INFLUENCE OF SOIL-STRUCTURE INTERACTION ON DYNAMIC RESPONSE OF STRUCTURES

by

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SYNOPSIS

Existing methods for analyses of dynamic response of structures applying assumption of the fixed structure in the soil media, considered soil as a rigid nondeformable media. This assumption is widely adopted since it simplifies mathematical solution of the problem, but we can hardly say that it has physical justification.

Using experimental results from dynamic tests of embedded foundations and a full-scale forced vibration studies of nine and five-story buildings for the same soil conditions, the soil-structure interaction parameters of the building were determined. Comparing dynamic response of the fixed and flexible base model, an increase of base shear of an order of 20 to 29 and20 to 50 percent for close and far distant earthquakes was obtained, respectively.

INTRODUCTION

Studies on the influence of the soil media flexibility on the damage ratio of the structures in the past earthquakes (Kanai 1949, Tanabashi 1953, Duke 1958, Seed 1967, Rose and Seed 1969, Seed and Alonso 1973) as well as recent forced vibration studies of the full scale structures and strong motion records (Jennings and Kuriowa 1970, Protonatarios and Whitman 1971, Petrovski et al. 1971, 1972 and 1973, Muto 1972 and others) had shown that the soil media flexibility has significant influence on the dynamic response of the structures.

From the above evidence it appears that widely used assumption treating the structure fixed in the soil media hardly has physical justification. In order to have more realistic prediction of the structural response, it is important in the formulation of the mathematical models of the structural systems to include the soil media flexibility.

The soil media flexibility, or as it is commonly used soil-structure interaction, depends basically on the mechanism of energy transmission between the soil media and the structure itself. The primary effects of interaction phenomena consist in the resonant frequancies modification and the energy absorbtion increase.

SOIL-STRUCTURE INTERACTION PARAMETERS EVALUATION

An effort for evaluation of soil-structure interaction parameters from the dynamic response of embedded footings has been presented in (9). Basic assumptions in their evaluation is that the equivalent linear dynamic properties of the soil media are valid if they are obtained from the dynamic test simulating the embeddment conditions and the excitation levels on the structural foundation model in the same soil conditions of the contact are as for the structural system considered.

Using approximate analytical solution for the coupled horizontal and rocking vibration of embedded footings (2,4) and field experimental results

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from the dynamic response of the foundation models, the equivalent linear dynamic properties of the soil media for different excitation levels (7,9) are identified. This procedure enables presentation of the nonlinear behaviour of the soil media with equivalent linear properties depending on the level of deformations involved in the system. In this manner the biggest insufficiency of the discrete model is exceeded. On Fig.1 the diagrams of equivalent shear moduli of the subsoil and the side soil, dependent on the deformations in the soil-foundation system for rectangular footings, are given.

In order the check validity of the presented assumptions a full-scale forced vibration study of the nine and five story large panel prefabricated building founded in the same soil conditions was performed. The dynamic properties of the nine story building for longitudinal direction and the five story building in transverse direction are given on Fig.2 and 3, respectively. For the magnitude of deformations on the foundation level and the diagrams on Fig.1 values for equivalent shear moduli of subsoil and sidesoil were obtained.

Values of the soil-structure interaction parameters could be obtained **using** corresponding equations given in (4) and (7). It has been found (7), that in the range of the resonance for each particular mode stiffness and damping coeficients could be treated practically as frequency independent.

FORMULATION OF THE MATHEMATICAL MODEL

For formulation of the mathematical model of the presented buildings, beside the soil-structure interaction parameters, it is required that the mass and stiffness matrix of the superstructure should be obtained. For the simplicity, a discrete linear model was considered and the mass matrix was obtained as diagonal matrix. The stiffness matrix is obtained as three diagonal one considering shear type structure fixed in the soil media. The soil-structure interaction parameters are considered as a constant frequency independent parameters (7,9).

DYNAMIC PROPERTIES OF THE BUILDINGS

In order to study the influence of the soil-structure interaction parameters on the dynamic response of the structure and to check the validity of the assumptions aplied in the evaluation of these parameters and consequently formulated mathematical model, both the fixed base and the flexible model were analysed. On Figs. 2 and 3 the dynamic properties, i.e.resonant frequencies and mode shapes for nine and five story buildings for both fixed and flexible base model are compared with the experimental one. It is evident that for five story building there is 100 percent difference in the resonant frequency and significant difference in the mode shape (Fig.3a). For the flexible model the difference in the first mode the resonant frequency is 4.5 percents and there is a good agreement of the mode shape (Fig.3b). For the nine story building the difference in the first mode resonant frequency of the fixed base model is about 23% and large discrepancy of the mode shape is present. In the case of the flexible base model the agreement of analytical and experimental results in both resonant frequency and mode shape is evident.

DYNAMIC RESPONSE OF THE BUILDINGS

For both considered models the dynamic response of both buildings was analysed for El Centro 1940 N-S component and Port Hueneme 1957 N-S component, representing far and close distance earthquakes, respectively. Comparing base shear for both models an increase of about 20 and 50 percents for El Centro earthquake for nine and five story buildings is obtained for flexible model. In the case of the Port Hueneme earthquake the increase of base shear for flexible model is 29 and 23 percents for nine and five story buildings.

CONCLUSIONS

Presented procedure for evaluation of the mathematical model of the structural systems including soil-structure interaction effect is demonstrated comparing analytical and experimental dynamic properties of the studied buildings.

There is evidence of an increase of 20-50 percents of the base shear due to influence of flexibility of the soil media on the studied structural system. Significant increase of the inertia forces in the rigid structural systems could be obtained due to effect of soil media flexibility, producing large damage on the superstructure in the case of firm soil and large foundation differential settlements in the case of soft soil. For the last one this effect could be larger due to more intensive modification of the resonant frequencies and the smaller effect of the energy absorbtion.

The largest number of the buildings in housing development in most of the countries are representing low story rigid structures, particularly those of large panel prefabricated buildings or similar. The existing design regulations and code of practice are neglecting the soil-structure interaction effect. Some of the intensive damage and collapse of the structural systems in the past earthquakes (Skopje, Anchorage, Niigata) could be better explained if the soil flexibility effect is considered. In order to minimize damage potential in the future construction it will be desirable to pay more attention studying soil-structure interaction phenomena and applying it in the building codes and regulations.

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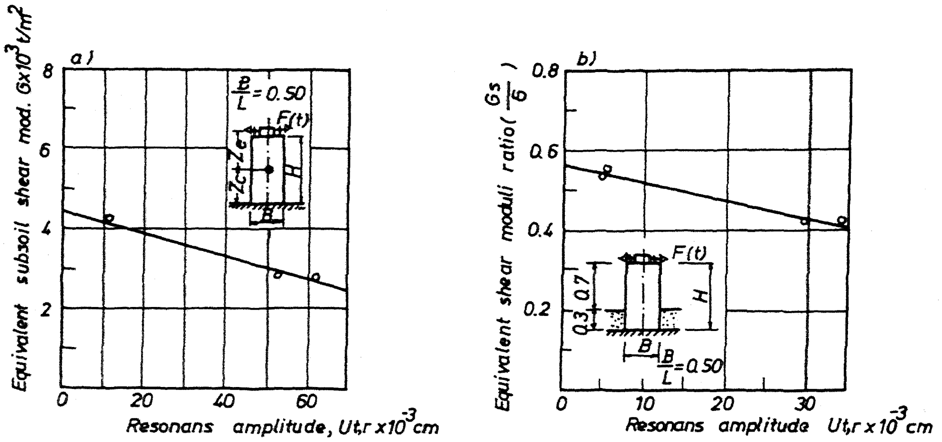


FIG. 1 EQUIVALENT SHEAR MODULI OF THE SUBSOIL (a) AND SIDESOIL (b) FROM DYNAMIC RESPONSE OF THE FOOTINGS FOR SANDY GRAVEL

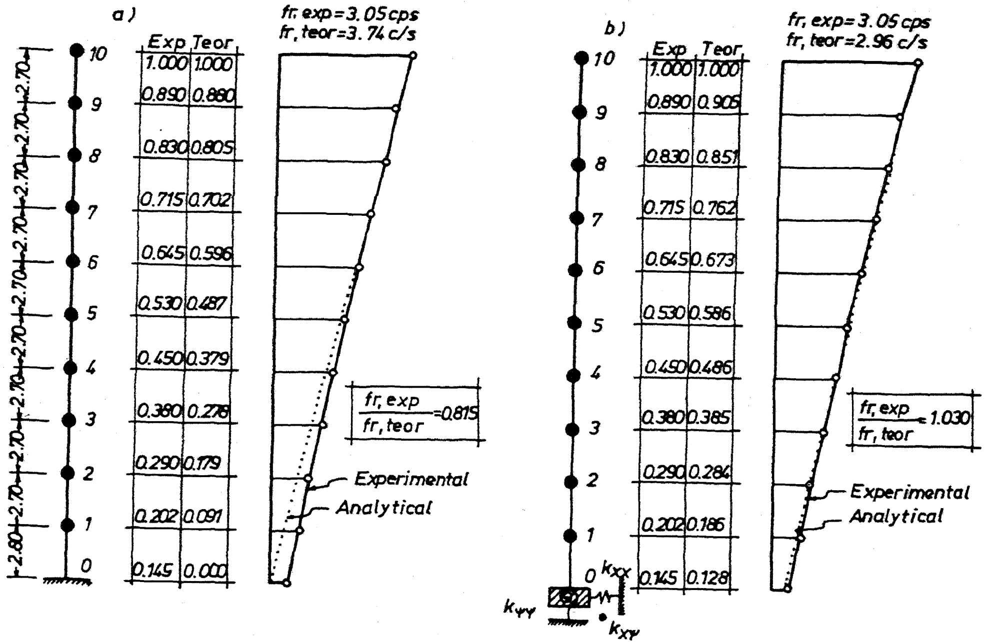
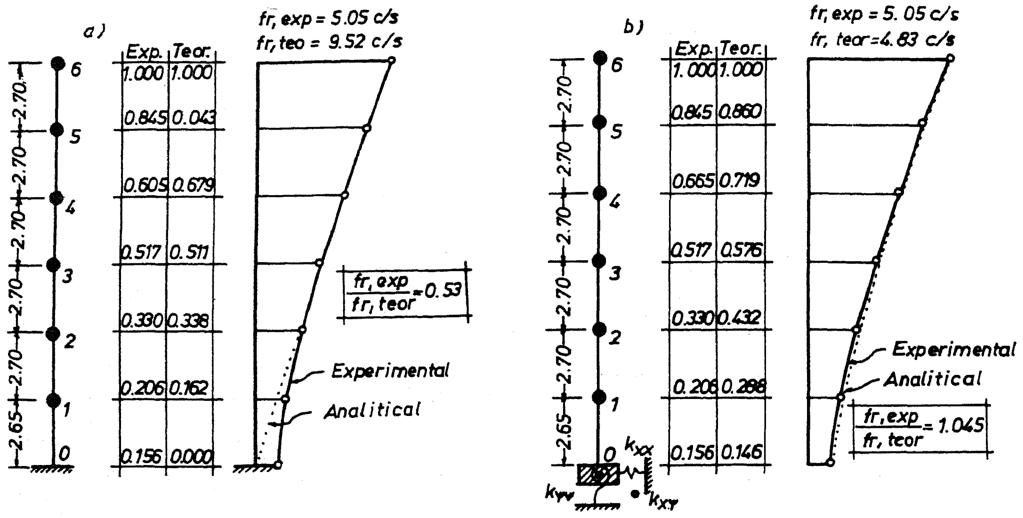


FIG. 2 COMPARISON OF EXPERIMENTAL AND ANALYTICAL DYNAMIC PROPERTIES a) FIXED BASE MODEL b) FLEXIBLE BASE MODEL FOR NINE STORY BUILDING



a)

Exp.	Teor.
1.000	1.000
0.845	0.043
0.605	0.679
0.517	0.511
0.330	0.338
0.206	0.162
0.156	0.000

b)

Exp.	Teor.
1.000	1.000
0.845	0.860
0.665	0.719
0.517	0.576
0.330	0.432
0.206	0.288
0.156	0.146

FIG. 3 COMPARISION OF EXPERIMENTAL AND ANALYTICAL DYNAMIC PROPERTIES (a) FIXED BASE MODEL (b) FLEXIBLE BASE MODEL FOR FIVE STORY BUILDING

DISCUSSION

M. Novak (Canada)

The author conducted a number of experiments with rigid footings exposed to horizontal harmonic excitation. The comparison of his experimental results with theoretical predictions indicates that the theory overestimates the horizontal resonant amplitudes by as much as a few hundred per cent.

The discussor also conducted very similar experiments and comparisons and found that this difference always appears with surface footings or with shallow embedment if material damping is neglected, because very little geometric damping is generated in such footings for the first mode of horizontal vibrations. Consequently, the difference between the theoretical and experimental amplitudes can be eliminated or at least reduced by the inclusion of material damping into the analysis. This is most conveniently achieved by substituting a complex shear modulus of soil

$$G^* = G_1 + i\, G_2 = G_1\, (1 + i \tan\delta)$$

for the real modulus G in the elastic solution. (This can be done in the sense of the correspondence principle). G^* replaces G explicitly and also in V_s and a_o.

In discussor's results $\tan\delta = G_2/G_1 = 0.1$ gave very satisfactory agreement between the theory and experiments.

P. Padmanabhan (India)

The building considered by the authors are very stiff, having natural periods of vibration below 0.3 sec. for the fixed base model. Their analysis showed an increase in the base shear of the order of 20 to 50 percent when soil-structure interaction is considered. This can be explained by considering the shape of the acceleration response spectra in the range of very low periods. However, many codes give design spectra (1) with the peak value extended for the entire range of periods lower than that corresponding to the peak, i.e. the design acceleration spectra are horizontal in the low period range. Hence the author's view that low rigid buildings designed according to codes of practice may be unsafe, may not be valid in respect of these codes even though they do not explicity deal with soil structure interaction phenomena.

(1) A.R. Chandrasekaran, "Design Spectra" 6WCEE, Panel 4 (Fig. 1 of this reference shows shape of design spectra in various codes).

Author's Closure

Not received.