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Riser-soil interaction model effects on the dynamic behavior of a steel catenary riser

Xinglan Bai [a], Weiping Huang [b], Murilo Augusto Vaz [c,*], Chaofan Yang [b], Menglan Duan [d]

[a] Department of Naval Architecture and Ocean Engineering, Zhejiang Ocean University, Zhoushan, Zhejiang, China
[b] Shandong Key Laboratory of Ocean Engineering, Ocean University of China, Qingdao 266100, China
[c] Ocean Engineering Program, COPPE, Federal University of Rio de Janeiro, 21945-970, Brazil
[d] Offshore Oil, Gas Research Center, China University of Petroleum, Beijing 102249, China

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ABSTRACT

A mathematical model employed to analyze the global dynamics of a Steel Catenary Riser (SCR) taking into account the interaction with the seafloor and the effect of the soil reaction forces is established. The choice of soil model plays an important role for the dynamic behavior of SCRs. The riser has been modeled using flexible beam with large curvature and elastic foundation beam to describe the riser-soil interaction by means of realistic nonlinear load-deflection (P–y) curves. The study is made to improve an existing finite element numerical code for dynamic analysis of mooring lines and risers, known as CABLE 3D, which is based on a slender rod assumption. Effects of nonlinear seabed model on the dynamic behavior of SCRs under vessel cyclic perturbation have further been investigated and discussed using a realistic P–y curve to simulate soil deformation and resistance forces. The interaction model depends on several factors, such as soil strength, penetration depth and riser characteristics. The dynamic responses of the riser Touchdown Point (TDP) excited by vessel periodic heave motion are studied and the results are compared with those from the linear spring model. SCR has been perturbed by 10 regular sinusoidal cycles and the responses calculated by improved code show a number of features such as suction force mobilization, gradual increasing penetration depth, and gradual reduction of soil resistance at maximum penetration. The riser behavior at the

* Corresponding author.
E-mail address: murilo@oceanica.ufrj.br (M.A. Vaz).

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touchdown zone (TDZ) depends on the riser top motion amplitude, nonlinear soil stiffness and suction force. The impact of the riser-soil interaction model on the dynamic behavior in the TDZ has been thoroughly studied in this paper.

1. Introduction

SCRs are a preferred solution for deepwater wet-tree production, water/gas injection and oil/gas export, connected to vessels via flexible joints and to the wells. For deeper waters, industry has designed longer and more flexible SCRs.

The touchdown zone, where the SCR starts to contact the seabed, proves to be a critical location for SCR fatigue damage. The motions of the floating body, especially heave motion, can cause severe riser cyclic response, leading to fatigue damage near its TDZ. The fatigue damage is directly related to the large bending stress variations that occur near TDZ. Previous studies show that prediction of the fatigue life depends on the seabed stiffness [19], therefore a reasonable seabed model is required. However, existing studies generally use either rigid connection or elastic spring disregarding the nature of the trenching development process into the soil and the suction force, to approximate the behavior of the seabed soil due to the complication of soil-riser interaction and geometric trench, which could lead to a non-realistic dynamic behavior and effect on fatigue life prediction. These approaches do not account for the soil plastic deformation. Therefore, it is important to develop better understanding and modeling of riser-soil interaction mechanism to provide a realistic technique for determining dynamic response and strength performance in the TDZ [8]. This study is made to develop a finite element code for the dynamic analysis of risers and mooring lines; to allow for a more realistic description of the riser behavior in contact with the seabed including nonlinear support force and soil suction. The influence of seabed model on soil resistance force and bending moment distributions within the TDZ and the dynamic response under top end vertical cyclic displacement are examined.

Induced by an oscillating floating structure, the flow-line segment of SCR repeatedly contacts the seafloor, which proportionally deepens the trench. Deeper trenches may reduce the maximum variation of bending moment, and it results in the reduction of the dynamic stress level near the riser TDZ [12]. When riser is lifted up from soft clay at the TDZ, it undergoes soil suction which involves three stages: mobilization, plateau and release [3,4]. The process of riser-soil interaction for each period can be represented by a typical P–y curve, where P is the soil resistance force and y is the vertical penetration of the riser into the soil. The P–y curve describes important phenomena occurring during the interaction between SCR and seabed, such as elastic rebound, partial riser-soil separation, re-contact and full separation [1]. The study of [20]; in which seabed is simulated with a linear hysteretic riser-soil vertical interaction model, indicates that the trench development favors longer riser fatigue life. However, this model does not capture the realistic nonlinear riser-soil interaction [17]. has used general-purpose finite element software, the AQUA module, based on hysteretic nonlinear model and studied the dynamic response in planar numerical simulations. The riser has been modeled using Euler-Bernoulli beam elements disregarding continuous distributed force of soil and large curvature near the TDZ. This is acceptable if appropriate meshing and soil model is used, but the analysis is time-consuming because the mesh should be very small.

The aim of this study is also to discuss the significance of riser-soil interaction relating to the fatigue damage of SCRs for deepwater developments and report the dynamic response of a SCR on soft clay in 1800 m of water depth using the improved code for a nonlinear time domain analysis. The numerical results for the assessment of SCR global analysis are compared, when considering a critical point in TDZ, for which the seabed is modeled using a P–y curve. The riser has been modeled with flexible beam elements with large curvature and considering continuous seabed distributed force. The numerical simulation can more realistically reflect the dynamic behaviors of SCR. Analyses have been conducted as periodic displacement controlled. The riser dynamics including drag force, inertia and added mass are calculated by modified Morison formula.