01 Jun 1988, 1:00 pm - 5:30 pm

In-Situ Determination of Dynamic Properties of Soil for Foundation of a Turbo-Generator

V. D. Miglani
Regional Engineering College, Kurukshetra, Haryana, India

Proceedings: Second International Conference on Case Histories in Geotechnical Engineering, June 1-5, 1988, St. Louis, Mo., Paper No. 4.36

In-Situ Determination of Dynamic Properties of Soil for Foundation of a Turbo-Generator

V.D. Miglani
Professor of Civil Engineering, Regional Engineering College,
Kurukshetra, Haryana, India

SYNOPSIS: The paper presents a case history of performance and analysis of results of vertical & horizontal resonance tests on a standard concrete block in a well, for in-situ determination of dynamic properties of soil required for design of a turbo-generator, under unusual conditions of high water table. Pumping from the two wells constructed for lowering the water level was not enough and pumping from within the main well had to be resorted to to bring down the water level to a little below the top surface of the model block. As expected, amplitude versus frequency curves for vertical resonance test showed dtwo resonant peaks instead of one, indicating occurrence of two modes of vibration. A method for estimating dynamic co-efficients of soil, through derived curves for ratio of natural frequencies in horizontal and vertical modes versus effective area of base, has been suggested. A repeat test under good conditions confirmed the adequacy of the method.

INTRODUCTION

Projects of progress have to be executed in a time bound frame. The author had an opportunity to carry out investigations for determining dynamic soil properties required for a 210 megawatt turbo-generator of such a thermal power project in India and was desired to make the recommendations within a limited time period.

The following dynamic properties of soil were required:

(i) Co-efficient of Elastic uniform comhpression (C_u)

(ii) Co-efficient of Elastic uniform shear (C_t)

(iii) Co-efficient of Elastic Non-uniform compression (C_ϕ)

(iv) Co-efficient of Elastic Non-uniform shear (C_ψ)

The Indian Standard Code (IS: 5249-1977) prescribes size of pit(4.5 m x 2.75 m in plan, depth = depth of foundation) and size of block (1.5 m x 0.75 m x 0.7 m high) and also method of conduct of tests. Dynamic tests include resonance & wave propagation tests. On account of site conditions, departure from the provisions of the code had to be resorted to.

SITE CONDITIONS & TEST ARRANGEMENT

The proposed depth foundation for the turbo-generator was 4.7 m below ground level (GL). The soil above and below was mainly sandy. Sub-soil water level (SSWL) was 2.5 m below GL. Because of these conditions, the resonance tests were planned to be conducted on a standard block 1.50 m x 0.75 m x 0.70 m of plain concrete constructed in a brick well of 3.5 m internal diameter at the proposed foundation depth. Two side wells of 2 m internal diameter were also constructed (Fig. 1).

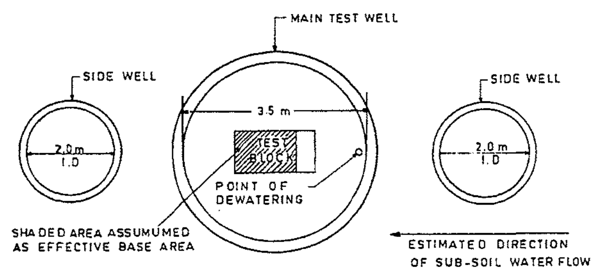

Fig. 1 - Plan of Test Arrangement

It was estimated that pumping out of water from the side wells would be enough to keep the water level in the main well below the surface of block during mounting of equipment & conduct of test. However, at the time of conduct of test, due to rise in SSWL, pumping out of water from the side wells was not enough to bring down the water level in the main well to desired extent. Water level in the test well remained at about 10 to 15 cm above the block. Although undesirable, pumping from within the main well had to be resorted to, on account of time bound programme of the project. The point chosen for this purpose was on the longer axis of the block, near the well boundary and as far as possible near the surface of water.

BLOCK RESONANCE TESTS

The following resonance tests were conducted on the model bdlock foundation:

1. Vertical resonance test
2. Horizontal resonance test

The wave propagation test was not possible on account of high water table.

The resonance tests were carried out by mounting a mechanical oscillator on top of the block. The oscillator was set to produce vertical or horizontal harmonic excitation. The oscillator was driven by a D.C.shunt motor, the speed of which was varied with an independent control unit. The vibrations of the model block were picked up by a velocity pick-up, the signals of which were integrated and amplified by means of a D.C. amplifier and observed on an amplitude meter. The line diagram of the set up of recording arrangement is shown in fig. 2.

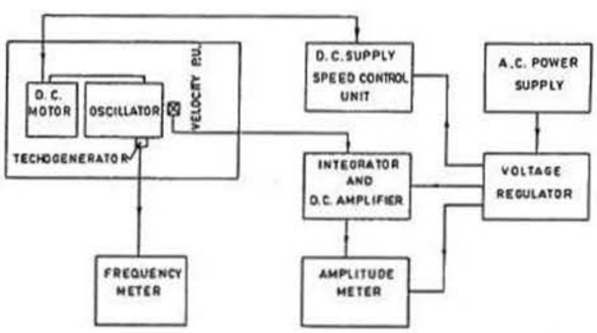

Fig. 2 - Line Diagram of Testing Equipment

VERTICAL RESONANCE TEST

The oscillator was mounted centrally on the block such that it produced vertical harmonic exciting force and the line of action of such excitation passed through the centre of gravity of the block. On top of the block, the velocity pick-up was fixed with its sensing axis in the vertical direction. Amplitudes were observed on an amplitude meter and recorded for different frequencies and at angles of eccentricity of oscillator equal to 72^o, 108^o and 144^o. Frequency-amplitude curves at these eccentricities from these observations were drawn. A typical curve is shown in fig. 3.

The corresponding resonant frequencies are shown in Table 1. The co-efficient of elastic uniform compression (C_u) is obtained by using the following expression:

$$C_u = \frac{4\pi^2 \cdot f_{nz}^2 \cdot m}{A} \qquad \ldots(1)$$

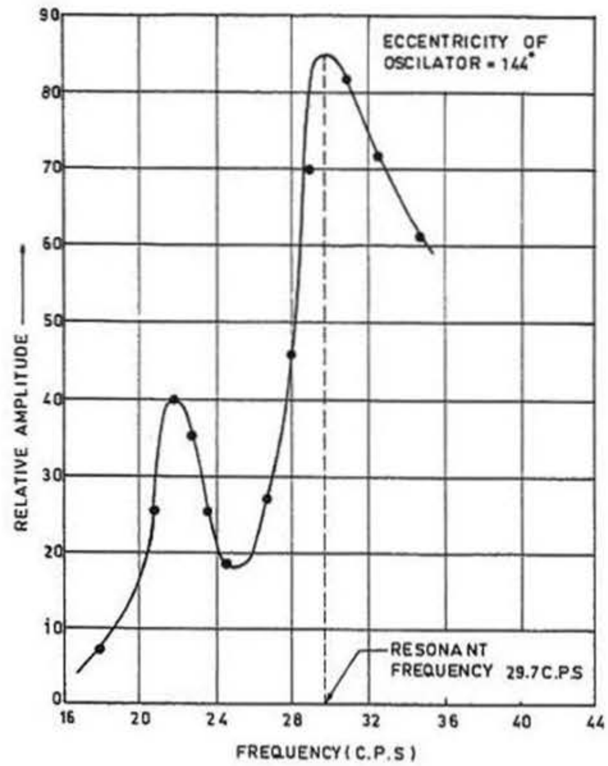

Fig. 3 - A Typical Amplitude v/s Frequency curve from Vertical Resonance Test

Where:-

m = mass of the block plus that of the motor, oscillator and other mountings

A = Base area of the block

= 150 cm x 75 xm

f_{nz} = Resonant frequency in the vertical mode

The values of the co-efficient of elastic uniform compression (C_u) corresponding to base area of model block are listed in column 4 of Table-1 and the values of C_u corresponding to 10 Sq m area of foundation are tabulated in column 5 of the table. These were calculated by using relationship:

$$\frac{C_{u_1}}{C_{u_2}} = \sqrt{\frac{A_2}{A_1}} \qquad \ldots(2)$$

Where:

C_{u_1} and C_{u_2} correspond to base areas A_1 & A_2

Such a relationship is valid for small areas upto about 10 Sq m . For base area greater than 10 Sq m, the value of C_u remains almost constant [Barkan (1962)].

TABLE - 1

Resonant Frequencies and Values of C_u from Vertical Resonance Test

ANGLE OF ECCENTRICITY OF OSCILLATOR	RESONANT FREQUENCY f_{nz} (c.p.s)	DYNAMIC FORCE (Kg)	C_u (Kg/Cm³) A=1·125m²	C_u Kg/Cm³ A=10 m²
1	2	3	4	5
72°	31·0	120.3	6.49	2·18
108°	30·2	157.2	6.16	2.07
144°	29·7	178·7	5·96	2·00

On account of dewatering from inside the main well, deviation from uniform reaction caused the block to vibrate in two modes:

(i) rocking about a horizontal axis passing through the centre of the base area,and

(ii) vertical.

Since the natural frequency (and hence resonant frequency) in the rocking mode is lower than that of the vertical mode, the first peaks appearing in amplitude v/s frequency curves have been ignored in computations.

It may be noted that the values of C_u in columns 4 & 5 need correction.

HORIZONTAL RESONANCE TEST

The mechanical oscillator was mounted on the block such that it generated horizontal harmonic excitation parallel to longitudinal axis of the block. The velocity pick-up was mounted on top of the block, with its sensing axis horizontal and parallel to the excitation. Horizontal amplitudes were recorded against different frequencies for different settings of angles of eccentricity of the oscillator.

Frequency v/s amplitude curves from the horizontal vibration test for angles of eccentricity of oscillator of 72°, 108° and 144° were drawn. A typical curve is shown in fig. 4.

The resonant frequencies obtained from these curves are listed in column 2 of the Table 2.

When an oscillator is mounted on the top of the block to produce horizontal excitation, such an excitation causes the block to vibrate in coupled translatory motion along the longitudinal axis and rocking motion about transverse axis of the block. Thus the system has two degrees of freedom and hence two natural frequencies as also two resonant frequencies. In order to determine whether the resonant frequency obtained is corresponding to first or second mode of vibration, the amplitudes were observed carefully for different frequencies of the oscillator which varied from 0 to about 30 c.p.s. in one case. It was observed that first resonance occurred near 12 c.p.s. The amplitudes were at the lowest at 24 c.p.s. and started increasing beyond 24 c.p.s. thereby indicating second mode occuring beyond 30 c.p.s. The resonant frequencies listed in column 2 of the table 2 correspond to the first mode of vibration. After determining the mode of vibration, the co-efficient of elastic uniform shear C_t is obtained using the following relationship:

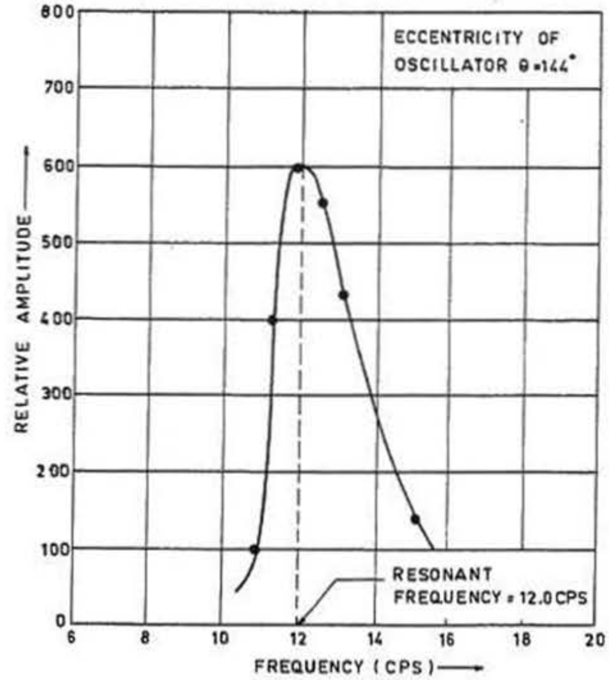

Fig. 4 - A Typical Amplitude v/s Frequency Curve from Horizontal Resonance Test

TABLE - 2

Resonant Frequencies and Values of C_t from Horizontal Resonance Test

ANGLE OF ECCENTRICITY OF OSCILLATOR	RESONANT FREQUENCY f_{nx} (c.p.s)	DYNAMIC FORCE (Kg)	C_t (Kg/Cm³) A=1·125m²	C_t Kg/Cm³ A=10 m²
1	2	3	4	5
72°	12·8	20.5	1.31	0.44
108°	12·4	26.5	1.23	0.41
144°	12·0	29.2	1.15	0.39

$$C_t = \frac{8 \pi^2 r f_{nx}^2}{(A_o + I_o) \pm \sqrt{(A_o + I_o)^2 - 4 A_o I_o r}} \quad \ldots(3)$$

where

$r = M_m / M_{mo}$

f_{nx} = Resonant frequency obtained from horizontal vibration test

A_o = A/m

I_o = 3.46 I/M_{mo}

M_m = Mass moment of inertia of block with mountings about the horizontal axis passing through centre of gravity of the block and prependicular to the direction of vibration

M_{mo} = Mass moment of inertia of block and mountings about the horizontal axis passing through centre of base area of the block and prependicular to the direction of vibration

I = Second moment of area of base of the block about the horizontal axis passing through the centre of gravity the area and prependicular to the direction of vibration

Use the +ve sign for 2nd mode of vibration and -ve sign for the first mode of vibration.

For the size of the block used in this test and first resonant frequency, equation (3) reduces to:-

$$C_t = f_{nx}^2/125 \qquad ...(4)$$

Using the above relation, the co-efficient of elastic uniform shear for the base area of the block was calculated and these values are listed in column 4 of Table 2.

The value of C_t corresponding to 10 Sq m area were computed using the relationship:

$$\frac{C_{t_1}}{C_{t_2}} = \sqrt{\frac{A_2}{A_1}} \qquad ...(5)$$

where C_{t_1} and C_{t_2} correspond to areas A_1 and A_2 respectively. These values of C_t are recorded in column 5 of the Table 2.

As per Table - 1, the values of C_t in columns 4 & 5 of table 2 need correction.

CO-EFFICIENTS OF ELASTIC NON-UNIFORM COMPRESSION (C_ϕ) AND ELASTIC NON-UNIFORM SHEAR (C_ψ)

No direct field tests are available at present for determination of these properties of soil. The following relationship, as given in IS:5249-1977 may be used for these co-efficients:

$$C_\phi = 3.46\ C_t \qquad ...(6)$$

$$C_\psi = 0.75\ C_u \qquad ...(7)$$

TEST RESULTS

The values of C_u corresponding to 10 Sq m base area as calculated from vertical resonance test conducted at different eccentricities of oscillator vary from 2.00 to 2.18 kg/cm^3 (Table 1).

The values of C_t corresponding to 10 Sq m base area as calculated from horizontal resonance test, similarly, vary from 0.39 to 0.44 kg/cm3, i.e., the values are of the order of one fifth of the values of C_u whereas actual val ues of C_t should be in the range of half to two third of values of C_u.

It is thus clear that the values of C_t have been affected considerably due to dewatering from inside the main well.

The values of C_u and C_t computed above, therefore, needed corrections.

CORRECTIONS OF TEST RESULTS

An attempt was made to estimate correction factors to be applied to the values of soil parameters obtained in the tests by assuming that certain base area of the block near the point of dewatering was of no effect (see fig.1).

From equations (1) & (2), ratio of f_{nz} & f_{nx} (corresponding to first mode) can be written as:

$$\frac{f_{nz}}{f_{nx}} = \sqrt{\frac{C_u}{C_t} \cdot \frac{2\ A}{(D - E)}} \qquad ...(8)$$

where

$$D = A_o + I_o$$

$$E = \sqrt{D^2 - 4\ A_o\ I_o}$$

Equation (8) reduces to:

$$\frac{f_{nz}}{f_{nx}} = \sqrt{\frac{C_u}{C_t} \cdot \frac{150}{d - e}} \qquad ...(9)$$

where

$$d = 121.1 + 223.9\ p2$$

$$e = \sqrt{d^2 - 70581\ p^2}$$

p = effective base area/total base area ratio

Using equation (9), f_{nz}/f_{nx} v/s per cent effective base area curve hasbeen drawn in fig. 5. Correction factor v/s per cent effective base area has been derived using equation (2) and plotted in fig. 5.

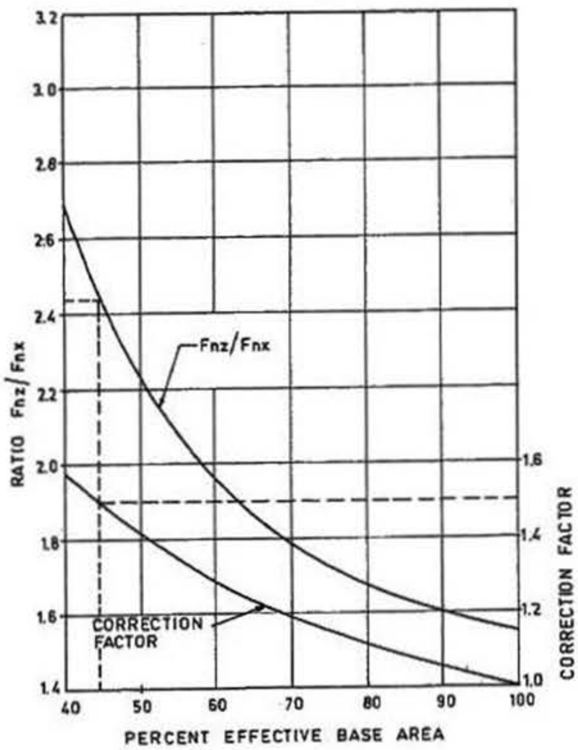

Fig. 5 - Ratio of Frequencies (f_{nz}/f_{nx}) & Correction Factor v/s Effective Base Area Curves

Average f_{nz} = 30.3 c.p.s. (Table 1)

Average f_{nx} = 12.4 c.p.s. (Table 2)

Ratio: (f_{nz}/f_{nx}) = 2.44

Per cent Effective area corresponding to this ratio on the curve is 44.9 (i.e., p=.449) and against this per cent effective area, correction factor is 1.5 . Therefore, corrected values of C_u are equal to 3.0 to 3.3 kg/cm^3 and hence corrected values of C_t are equal to 1.5 to 1.7 kg/cm^3 for base areas of 10 Sq m .

These values could well serve the purpose of preliminary design of the foundation.

REPEAT TEST

The resonance tests were repeated after a lapse of about 4 months under very low draw-down conditions. The general water table was low on account of dewatering in the surrounding area. The level of water within the test well was further lowered by means of pumping out from the two side wells. Amplitudes observed were plotted against frequencies of the oscillator. In vertical resonance test, no second peak was observed indicating absence of rocking mode.

A typical amplitude v/s frequency curve from vertical resonance test is shown in fig. 6. The results are shown in tables 3 & 4.

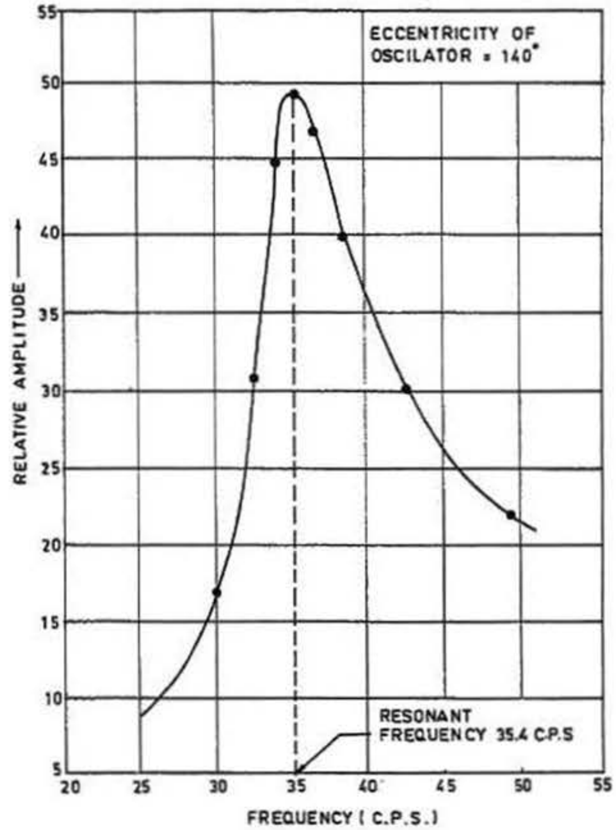

Fig. 6 - A Typical Amplitude v/s Frequency Curve from Vertical Resonance (Repeat) Test

TABLE - 3
Resonance Frequencies and Values of C_u from Vertical Resonance (Repeat) Test

ANGLE OF ECCENTRICITY OF OSCILLATOR	RESONANT FREQUENCY f_{nz} (c.p.s)	DYNAMIC FORCE (Kg)	C_u (Kg/Cm³) A=1.125m²	C_u Kg/Cm³ A=10 m²
1	2	3	4	5
72°	36.0	163	8.75	2.95
104°	35.4	211	8.47	2.85
140°	34.8	254	8.18	2.76

TABLE - 4

Resonant Frequencies and Values of C_t from Horizontal Resonance (Repeat) Test

ANGLE OF ECCENTRICITY OF OSCILLATOR	RESONANT FREQUENCY f_{nx} (c.p.s)	DYNAMIC FORCE (Kg)	C_t (Kg/Cm³) A = 1·125 m²	C_t Kg/Cm³ A = 10 m²
1	2	3	4	5
72°	28.5	102	6.50	2.19
104°	25.5	110	5.20	1.75
140°	25.0	127	4.95	1.67

The other details of the tests are available elsewhere (Miglani - 1982).

CONCLUSION

Comparison of the results with corrected values of C_u & C_t indicates a reasonable prediction of design values of dynamic soil parameters and confirms the adequacy of the suggested method of correction.

REFERENCES

Barkan, D.D. (1962), "Dynamics of Bases and Foundations", McGraw-Hill Book Co. Inc., New York.

IS:5249-1977, "Indian Standard Method of Test for Determination of Dynamic Properties of Soil (First Revision)", Indian Standards Institution, New Delhi.

Miglani, V.D. (1982), "Report on Dynamic Tests for Foundation of Turbogenerator at RTP, Ropar (C/GEOT/605)", Regional Engineering College, Kurukshetra.