks, 1 m×1 m×1 m high (Block 1) and 1.5 m×0.75 m×0.75m high (Block 2) weighing 2.2 tonnes and 1.860 tonnes respectively constructed in 1 : 2 : 4 cement concrete on the surface of medium sand (SP) according to Indian Standard code up to a depth of about 5 m resting on 12 m thick deposit of silty sand (SM).

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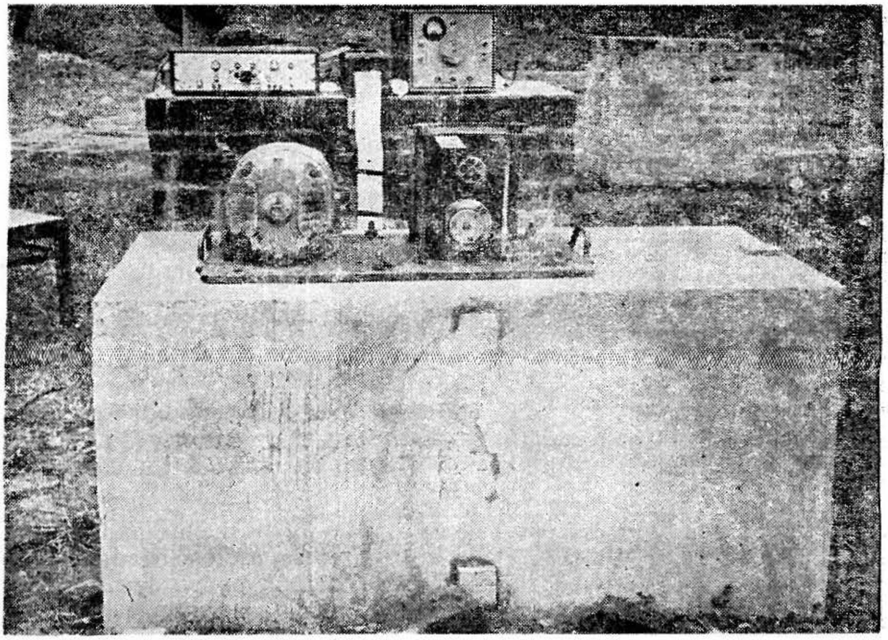

FIGURE 1 : **Block 2 under horizontal excitation with Lazon type oscillator.**

In forced vibration tests the block was excited to resonance with the help of a commercially available vibrator. The vibrator can generate unbalanced force in any one direction at a time, and it varies sinusoidally with time.

The oscillator, Figure 1, was driven with a 3 H.P. D.C. Motor of variable speed and vibrations were sensed with Miller's Acceleration* pick-up and amplitude computed at each frequency of excitation.

The blocks were tested in vertical and horizontal forced vibrations beyond their natural frequency. The level of dynamic force was set at four levels by adjusting the angular setting of the eccentric masses of the oscillator to $17\frac{1}{2}°$, 35°, 70° and 140° in horizontal excitation and 35°, 70°, 105° and 140° in vertical tests.

Free vibration tests in vertical mode were conducted by hitting the blocks with a 7.5 kg hammer falling freely through different heights. The natural frequency of free vibrations in horizontal direction was measured by hitting with the hammer at 5 cm below top, at mid height and at 5 cm above bottom for forced and free vibration tests. Typical vibration records are shown in Figure 2.

Test Data and Interpretation

Figure 3 shows plot of amplitude versus frequency of excitation for four different angles of settings of the eccentrics for horizontal vibration tests on Block No. 1. Similar data was obtained for Block No. 2 (Puri 1969) and in vertical vibrations. In Table II are listed observed natural frequencies in horizontal and vertical vibration tests.

* For details reference may be made to manufacturers catalogues.

TABLE I

Usual range of ratio of (i) unbalance force and (ii) static weight in actual machine foundations.

Sl. No.	Type of machine	Area of contact of foundation m^2	Wt. of m/c and foundation 'W' tonnes	Unbalance force 'F' tonnes	$\frac{F}{W} \times 100$
1	2	3	4	5	6
1.	Vertical Reciprocating Engine	18.0	68.0	4.2	6.18
2.	Horizontal Reciprocating Engine	48.0	212.0	12.8	6.04
3.	Vertical Reciprocating Engine	12.5	115.0	2.60	2 26
4.	Vertical Reciprocating Engine	96.0	1136.0	10.8	0.95
5.	6-Cylinder Diesel Engine	103.0	1181.0	103.0	8.70
6.	Diesel Engine	12.5	42.7	1.20	2.81
7.	Compressor, Reciprocating	23.2	166.5	10.24	6.15

1-4 Ref. Barkan 1962, 5, 6, 7 Ref. Major 1963.

TABLE II

Observed resonant frequencies in horizontal and vertical vibration tests.

Angle of setting of eccentrics (Degrees)	Observed Natural Frequencies c.p.s. (Horizontal)		Observed Natural Frequencies c.p.s. (Vertical)	
	Block 1	Block 2	Block 1	Block 2
$17\frac{1}{2}$	15.5	22.5	—	—
35	14.5	20.9	30.0	32.0
70	13.0	18.3	28.0	30.0
105	—	—	27.0	29.0
140	12.0	17.4	26.0	28.5

In free horizontal vibration tests, the variation in natural frequency with change in height of fall of the hammer was negligible. In free vertical vibration tests also similar results were obtained.

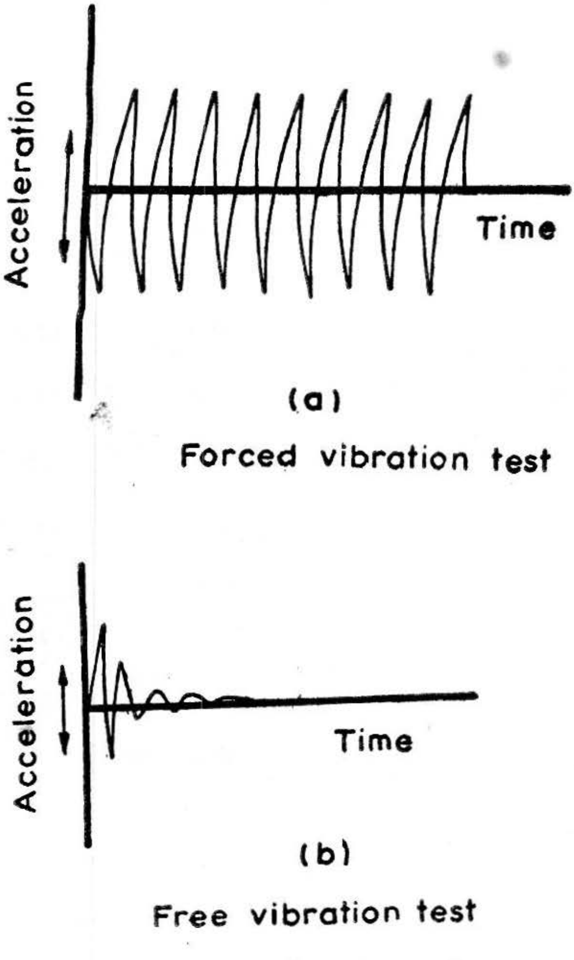

FIGURE 2 : Typical vibration records :
(*a*) Forced vibration test
(*b*) Free vibration test.

Table II shows that the resonant frequencies of two blocks in horizontal vibration are considerably different whereas for vertical vibrations they are nearly equal. In horizontal vibrations, the block is simultaneously excited in rocking and sliding. Sliding frequency and the frequency of vertical vibration depend only on the base area of the block and the mass, but the frequency in rocking depends not only on the mass and area of the block but also on the shape of the contact area and distribution of mass about the axis of rotation. In horizontal vibrations, the observed natural frequency, is a combination of the natural frequencies in rocking and sliding and hence are considerably different. Small difference in the natural frequencies of vertical vibrations of the two blocks may be attributed to the difference in their mass and base area, in addition to experimental error.

Derivation of Frequency Equation

A plot of the ratio of (*i*) resonant frequency in forced vibrations (f_n') and (*ii*) natural frequency in free vibrations (f_n') *versus* the ratio (*i*) dynamic force and (*ii*) static weight has been made in Figure 4 for the case of horizontal vibrations and for blocks 1 and 2. Similar plot for vertical vibrations has also been obtained.

These plots reveal that the observed points for both the blocks for any particular mode under consideration lie in continuation on the same curve. This shows that the relation connecting the above parameters can be represented by a single equation for both the blocks for any particular mode of vibrations. On a log-log plot (Puri 1969), it becomes a straight line suggesting a relation of the type

$$y = a \times b \qquad ...(1)$$

Where

$$y = \frac{f_n'}{f_n} \quad \text{and} \quad x = \frac{F}{W}$$

The straight line was fitted through the observed points by the method of least squares.

For the case of horizontal vibrations, within the range tested, following equation was obtained

$$\frac{f_{n'l}'}{f_{nl}} = 0.374 \left(\frac{F_h}{W} \right)^{-0.1455} \qquad ...(2)$$

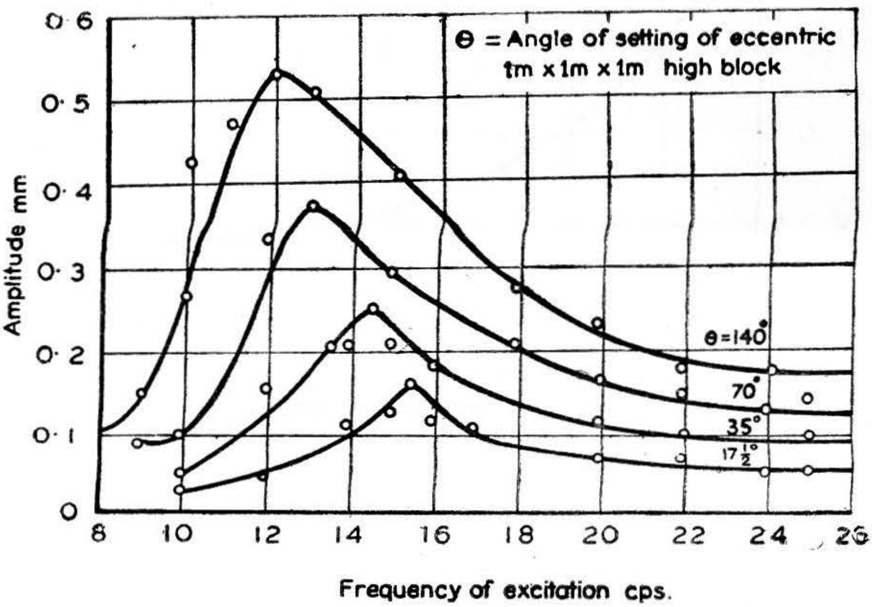

FIGURE 3 : Amplitude versus frequency, Block 1 in horizontal vibrationr with pick up at 5 cm below top.

While for vertical mode of vibration, the following relationship was obtained :

$$\frac{f_n'}{f_n} = 0.430 \left(\frac{F_v}{W}\right)^{-0.124} \qquad ...(3)$$

The subscript 'h' and 'v' for the force 'F' stand for horizontal and vertical respectively. f_n' stands for natural frequency in forced vibrations and f_n for natural frequency in free vibrations.

The above relationships are valid in the range of F/W ratio used in the tests. It was not possible to check the validity of the relation at still lower values of F/W ratio because at very low values of dynamic force, the recording instruments did not respond.

The natural frequencies were computed back with the help of Equations (2) and (3) for horizontal and vertical modes respectively. The computed and observed values have been plotted in Figure 5(a) and (b) respectively.

Test data reported by Gupta (1965) and Prakash and Basavanna (1968) has also been analysed. From a knowledge of the resonant frequency at one value of dynamic force, the resonant frequency at other values of dynamic force has been computed from Equations (4) and (5).

$$\frac{(f'_{nl})h_1}{(f'_{nl})h_2} = \left(\frac{(F_{h1})}{F_{h2}}\right)^{-0.1455} \qquad ...(4)$$

$$\frac{(f_{nz})V_1}{(f_{nz})V_2} = \left(\frac{(F_{v1})}{F_{v2}}\right)^{-0.124} \qquad ...(5)$$

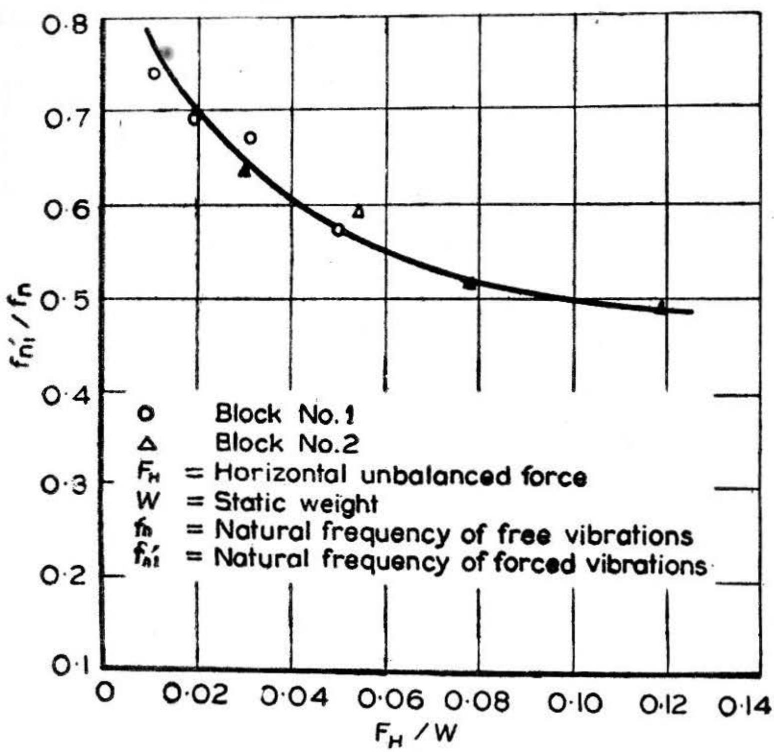

FIGURE 4 : F'_{nl}/F_n versus F_H/W in horizontal vibrations.

The frequency at one force level was taken as reference for computing frequencies at other force levels.

Figure 6(*a*) and (*b*) indicates that the computed values of natural frequency are in close agreement with observed values.

The importance of the frequency Equations (2) and (3) lies in the fact that if the frequency of free vibrations is known, the frequency at any

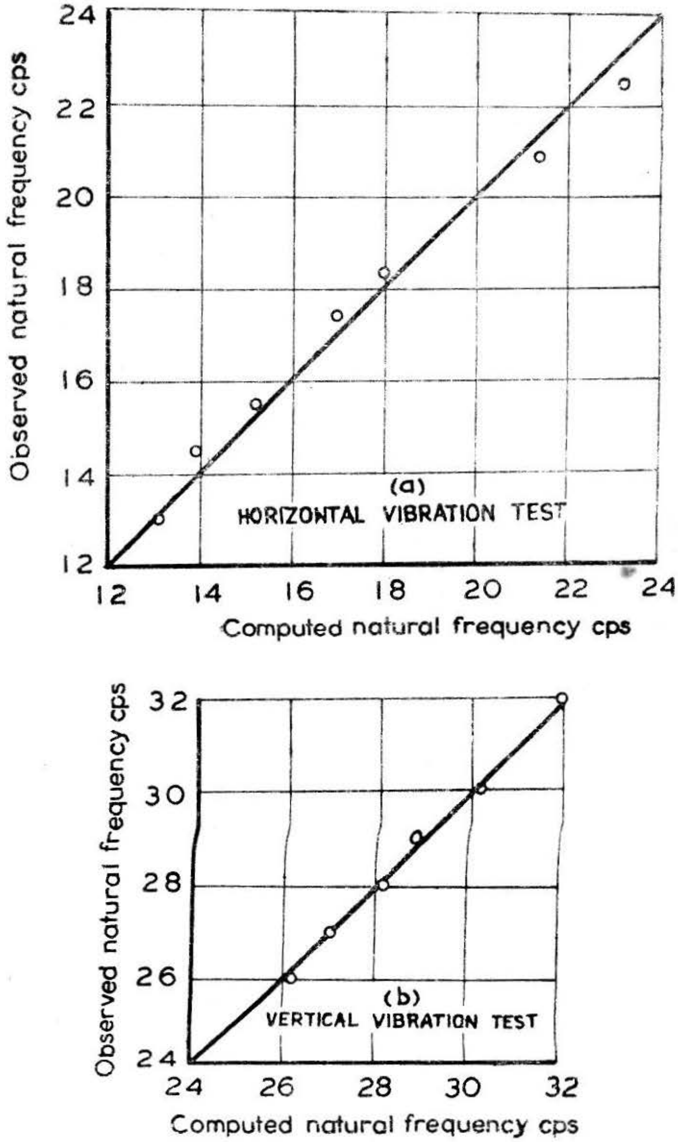

FIGURE 5 : Observed and computed natural frequency of Block 1 and Block 2 :
(*a*) Horizontal vibrations,
(*b*) Vertical vibrations.

known value of the dynamic force can be determined. The natural frequency of free vibrations is relatively easy to determine. It can be found out by hitting the block with a hand hammer.

Conclusions

Simple relationships correlating natural frequencies with dynamic force level in relation to the static weights of the machine foundation have

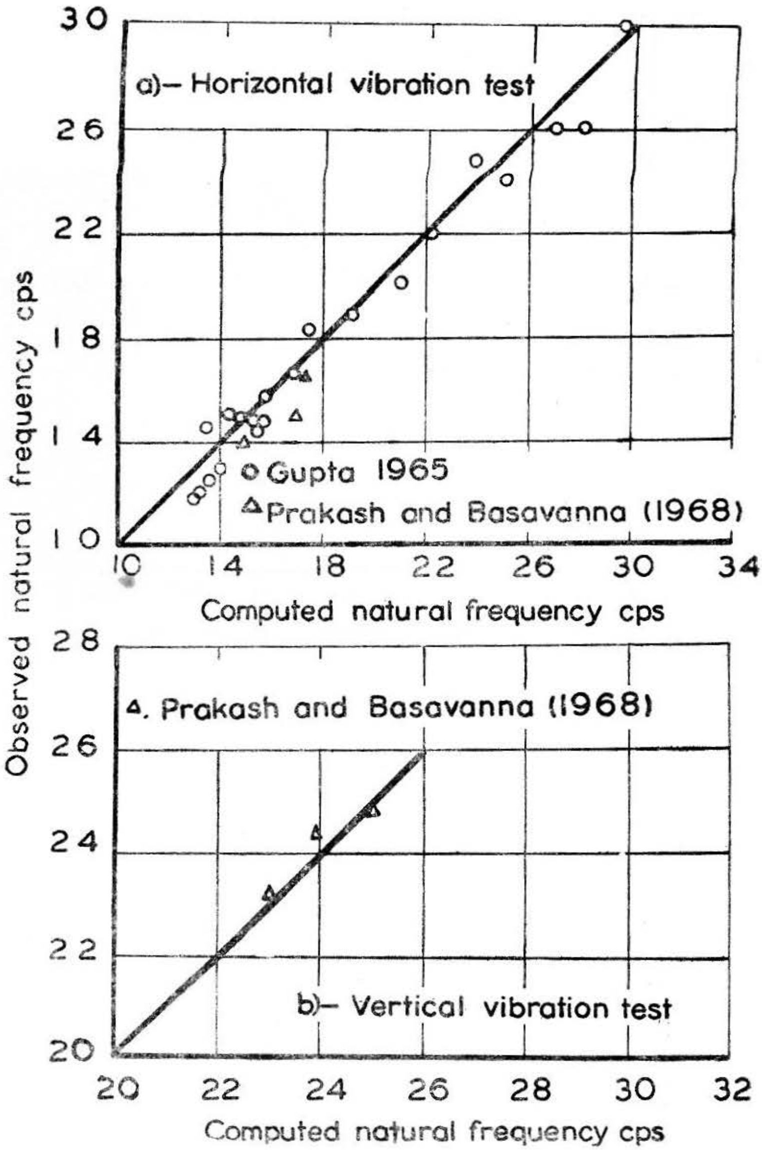

FIGURE 6 : Observed and computed natural frequencies :

(*a*) Horizontal vibration tests,

(*b*) Vertical vibration tests.

been proposed. These have been found to hold good separately for horizontal and vertical vibrations.

These need be checked for actual machine foundations.

The range of dynamic force level corresponded to the practical range in relation to the static weight of the machine foundation.

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References

BARKAN, D.D. (1962) : "*Dynamics of Bases and Foundations*". McGraw Hill Book Co., New York.

GUPTA, D.C. (1965) : "*A Study of Resonant Frequency of Machine Foundations Subjected to Horizontal Imbalance Forces*". M.E.Thesis, U.O.R. Roorkee, August 1965, pp. 1-113.

MAJOR, A. (1963) : "*Vibration Analysis and Design of Foundations for Machines and Turbines*". Collett's Holding Limited, London, pp. 1-828.

PRAKASH, S. and GUPTA. D.C. (1967) : "*Determination of Soil Constants for Machine Foundations*". *Bulletin, Indian Society of Earthquake Technology*, Roorkee, Vol. IV, No. 4, pp. 9-11.

PRAKASH, S. and BASAVANNA, B.M. (1968) : "Report on Soil Characteristics for Heavy Engine Test Beds, A.E.F. Chandigarh". *Earthquake Engineering Studies*, Roorkee, July 1968.

PURI, V.K. (1969) : "*Natural Frequency of Block Foundations Under Free and Forced Vibrations*". Master of Engineering Dissertation, University of Roorkee.

Indian Standard Code of Practice on Determination of In situ Dynamic Properties of Soils, I.S. : 5242, 1969.

Indian Standard on Classification of Soils for General Engineering Purposes, I.S. :1498-1959.