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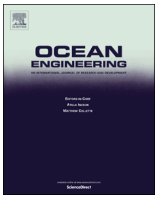

An analysis of dynamics of risers during vessel motion by means of the rigid finite element method

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ABSTRACT

The widespread use of lines, cables and risers in offshore applications requires research on the dynamic behavior of such systems. Accurate prediction of riser motion during operations is crucial. The models presented in the paper are used for static and dynamic analysis of planar slender systems undergoing large elastic deformations. Slender links are discretized by means of a modification of the rigid finite element method, which allows us to consider both bending and longitudinal flexibility. The method consists in dividing a link into rigid finite elements assuming inertial features connected by massless spring-damping elements; additionally, a spring element reflecting longitudinal flexibility is added. The formulation of the method presented allows us to take into account hydrodynamic forces and added mass. Correctness of the models and programs developed is proved by comparison of the results with an analytical solution and commercial software.

When installing or moving a riser to a new site, any contact between it and another object should be prevented if possible. Thus, the numerical simulations presented in the paper concern the movement of a vessel with an attached riser (with and without fluid) in such a way that an obstacle on the seabed can be avoided.

1. Introduction

A general feature of cables, pipelines and risers, which we refer to as slender systems or links, is the one dominant dimension (length) and the possibility of occurrence of large deflections.

Risers are the most efficient way to transfer fluids over large distances and from large depths. Dynamic analysis of such systems is essential for the safety of constructions. There is a large amount of research carried out in this field. Nevertheless, new methods and models are desirable, especially when they enable the external water environment characterised by unstable behaviour due to waves and sea currents to be included.

A historical review of modelling methods and analysis of flexible risers was given by Patel and Seyed (1995). The most popular method used for modeling risers (Park and Jung, 2002; Jensen et al., 2010; Zheng-Shou and Wu-Joan, 2010) is the finite element method (Zienkiewicz and Taylor, 2000). Park and Jung (2002) present an analysis of the dynamics of slender structures loaded with parametric and forced excitations. The results are obtained for various depths of water and motions of a vessel. Dynamic analysis of a hanging pipe with bending flexibility presented by Jensen et al. (2010) takes into account the motion of a vessel to which the pipe is attached. Verification of the method is carried out by means of comparison of the authors' own results with those obtained from RIFLEX and an analytical solution for a catenary line. Raman-Nair and Baddour (2003) present an interesting description of the lumped mass method used for modeling spatial slender systems in offshore engineering. The finite segment method is used for modeling risers by Xu and Wang (2012). It should be underlined that modeling of slender links which are applicable in ocean engineering requires considerations of such phenomena as sea waves, sea currents or fluid flow in the risers (Liping and Bo, 2011).

Despite the large number of existing software packages, for example RIFLEX, OrcaFlex, Flexcom and Ariane-3Dynamic, there is a continuing need for new packages which apply new modeling methods. A summary of existing packages and their capabilities used as the context for presentation of the authors' software is presented by Silveira et al. (2012).

The rigid finite element method (RFEM) (Wittbrodt et al., 2006) has similar features to the finite segment and lumped mass methods. Wojciech et al. (1990) and Wojciech and Adamiec-Wójcik (1993, 1994) show how the method is used to model vibrations with large

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amplitudes of viscoelastic beams. The modification of the RFEM presented in those papers enables bending and torsional vibrations to be analyzed, while longitudinal flexibility is omitted. Additionally friction and clearance in joints can also be easily considered (Adamiec-Wójcik and Wojciech, 1993). A review of models developed by means of the RFEM can be found in books by Wittbrodt et al. (2006, 2013).

There are two well-known approaches to modeling a continuous body by means of the rigid finite element method (Fig. 1).

In the first approach (Fig. 1a), called the classical rigid finite element method (CRFEM), the planar motion of each rigid finite element (rfe) is described by three generalized coordinates $[x_{C_i} \quad y_{C_i} \quad \varphi_i]$, which are the coordinates of the center of mass and angle of rotation, respectively. Rigid elements are connected by means of spring-damping elements (sde) reflecting shear and both bending and longitudinal flexibilities. A diagonal mass matrix with constant coefficients is the characteristic feature of this approach. Deformations of sdes are calculated using generalized coordinates, and the nonlinearity of the system entails nonlinear components in the spring energy terms. Continuity of displacements is not ensured.

In the second approach, called the modified rigid finite element method (MRFEM), each rfe has one degree of freedom in the motion with respect to the preceding element. The generalized coordinate can be either $\Delta\varphi_i$ or angle φ_i (Fig. 1b). Only rfe 0 has three degrees of freedom (x_0, y_0, φ_0). The coordinates of the center of mass x_{C_i}, y_{C_i} depend on all generalized coordinates of the preceding rfes, and thus the mass matrix depends on angles φ_i $(i=0, 1,\ldots,n)$.

In this paper we discuss a new formulation of the modified RFEM, which allows us to consider bending and longitudinal deformations of planar slender links. This formulation is well suited to modelling of slender systems. Having formulated the new approach, we compare advantages and disadvantages of different formulations of the method. The formulation proposed in this paper uses absolute coordinates, and each element has four degrees of freedom $\begin{bmatrix} x_i & y_i & \varphi_i & \Delta_i \end{bmatrix}$ (Fig. 1c). The mass matrix consists of uncoupled 4×4 mass matrices, the inverse of which can be calculated analytically. The reaction forces are introduced in the connections between rfes, and geometrical constraint equations are formulated. This enables us to calculate joint forces including shear forces. In the paper we also consider drag forces, uplift forces and the influence of sea currents and added mass. The models are verified for static problems by comparison of our results with the analytical solution for a catenary line, and for dynamic problems by comparing our results with those obtained using commercial software. Verification also includes calculations of free vibrations which are compared both with the analytical solution and results obtained from commercial software. Reliable prediction of riser motion during operations is very important so that the method is used for simulations of motion of the vessel during the reinstallation of a riser. Numerical simulations are carried out in order to examine the influence of the velocity and acceleration of the vessel on displacements of the tip of the riser. Although some research on contact between risers has been carried out (He and Low, 2014), contact between risers and other objects should generally be avoided. Thus, the study enables us to choose parameters of the vessel motion so that the riser tip avoids contact with a possible obstacle occurring on the seabed.

2. Formulation of the model

Fig. 2 shows the method of discretizing the system into rigid finite elements (rfes) and spring-damping elements (sdes).

Let us consider a segment of the link of length L with a constant cross-section. First, a primary division into segments of equal length $d=L/n$ is carried out. During the first stage of the secondary division, as in the modified rigid finite element method (Wittbrodt et al., 2006), spring-damping elements (sde_b 1 to sde_b n) reflecting bending

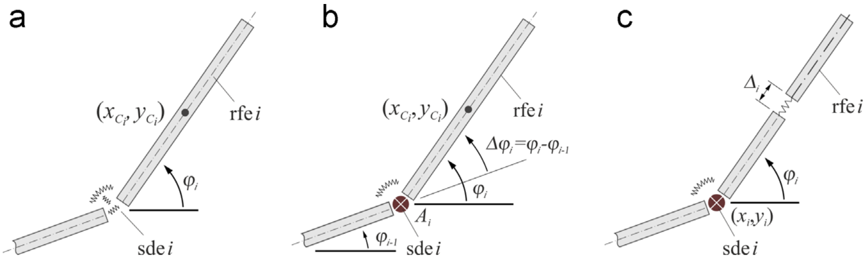

Fig. 1. Generalized coordinates for different approaches in the rigid finite element method (a) classical formulation (CRFEM), (b) modified formulation (MRFEM), (c) formulation with longitudinal deformation proposed in this paper.

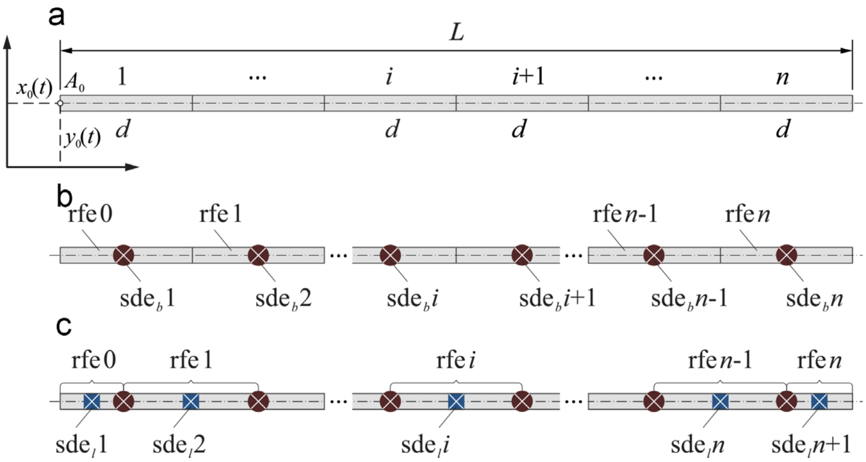

Fig. 2. Discretization of the flexible link: (a) primary division (b) first stage of secondary division (c) second stage of secondary division.