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An efficient hydro structure interface for mixed panel-stick hydrodynamic model

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Introduction

The hydro-structure interfacing in seakeeping is an important problem in the context of the direct calculation approach for approval of floating systems. Both fatigue and extreme structural response calculations need to be performed. An efficient tool ensuring the perfect transfer of the loadings issued from hydrodynamic analysis is a key element in the overall procedure. The seakeeping calculations are usually done within the potential flow assumptions, using the Boundary Integral Equation (BIE) techniques. Within this approach, the fluid flow is represented by a distribution of singularities over the 3D wetted part of the body which is subdivided in a certain number of panels. In that case an efficient procedure of load transfer was presented in [2, 4]. For some applications, such as semi-submersible platforms, the hydrodynamic model includes not only the parts modeled by the panels but also some slender elements (bracings) which are usually modeled using the Morison formula (e.g. see [1]). Morison formula uses the informations of the undisturbed fluid flow at the position of element and applies explicit expressions which gives the drag force and the added inertia forces. The use of the Morison formula in combination with the BIE method implies several changes in the hydro structure coupling procedure and these changes are discussed in the present abstract.

General methodology

First we briefly describe the basics of the hydrodynamic and structural modeling principles. Typical hydrodynamic and structural meshes are shown in Figure 1.

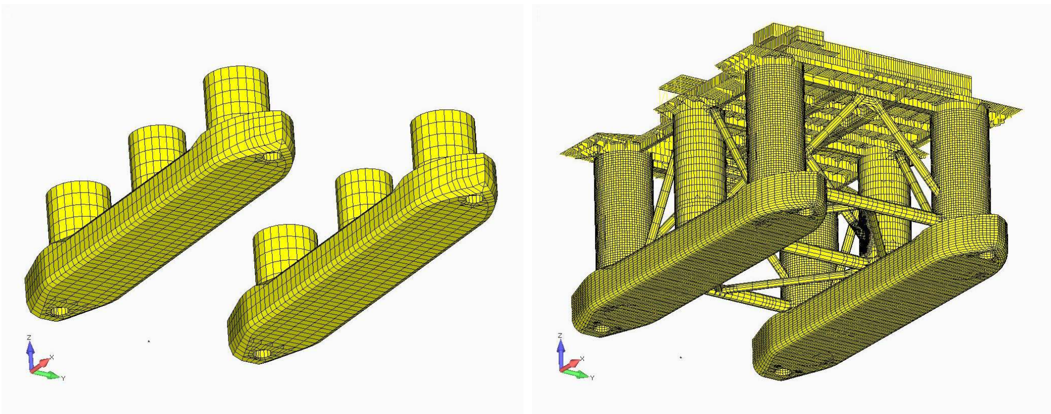


Figure 1: 3D hydrodynamic panel model (left) and 3D FE model of semi-submersible (right).

Hydrodynamic model

As stated in the introduction the hydrodynamic model is composed of two parts: the 3D panel model and the Morison model. We discuss them separately in the following sections.

3D hydrodynamic panel model

The problem is solved within the potential flow assumptions in frequency domain. The total velocity potential is decomposed into incident φ_I, diffracted φ_D and 6 radiated components φ_{Rj} each corresponding to one of the 6 rigid body motions ξ_j:

$$\varphi = \varphi_I + \varphi_D - i\omega \sum_{j=1}^{6} \xi_j \varphi_{Rj} \tag{1}$$

The corresponding boundary value problems (BVP) are defined:

$$\left.\begin{array}{ll} \Delta\varphi = 0 & \text{in the fluid} \\ -\nu\varphi + \dfrac{\partial\varphi}{\partial z} = 0 & z = 0 \\ \dfrac{\partial\varphi}{\partial n} = V_n & \text{on } S_B^H \\ \lim\big[\sqrt{\nu R}(\dfrac{\partial\varphi}{\partial R} - i\nu\varphi)\big] = 0 & R \to \infty \end{array}\right\} \tag{2}$$

where V_n denotes the body boundary condition which depends on the considered potential:

$$\frac{\partial\varphi_D}{\partial n} = -\frac{\partial\varphi_I}{\partial n} \quad , \quad \frac{\partial\varphi_{Rj}}{\partial n} = n_j \tag{3}$$

where n_j denotes the generalized normal vector: $n_j = \boldsymbol{n}$ for $j = 1, 2, 3$ and $n_j = (\boldsymbol{R} - \boldsymbol{R}_G) \wedge \boldsymbol{n}$ for $j = 4, 5, 6$.
Within the BIE approach, the source formulation is used so that the potential at any point in the fluid is defined by:

$$\varphi = \iint_{S_B^H} \sigma G dS \tag{4}$$

where the source strength σ is found by solving the following integral equation:

$$\frac{1}{2}\sigma + \iint_{S_B^H} \sigma \frac{\partial G}{\partial n} dS = V_n \quad , \quad on \quad S_B^H \tag{5}$$

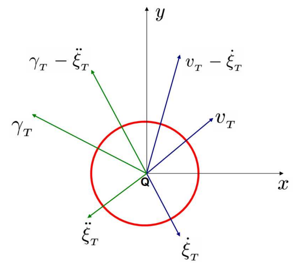
Morison hydrodynamic model

The use of Morison equation assumes that the body is small compared to the wave length so that the diffraction effects on these parts can be neglected. At the same time a kind of strip approach is adopted and the slender structure is divided into a number of strips (sections) on which the local force is computed and the total force is obtained by integrating the different contributions over the length. The total Morison force is composed of two parts: the added inertia and the drag force which in turn depend on the local relative accelerations and velocities respectively. The local relative velocity (acceleration) is the difference between the local fluid velocity and local body velocity. Local velocities and accelerations in the global coordinate system can be written in the following form:

$$\boldsymbol{v} = \Re\{\nabla(\varphi_I + \varphi_D - i\omega \sum_{j=1}^{6} \xi_j \varphi_{Rj}) e^{-i\omega t}\} \quad , \quad \gamma = \Re\{-i\omega\nabla(\varphi_I + \varphi_D - i\omega \sum_{j=1}^{6} \xi_j \varphi_{Rj}) e^{-i\omega t}\}$$

$$\dot{\boldsymbol{\xi}} = \Re\{-i\omega(\boldsymbol{\xi} + \boldsymbol{\Omega} \wedge \boldsymbol{R}_{GQ}) e^{-i\omega t}\} \quad , \quad \ddot{\boldsymbol{\xi}} = \Re\{-\omega^2(\boldsymbol{\xi} + \boldsymbol{\Omega} \wedge \boldsymbol{R}_{GQ}) e^{-i\omega t}\}$$

and $\boldsymbol{\xi} = \xi_1\boldsymbol{i} + \xi_2\boldsymbol{j} + \xi_3\boldsymbol{k}$, $\boldsymbol{\Omega} = \xi_4\boldsymbol{i} + \xi_5\boldsymbol{j} + \xi_5\boldsymbol{k}$. $\boldsymbol{R}_{GQ}$ is the vector joining the overall center of gravity to the local point $\boldsymbol{Q}$.
As already mentioned, the Morison equation is applied locally on each strip in its transverse direction, which means that the above defined velocities and accelerations should be projected in the local coordinate system. We place ourselves in the local coordinate system of the strip and the following notations are adopted:



v_T	local fluid velocity
γ_T	local fluid acceleration
$\dot{\xi}_T$	local body velocity
$\ddot{\xi}_T$	local body acceleration

The Morison force can be written in the following form (e.g. see [3]):

$$dF_M = \frac{1}{2}\varrho C_D D(v_T - \dot{\xi}_T)|v_T - \dot{\xi}_T|dl + \varrho\pi\frac{D^2}{4}[\ (1+C_M)\gamma_T - C_M\ddot{\xi}_T\ ]dl \tag{6}$$

where C_D and C_M are the drag and added mass coefficients respectively, and D denotes the diameter of the section.

Structural model

Structural model includes all the structural elements regardless of their position with respect to the water level. Typical model is presented in Figure 1. Obviously the bracings are part of this model. This means that the pressure/load transfer should be done on all wetted finite elements. Here below we briefly explain how this is done for the 3D panel part and for the Morison part.

Coupling procedure

Due to the fundamentally different approaches in 3D hydrodynamic panel model and Morison model, different strategies are applied for two cases.

Transfer of loads from 3D hydrodynamic model to 3D FE model

In order to ensure a perfect equilibrium of the structural loading, the hydrodynamic pressure components issued from the solution of the 3D hydrodynamic calculations are integrated over the structural mesh [2]. In order to be able to do this the corresponding pressure should be recalculated on the representative structural points. This is possible thanks to the source method which is used here and which allows to recalculate the potential at any point in the fluid:

$$\varphi(\boldsymbol{x}_s) = \iint_{S_B^H} \sigma(\boldsymbol{x}_h)G(\boldsymbol{x}_h;\boldsymbol{x}_s)dS \tag{7}$$

where $\boldsymbol{x}_s = (x_s, y_s, z_s)$ denotes the structural point and $\boldsymbol{x}_h = (x_h, y_h, z_h)$ the hydrodynamic point.
Let us also note that, in the present procedure, the representative points of the structural model are chosen to be the Gauss points of the finite elements. Indeed, the hydro-structure interface transfers the hydrodynamic pressure to nodal forces so that the final loading of the FE model consist of the nodal forces instead of the pressures which is the common procedure in most of the methods in practice. At the same time the different parts of the pressure are integrated separately, which means that the hydrodynamic coefficients (added mass, damping, restoring and excitation) will be obtained after the integration over the FE mesh, which will ensure the perfect equilibrium of the FE model. In summary the FE loading coming from the hydrodynamic pressure can be written in the form:

$$\{\boldsymbol{F}_H^{3D}\}^S = \{\boldsymbol{F}^{DI}\}^S + \Big(\omega^2[\ \mathbf{A}\ ]^S + i\omega[\ \mathbf{B}\ ]^S - [\ \mathbf{C}\ ]^S\Big)\{\boldsymbol{\xi}\}^S \tag{8}$$

where the superscript ^{S} denotes the fact that the integration is performed over the structural mesh.

Transfer of loads from Morison model to 3D FE model

As already mentioned, the Morison equation (6) gives the overall force on the particular section. This force should be redistributed on the nodes of the finite elements. This can be done in several ways by assuming different types of pressure distribution. For the sake of simplicity, here we chose to redistribute the force equally on different FE nodes in the direction of the sectional force. In order to be able to solve for the body motions the Morison force should be decomposed into the part depending on the body motions and the part which is motion independent. At the same time the local sectional forces are integrated over the length of the slender elements and the total force is formally written in the form:

$$\{\boldsymbol{F}_M\}^S = \{\boldsymbol{F}_M^{DI}\}^S + \omega^2[\boldsymbol{A}_M]^S\{\boldsymbol{\xi}\}^S + i\omega[\boldsymbol{B}_M]^S\{\boldsymbol{\xi}\}^S \tag{9}$$

Note that several coordinate transformations are necessary in order to derive the above hydrodynamic coefficients which are defined with respect to the global coordinate system placed in the overall center of gravity.

We can now write the final motion equation for the floating body:

$$\left(-\omega^2([\,\mathbf{M}\,] + [\,\mathbf{A}\,]^S + [\boldsymbol{A}_M]^S) - i\omega([\,\mathbf{B}\,]^S + [\boldsymbol{B}_M]^S) + [\,\mathbf{C}\,]^S\right)\{\boldsymbol{\xi}\}^S = \{\boldsymbol{F}^{DI}\}^S + \{\boldsymbol{F}_M^{DI}\}^S \tag{10}$$

It is important to note that an iterative procedure should be used to solve the motion equation because of the drag component of the Morison loading. Due to the fact that all the integrations are performed over the structural FE mesh, it is clear that the inertia created by the motion issued from the above equation will be in perfect equilibrium with the external pressure loading.

Few results and conclusions

In Figure 2 (left) first we present the heave motion of semi-submersible platform with and without the stick hydrodynamic model i.e. with and without the damping induced by the Morison drag forces. The difference in between two classes of results is significant justifying the present approach. In the same figure (right) the RAO of the local stresses at the connection of the bracing with the column are presented.

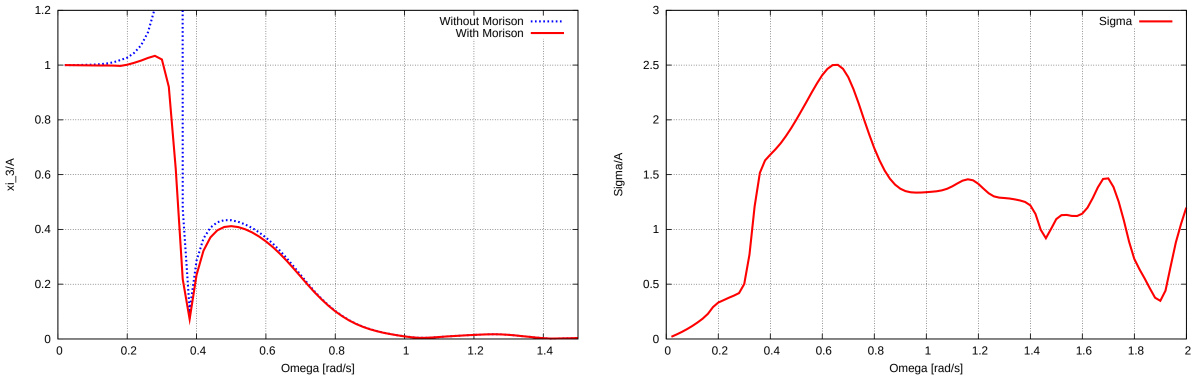


Figure 2: Heave RAO in head waves with and without drag induced damping (left), and corresponding stress at a particular structural detail (right).

A consistent hydro-structure interfacing method for loading of the semi-submersible type of off-shore platforms is presented. The method takes into account all parts of the hydrodynamic loading and ensures the perfect equilibrium of the FE model.

References

[1] Leblanc L., Petitjean F., Le Roy F. & Chen X.B. 1993. : "A mixed panel stick hydrodynamic model applied to fatigue life assessment of semi-submersibles.", In Proceedings of OMAE Conf., Glasgow, Scotland

[2] Malenica S., Stumpf E., Sireta F.X. & Chen X.B. 2008. : "Consistent hydro-structure interface for evaluation of global structural responses in seakeeping", In Proceedings of OMAE Conf., Estoril, Portugal

[3] Molin B., 2002. : *"Hydrodynamique des structures off-shore"*, Editions Technip

[4] Tuitman J.T., Sireta F.X., Malenica S. & Bosman T.N. 2009. : "Transfer of non-linear seakeeping loads to FEM model using quasi static approach". In Proceedings of ISOPE, Osaka, Japan