PREDICTION OF DYNAMIC RESPONSE OF EMBEDDED FOUNDATIONS

by

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SYNOPSIS

Prediction of dynamic response of foundations and structures, using soil-structure interaction parameters determined from the theory of surface footings, is overestimated. In order to establish suitable procedure for evaluating the soil-structure interaction parameters, an intensive experimental programme on surface and embedded footings as well as full-scale structures has been performed at IZIIS, University of Skopje. Using experimental results and modified theoretical solutions,procedure for determination of equivalent linear dynamic properties of soil media and soil-structure interaction parameters, has been evaluated. It is found that with performance of dynamic field tests on embedded footings and using described procedure, dynamic response of embedded foundations as well as structural systems could be predicted accurately.

INTRODUCTION

First efforts in analytical evaluation of the soil-structure interaction effect started 1938 by Jacobsen, but only in the last several years more of the researchers have paid attention to this problem. Particularly Parmelee et al. (1964), Parmelee (1967), Kastelani (1970), Kobori et al. (1970), Liu and Fogel (1971), Luco and Westman (1971), Parmelee et al. (1972), Matsushima (1972). In most of these works the evaluation of soil-structure interaction parameters was done using the solution of circular disk on elastic halfspace.

Beredugo and Novak (2) using Baranov's (1) approach formulated an approximative analytical solution for coupled horizontal and rocking vibration of embedded footings incorporating the effect of the backfill. The validity of this solution was supported by experimental studies.

These analytical solutions, and in particular the latest by Beredugo and Novak, are offering a qualitative understanding of the effect of soil-structure interaction, but unfortunately they do not satisfy the evidence from the field tests performed at IZIIS. This is mainly due to the lack of evaluation of the dynamic properties of the soil media for the corresponding level of excitation in the soil-foundation system, particularly when the soil behaves nonlinearly. Evaluated soil properties from the shear wave velocity measurements and existing laboratory procedures used for the dynamic response analyses of the tested foundation models does not satisfy the resonant frequencies and in particular resonant amplitudes obtained experimentally. In order to study the possibility of more adequate evaluation of equivalent dynamic soil properties and consequently the soil-structure interaction parameters of each level of excitation, an identification procedure was used. Due to nonhomogenity of the soil media and difficulties of studying all soil components separately, the basic approach in evaluation of equivalent dynamic soil properties should be by testing the simulated soil-structural system covering the range of the expected dynamic excitation into the system. It has been found that equivalent soil properties are mainly controlled by amplitudes of displacements due to vibration of the soil-structure system. The established relationship of the shear moduli versus displacement amplitude are

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makiug possible the discrete model to be easily used in prediction of dynamic response of machine foundation or structures for each level of excitation under dynamic loeads.

EXPERIMENTAL INVESTIGATIONS

In order to apply basic approach of the study presented in this paper, an intensive experimental programme was performed. About 200 dynamic field tests were conducted on the rectangular (1.0 x 2.0 x 2.0 m.) and circular (ϕ = 1.0 m.) shaped footings,embedded 2.0 m. into the soil media. The dynamic tests on the footings were conducted for four different stages of embeddment (d/H = 1.0;2/3, 1/3 and 0.0), under the different excitation levels for each case of embeddment. On Figs. 1 and 2 some of dynamic response of the rectangular transverse vibration has been shown for nonembedded and 1/3 embeddment case, respectively. From the experimental study the following conclusions could be drawn:(i) The shape of the resonant frequency curves in the sequence of increasing exciting vibrational force into the system is showing nonlinear behaviour with the softening effect;(ii) For the surface and embedded footings the response is dominated only by the first resonant peak (observed also by Ratay and Beredugo and Novak (2);(iii) With the increasing of the existing vibrational force in both cases of the embedded and surface footings the resonant amplitudes increase and the resonant frequencies decrease, while the damping coefficients increase, and (iv) Comparing the embedded and surface footings response it is evident that with the increasing of embeddment the resonant amplitudes decrease, the resonant frequencies increase and the damping coefficients increase twice or more. Some of the comparative values for transverse vibration of the rectangular footing are given in Table 1 and shown in Figs. 1 and 2.

EQUIVALENT DYNAMIC SOIL-PROPERTIES AND SOIL-STRUCTURE INTERACTION PARAMETERS

In order to evaluate adequate soil-structure interaction parameters, it was necessary first to determine corresponding dynamic soil properties for each level of excitation of the tested models. Fitting experimentally obtained resonant frequencies and applying modified analytical solution described in (2), the subsoil and sidesoil equivalent dynamic shear moduli-resonant amplitude diagram have been obtained (Figs. 3, 4 and 5).

The evaluation of the equivalent dynamic soil properties the following assumptions have been applied:(i) Soil-structure interaction parameters could be evaluated for the structural system if the simzlation of the foundation geometry and the range of the dynamic excitation is performed in the same field conditions on the footings model (3);(ii) Approximate analytical solution for dynamic response of embedded footings correlates with the experimental data (2,3), and (iii) Equivalency of the linear viscoelastic system with nonlinear one is valid for the magnitude of deformations considered.

In order to asses the validity of this approach a full-scale forced vibration study on a five and nine-story large panel prefabricated building was performed. Using equivalent soil properties evaluated from the footing tests for corresponding deformations on the foundation level, the soil-structure interaction parameters were obtained. It was found that there is a very good agreement between the experimental and analytical dynamic properties of the tested structural system (3).

Out of this study, several other findings were obtained:(i) The interaction parameters could be practically treated as a frequancy independent (Figs. 6 and 7);(ii) Evaluated equivalent soil properties could be used in analyses of the dynamic response of the system using FEM procedure. Some of the results from analyses of the studied system are given in Table 2. It has been found that physical approximation of the discrete and finite element model is equally valid;and (iii) Resonant amplitudes from the calculated response are several times bigger than the experimental values (Table 3).

CONCLUSIONS

Presented procedure for evaluation of the soil-structure interaction parameters could be used for prediction of the dynamic response of machine foundations and structural systems including the effect of nonlinear behaviour of the soil media. Damping parameters in the approximate analytical solution for embedded footings should be corrected in order to meet experimental evidence. More experimental tests in different soil conditions on the models and full scale structures are needed in order to obtain general evidence.

REFERENCES

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2.Beredugo, Y.O., and Novak, M. (1972), "Coupled Horizontal and Rocking Vibration of Embedded Footings", Canadian Geotechnical Journal Vol.9, No.4, 1972, pp.477-497.

3. Petrovski, J. (1977), "Influence of Soil-Structure Interaction on Dynamic Response of Structures", VI WCEE, New Delhi, Jan.1977.

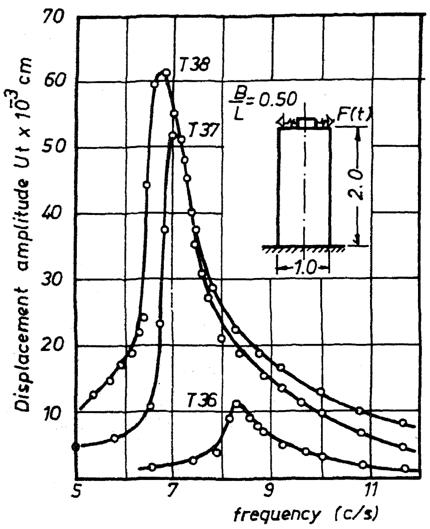


FIG. 1 DYNAMIC RESPONSE OF RECTANGULAR FOUNDATION, TESTS 36, 37 AND 38 EMBEDDMENT d = 0.0 m

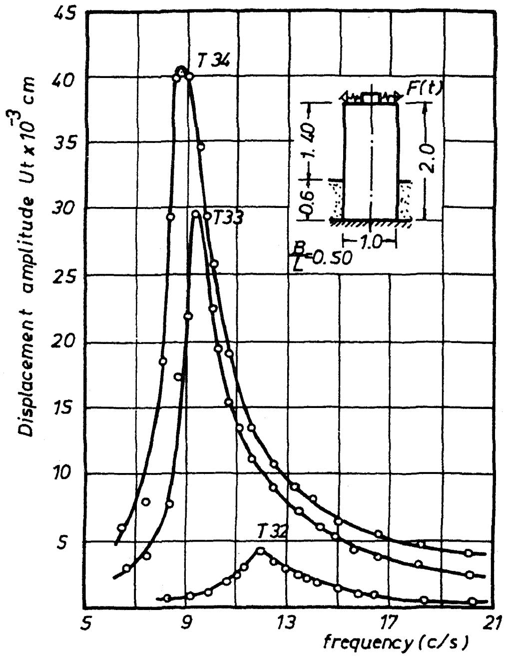


FIG. 2 DYNAMIC RESPONSE OF RECTANGULAR FOUNDATION, TESTS 32, 33 AND 34 EMBEDDMENT $d = \frac{1}{3} H$

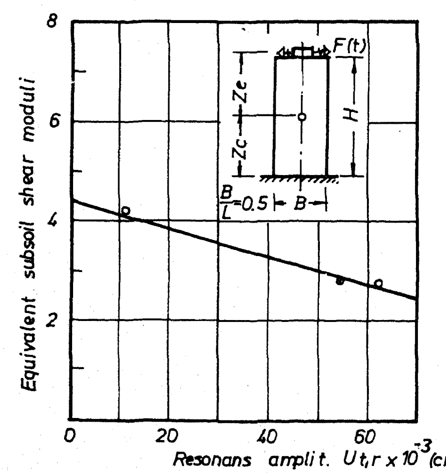


FIG. 3 EQUIVALENT DYNAMIC SUBSOIL SHEAR MODULI VS. RESONANT DISPLACEMENT AMPLITUDE FOR RECTANGULAR FOUNDATION

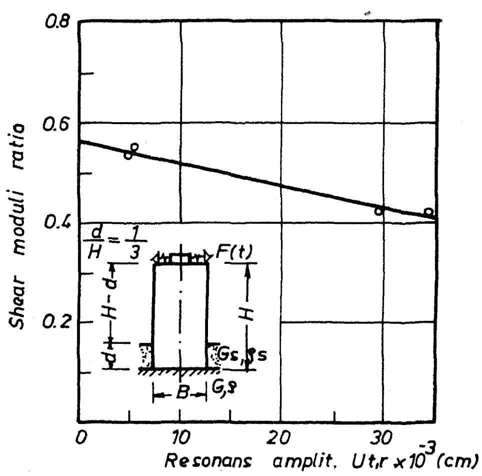


FIG. 4 EQUIVALENT DYNAMIC SIDE-SOIL SHEAR MODULI RATIO VS. RESONANT DISPLACEMENT AMPLITUDE FOR RECTANGULAR SHAPE FOUNDATION

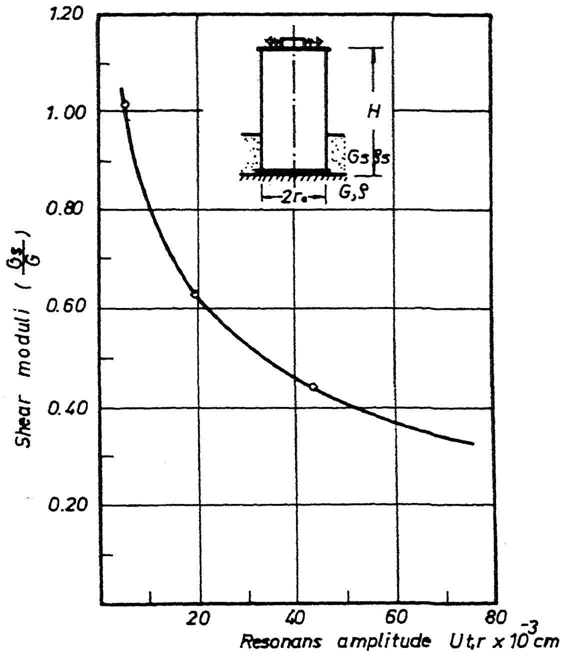


FIG. 5 EQUIVALENT DYNAMIC SIDE-SOIL SHEAR MODULI RATIO VS. RESONANT DISPLACEMENT AMPLITUDE FOR CIRCULAR SHAPE FOUNDATION

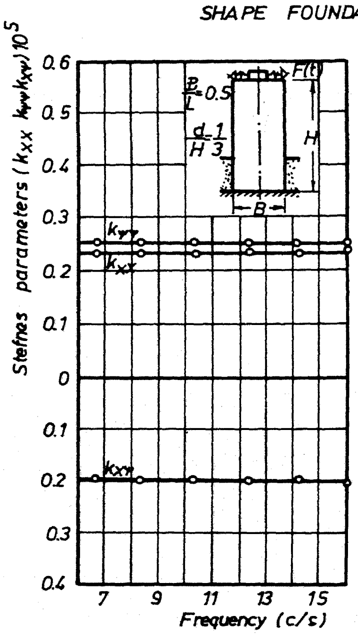


FIG. 6 FREQUENCY DEPENDENCE OF STEFFINES PARAMETERS

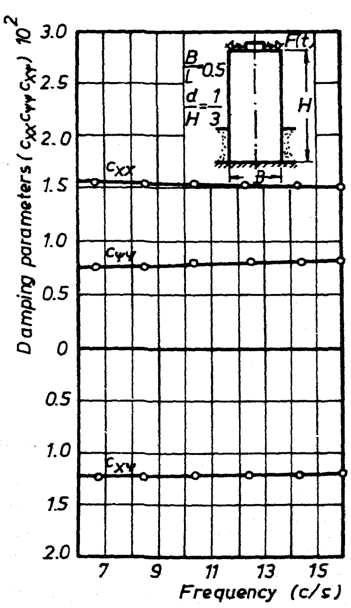
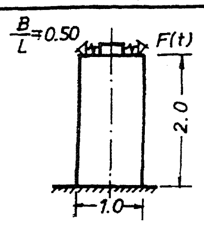
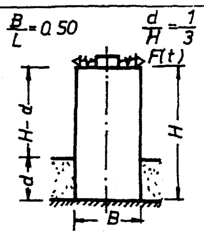


FIG. 7 FREQUENCY DEPENDENCE OF DAMPING PARAMETERS

TABELE 1 : COMPARISON OF THE DYNAMIC RESPONSE OF THE SURFACE AND EMBEDDED FOOTINGS (EXPERIMENTAL DATA)

Test No	Embedment Conditions	Unbalance moment Mo (kg/cm)	Resonant Frequency (cps)	Displacement Amplitude x 10^{-3} cm	Damping %
36		5.0	8. 35	10. 5	2. 50
37		25.0	7. 02	52.04	3. 58
38		35.0	6. 84	61.0	3. 90
39		5.0	7. 50	9. 46	3. 56
32		5.0	11. 66	4. 64	5. 0
33		25. 0	9.60	29.80	6. 52
34		35.0	9.02	34.00	6. 95
35		5.0	10.07	4. 45	6. 15

TABELE 2: COMPARISON OF EXPERIMENTAL AND CALCULATED RESONANS FREQUENCIES FROM THE FEM ANALISIS (99 AND 111 NODES)

Test No	Embedment Conditions	Resonance frequencies (cps)		
		Experiment	Calculated	Diference %
36	$\frac{d}{H}=0.0$	8. 35	7. 87	5. 75
37		7.02	6.57	6. 41
38		6. 84	6. 41	6. 29
39		7. 50	7. 03	6. 27
32	$\frac{d}{H}=\frac{1}{3}$	11. 66	12. 56	7. 72
33		9. 60	9. 91	3. 23
34		9. 02	9. 62	6. 65
35		10. 70	11. 18	4. 49

TABELE 3: COMPARISON OF EXPERIMENTAL AND CALCULATED DYNAMIC PROPERTIES OF THE EMBEDDED FOOTING

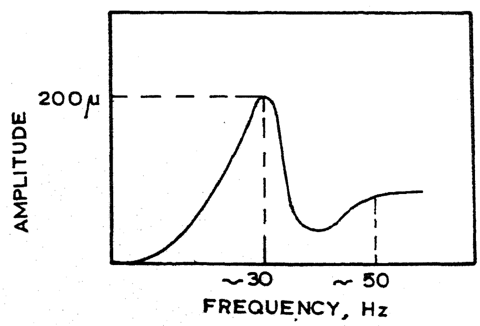
Test	Dynamic Properties	Experim.	Calculated	Diference or Ratio
32	a) Resonant Frequencies (cps)	11. 66	11. 81	+ 1. 30%
33		9. 60	9. 63	+ 0. 30
34		9. 02	9. 13	+ 1. 20
35		10. 70	10. 62	- 0. 70
32	b) Resonant Amplitudes (10^{-3} cm)	4. 64	13. 60	2. 93
33		29. 80	115. 80	3. 88
34		34. 00	174. 60	5. 13
35		4. 45	13. 89	3. 12
32	c) Damping Ratio (%)	5. 00	5. 28	1. 06
33		6. 52	3. 71	0. 57
34		6. 95	3. 56	0. 51
35		6. 15	4. 94	0. 80

DISCUSSION

N. Lakshmanan (India)

The author has suggested a method for evaluating the equivalent dynamic soil properties depending on the level of excitation using the resonant amplitude as a parameter. He has pointed out that "evaluated soil properties from the shear wave velocity tests and existing laboratory procedures used for dynamic response analyses" do not satisfy the resonant frequencies and resonant amplitudes obtained experimentally. A similar observation has been made by M.S. Subrahmanyam on the behaviour of footings under vertical vibrations. In his Ph.D. thesis submitted to the Indian Institute of Technology, Madras, Dr. M.S. Subrahmanyam suggests that the values of G and μ be treated only as intermediate parameters. He suggested many ring type distribution and has shown that more than one pressure distribution, at the base can lead to nearly identical resonant frequencies and amplitudes, though the intermediate values of G and μ obtained using individual pressure distributions are clearly distinct. In this present paper also an attempt has been made to modify the shear modulus G, based on the resonant amplitudes and levels of excitation, thus making it an intermediate parameter to achieve the end objective of "a correct resonant frequency".

The discussor on certain tests conducted on stiff clayey soils has found that the dynamic response curve is as shown in Fig. 1, schematically under coupled horizontal and rocking vibrations.



The response curve shows that though the first resonant peak dominantes, the subsequent response amplitude is not small enough to be ignored.

Again, the evaluation of equivalent dynamic properties of the soil are necessitated to partially account for the non linearity of the soil-foundation system. The discussor feels that the absolute maximum acceleration also must find a place in making suitable modification to G and μ values, as the acceleration modifies the inertial forces.

A stage by stage alteration of the damping value with increase in absolute response acceleration has been suggested by M.G. Joseph and R. Radhakrishnan, (3-26), for the analysis of multistoreyed buildings. A similar modification of Poisson's ratio with absolute acceleration level may bring about a good correlation between predicted and computed resonant amplitudes.

A.R. Chandrasekaran (India)

The author has reported that as far as amplitudes are concerned, there is a large difference between the experimental and theoretical values. The writer believes the theoretical values were obtained using the analogy proposed by Prof. Novak, who is incidentally the theme reporter of this session. This question could be answered by both of you. Do you feel that there is a change needed in the recommendations as far as damping is concerned. As far a frequencies are concerned, it appears that there is reasonable agreement.

Author's closure

Not received.