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Coupled analysis of floating production systems

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Abstract

Fully coupled global analysis of Floating Production Systems, including the vessel, the mooring system and the riser system is described. Design of the system can be a daunting task, involving more than 1000 load cases for global analysis. The primary driver for the mooring system and for the riser system is motion of the vessel. Vessel motions are driven by environmental forces, but are restrained by forces from the mooring and riser systems. Numerical models and procedures that provide accurate and efficient global modeling of the Floating Production System are presented. Both Time Domain and Frequency Domain procedures are included. The accuracy and efficiency of the procedures are illustrated in an example: a large semi with 16 mooring lines and 20 risers. The procedures provide the accuracy and efficiency for use of fully coupled analysis in design of Floating Production Systems from concept selection to final design, installation and operation.

Keywords: Coupled; Analysis; Mooring; Risers; Dynamic; Vessel; Motion; Floating; Production

1. Introduction

The need for coupled analysis has long been recognized (Paulling and Webster, 1986). More recently, a number of coupled analysis tools have been introduced e.g. (Chakrabarti et al., 1996; Ormberg and Larsen, 1998; Ma et al., 2000; Colby et al., 2000; Heurtier et al., 2001; Senra et al., 2002; Correa et al., 2002; Garrett et al., 2002a).

With the exception of Stress Engineering Services' RAMS (Garrett et al., 2002a) and Shell's COSMOS (Schott et al., 1994; Phifer et al., 1994) programs, all of these coupled analysis tools are limited to the time domain. Both RAMS and COSMOS have the ability to solve the coupled problem in either the frequency or time domain.

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The computational effort required by time domain simulation led to development of frequency domain procedures for the coupled analysis. A key part of the development was an accurate and efficient method for statistical linearization of velocity-squared drag (Rodenbusch et al., 1986). An accurate and efficient finite element model for mooring lines, risers and tendons, was developed (Garrett, 1982; 1992; Paulling and Webster, 1986). The frequency domain procedures made coupled analysis for design practical (Schott et al., 1994).

The subject of this paper is the numerical modeling to allow accurate and efficient global analysis of Floating Production Systems. Modeling of the vessel, mooring lines, risers, and the links connecting the vessel to the mooring lines and risers are included. A companion paper provides an example that illustrates use of the analysis in design of mooring and riser systems for an FPSO (Garrett et al., 2003).

2. Models

2.1. Rigid body model

A Floating Production System has three types of components: (1) the vessel, modeled as a rigid body, (2) mooring lines and risers, modeled as slender elastic rods, and (3) connecting links.

The motions of a rigid body may be described in terms of the position of a reference point and three Euler angles. The position of a point, **P**, fixed to the rigid body is

$$\mathbf{P} = \mathbf{X} + \mathbf{R}\mathbf{p} \text{ in vector notation, or } \quad P_i = X_i + R_{ij}p_j \text{ in subscript notation} \tag{1}$$

where **X** is the reference position of the rigid body in global coordinates;

p is a point on the rigid body in body-fixed coordinates;
P is the point **p** in Global Coordinates;
R is an orthogonal transformation defined by the Euler angles.

Kinematics of the rigid body elements includes finite displacement and rotation. The orthogonal transformation representing the rotation may be written as

$$\mathbf{R} = \mathbf{R}_\phi \mathbf{R}_\theta \mathbf{R}_\psi \quad [\mathbf{R}_\phi] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \sin(\phi) & \cos(\phi) \end{bmatrix}$$
$$[\mathbf{R}_\theta] = \begin{bmatrix} \cos(\theta) & 0 & \sin(\theta) \\ 0 & 1 & 0 \\ -\sin(\theta) & 0 & \cos(\theta) \end{bmatrix} \quad [\mathbf{R}_\psi] = \begin{bmatrix} \cos(\psi) & -\sin(\psi) & 0 \\ \sin(\psi) & \cos(\psi) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{2}$$

For small angles, the Euler angles represent roll, pitch and yaw. The six degrees of freedom of the rigid body are the position of the reference point and the three Euler angles.