Critical Evaluation of IS: 5249-1969

by

Shamsher Prakash*

V.K. Puri**

Introduction (Philosophy of the Code)

The present code for in-situ determination of dynamic soil properties was framed in 1969 for providing a standard procedure for conducting the field tests and analysis of the data obtained. The code recommends the following tests for the purpose.

(*a*) Resonance test

(*b*) Shear Modulus test.

Both these tests are performed on concrete block of 1.5m × 0.75m × 0.7m high cast at the site. The resonance test is conducted on the block by exciting it at different frequencies and the corresponding amplitude of motion is recorded.

The test can be conducted by exciting the block in vertical direction (Vertical resonance test) or by exciting in the horizontal direction (Horizontal resonance test).[1] The test is conducted at different magnitudes of dynamic force by adjusting the angle between eccentric masses.

The shear modulus test is conducted[1] using the same set up as for vertical resonance test. The block is excited at a known frequency and the distance between the two geophones (one of which is kept fixed near the block and the other being movable and kept at different points) is adjusted such that the phase difference of the waves reaching these two points is 90°. The test is repeated for different frequencies and at different magnitudes of dynamic force.

From the data of the block vibration test, amplitude vs frequency curve is plotted, for each eccentricity and corresponding resonant frequency obtained. Knowing the resonant frequency of vertical vibration of horizontal vibrations (the mode of vibration in the horizontal case is ascertained), the cofficient of elastic uniform compression '*Cu*' can be determined[1] using the relation recommended in the code. From the amplitude versus frequency plots for the vertical resonance test, the damping can be obtained using the Band width method.

---

*Professor, Department of Civil Engineering, University of Roorkee, Roorkee, U.P. India.

**Lecturer, School of Research and Training in Earthquake Engineering, University of Roorkee, Roorkee, U.P. India.

This paper is open for discution till the end of June 1977.

TABLE I

Values of Dynamic Elastic Properties from Field Tests at different sites

Site No.	Description	Soil Type	Type of Test	Size of Block/Plate	Dynamic Shear Modulus 'G' kg/cm²	Cu kg/cm³ for contact area tested	Strain Level Associated	Cu kg/cm³ for $\bar{\sigma}_c = 1$ kg/cm² and for contact area of 1.5m+0.75m	Dumping Coefficient	Remarks
1	2	3	4	5	6	7	8	9	10	11
1.	Forging Hammer Foundation of HAL Koraput		Forced Vertical Vibration Tests	Block 1.5m×0.75m×0.7 m high	—	11.64	1.5×10^{-4}	32.11	6.08	Location 1
					—	15.16	2.8×10^{-5}	41.32	11.34	Location 2
					—	13 75	5.6×10^{-5}	37.93	10.45	Location 3
					—	15.30	1.2×10^{-4}	45.0	6.4	Location 4
					—	14.21	1.26×10^{-4}	39.20	8.5	Location 5
			Shear Modulus Test	Block 1.5m×0.75m ×0.70m high	347.0	9.25	2.8×10^{-6}	27.15	—	Location 2
					616.0	17.50	5.6×10^{-6}	48.28	—	Location 3
					460.0	13.06	1.26×10^{-5}	36.03	—	Location 4
			Cyclic Plate Load Test	Plate size 30.5cm× 30.5cm	—	177.0	3.1×10^{-3}	49.1	—	Location 1
					—	35.8	3.9×10^{-3}	16.82	—	Location 2
					—	310.0	1.3×10^{-3}	95.75	—	Location 3
					—	57.6	6.5×10^{-3}	19.45	—	Location 4
2.	Heavy vibratory Equipment, Fertilizer's Kanpur	Stiff brown grey silty clay (about 1 m) underlain by to dense sandy silt and silty fine sand (about 9.0m)	Forced Horizontal Vibration Test	Block 1.5m×0.75m ×0.7m high	—	2.11	8.6×10^{-4}	5.82	—	Location 1
					—	2.33	1.26×10^{-4}	6.42	—	Location 2
					—	1.69	6×10^{-5}	4.68	—	Location 3
					—	2.44	1.1×10^{-4}	6.74	—	Location 4
			Cyclie Plate Load Test	Plate size 30.5cm× 30.5cm	—	13.8	10.94×10^{-1}	2.36	—	Location 1
					—	23.65	6.2×10^{-2}	4.04	—	Location 2
					—	22.2	6.2×10^{-2}	3.79	—	Location 3
					—	13.85	4.26×10^{-1}	2.36	—	Location 4

1	2	3	4	5	6	7	8	9	10	11
3.	Aero-Engine Test Beds AEF Chandigarh		Forced Vertical Vibration Test	Block 1.5m × 0.75m × 0.70m high	—	4.17	4×10^{-4}	11.51	11.51	Location A
					—	4.64	2×10^{-4}	12.8	8.45	Location B
					—	6.48	1.5×10^{-4}	17.87	9.63	Location C
			Forced Horizontal Vibration Tests	Block 1.5m × 0.75m × 0.70m	—	5.73	5.8×10^{-4}	15.94	—	
					—	4.16	6.1×10^{-4}	11.53	—	Location B
					—	5.40	7.2×10^{-4}	14.89	—	
			Cyclic Plate Load Test	Plate 30.5cm × 30.5cm	—	21.2	1.63×10^{-2}	5.69	—	
4.	Diesel Power House Sirhind	Fine to medium sand with some silt	Forced Vertical Vibration Test	Block 1.5m × 0.75m × 0.70m	—	2.84	8.6×10^{-5}	7.83	15.1	$\theta = 35°$
					—	2.87	1.6×10^{-4}	7.91	8.7	$\theta = 70°$
					—	2.95	3.06×10^{-4}	8 13	10.4	$\theta = 105°$
					—	3.17	3.6×10^{-7}	8.76	8.4	$\theta = 140°$
			Forced Horizontal Vibration Test	Block 1.5m × 0.75m × 0.70m	—	3.38	4.26×10^{-4}	9.32	—	$\theta = 35°$
					—	2.96	7.5×10^{-4}	8.16	—	$\theta = 70°$
					—	2.66	9.0×10^{-4}	7.33	—	$\theta = 105°$
					—	2.32	1.0×10^{-3}	6.40	—	$\theta = 140°$
			Cyclic Plate Load Test	Plate 30.5cm × 30.5cm	—	8.55	1.66×10^{-2}	4.01	—	
5.	Diesel Power House Nakodar	Medium Sand	Forced Vertical Vibration Tests	Block 1.5m × 0.75m 0.70m	—	4.95	1.1×10^{-4}	13.65	—	$\theta = 35°$
					—	4.30	2.2×10^{-4}	11.86	9.3	$\theta = 70°$
					—	4.03	2.8×10^{-4}	11.11	7.8	$\theta = 105°$
					—	3.74	3×10^{-4}	10.31	7.5	$\theta = 140°$
			Forced Horizontal Vibration Tests	Block 1.5m × 0.75m × 0.70m	—	4.46	3.6×10^{-4}	12.30	—	$\theta = 35°$
					—	4.10	7.6×10^{-4}	11.31	—	$\theta = 70°$
					—	3.84	9×10^{-4}	10.59	—	$\theta = 105°$
					—	3·80	9.8×10^{-4}	10.48	—	$\theta = 140°$

1	2	3	4	5	6	7	8	9	10	11
			Shear Modulus Test	Block 1.5m × 0.75m × 0.70m	312	9.56	3.0×10^{-6}	26.40	—	—
			Cyclic Plate Load test	Plate 30.5cm × 30.5cm	—	21.0	3.9×10^{-6}	5.05	—	—
6.	Cement Factory Rajban		Forced Vertical Vibration Test	Block 3.05 × 1.5m × 1.0m high	— — — —	9.10 8.75 7.94 7.58	4.2×10^{-5} 4.6×10^{-5} 3.06×10^{-5} 3.6×10^{-5}	39.90 33.2 34.80 32.96	— — — —	Location RB_1 Location RB_1 Location RB_2 Location RB_2
			Forced Horizontal Vibration Test	Block 3.0m × 1.5m × 1.0m		10.4 11.72 10.62 10.21	7.2×10^{-5} 7.6×10^{-5} 1×10^{-4} 1.06×10^{-4}	45.60 51.38 47.56 45.06	— — — —	Location RB_1 Location RB_1 Location RB_2 Location RB_2
			Free Vertical Vibration Test	Block 3.0m × 1.5m × 1.0m	— —	11.6 10.4	1×10^{-6} 1×10^{-6}	50.96 45.60	— —	Location RB_1 Location RB_2
			Free Horizontal Vibn. Test	Block 3.0m × 1.5m × 1.0m	— —	16.96 14.72	1×10^{-6} 1×10^{-6}	74.36 64.54	— —	Location RB_1 Location RB_2
			Cyclic Plate Load Test	Plate 60cm × 60cm	— — — —	12.5 11.0 16.0 12.0	9.1×10^{-3} 1.03×10^{-2} 7.1×10^{-3} 1.1×10^{-2}	4.72 4.15 6.04 4.53	— — — —	Location VP_1 Location VP_2 Location VP_3 Location VP_4
7.	University of Roorkee, Roorkee	SP. Soil upto 5m followed by 8m soil upto 17.75m	Forced Vertical Vibration Test	Block 1.5m × 0.75m × 0.75m	— — — —	8.90 7.64 5.84 5.30	6.4×10^{-5} 1.24×10^{-4} 1.45×10^{-4} 1.58×10^{-4}	24.55 21.07 16.11 14.62	12.0 13.7 15.1 16.0	$\theta=35°$ $\theta=70°$ $\theta=105°$ $\theta=140°$

1	2	3	4	5	6	7	8	9	10	81
				Block 1×1m×1m	—	6.66	6.4×10^{-5}	16.38	11.65	$\theta=35°$
					—	5.84	1×10^{-4}	14.36	26.4	$\theta=70°$
					—	5.63	1.3×10^{-4}	11.31	31.6	$\theta=105°$
					—	4.0	1.5×10^{-4}	9.81	32.6	$\theta=140°$
			Forced Horizontal Vibration Tests	Block 1.5m×0.75m ×0.75m	—	3.35	2×10^{-4}	23.03	—	$\theta=35°$
					—	7.38	3×10^{-4}	20.36	—	$\theta=70°$
					—	6.85	4.6×10^{-4}	18.89	—	$\theta=105°$
					—	6.38	7.3×10^{-4}	17.60	—	$\theta=140°$
				Block 1m×1m×1m	—	7.16	2.1×10^{-4}	17.46	—	$\theta=35°$
					—	6.24	3.4×10^{-4}	15.34	—	$\theta=70°$
					—	5.84	5×10^{-4}	14.36	—	$\theta=105°$
					—	5.43	6.9×10^{-4}	13.35	—	$\theta=140°$
			Free Vertical Vibration Tests	Block 1.0m×0.75 ×0.75m	— —	19.71	1×10^{-6}	54.37	19.3 to 22.0	
				Block 1m×1m×1m	— —	22.8	1×10^{-6}	54.72	18.2 to 23.0	
			Free Horizontal Vibration Tests	Block 1.5m×0.75 ×0.75m	— —	22.08	1×10^{-6}	60.91	17.0 to 21.0	
				Block 1m×1m×1m	— —	12.25	1×10^{-6}	30.12	17.6 to 19.8	

θ=Angle of setting of eccentric masses

In the shear modulus test, shear wave velocity is determined from the frequency and the corresponding wave length (Wave length is four times the distance between the geophones when the phase difference between the waves reaching these two points is 90°) and then the shear modulus is obtained[1].

Field Test Data From Different Sites in India

Field tests were conducted at a number of sites in India for the determination of dynamic soil properties primarily for the design of foundations for machines of different types. At most of the locations the resonance test was performed on a block 1.5m × 0.75m × 0.70m. The shear modulus test using the method recommended in the code was also conducted at some of the locations. The data was analysed using the procedure given by the code. The values of the coefficient of elastic uniform compression '*Cu*' the damping coefficient ξ and the shear modulus 'G' (Where-ever the shear modulus test was performed) are shown in Table-I. In addition to these tests as proposed by the code, cyclic plate load tests were conducted at most of the locations and free vibration test, at some of the locations. The values of '*Cu*' obtained from these tests are also shown in Table-I. The values of damping coefficient are also shown in the same table.

Factors Affecting Dynamic Elastic Properties of Soils

The dynamic elastic constants of soils which are used for finding the stiffness of soil springs in the elastic soil-structure interaction problem under dynamic conditions, can all be expressed as functions of dynamic shear modulus 'G'. Dynamic shear modulus is effected by a number of factors such as (*i*) void ratio '*e*' (*ii*) average effective confining pressure '$\bar{\sigma}_o$', (*iii*) shear strain amplitude 'γ_θ', (*iv*) frequency of vibration and (*v*) grain characteristics. The confining pressure and strain amplitude exert the largest influence on dynamic shear-modulus. Figure 1 shows the trend of

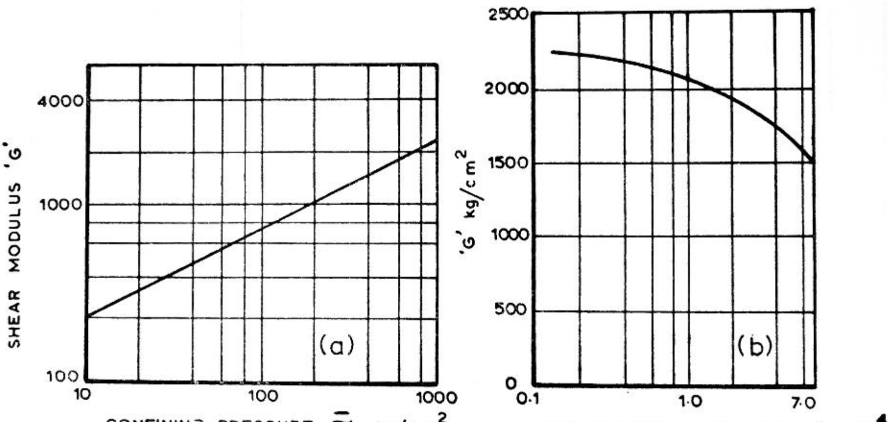

FIGURE 1. Variation of dynamic shear modulus with confining pressure and shear strains amplitude (a) shear modulus vs confining pressure(b) shear modulus vs shear strain (Drnevich, Hall and Richart, 1969)

[1]For the detailed procedure for conducting the test and interpretation of data reference may be made to I.S. 5249-1969. "Method of Test for determination of in-situ dynamic properties of soils."

vibration of 'G' with $\bar{\sigma}_o$ and γ_θ.

These parameters may be expected to exert a similar effect on the value of '*Cu*'.

Interpretation of Field Test Data

The data obtained from the different type of field tests was analysed further taking into consideration the parameters affecting '*Cu*'. The value of '*Cu*' as obtained by different methods for the same site varies considerably. This is essentially because of the fact that the average effective confining pressures and straing levels associated with each type of test are different. Figure 2 shows the order of strain levels associated with different in-situ

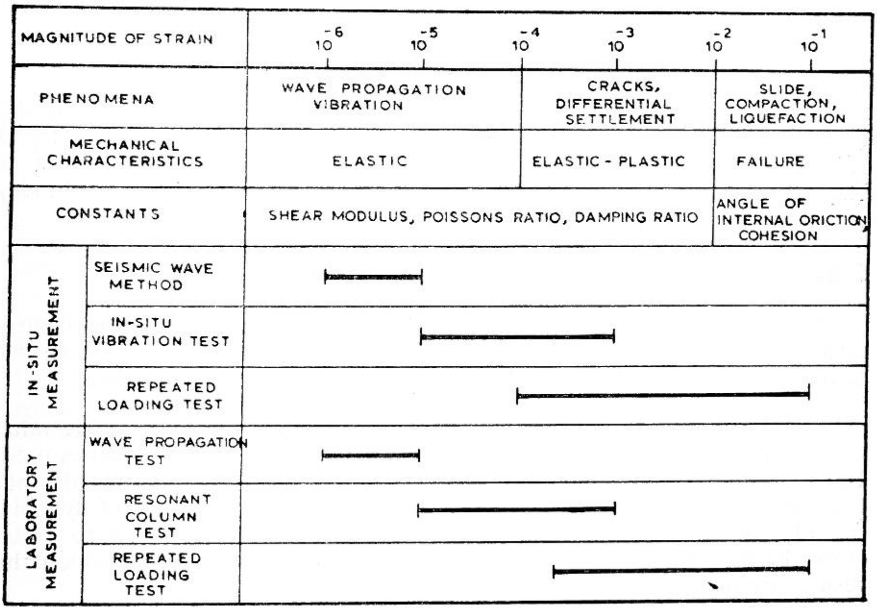

FIGURE 2. Strain level associated with different in-situ and laboratory tests *(Ishihara, 1971)*

and laboratory tests (Ishihara, 1971). The confining pressures and strain levels associated with the various field tests conducted were estimated. The value of '$\bar{\sigma}$' is obtained from Equation 1.

$$\bar{\sigma}_o = \sigma_v \frac{(2K_o+1)}{3} \quad \cdots(1)$$

Where σ_v=Vertical stress induced at the centre of pressure bulb having its depth equal to width of the test area because of superimposed static loads and weight of soil mass above that point and K_o=coefficient of earth pressure at rest. The strain levels have been computed as the ratio of amplitude or deflection to the depth of soil mass undergoing strain and may be taken approximately equal to width of the block. The strains so computed are shown in column 8 of Table I. The values of '*Cu*' obtained were then computed for a confining pressure of 1 kg/cm² in all cases using Equation (2).

$$\frac{Cu_1}{Cu_2}=\left(\frac{\bar{\sigma}_{o1}}{\bar{\sigma}_{o2}}\right)^{\frac{1}{2}*} \qquad ...(2)$$

Where Cu_1 and Cu_2 are the values of '*Cu*' corresponding to mean effective confining pressures of $\bar{\sigma}_{o1}$ & $\bar{\sigma}_{o2}$ respectively. These values are shown in column 9 of Table 1. The values of '*Cu*' in case of cyclic plate load test and where the test block is different from the standard size e.g. 1.5m × 0.75m × 0.70m, the values have been further computed for the contact area of standard size block using Equation (3)

$$\frac{Cu_1}{Cu_2}=\sqrt{\frac{A_2}{A_1}} \qquad ...(3)$$

Where Cu_1 and Cu_2 are the values for areas A_1 and A_2 respectively.

The values of '*Cu*' (for same confining pressure and area) and the corresponding strain levels have been plotted in Figure 3. A regular trend of variation of *Cu* with strain levels is obtained for each site which is qualitatively similar to the trend of variation of *G* with strain amplitudes observed in controlled laboratory tests as shown in Figure 1 (b).

Critical Evaluation of the Provisions of IS: 5249-1969:

An attempt will now be made to examine as to how far the factors affecting the dynamic elastic properties of soil as briefly discussed earlier have been incorporated by the code in interpreting the field test data.

(*a*) When resonance tests are conducted at the same location, the value of observed natural frequencies are different at different eccentricities used. For determination of dynamic elastic constants, the code recommends that the natural frequency should be chosen such that the ratio of dynamic force to static weight or in other words the ratio of dynamic stress to static stress below the block is the same as in case of prototype for which the results are to be used.

This does not ensure that the absolute stresses induced below the block are also the same. It is the mean effective confining pressure which influences the values of dynamic elastic properties of soils rather than the ratio of dynamic to static stress.

(*b*) Even if the resonance test is conducted by simulating the same static and dynamic stresses as in case of prototype foundation, the shear strain induced in the soil are much different in case of test block and the prototype because of size effects. Further extremely large shear strains are associated with the resonance phenomenon in case of test block as compared to a properly designed machine foundation.

---

* Variation of '*G*' with confining pressure can be expressed as $\frac{G_1}{G_2}=\left(\frac{\bar{\sigma}_{o1}}{\bar{\sigma}_{o2}}\right)^m$. The value of '*m*' varies from 0.3 to 0.7 (Silver and Seed, 1971). An average value of $m=0.5$ may be taken in genearal. '*Cu*' may be considered to vary like '*G*' with confining pressure.

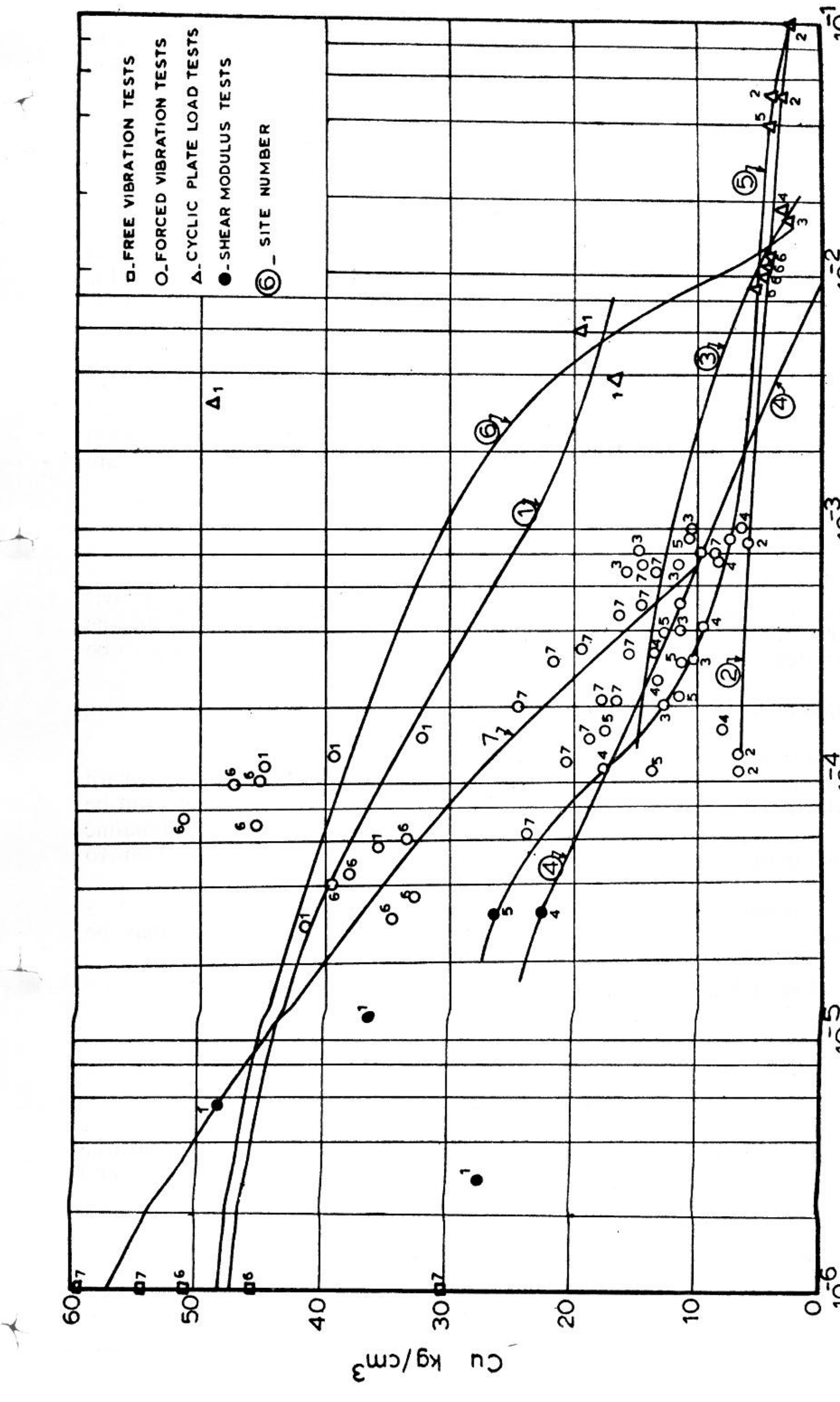

FIGURE 3. Coefficient of elastic uniform compression vs shear strain amplitude fcr different sites

(*c*) In order to account for the difference in area of the test block and the actual foundation, the code recommends the use of Equation (3) without any limitation. The value of '*Cu*' is found to decrease with increased contact area but the rate of decrease becomes less prominent as the size of contact area increases beyond a certain value. Infact for very large areas the values of '*Cu*' may increase some what Equation (3) may therefore be used upto contact area of 10 sqm beyond which the same value of '*Cu*' as for 10 sqm area may be used (Barkan, 1962).

(*d*) The natural frequency is observed to show a marked decrease with increase in moisture content of the soil and rise in water table. The value of '*Cu*' shall therefore decrease with rise in water table. No correction is suggested by the code in the present form.

(*e*) Code recommends the Band width method* for determination of damping coefficient 'ξ'. The method can be used for a single degree of freedom system. However the value of damping associated with different modes of vibration is different. Other methods of determining 'ξ' are therefore necessary.

Proposals for Revision

In the light of discussion given above certain modification in the provisions of the code to enable a more rational interpretation of data from the field tests and some more testing procedures as proposed below need to be incorporated.

1. Proposals for inclusion of new field tests

(*a*) **Necessity**: It is observed that the order of strains associated with different phenomenon is different. A correction for strains can not be applied directly. Therefore field tests which can give values of dynamic elastic constants at different strain levels may be considered in addition to the existing ones.

(*b*) **Proposed Methods**: The following additional methods of test may be included.

(*i*) Free vibration tests on the block

(*ii*) Wave propagation test with hammer impact

(*iii*) Cycle plate load test.

Free vibration tests can be performed by exciting the block into free vibrations by hitting or by pulling and suddenly releasing the pull and taking the record of vibrations.

Wave propagation test with hammer impact can be performed by hitting the ground with a hammer and determining the time taken by the waves to travel a known distance. Both these tests are quite simple to perform. Hammer test has the further advantage that it can be performed at

* For details reference may be made to IS 5249-1969.

a large number of locations in an area in a very short time.

The cyclic plate load test utilizes the set-up for a standard plate load test using reaction loading. The procedures consists of applying a static load increment, measuring the settlement, releasing the load and finding the elastic rebound. The load is increased and the process is repeated.

From the test data, elastic settlement versus load are plotted and the slope of the line so obtained gives the value of '*Cu*'. The test has the advantage that it involves no electronic instrumentation.

2. Proposals for inclusion of methods for interpretation of test data

(*i*) As the mean effective confining pressure for which the values are obtained in the field tests are different from that of the prototype, a correction should be applied to the value of '*Cu*' using equation (2) and to the value of dynamic shear modulus using Equation (4)

$$\frac{G_1}{G_2}=\left(\frac{\bar{\sigma}_{o1}}{\bar{\sigma}_{o2}}\right)^{0.5} \qquad \ldots(4)$$

Where G_1 and G_2 are the values corresponding to mean effective confining pressures of $\bar{\sigma}_{o1}$ and $\bar{\sigma}_{o2}$ respectively.

(*ii*) When the values of the dynamic elastic constants are to be used in a situation involving strains other than those associated with the field tests, the values may first be modified for the confining pressure expected using Equation (2) or (4) and the variation with strain can be studied to choose the appropriate value for analysis.

(*iii*) From free vibration tests damping may be computed using Equation (5).

$$\xi=\frac{X_m-X_{m+1}}{\pi(X_m+X_{m+1})} \qquad \ldots(5)$$

Where X_m, X_{m+1} etc. are indicated in Figure 4

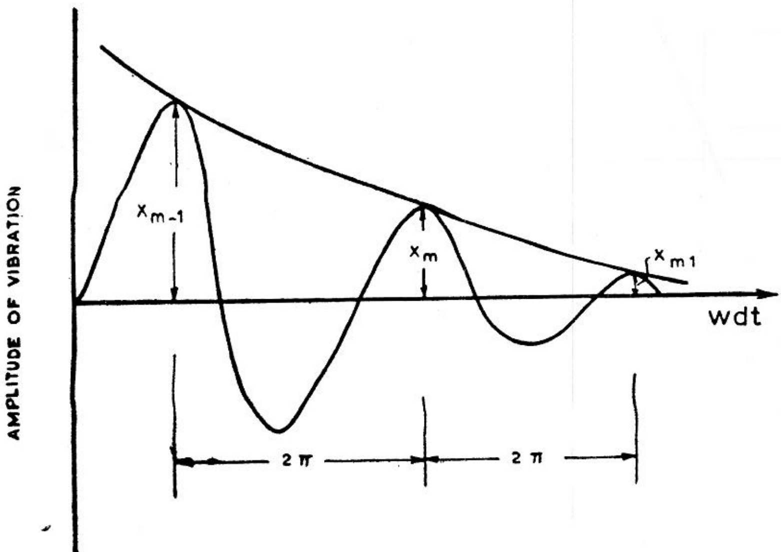

FIGURE 4. Damping from free vibration records

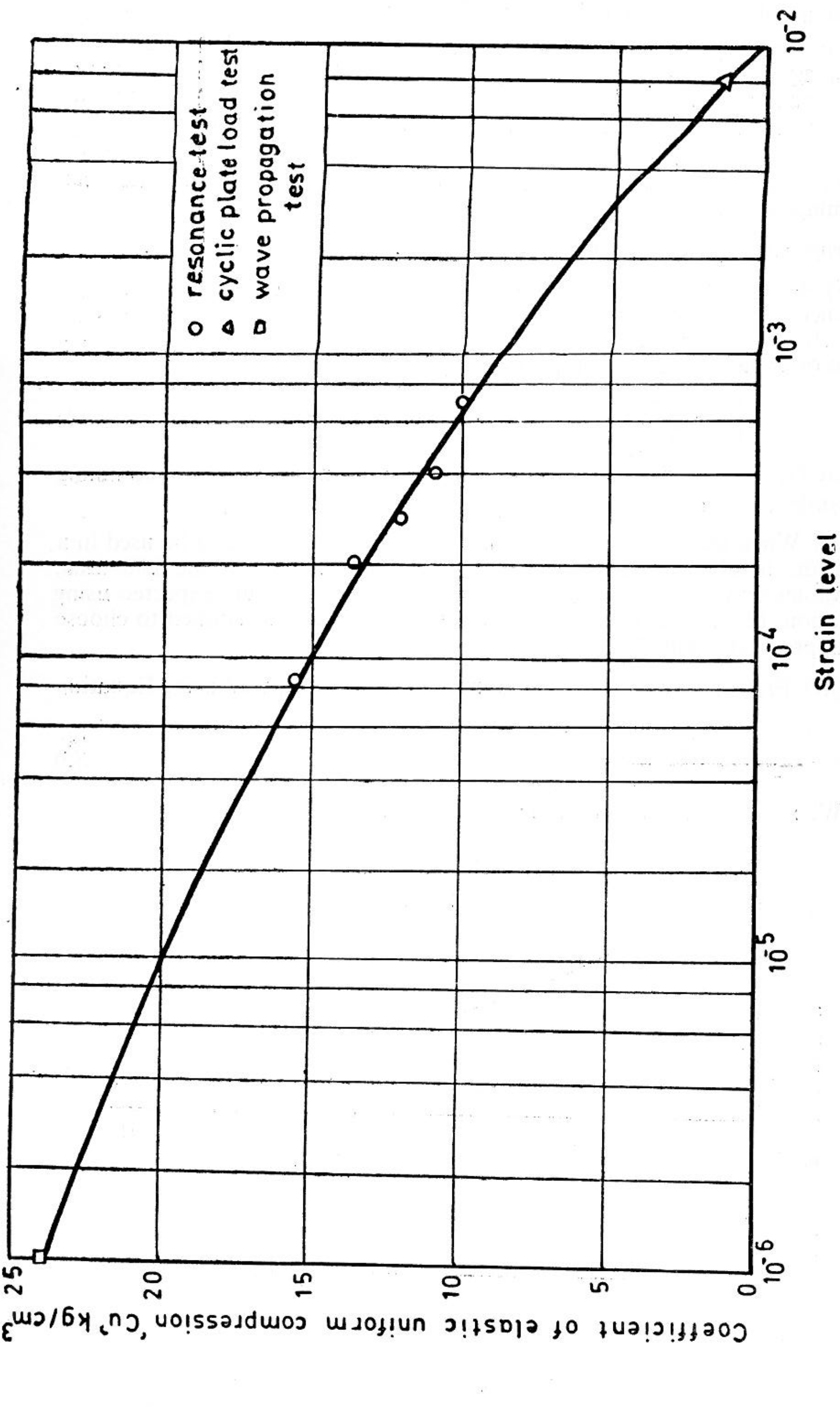

FIGURE 5. Coefficient of elastic unifrom compression '*Cu*' vs ratio of dynamic force to static weight (example)

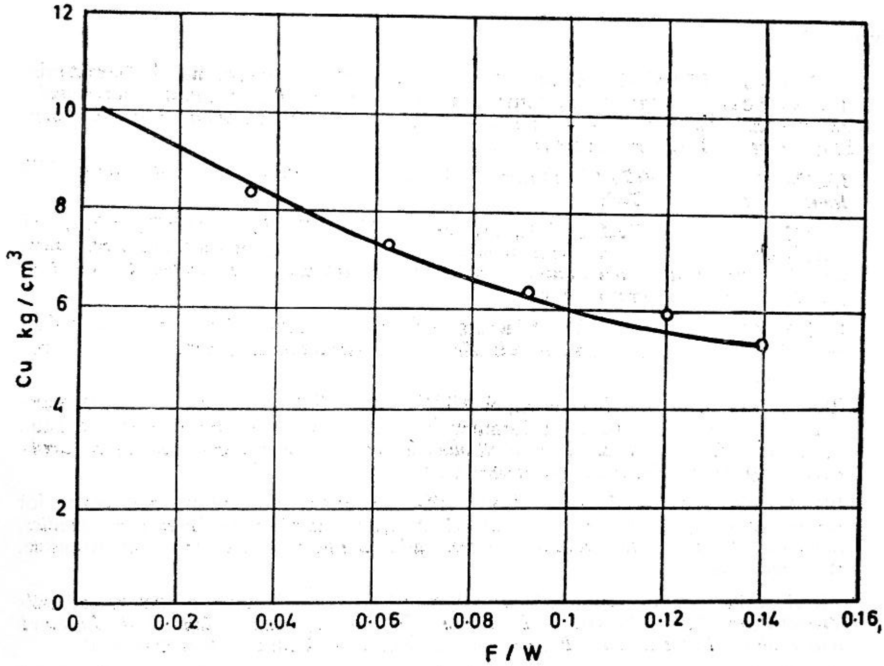

FIGURE 6. **Coefficient of elastic unifrom compresssion '*Cu*' vs strain level (example)**

(*iv*) The value of '*Cu*' may be corrected for water table effects by considering the effective stresses and using Equation 4. Alternatively the value of '*Cu*' may be multiplied by a factor 'C_w' given by Equation (6).

$$C_w = \left\{ 0.5 + 0.5 \frac{D_w}{Df + B} \right\}^{\frac{1}{2}} \qquad \ldots(6)$$

Where C_w = Correction factor for rise in water table

D_w = Depth of water table below group surface

B = Width of footing

Df = Depth of embedment of footing

No Correction is necessary if $D_w > Df + B$.

Summary

Methods have been proposed for conducting field tests for determination of in-situ dynamic elastic and damping properties of soils for important projects. Suggestion have been made for interpretation of the field test data on a more rational basis incorporating factors such as confining pressure and strain amplitudes which have by far the most significant influence on dynamic elastic properties of soil. A relation has been proposed for applying correction for the effect of water table on value of '*Cu*'. Field test data from a number site has been analysed using the proposed methods which illustrates that the values from the field test must be corrected rationally to arrive at appropriate design parameters. Reasonable values of damping can be obtained from free vibration tests.

References

ARYA, A.S., PRAKASH, S. and GUPTA, D.C. (1967), "Report on Soil Characteristics for Heavy Vibratory Equipment of Fertilizer Project, Kanpur" *Earthquake Engineering Studies School of Research and Training in Earthquake Engineering,* University of Roorkee, Roorkee. U.P.

BARKAN, D.D. (1962), "Dynamics of Bases and Foundations". *Mc Graw Hill Book Co. Inc.* New Delhi.

DRNEVICH, V.P., HALL, J.R., Jr. and RICHART, F.E. Jr (1967), "Effect of Amplitude of Vibration on Shear Modulus of sand." *Proc. International Symposium on Wave propagation and dynamic properties of Earthmaterials University of New Mexico Press,* Albuqerque, N.M.

ISHIHARA, KENJI (1971), "Factors Affecting Dynamic Properties of soils" *Proc. IV Asian Regional Conf. on soil Mech. and Foundation Engineering* Vol. II, Aug. 1971, Bangkok.

PRAKASH, S., BASVANA, B.M., & ARYA, A.S. (1968), "Report on soil characteristics for Heavy duty Forgoing Hammer Foundation of Hindustan Aeronautics Ltd., Koraput". *Earthquake Engineering Studies School of Research and Training in Earthquake Engineering,* Roorkee, Roorkee, U.P.

PRAKASH, S. and BASVANA, B.M. (1968), "Report on soil characteristies for Heavy Aero-Engine. Test Beds, A.E.F. Chandigarh" *Earthquake Engineering Studies, School of Research and Training in Earthquake Engineering,* University of Roorkee, Roorkee, U.P.

PRAKASH, S., and GUPTA, M.K. (1970), "Report on dynamic properties of soils Diesel Power House Nakodar" *Earthquake Engineering studies School of Research and Training in Earthquake Engineering,* University of Roorkee, Roorkee, U.P.

PRAKASH, S., and GUPTA, M.K., (1971), "Report on Dynamic properties of soil for Diesel power House Sirhind" *Earthquake Engineering studies, School of Research and Training in Earthquake Engineering,* University of Roorkee, Roorkee, U.P.

PRAKASH, S., RANJAN, G., NANDAKUMARAN, P., GUPTA M.K., JOSHI, V.K. and SRIVASTAVA, L.S., (1973), "Report on soil Investigations for Cement Factory at Rajban (H.P.)" *Studies carried at Civil Engineering Department and Earthquake School,* University of Roorkee, Roorkee, (U.P.), March 1973.

PURI, V.K. (1969), "Natural Frequency of Block Foundation Under Free and Forced Vibrations" *A dissertation* submitted in partial fulfilment of the requirements for the degree of Master of Engg. in Soil Mech. and Foundation Engg., University of Roorkee, Roorkee. U.P.

RICHART, F.E., HALL, J.R and WOODS, R.D. (1970), "Vibrations of Soils and Foundations" *Prentis & Hall. Inc. Englewood Cliffs* New Jersey.