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A Numerical Simulation Scheme for Dynamics of Flexible Riser and Its Validation by Forced Oscillation Experiments

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ABSTRACT

This paper presents a numerical simulation scheme for the dynamics of a highly flexible riser, and the validation of the scheme by forced oscillation experiments. Governing equations of motion for riser dynamics are derived using Hamilton's principle, and nonlinear terms of a small-order magnitude in the derived equations are neglected by using appropriate assumptions. The Galerkin and Newmark-β methods are used for spatial and time integration of the governing equations. Sinusoidal modal functions are adopted for the description of the variables. Inertia and drag coefficients used in the numerical scheme depend on the Keulegan-Carpenter number. A series of model experiments with 2 different boundary conditions is executed for the purpose of validating the developed simulation scheme. A highly flexible riser model is used, and the boundary conditions are either simple or fixed at the top end of the riser and free at the bottom. Three-dimensional riser motion is measured using 10 to 12 CCD cameras, and force/moment are obtained by using a 5-component load cell. The results of the numerical simulation and experiment are compared in various ways. They showed quite good agreement and confirmed the good performance of the developed numerical simulation scheme.

INTRODUCTION

The marine riser has been playing one of the most important roles in various offshore activities, such as deep-sea oil exploration and production, ocean thermal energy conversion (OTEC), and ocean-bed manganese production. Nowadays, the working area of these activities is moving to deeper sea than ever before, which makes the riser very long and the dynamics of the riser much more important. As risers go into deeper sea, their characteristics are those of a highly flexible slender body, and this motivates many experimental and numerical studies of a marine riser's dynamic behavior.

The numerical approaches are getting more weight despite many difficulties, because it is hard to satisfy the dynamic parameters in physical modeling due to the depth limitation of most existing experimental facilities. A variety of studies has targeted the numerical modeling of the dynamics of a slender body such as a cable and riser.

In this research, 3-dimensional equations of motion for riser dynamics are derived using Hamilton's principle in a generalized coordinate system, and high-order nonlinear terms of small magnitude in the derived equations are neglected for the simplicity of the numerical work. J. S. Chung and B-R Cheng (1995, 1996) and Chung, Cheng and H.-P. Huttelmaier (1994a, b) also used the generalized coordinates of the entire riser and the substructure in describing the motion of the riser, but their research differs in that they used an implicit method to solve the 3-D nonlinear motion of a marine riser, while this research uses an explicit method to solve the equations of motion.

A numerical simulation scheme for riser dynamics is developed based on the Galerkin and Newmark-β methods, and the modal expansion method. Many of the studies on riser dynamics used the Galerkin method in the numerical integration scheme; for example, Garrett (1982) derived an equation of motion and a numerical scheme for a flexible slender structure model using the Galerkin and Adams-Molton methods, and Paulling and Webster (1986) expanded this theory to include the stretch of cable as well as the various loads acting upon it. The modal expansion method is used to describe the unknown deflection variables.

The simulation scheme is verified by forced oscillation experiments. The motion of the riser model is measured in 3-D under the forced harmonic oscillation of the top end without current and wave.

EQUATIONS OF MOTIONS

In various studies, the equations of motion for a marine riser are derived using the work-energy principle. For example, Ohkusu (1990) derived a governing equation of motion for the dynamics of a marine riser by using a Lagrangian expression considering bending stiffness; Huang (1992) and Chucheepsakul and Huang (1995) derived a variational formulation for marine cables based on the work-energy principle without considering bending stiffness. Among many others, Hideyuki Suzuki (1993) has derived a 2-D equation of motion for the dynamics of risers by using Hamilton's principle, and this paper extends it into 3-D equations of motion.

Fig. 1 shows the riser motion described in a generalized coordinate system. The relation between the space-fixed coordinate *O-XYZ* and the local-moving coordinate *o-xyz* is expressed using Euler angles, which is a widely used concept in describing the riser or cable motion; for example, Triantafyllou (1994) and Howell (1992) treated a continuous cable without considering bending stiffness and described its motion using Euler angles. To get the rotation relation between the 2 coordinates, we rotate the space-fixed coordinate system *O-XYZ* with respect to the *O-X* axis by the angle of ϕ_1, and then rotate the intermediate coordinate system with respect to the new *O-Y* axis by the angle of ϕ_2, so

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KEY WORDS: Riser, modal expansion method, Galerkin method, Newmark-β method, model experiment, forced oscillation.