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SYNOPSIS The dynamic response of the embedded foundation subjected to vertical dynamic loads has been studied through carefully conducted field tests. The block was excited in vertical and coupled modes of vibrations. Four excitation levels were used. Tests, with different embedment depths were carried out.The foundation block was instrumented to monitor dynamic contact pressure at various embedments with specially designed contact pressure cells. Side shear resistances were measured through dynamic shear resistance cells specially designed for the puroose. Also, frequency amplitude characteristics were observed during each test .The analysis of data indicates that as the depth of embedment increases, damping factor, stiffness and in-phase soil mass increase.

Dynamic pressure distributions exhibit marked changes with embedment depth. The dynamic snear resistances developed on the vertical side surfaces, vary non-linearly.

INTRODUCTION

In practice the foundations for machine are partly or wholly buried into the ground. The two approaches commonly adopted for analysis of machine foundations,i.e. elastic half space theory and mass spring dashpot system, treat the foundation as if resting on the ground surface. Only the base reactions are taken into account and the side reactions are neglected. For embedded low tuned foundations, ignoring the effect of side reactions is likely to effect the dynamic stability of the foundation. Thus in order to have the realistic dynamic response of the foundation, side reactions need be considered. Based on siiplified assumptions of the side resistance analytical solutions to embedded foundations response have been attempted (Novak et al. 1972, Anand Krishnan et al. 1973). A rational analysis for predicting the response of embedded foundation has also been developed (Ranjan, Saran and Vijayvargiya,1981) Experimental investigations have also brought out the influence of depth on response (Barkan 1962, Fry 1963). In the present paper results of tests on an instrumented block subjected to vertical dynamic loads are presented. The data is analysed to bring out the influence of embedment on various parameters.

EXPERIMENTATION

Block vibration tests were carried out on a 1.5m x 0.75m x 0.70m (high) concrete block resting in/on a deposit of silty sand.The average density of silty sand was 1.63 t/m^3 with an average N-value of 7 upto a depth of 5.0m. The velocity of primary waves in the top about 1m layer as observed by seismic method was 233 m/sec. Embedment of block was varied with embedment ratio (i.e. depth/ width) of 0 to 0.75 at an interval of 0.25. The block was instrumented with specially designed dynamic pressure cells(Fig.1)and shear resistance cells (Fig.2). Twelve pressure cells were

Fig. 1. Dynamic Pressure Cell

Fig. 2. Shear Resistance Cell

suitably mounted at the base to get the base pressures where as 4 friction cells were mounted on the side to measure side shear resistances. In addition to this acceleration pickups were mounted on the block for measurements of acceleration during the test. The frequency meter was used for measurement of frequency. The block was subjected to vertical mode of vibration. Tests were carried out at different excitation levels expressed in terms of eccentricity angles (θ). Figure 3 shows the test set-up. Tests at different embedment ratios

Fig. 3. Test-Set up.

were performed under two conditions namely (a) with an air gap round the block and (b) without air gap. In all 28 tests were conducted under different embedment ratios and dynamic load level. The details are summarized in Table I.

TABLE I. Details of Tests Performed

Without air gap			With air gap		
Test No.	D/B	θ (Deg.)	Test No.	D/B	θ (Deg.)
1	0.0	35	17	0.25	35
2	0.0	70	18	0.25	70
3	0.0	105	19	0.25	105
4	0.0	140	20	0.25	140
5	0.25	35	21	0.50	35
6	0.25	70	22	0.50	70
7	0.25	105	23	0.50	105
8	0.25	140	24	0.50	140
9	0.50	35	25	0.75	35
10	0.50	70	26	0.75	70
11	0.50	105	27	0.75	105
12	0.50	140	28	0.75	140
13	0.75	35			
14	0.75	70			
15	0.75	105			
16	0.75	140			

TEST RESULTS AND DISCUSSION

As mentioned earlier, using the instrumentation of the block test data from each test was analysed to obtain frequency, amplitude, base pressure and side soil resistance. The variation of different parameters on the response of the block is discussed.

Amplitude frequency response - Typical frequency versus amplitude curves for embedment ratio of 0.5 without air gap and with air gap tests are shown in Figs 4 and 5 respectively. Similar observations were made for other embedment ratios. These figures indicate that at a constant

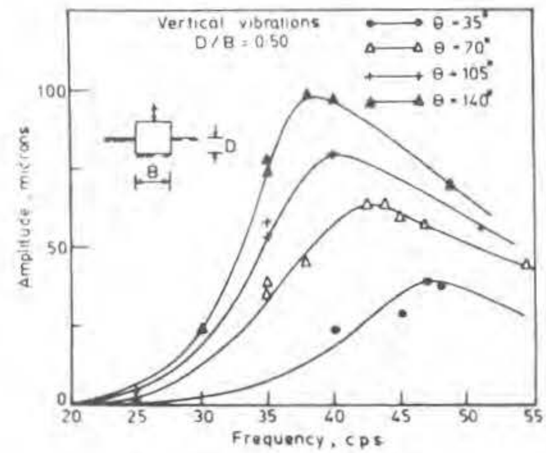

Fig. 4. Frequency Amplitude Plot for Embeded Block

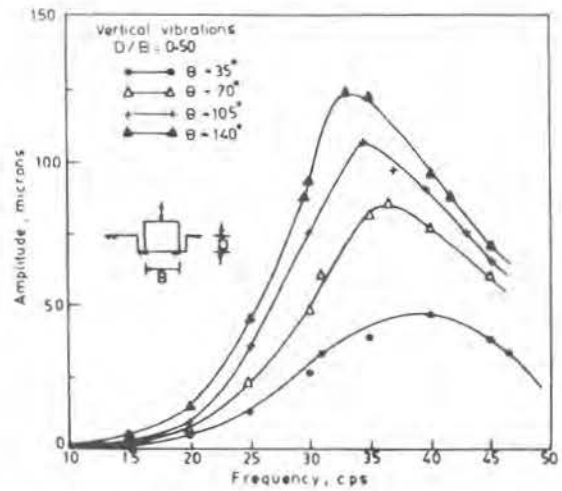

Fig. 5. Frequency Amplitude Plot for Embeded block with air gap

frequency the amplitude increases with the increase in the eccentricity angle, θ i.e., dynamic force. This is in order. Further it may be noted that in tests with no air gap (Fig. 4) resonant frequency decreases with the increase in the dynamic load level. However, the dynamic load level has practically no influence on the resonent frequency in case of test with air gap. The same trend is observed in other tests.

Test data (Fig. 6) has been plotted to investigate the effect of embedment on the amplitude frequency curve. It is evident from this figure that at a constant excitation level the increase in embedment ratio, results in the decrease of amplitude but increase in the resonant frequency In the present case the increase in resonant frequency is about 30 per cent and decrease in resonant amplitude is about 50 per cent as the embedment ratio is increased from 0 to 0.75. Such a behaviour is probably due to the fact that increasing embedment of block results in a stiffer foundation system. Embedment influences resonant frequency to a lesser degree as compared to the amplitude. This is due to the fact that increase in embedment results in an increase of inphase soil mass, since the stiffness also increases the net effect on resonant frequency is much less. Embedment is thus an important parameter influencing frequency and amplitude. Similar results were observed in case of tests with an air gap though the magnitude of decrease in resonant amplitude and increase in resonant frequency were less (Fig. 7). This is because of absence of side soil resistance due to air gap. Though the foundation base becomes stiffer on account of surcharge provided by the soil above the base level.

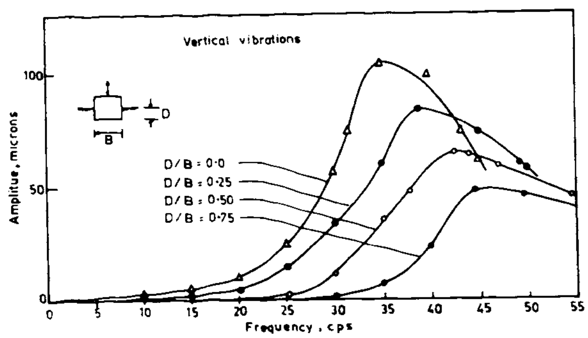

Fig. 6. Frequency - amplitude plots for different embedment ratios (θ=70^{o}, no air gap)

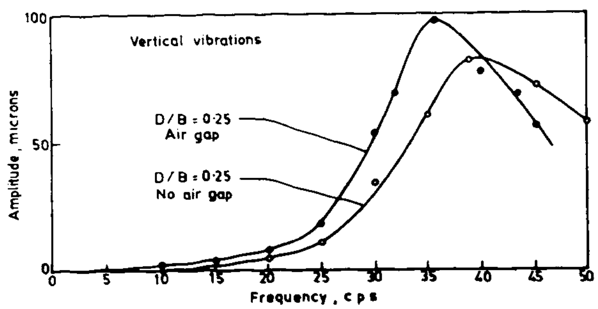

Fig. 7. Comparison of Frequency - Amplitude plot for Embedded Block with and without Air Gap.

Experimental amplitude frequency data is further analyzed to obtain the damping factor, D_{ze}, coefficient of elastic uniform compression, C_{ue} and the inphase soil mass, m_s. Damping factor is obtained from the band-width method (IS:5249-1978). The undamped natural frequency, f_{nze} and stiffness coefficient, K_{ze} of the system are obtained from equations 1 and 2 respectively (Ranjan, Saran and Vijayvargiya, 1981)

$$f_{nze} = f_{nr} \sqrt{1-2\,D_{ze}^2} \qquad (1)$$

$$K_{ze} = \frac{m_e\, e\, w^2}{(A_z)_{max}\; 2D_{ze} \sqrt{1-D_{ze}^2}} \qquad (2)$$

where f_{nr} = observed resonant frequency
$(A_z)_{max}$ = Maximum amplitude
m_e = eccentric mass
e = eccentricity of oscillator
w = circular frequency.

Knowing f_{nze} and K_{ze} the mass, m of the system is calculated from equation 3.

$$m = \frac{K_{ze}}{4\pi^2 f_{ze}^2} \qquad (3)$$

Since mass of the foundation block and machine, m_o is known, the soil mass, m_s taking part in the vibration is obtained from equation 4.

$$m_s = m - m_o \qquad (4)$$

Using the stiffness coefficient K_{ze} of the soil system, the coefficient of elastic compression, C_{ue} for the given embedment ratio, is obtained from equation 5.

$$C_{ue} = K_{ze} / A \qquad (5)$$

Knowing the dynamic force at resonant frequency, f_{nr} (equation 6)

$$F = m_e\, e\, 4\pi^2 f_{nr}^2 \qquad (6)$$

and the weight of the block, W, ratio F/W is worked out.

The amplification ratio, η, the ratio of resonant amplitude, $(A_z)_{max}$ and static displacement $z_{st}(= F/K_{ze})$ are then obtained from equation(7)

$$\eta = \frac{(A_z)_{max}}{F/\,K_{ze}} \qquad (7)$$

Analysing the data as indicated above variation of D_{ze} with F/W ratio for different embedment ratios and tests with /without air gap are plotted in Fig. 8. This figure indicates that for a constant F/W ratio, the damping factor, D_{ze} increases with increase in embedment ratio. Also at a constant D/B ratio the damping factor shows a little decrease with increase in F/W ratio. Also the value of D_{ze} for same D/B ratio is more in case of blocks with no air gap as compared to the blocks with air gap. This is in order since the presence of airgap around the block makes the soil less effective.

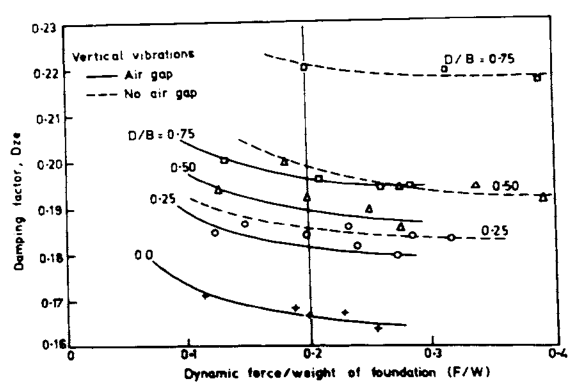

Fig. 8. Variation of Damping Factor with Dynamic force/Weight

Variation of stiffness, K with F/W ratio is plotted in Fig. 9. This figure indicates the same

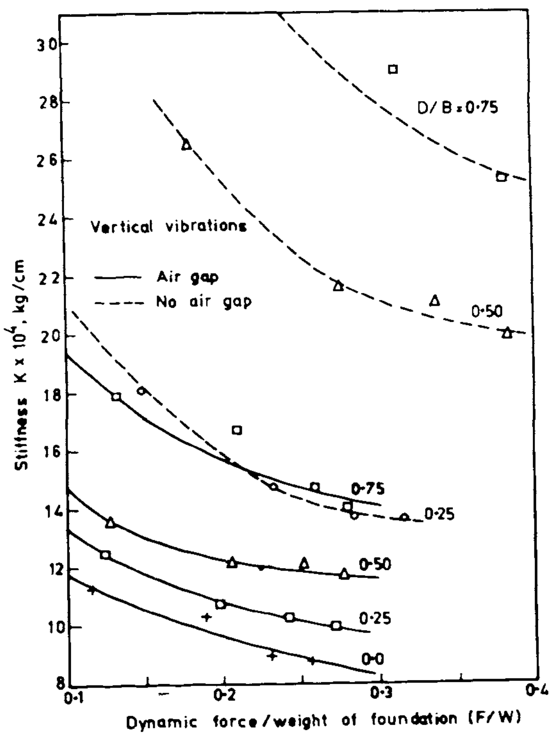

Fig. 9. Variation of Stiffness with Dynamic Force/Weight of Foundation

trend with respect to D/B and F/W as discussed above for D_{ze}. Figure 10 shows the plot of variation of m_s with F/W ratio. The figure indicates that the magnitude of inphase soil mass increases with increase in embedment ratio and also F/W ratio. Further the results indicate that the magnitude of in-phase soil mass is more in case of embedded blocks with no air gap to the blocks having air gap.

Dynamic Base Pressures

The dynamic pressure at 12 different points were obtained using contact pressure cells. The dynamic pressure distribution were measured at various embedment ratios for excitation level, θ of 140° and a frequency of 35 cps. The observed dynamic pressure of a cell was divided by the maximum dynamic pressure recorded and the variation along the width for the central section, mid-section and edge section for D/B of 0.75 and frequency of 35 cps is plotted in Fig. 11. Similarly the ratio of dynamic pressure to maximum dynamic pressure along the width for various D/B ratios is shown in Fig. 12. This figure indicates that the pressures are maximum at the centre and as we move towards the edges, the ratio of dynamic pressure to maximum dynamic pressure tends to decrease upto about B/5 from the edges beyond which it indicates a reverse trend i.e., increasing at the edges. The trend of base pressure variation is different as commonly observed in the case of footings subjected to static loads in the

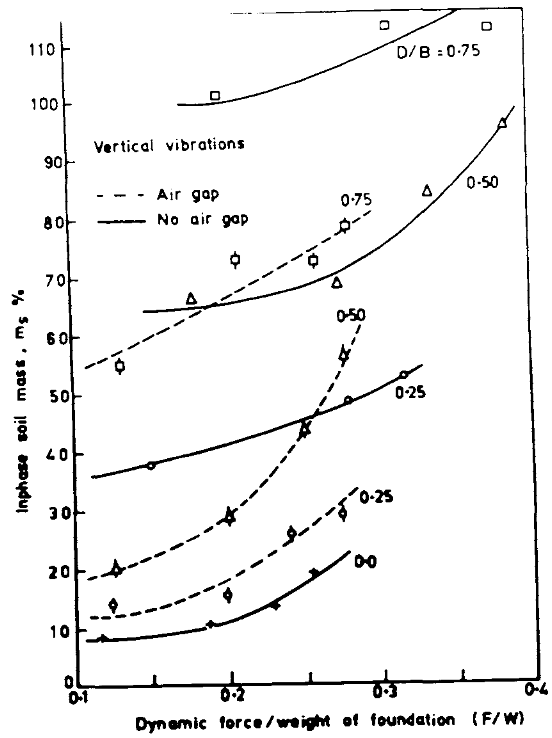

Fig. 10. Variation of Inphase Soil Mass with Dynamic Force/Weight of Foundation

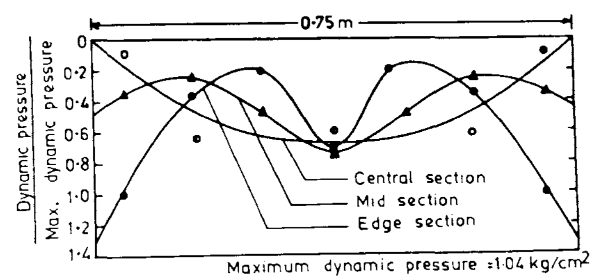

Fig. 11. Dynamic Base Pressures at Various Sections (f = 35cps, D/B= 0.75)

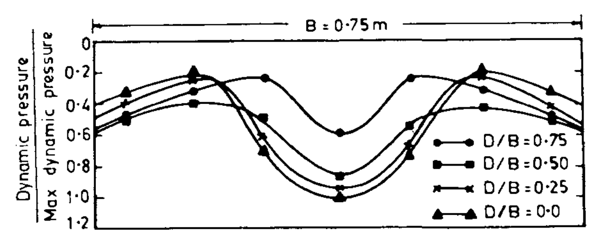

Fig. 12. Dynamic Base Pressure Distribution at Different Embedment Ratios (f = 35 cps, θ = 140°)

sense that the pressure at the edges are more upto a distance of about B/5 from edges.

Coefficient of Elastic Average Shear Resistance $C_{\tau av}$

The elastic shear resistance is measured with shear resistance cells. Its distribution with depth is plotted in Fig. 13. The trend of the curve (Fig. 13) indicates that the shear resistance increases nonlinearly with depth and can be approximated by Equation 8. The non-linear increase in shear resistance with increasing depth is due to the increase in horizontal earth pressure on the sides of the block. Saran and Prakash (1970) reported non-linear increase in earth pressure with depth.

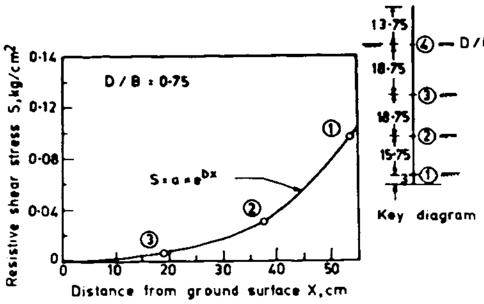

Fig. 13. Variation of Elastic Shear Stress (f = 35 cps, θ = 140°)

$$S = a \times e^{bx} \quad (8)$$

where S = elastic shear stress kg/cm²
x = depth of cell below ground surface, cm
a, b = constants

Utilizing the experimental data and using Eq. 8, the values of constants a and b have been computed. The results indicate the non-linear variation of shear resistance for all the embedment ratios tested. Computation for 'a' and 'b' for different D/B ratios indicate that these constants depend upon D/B ratio and are found to increase with increase in D/B ratio. The average shear resistance s_{av} is computed from equation (9).

$$s_{av} = \frac{1}{D}\int_0^D S\,dx \quad (9)$$

Substituting the value of S from equation(8) and integrating we get

$$s_{av} = \frac{1}{D}\left[\frac{a}{b}D\,e^{bD} - \frac{a}{b^2}\,e^{bD} + \frac{a}{b^2}\right] \quad (10)$$

Knowing the amplitude of motion, the coefficient of elastic average shear resistance $C_{\tau av}$ is obtained using equation (11)

$$C_{\tau av} = \frac{s_{av}}{(A_z)_{max}} \quad (11)$$

The values of $C_{\tau av}$ are computed for various D/B ratios and tabulated (Table II).

The $C_{\tau av}$ are used in the analytical solution proposed (Ranjan, Saran and Vijayvargiya, 1981) to predict the response of embedment block foundation under vertical vibrations. According to the analytical procedure (Ranjan, Saran and Vijayvargia, 1981) in case of vertical vibrations, the equation of motion is

Table II - Coefficient of Elastic Average Shear Resistance $C_{\tau av}$ as Computed

1. Depth of embedment, cm	18.75	37.50	56.25
2. Embedment ratio	0.25	0.50	0.75
3. Maximum Amplitude, microns (no air gap θ=140°)	121.50	98.00	75.00
4. Average shear stress, kg/cm²	0.0568	0.0527	0.0292
5. $C_{\tau av}$ experimental, kg/cm³	4.6749	5.3745	3.8927

$$m\ddot{z} + C_{ze}\dot{z} + K_{ze}z = m_e\,e\,w^2 \quad (12)$$

where K_{ze} = total stiffness of soil

or $$K_{ze} = K_{za} + K_{\tau D} \quad (13)$$

where K_{za} = stiffness with air gap

$K_{\tau D}$ = Stiffness due to elastic shear resistance

$$= C_{\tau av} \cdot A_e \quad (14)$$

A_e = area of foundation block in contact with soil

$$A_e = 2(B + L)D \quad (15)$$

K_{ze} and K_{za} are computed from the field test data obtained respectively in without air test and with air gap test. $K_{\tau D}$ is computed from measurement of $C_{\tau av}$ from shear resistance cells.

Values of K_{ze} computed analytically using equation (13) and observed experimentally are presented in Table III.

Table III Analytically Computed and Experimentally Observed K_{ze} Values

D/B ratio	$K_{\tau D}$ kg/cm	Soil stiffness, K_{ze} Analytically $K_{ze} = K_{za} + K_{\tau D}$ kg/cm	Soil stiffness, K_{ze} Experimentally kg/cm
0.25	36756.378	137346.07	137260.00
0.50	85655.604	203120.50	199582.00
0.75	93060.337	233720.33	247450.00

The experimental values exhibit a reasonably good agreement with the analytically computed values.

CONCLUSIONS

The effects of embedment upon vertical forced vibrations of a rigid foundation block have been investigated through carefully conducted field tests. The main conclusions can be summarized as :

1. As the excitation level, θ increases the amplitude of vibration increases and the resonant frequency decreases.

2. For a constant excitation level, the

increase in embedment ratios results in an increase in the resonant frequency and decrease in the resonant amplitude.However if an air gap is provided around the block the amplitude of vibration shows an increase whereas the resonant frequency shows a decrease when compared with corresponding test with no air gap around the block.

3. For the same value of dynamic force to weight ratio the increase in embedment ratio causes increase in damping factor, stiffness coefficient and in-phase soil mass. However, when air gap is provided around the foundation block, the damping factor stiffness coefficient and in-phase soil mass decrease as compared to the no air gap condition.

4. The dynamic contact pressure is observed to be maximum at the centre. The ratio of dynamic pressure to maximum pressure which is maximum at the centre tends to decrease upto about B/5 from the edges, beyond which it indicates a reverse trend. The dynamic pressure increases with increase in frequency.

5. The elastic average shear resistance developed at the vertical side surface varies non-linearly with the increase in depth of embedment.

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