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Trenching effects on structural safety assessment of integrated riser/semisubmersible in cohesive soil

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ABSTRACT

This paper models an integrated riser/semisubmersible system and subjected to irregular waves. The riser's pipe is suspended from a semisubmersible and smoothly extending down to the cohesive seabed soils at the touchdown point in a catenary shape. Pipe–soil interaction is modelled using a hysteretic non-linear model in the vertical seabed direction and Coulomb friction model in the lateral direction together with an improved model that includes the breakout soil resistance. Initially, this study discusses the significance of pipe–seabed interaction on the riser response for deepwater applications when subjected to random waves on cohesive clay. In the next step, this study investigates the sensitivity of fatigue performance to geotechnical parameters through a parametric study. The influence of the uncertainty in the geotechnical parameters and the development of the trench in the seabed on the dynamic response are determined. The structural behaviour and the uncertainty of fatigue performance in the touchdown zone are presented. It is noted that the confidence in seabed interaction modelling and geotechnical parameter values is needed in order to have structural safety assurance in the final numerical analysis results.

1. Introduction

A steel catenary riser (SCR) is commonly used with tension leg platform (TLPs), floating production, storage and offloading (FPSOs), semisubmersibles and spars, as well as fixed structures, compliant towers and gravity structures. An SCR attached to a semisubmersible at its upper end encounters oscillations in and near its touchdown zone (TDZ), which results in interaction with the seabed. The motions of the semisubmersible can induce severe riser responses, which must be predicted as accurately as possible to determine the dynamic structural strength and fatigue performance of the SCR in the TDZ. The challenges regarding the fatigue damage assessment of an SCR in the TDZ are primarily due to the non-linear behaviour of SCR–seabed interaction and considerable uncertainty in seabed interaction modelling and geotechnical parameters. This study is concerned with the modelling of integrated SCR/semisubmersible with seabed interaction on soft clay when subjected to random waves. Analysis techniques have been developed in the two main areas: SCR–seabed interaction modelling and the influences of the uncertainty in the geotechnical parameters on the dynamic response and fatigue performance of SCRs in the TDZ.

The objective of this study is to evaluate the effects of trenching interaction on the structural safety assessment of an SCR which is fully coupled with a semisubmersible. In this study, the vertical embedment and large lateral movements of the SCR in the TDZ is investigated by using the commercial code OrcaFlex for non-linear time domain simulation. During the simulations the seabed is modelled using a hysteretic non-linear load/deflection model in the vertical seabed direction and Coulomb friction model in the lateral direction together with an improved model that includes the breakout soil resistance. The results of numerical simulations of the global responses of the SCR considering a critical point in the TDZ are presented. This study also investigates the sensitivity of fatigue performance to geotechnical parameters through a parametric study. In this paper, global analyses are performed to assess the influence of vertical linear and non-linear seabed model, including trench evolution into the seabed, seabed normalised stiffness, re-penetration offset parameter and soil suction resistance ratio on the fatigue life of an SCR in the TDZ.

The fatigue analyses results prove that the confounding results indicated by the previous research studies on the SCR in the TDZ are due to different geotechnical parameters imposed with the soil model and trench development. The trench deepening and the

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Nomenclature

a, b	power law parameters
D	pipe outer diameter
D_{tot}	total fatigue damage accumulation
E	pipe eccentricity
f_b	soil buoyancy factor
F_F	sliding resistance of the pipeline along soil surface
F_R	passive soil resistance due to soil shear strength, load history and pipe penetration (kN/m)
$(F_y)_{breakout}$	soil–pipe breakout friction resistance (kN/m)
$(F_y)_{res}$	residual soil resistance (kN/m)
f_{suc}	suction resistance ratio
H_s	significant wave height (m)
K_{max}	normalised maximum stiffness. This is the pipe–soil stiffness normalised by the ultimate net-bearing pressure
SCF	stress concentration factor
SCR	steel catenary riser
S–N	stress–life curve approach
S_i	denotes the applied stress level (MPa)
S_{oi}	nominal stress range (MPa)
S_{u0}	shear strength of soil at the seabed level (kN/m^2)
S_{ug}	shear strength gradient (kN/m)
T	pipe wall thickness
TDP	touchdown point
TDZ	touchdown zone
T_P	wave peak period (s)
V	vertical seabed reaction force (kN/m)
VIV	vortex induced vibration
Y	displacement from the un-sheared position in lateral direction (m)
z	embedment depth of pipe below the seabed (m)
z_{init}	initial penetration depth (m)
γ'	submerged unit weight of soil (kN/m^3)
λ_{rep}	re-penetration parameter
λ_{suc}	suction decay parameter
μ	sliding friction factor
ρ_{soil}	saturated soil density

gradual embedment of riser and soil stiffness have a substantial influence on the fatigue life of SCRs in the TDZ. The main benefit of employing non-linear seabed approach is to capture the entity of realistic soil interaction behaviour in modelling and analysis and to predict the likelihood of the fatigue damage of the SCR with seabed interaction, thereby minimising the risk of the loss of the containment with the associated environmental impact.

2. Problem description of pipe embedment

For SCRs, the most critical fatigue hotspot occurs in the TDZ due to complex interaction between the SCR and seabed. The SCR–seabed interaction is an essential key factor that should be considered in strength and fatigue assessment. How to precisely model this interaction response is still an issue and has been a hot field for academic research. Current SCR–seabed interaction modelling approaches the seabed as a rigid or linear elastic model with friction coefficients appointed in the axial and lateral directions relative to the axis of the SCR. However, the linear seabed model does not simulate the actual behaviour of the seabed. Therefore, several studies have recently focused on load/deflection (V–z) curves for the response of SCR–seabed interaction, where V stands for the resistance force of soil and z stands for the vertical penetration of the SCR's pipe. Researchers determined the empirical equations for (V–z) curves from experiments. SCR pipe penetration is defined as the depth of penetration of the pipe invert (bottom of pipe), relative to the undisturbed seabed as shown in Fig. 1. Pipe penetration affects the riser pipe–seabed contact area, which subsequently affects the axial and passive soil resistance against the riser. Consequently, the passive soil resistance influences the lateral breakout force. Heave of seabed soil during embedment increases the local penetration of the SCR pipe by raising the soil surface level against the shoulders of the pipe.

3. Why an SCR/semisubmersible system?

As offshore hydrocarbon exploration is pushed into deeper and deeper water with the heavier payload, many innovative floating offshore structures are being proposed for economic savings. SCRs have been enjoying a widespread acceptability for many types of different deepwater floaters including spar, TLP, semisubmersible and FPSO, in worldwide deepwater developing fields, such as the west of Africa, offshore Brazil, Northern North Sea and the Gulf of Mexico. The main concerns for the design of SCRs hanged on floaters are the dynamic behaviour and fatigue performance of an SCR due to cyclic dynamic motion. However, SCR designs are very sensitive to motion response of a host vessel as well as environmental loadings. Fig. 2 shows typical heave natural period ranges and heave Response Amplitude Operators (RAOs) of spar, TLP, semisubmersible and FPSO. Therefore, SCR can be accompanied by all floaters without any constraints although motion optimisation is needed for Semisubmersible as well as mild environment operating condition for FPSO.

A semisubmersible floating system introduces a number of advantages, including less sensitivity to water depth, large payload capacity and the ability to relocate after field abandonment. This system consists of a buoyant floating facility moored to the seabed. Semisubmersible units offer reduced motions compared to FPSO. A semisubmersible has been applied in environments from harsh (e.g., North Sea) to the benign (e.g., Brazil). During the last decades, semisubmersibles with compliant risers have proven their excellence in use for deepwater development of oil/gas fields. Deepwater semisubmersibles with over fifty SCRs are being built nowadays [1,2].

4. Non-linear soil model approach

Recent SCR–soil interaction models are too simplified to simulate the complex interaction between the seabed and riser pipe. The non-linear seabed model is more sophisticated than the common linear model, in that it models the non-linear hysteretic behaviour of the seabed in the vertical direction, including modelling of soil suction effects. Randolph and Quiggin [4] introduced a non-linear mathematical model for cyclic SCR–seabed interaction in the TDZ, which is established on hyperbolic secant stiffness formulation, such as those indicated by Bridge et al. [5] and

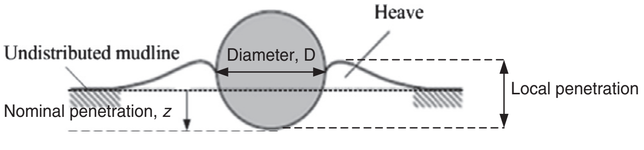

Fig. 1. Initial penetration of an SCR pipe.