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Preface

Madrid, 20 de Junio de 2018,

La dinámica estructural es un campo de interés común y de importancia creciente en diversas especialidades de la ingeniería y de la ciencia. Mientras que en algunos campos como las máquinas o los vehículos de transporte ha sido siempre un elemento básico, en otros como la ingeniería civil y la arquitectura, más preocupados tradicionalmente con la estática, se ha convertido en un aspecto muy relevante.

Esta primera conferencia a nivel nacional pretende ser un foro en el que tengan cabida los trabajos de investigación, desarrollo y aplicaciones, permitiendo la discusión, difusión, contacto con otros grupos y establecimiento de colaboraciones. Se organiza con proyección internacional y europea, contando con el apoyo de la European Association for Structural Dynamics (EASD) organizadora de los congresos EURODYN, así como con el apoyo de la Sociedad Española de Métodos Numéricos (SEMNI).

La participación incluye tanto trabajos basados en métodos teóricos y computacionales como experimentales. Por otra parte abarca todos los campos de la dinámica estructural, como son la ingeniería mecánica, el transporte, ingeniería civil y arquitectura, ingeniería sísmica e ingeniería de materiales. Aunque ubicados en especialidades de ingeniería distintas todos estos campos comparten conceptos y métodos comunes de dinámica.

Esta primera conferencia pretende iniciar una serie que se desarrolle de forma periódica. Asimismo se propone constituir una Asociación Española de Dinámica Estructural que articule las actividades de colaboración y difusión, y que sirva de interlocutora con otros órganos nacionales e internacionales como la EASD.

Desde el comité organizador queremos dar la bienvenida a todos los participantes y ponernos a disposición para el desarrollo de la conferencia.

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SECTION 4: Computational dynamics

GENERAL MULTI-REGION BEM-FEM MODEL FOR FLUID/SOIL AND SHELL INTERACTION PROBLEMS

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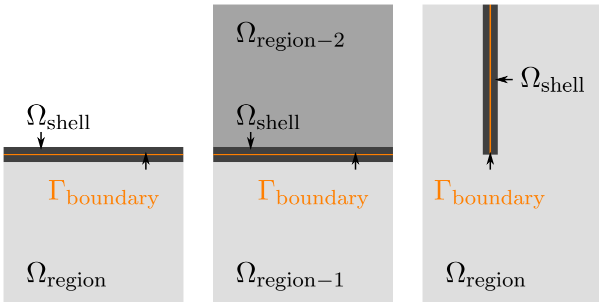
Abstract. In this contribution, we present a general multi-region boundary element and finite element dynamic model for fluid and/or soil interacting with shell structures. Shell structures can be surrounded by any combination of regions among inviscid fluids, elastic solids or poroelastic media. An approach based on Hypersingular Boundary Integral Equations is used when dealing with open shell structures. This idea avoids any superfluous subregioning of the problem, which leads to a natural, direct and efficient treatment of such structures. The use of this model is demonstrated through a fluid/soil-structure interaction problem.

Key words: boundary element, finite element, hypersingular formulation, shell structures, soil-structure interaction, fluid-structure interaction

1 INTRODUCTION

The Finite Element Method (FEM) and the Boundary Element Method (BEM) are well known numerical methods for the dynamic analysis of solid and structural mechanics problems. However, there are problems where neither of these are capable of solving these problems in a natural and efficient manner. The main advantages of the FEM are its versatility in handling structural members. However, when unbounded domains are present in a wave propagation problem, it requires a truncation of the volume mesh and the presence of some absorbing device to impose the Sommerfeld radiation condition. In that sense, the BEM is more appealing as it intrinsically satisfies the radiation condition [9].

In the present proposed model, both numerical methods are combined in order to solve three-dimensional linear Fluid-Structure and Soil-Structure Interaction problems, where the fluid is inviscid, the soil can be an isotropic and homogeneous elastic solid or a Biot poroelastic medium [4], and the structure is an elastic shell structure immersed or buried in such types of surrounding media. The main difference to other BEM-FEM models is its ability to deal with open shell structures, where both shell faces are in contact with the same region, in a natural and efficient way by resorting to the Hypersingular Boundary Integral Equation (HBIE) [6, 7, 8]. The Singular Boundary Integral Equation (SBIE) alone solves the other two situations: shells in contact with fluid or soil only on one face, and shells in contact with different fluids and/or soils on each face. Fig. 1 illustrates all three previously described situations. In the present research, the model from [8] is generalized and used in a illustrative example.



(a) (b) (c)

Figure 1: Shell interaction with surrounding media: (a) one-face interaction, (b) two-faces interaction with different regions, and (c) two-faces interaction with one region.

2 METHODOLOGY

The model is based on an appropriate combination of BEM and FEM equations.

BEM equations for fluid and soil regions are obtained from the discretization of Boundary Integral Equations (BIE) that relate primary and secondary variables throughout domain boundaries to variables at the collocation point where the point load (fundamental solution or Green's function) is applied. Let Ω be a region, and $\Gamma = \partial\Omega$ its boundary with outward unit normal $\mathbf{n}$. For a collocation point $\mathbf{x}^{\text{i}} \in \Omega$, the SBIE and the HBIE are respectively [10]:

$$u_l^{\text{i}} + \int_\Gamma t_{lk}^* u_k \, \text{d}\Gamma = \int_\Gamma u_{lk}^* t_k \, \text{d}\Gamma \tag{1}$$

$$t_l^{\text{i}} + \int_\Gamma s_{lk}^* u_k \, \text{d}\Gamma = \int_\Gamma d_{lk}^* t_k \, \text{d}\Gamma \tag{2}$$

where body loads have been neglected, and an elastic region is assumed in the following for the sake of brevity. u_k and $t_k = \sigma_{kj} n_j$ denote displacement and traction components respectively, u_k^{i} and t_k^{i} represent their value at the collocation point, and u_{lk}^*, t_{lk}^*, s_{lk}^* and d_{lk}^* are the fundamental solutions. For inviscid fluids and poroelastic soils, these can be found in [9, 10, 8, 5]. These equations contain only regular integrals, and they are useful at a post-processing stage for determining displacements and stresses at internal points. In order to obtain boundary displacements and tractions at boundaries, it is necessary to collocate these at a boundary point $\mathbf{x}^{\text{i}} \in \Gamma$, which results in the following regularized BIEs:

$$\frac{1}{2} u_l^{\text{i}} + ⨍_\Gamma t_{lk}^* u_k \, \text{d}\Gamma = \int_\Gamma u_{lk}^* t_k \, \text{d}\Gamma \tag{3}$$

$$\frac{1}{2} t_l^{\text{i}} + ⨎_\Gamma s_{lk}^* u_k \, \text{d}\Gamma = ⨍_\Gamma d_{lk}^* t_k \, \text{d}\Gamma \tag{4}$$

where a smooth boundary at the collocation point is assumed $\Gamma(\mathbf{x}^{\text{i}}) \in \mathcal{C}^1$ for the sake of simplicity. Regularized BIEs are obtaining after a regularization process which reduces Cauchy Principal Value (⨍, CPV) and Hadamard Finite Part (⨎, HFP) integrals into regular and weakly singular integrals, which can be found in [10, 8]. The SBIE are used for exterior boundaries and interfaces between regions, and also when coupling with shells located at those (Figs. 1(a) and 1(b)). The use of the regularized HBIE is commonly limited to treating fictitious eigenfrequencies [9] through the Burton and Miller formulation and crack analysis [2] through the Dual Boundary Element Method (DBEM). In the latter case, both BIEs are simultaneously used in order to solve the indeterminacy posed by the idealization of a crack as two coincident faces (Fig. 1(c)). When both BIEs are used to that purpose, they are called Dual BIEs, and become:

$$\frac{1}{2}\left(u_l^{\text{i}+} + u_l^{\text{i}-}\right) + ⨍_\Gamma t_{lk}^* u_k \, \text{d}\Gamma = \int_\Gamma u_{lk}^* t_k \, \text{d}\Gamma \tag{5}$$

$$\frac{1}{2}\left(t_l^{\text{i}+} - t_l^{\text{i}-}\right) + ⨎_\Gamma s_{lk}^* u_k \, \text{d}\Gamma = ⨍_\Gamma d_{lk}^* t_k \, \text{d}\Gamma \tag{6}$$

where geometrically coincident displacements and tractions (u_k^+, u_k^-, t_k^+ t_k^-) at both faces of the crack can be determined.

The shell structure is modeled using shell finite elements based on the degenerated solid approach [1], which are versatile and relatively easy to handle. However, in its original conception they have shear and membrane locking, which are due to the inability of the displacement interpolation to represent thin shell (vanishing out-of-plane shear stresses in bending) and curved shell (vanishing in-plane stresses in inextensional bending) situations, respectively. Locking can be improved by using selective or reduced integration, but the resulting shell elements contain spurious zero-energy (hourglass) modes and hence are not reliable. There are several approaches to obtain shell elements free from locking and spurious modes. In the present model, the family of Mixed Interpolation of Tensorial Components (MITC) shell elements [3] developed by Bathe and co-workers is chosen due to its robustness. The equilibrium equation of an element e can be written as:

$$\tilde{\mathbf{K}}^{(e)}\mathbf{a}^{(e)} - \mathbf{Q}^{(e)}\mathbf{t}^{(e)} = \mathbf{q}^{(e)} \tag{7}$$

where $\tilde{\mathbf{K}}^{(e)} = \mathbf{K}^{(e)} - \omega^2\mathbf{M}^{(e)}$ is the stiffness matrix for time harmonic analysis, $\mathbf{Q}^{(e)}$ is the distributed mid-surface load matrix and $\mathbf{q}^{(e)}$ is the vector of equilibrating nodal forces and moments. Vector $\mathbf{a}^{(e)}$ contains the nodal degrees of freedom:

$$\mathbf{a}^{(e)} = \begin{pmatrix} \mathbf{a}_1^{(e)} & \dots & \mathbf{a}_p^{(e)} & \dots & \mathbf{a}_N^{(e)} \end{pmatrix}^T \tag{8}$$

where N is the number of nodes of the shell finite element. Each node p has three DOF associated with the displacement of the mid-surface ($u_{kp}^{(e)}$, $k = 1, 2, 3$), and two local ($\alpha_p^{(e)}$ and $\beta_p^{(e)}$) or three global ($\theta_{kp}^{(e)}$, $k = 1, 2, 3$) rotations. The vector of nodal values of the distributed mid-surface load $\mathbf{t}^{(e)}$ can be written as:

$$\mathbf{t}^{(e)} = \begin{pmatrix} \mathbf{t}_1^{(e)} & \dots & \mathbf{t}_p^{(e)} & \dots & \mathbf{t}_N^{(e)} \end{pmatrix}^T \tag{9}$$

$$\mathbf{t}_p^{(e)} = \begin{pmatrix} t_{1p}^{(e)} & t_{2p}^{(e)} & t_{3p}^{(e)} \end{pmatrix}^T \tag{10}$$

where $\mathbf{t}_p^{(e)}$ is expressed in global coordinates.

A direct boundary element - finite element coupling after discretization is considered, where both boundary element mesh and shell finite element mesh must be conforming. It is assumed that the shell mid-surface and the fluid/soil boundaries are in perfectly welded and impermeable contact.

3 EXAMPLE

In order to show the coupling capabilities of the present model, an illustrative example consisting of a buried shell structure under an SH incident wave field (along y axis) is analyzed, see Fig. 2. The shell structure consist of a cylindrical shell with a circular plate joined in the middle, in such a way that the upper part is a fluid tank, and the lower part is a cylindrical caisson. Its diameter is 20 meters, and the total length is 40 meters. The soil has a density $\rho_{\text{soil}} = 2060$ kg/m^3, shear modulus $\mu_{\text{soil}} = 74$ MPa, Poisson's ratio $\nu_{\text{soil}} = 0.4942$ and hysteretic damping ratio $\xi_{\text{soil}} = 0.03$. Fluid is assumed to be water with density $\rho_{\text{water}} = 1000$ kg/m^3 and phase velocity $c_{\text{water}} = 343$ m/s. The shell structure is made of concrete with density $\rho_{\text{shell}} = 2400$ kg/m^3, shear modulus $\mu_{\text{soil}} = 12$ MPa, Poisson's ratio $\nu_{\text{soil}} = 0.4942$ and hysteretic damping ratio $\xi_{\text{soil}} = 0.05$, and its thickness is 0.3 meters.

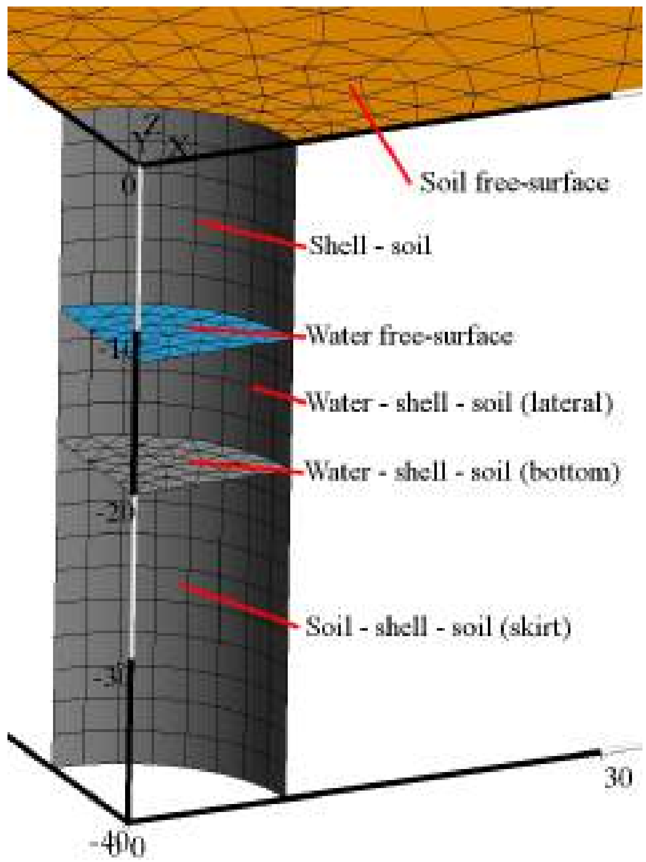


Figure 2: Buried shell structure example (water level at 40%)

Fig. 3 shows the displacement amplification u_2/u_2^{SH} in the excitation direction at a shell point ($\mathbf{x} = (0, 10, 0)$ meters). As expected, peaks related to system natural frequencies reduces their values as tank water level increases.

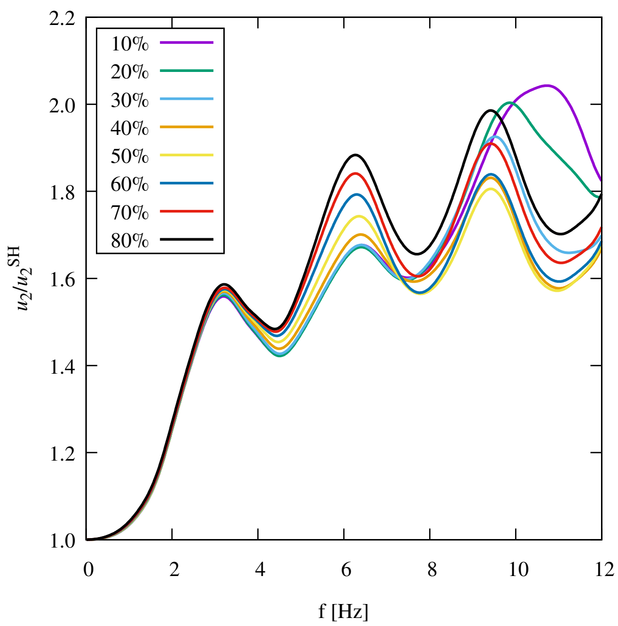


Figure 3: u_2/u_2^{SH} at shell point $\mathbf{x} = (0, 10, 0)$ meters.

4 CONCLUSIONS

In this contribution, we have presented a three-dimensional multi-region model for the dynamic analysis of shell structures interacting with surrounding soils and/or fluids. In the example, we have illustrated the range of couplings between shell and the surrounding media allowed.

5 ACKNOWLEDGMENTS

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