An Overview of Models for Soil-Foundation-Structure Interaction

M.R. Resheidat
Yarmouk University, Dept. of Civil Engineering, Irbid, Jordan

Abstract

This paper focuses the light on many significant studies where different soil-foundation-structure interaction phenomena are investigated. Elastic half-space or finite element methods were used. Loads are of static or dynamic nature. Behavior of soil is assumed to linear and in few cases, nonlinear behavior is also considered. Two-dimensional and three-dimensional analytical models were also used. From this overview, some conclusions and recommendations have been drawn from this survey.

1. Introduction

The analysis of structures as integrated systems of three media: soil, foundation and super structure demonstrates the soil-foundation-structure interaction under static or dynamic loadings. Structural response to such loadings is influenced by the deformability of the foundation. The mechanism of soil-foundation-structure interaction depends mainly on the properties of the structure and the supporting soil medium.

Basically, two types of interaction models are used. One method characterizes the interaction be means of soil modeling as an elastic half space for infinite or very deep deposits or as a Winkler foundation. The other method involves modeling the soil by using finite elements. The results obtained from the use of these two approaches are significantly different. This had led to a serious debate on the merits of each.

2. Discrete Soil Spring Method

A number of analytical works using lumped parameter mass-spring-dashpot models appeared most frequently. The interaction phenomenon was investigated and related the depth of soil to the width of the building [3, 13] . Some guidelines for the selection of spring constants and masses could be abstracted. Parmele et al. [7] developed a model consisting of a circular rigid plate on elastic half-space and a mass above the ground which has three degrees of freedom. Minami et al. 6 included the physical properties of both the soil and the structure in addition to the depth of the substructure. A comparison was made between systems with and without an equivalent soil mass [5] . Other studies [7] were reported in attempt to perform a general soil-foundation-structure interaction analysis.

3. Finite Element Method

The finite element method makes it possible to represent a continuous medium with a system that has large but finite number of degrees of freedom. The use of the method to simulate the soil medium in a soil-structure model has been extensively used. Khana [4] developed a two-dimensional soil-structure model in which a rectangular frame structure was hinged at the ground surface and fixed artificial side boundaries were close to the structure. Brandow [2] developed a linear elastic three-dimensional SFSI model using a combination of a tier building, a rigid foundation block, and rectangular prism finite elements for soil deposits. This approach is very promosing, if expanded, for investigating the interaction phenomenon. Agrawal et al. [1] presented the results of a soil-structure interaction analysis for a nuclear power plant with circular foundation. Results were obtained by using both methods. The authors presented a comparison between the two methods of analysis from one side and the 2-D to 3-D modeling in the finite element method from the other side. They emphasized the need to adopt a unique approach. The method is best described in Ref. [10] . Resheidat [8] has presented the interaction phenomenon for framed structures under static loadings. The soil is simulated by an elastic half space model in which the finite elements were used for the foundation. Setlur et al. [9] presented a new approach to soil-structure interaction problems. They developed a new "plate-like" soil element to represent 3-D elastic continuum of soil beneath and around the structure. They concluded that the results of statically loaded foundations obtained by their new finite element approach were in good agreement with both methods of analysis. Recently, Takeniya and Utani [11] presented a 3-D seismic analysis for soil-foundation-superstructure system. Axisymetric modeling is taken to expand the response into the Fourier series in the circumferential direction. The coupled motion between the sub- and superstructure is restablished from the component modes method to attain a drastic reduction of the degrees of freedom for frequency response analysis of the whole system.

Ukaji [12] developed a procedure to determine the response of SFSI system as well as to investigate the nature of soil effect and the interaction phenomenon. The soil is treated as linear elastic or elastic-plastic material. Some other studies have also been reported, but because of space limitations; the auther is presenting an overview of the models of soil-foundation-structure models under static or dynamic loadings.

4. General Remarks

From the overview of the previous studies cited in the this paper and many others which are not cited, one can arrive to draw the following comments:

- The difference in the analytical results obtained from the two methods of SFSI models is great in most cases of studies.
- There is no reason to believe that two methods of solving the same problem should give different results.
- If they differ, at least one of them is erroneous.
- It appeared that finite element modeling is superior to that of a lumped soil model. However, extensitive data recordings is needed to verify the results of any theoretical analysis.

5. Conclusions

5.1 Static Analysis: The following conclusions may be drawn [8] :

(1) For soft clays, the contact soil pressure tends to be uniform under vertical loads and of linear distribution under both vertical and equivalent seismic forces. An exception to that is at free edges where the soil exhibts very high values of contact pressure. For medium stiff to very stiff soils, the contact soil pressure distribution exhibts high values beneath the column loads.

(2) As a guideline for modeling the soil-foundation-structure interaction, spring constants seem to be adequate for rigid foundation resting on soft soils modeled by elastic half-space, whereas for flexibile foundation, finite element modeling seems more adequate.

5.2 Dynamic Analysis

5.2.1 Linear behaviour [2] . The following observations can be made:

(1) Accelerations at the foundation slab are larger than bedrock acclerations only for relatively shallow soil depths. The surface accelerations decrease substantially at greater depths.

(2) The effect of varying the soil stiffness is clearly indicated by the increased tractions in the building for intermediate values of Young's modulus of soil.

(3) The resonance condition appears to some extent at a ratio of the soil period to the building period of about 0.6. If resonance is present it should occur at a ratio of less than 1.0 for the combined system.

5.2.2 Nonlinear behavior [12] . The following conclusions may be cited:

(1) Nonlinear analysis seems to be needed when the soil has relatively low strength; otherwise linear elastic assumption provides adequate results.

(2) The amplification of acceleration response decreased as the foundation embedment depth is increased. This decrease may reach 20% if compared to the case of zero embedment.

(3) The base shear decreases as much as 50% when the period of the soil is close to that of the structure.

6. Recommendations

More studies are needed to cover a greater variety of structures; soil with material properties that vary with depth should be examined; and more foundation schemes should also be examined.

Further work is needed to compare two-dimensional analytical and three-dimensional analytical models.

The interaction phenomenon depends on many factors. The probabilistic approach may be well suited the soil-foundation-structure interaction. This approach has merit and should be examined.

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