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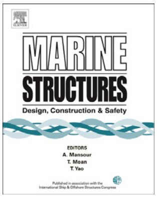

A simple parametric formulation for the seabed trench profile beneath a steel catenary riser

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ABSTRACT

Seabed trench has a profound influence on the fatigue performance of a steel catenary riser (SCR) at the touchdown zone. At present, the most well-regarded approach for simulating the complex trench development process is by applying a nonlinear hysteresis seabed contact model, which is time consuming. Field observations have indicated that the trench depth almost stabilizes after a few months following installation. Hence, for practical fatigue design, it is expedient to specify an initial static trench profile to perform the dynamic simulations. This paper presents a new simple parametric formulation for delineating an initial trench profile, as there appears to be no such approach in the literature. The formulation entails two unknown trench parameters (trench length and global trench position), which can be determined using a new iterative static analysis method proposed herein. However, the analysis involves solving a constrained optimization problem, and is not ideal for practical applications. Thus, a surrogate model is devised, by approximating the trench parameters as multivariate polynomial functions of three dimensionless variables of the SCR. A case study comparing the trenches obtained from seabed contact model, static analysis, and surrogate model, shows that the different trench profiles and the associated maximum fatigue damage are in close agreement.

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1. Introduction

Steel catenary riser (SCR) is a technically feasible and cost-effective option for transportation of hydrocarbons, and it is widely used in many deepwater fields. In the SCR design, fatigue assessment at the touchdown zone (TDZ) is one of the most challenging issues. At the TDZ, the fatigue damage is most pronounced, and also most difficult to predict accurately due to many complex mechanisms involved, such as slug flow, vortex-induced vibration, and SCR-seabed interaction. The effect of seabed interaction can be broadly classified into three aspects, namely soil stiffness, soil suction, and seabed trench, all of which have significant influence on the fatigue performance at the TDZ [1,2]. This paper focusses on the seabed trench, which develops progressively beneath the SCR owing to repeated contact.

One of the earliest research efforts on SCR-seabed interaction are the STRIDE and CARISIMA joint industry projects (JIPs) [1,3], in which full scale field tests were conducted. Some observations were reported, including trench development and nonlinear hysteretic relationship between seabed resistance and riser penetration. The JIPs spurred subsequent research on SCR-soil interaction, and there is still intensive interest on this topic today. Recent experimental studies include Elliott et al. [4], who performed centrifuge tests, and Wang et al. [5], who carried out large scale indoor tests. Trench development is a highly complex process involving interactions between the fluid, structure and soil. Numerical techniques have been developed to simulate this process. Sen and Haser [6] carried out SCR global analysis, in which the local SCR-seabed interaction was simulated by Abaqus/Explicit. Clukey et al. [7] investigated the seabed response and trenching due to riser loading using ANSYS/LS-DYNA, and the results were compared with laboratory tests.

Undoubtedly, experimental tests and detailed numerical analysis are time consuming and costly. Therefore, researchers have developed semi-empirical SCR-soil models, which can be easily incorporated into global dynamic analyses. Aubeny and Biscontin [8,9] proposed empirical formulas for the seabed plastic deformation, and a P-y model that accounts for the initial penetration, uplift and re-penetration. Several researchers [2,10] have applied the models by Aubeny and Biscontin for fatigue analysis of SCR at the TDZ. Randolph and Quiggin [11] proposed a nonlinear hysteretic seabed model, which has been validated with experimental data [12], and can be used to simulate trench development. To better reflect the seabed degradation, this model gave relatively smaller seabed resistance than the initial P—y curve at the trench bottom for the re-penetration curve. Randolph and Quiggin's seabed model has been incorporated into the commercial software Orcaflex, which is widely used for riser dynamic analysis. Subsequently, many researchers [13–16] have applied this seabed model for SCR fatigue analysis, either within Orcaflex, or in conjunction with other riser dynamics codes.

The collective efforts of the abovementioned research studies have firmly established the importance of seabed trench on SCR fatigue behavior at the TDZ. The empirical seabed models can be used to simulate the development of trench profile caused by repeated SCR-seabed contact; however, the simulations are computationally demanding due to the slow rate of trench development. Field observation by remote operated vehicle (ROV) in Gulf of Mexico indicated that the trench depth trends to stabilize after reaching four to five times the riser diameter after a few months following the SCR installation [17]. Since a few months constitutes only a small fraction of the total design life of a riser (typically 20 years), in practical fatigue design, it is expedient to specify an initial static trench profile to perform the dynamic simulations. However, so far there appears to be no simple and reasonable approach to determine the initial trench. One reason is that ROV recordings are limited and the trench creation speed depends on the nature of the environmental loads, among other factors.

Clearly, the specified trench profile needs to be realistic. Shiri [18] asserted that unrealistic formulation of the trench may be the reason that some previous studies reported conflicting results for the trench effect on fatigue damage. Several authors have proposed parametric formulas for the trench profile, for example cubic polynomial model [8], quadratic exponential model [18], shifted lognormal distribution [19]. However these formulas have not been validated, and the selection of the parameters of the formulas is also an unresolved issue. Motivated by practical needs, this paper aims to develop a parametric formulation for the trench profile that is straightforward to apply. The trench profile can