Investigation of dynamic behavior of Structure on a layered soil and evaluation of the Influence of the soil layers and embedment on the foundations

ABSTRACT

This study is organized on 120 pages, generally divided in two main content segments and two appendixes. In the first, it is explicitly discussed about the theoretical background, necessary to understand and solve the problem of Soil Structure Interaction. This ***Introductory*** part is comprised of three sections or Chapters.

The first of these three chapters gives the objectives of *Structural Dynamics*, general definition of Impedance functions and damping measures. Further it is discussed about Direct and Substructure method in dynamic analysis and advantages of Analysis through frequency-domain including the Fourier Transformation as connection (relation) to time domain. The analysis of soil structure interaction requires understanding of wave propagation in an elastic continuum. Therefore this issue is briefly addressed, where the equations for different types of waves are derived.

The second chapter is dedicated only to the problem of *Soil Structure Interaction* where the basic equation of motion formulated through total displacement is derived using the substructure method with emphasis on the coupling of the two subsystems. Separately, cases of rigid and flexible foundation are considered for different types of excitation. At the end of this chapter, the problem of Kinematic and Inertial Interaction is analyzed where the consequences and the effects of these two types of interaction are pointed out.

In the third chapter, the *Boundary Element Method* as a powerful numerical tool in combination with FEM for solving problems of Soil Structure Interaction is examined. From the equation of motion for harmonic elastodynamic problems, using the “Reciprocal Theorem” from Betti, the Boundary Integral Equation is derived where the full-space fundamental solution is assumed. Then the Boundary Integral Equation is cast to an algebraic form.

The second segment and the main part of this study deals with an ***Investigation of dynamic behavior through application of BEM/FEM for computation of SSI***. Namely two different types of analyses and investigations are made here.

In the first part, *Parametric Analysis and Investigation of foundation vibration*, systematic numerical investigation is made, where harmonically exited rigid foundations resting on a halfspace or layered halfspace are examined, and the influence on the dynamic behavior is evaluated by:

(1)- Variation of the foundation embedment depth,
(2)- Variation of the thickness of the soil-layer,
(3)- Variation of the foundation mass,
(4)- Variation of the foundation dimensions,
(5)- Considered different contact conditions between the foundation and the ground.

The *3D* -Dynamic Soil Structure Interaction analysis of a rigid foundation is performed in frequency domain, with the help of the "*SSI-3D"* program package. The dynamic behavior of the soil, represented by impedance or compliance functions of embedded and surface foundation is obtained using the BEM. Dynamic stiffness matrices (or impedance functions) and dynamic flexibility matrices (or compliance functions) are computed and then comparison between obtained results is made, from which the conclusions are drawn. Also as an interesting phenomenon, the wave propagation in the soil-layer resting on a bedrock and "cut-off"- frequency is evaluated. As far as possible the obtained numerical results are compared with those given in literature.

The goal of this first part or objective in this foundation vibration analysis is to examine and evaluate the general influence of the soil on the dynamic behavior of foundation in the problem of soil-structure interaction. Therefore it's assumed the structure simply to be represented by rigid square foundation and the model of the soil is also adopted with some standard material properties with this assumption the kinematic part of the interaction is examined. The obtained results from this study are presented in form of functions, namely Impedance and Compliance, which are frequency dependent and practically give the response of the analyzed structure (foundation). Besides the acknowledgments of the effects and the influence of the different soil layers and contact conditions on the dynamic behavior this study has also it's own practical use since the computed functions are in dimensionless form which means that they can be used for any other similar problem when certain or immediate solution is needed (e.g. settlement under harmonically excited foundation).

In the second part *Investigation of the dynamic behavior of a Structure* on a soil-layer over halfspace is carried out. Dynamic interaction between structure and layered soil is examined for external (seismic) and for internal (wind) excitation. Using the Substructure method the problem of Soil Structure Interaction is separated into two parts, namely the soil which is analyzed by BEM and the structure by FEM. The whole analysis is performed in the frequency domain. Afterwards the procedure of Fast Fourier Transformation is used to transform the results to the time domain.

The dimensions of the structure are finite; it is thus straightforward to determine the dynamic model with the finite number of degrees of freedom. In general, however, the structure will interact with the surrounding soil. It is thus not permissible to analyze just the structure. It must also be considered that in many important cases (e.g. earthquake excitation) the loading is applied to the soil region around the structure. The soil is a semi-infinite medium, an unbounded domain. For a static loading, a fictitious boundary at a sufficient distance from the structure, where the response is expected to have died out, can be introduced. This will subsequently lead to finite domain for the soil, which can be modeled similarly as the structure. However, for dynamic loading, this procedure cannot be used. The fictitious boundary would reflect waves originating from the vibrating structure back

into the discredited soil region instead of letting them pass through and propagate toward infinity. This asks for modeling the soil in unbounded medium using somewhat different technique (e.g. Boundary element method). A usually made assumption with respect to structural response to earthquakes is that the foundation medium is very stiff and the seismic motions applied at the structure support points are equivalent as the free-field earthquake motions at that location; in other words, the effects of soil structure interaction have been neglected. In reality, the structure always interact with the soil to some extent during earthquakes, imposing soil deformations that cause the motions of the structure soil interface to differ from those would have been observed in the free-field. The final response of the structure therefore will be dependent of the dynamical characteristics of the soil. The nature and amount of this Interaction strongly depends on the dynamic soil stiffness, when there is a presence of softer soil layers we can experience the amplification of the incoming seismic waves. Therefore it is from great importance when reliable structures are constructed especially for special types of structures (e.g. bridges, sport arenas, nuclear power plants, etc.) to be properly treated or analyzed including effects of the soil structure interaction. In this context this study analyzes and determines the influence on the overall response of the structure.

Keywords: *Soil Structure Interaction, Boundary Element Method, Investigation of foundation vibration through application of BEM/FEM for computation of SSI, Parametric Analysis, Investigation of the dynamic behavior of a Structure*