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Influence of seabed trench formation on fatigue performance of steel catenary risers in touchdown zone

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ABSTRACT

The subsea survey results using remote operating vehicles (ROV) show that trenches with a depth of several riser diameters can be developed underneath the steel catenary risers (SCR). Therefore, an important question in respect of the riser–seabed interaction is, how the trench formation beneath the riser affects the riser fatigue performance in the touchdown zone. A common methodology reported in literature to study the impact of trench formation on riser fatigue life is the insertion of an artificial mathematical expression of the riser profile into the seabed. This study shows that such methodology can be inconsistent and leading to contradictory results. The current paper has employed ABAQUS finite element software and coded a non-linear soil hysteretic model to automatically simulate the variable seabed stiffness and the gradual trench development through the touchdown zone. In this method, the seabed model parameters are initially adjusted to extreme values allowing trench with desired depth to be developed over a moderate number of displacement cycles of the SCR. The design wave scatter diagram is then applied, simulating a generic Spar system, after switching the model parameters to values with normal range. The paper presents the impact of trenches of different depths on the fatigue performance of SCRs in the touchdown zone.

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1. Introduction

Steel catenary riser (SCR) is a popular solution in development of deep-water hydrocarbon fields and its fatigue performance in touchdown zone (TDZ) is still a challenging area of design, where the most uncertainty comes from the complex nature of riser–seabed interaction in TDZ. The surveys conducted by remote operating vehicles (ROV) show that trenches with a depth of several riser diameters can be developed underneath the SCRs. Therefore, an important question in respect of the riser–seabed interaction is how the trench formation beneath the riser affects the fatigue performance in touchdown zone. Various research works have been conducted addressing the above question, but the published results are surprisingly found to be contradictory. Some authors report an increase in fatigue damage due to trench formation [5,7], while others report damage reduction [3,6,8]. The current research work has been carried out to first explore the source of scattered results and then possibly provide a solution to find a unique and robust response to the main question raised above. As the first step, the works performed by various authors were repeated and the most probable source of contradiction in published results was determined. As will be illustrated in coming sections, the way authors are modeling a trench beneath the riser can simply trigger the error leading to scattered and unreliable results. In most of the studies, a mathematically expressed trench profile in TDZ has been replaced with flat seabed. Then the fatigue analysis has been performed and the impact of the trench on fatigue performance has been reported. This method was found to be unstable because of enforcing pressure hot spots between the riser natural catenary and the theoretically expressed trench profile. These spot pressures can violate the stress profiles and also the fatigue damage distribution. In the second step of the current research, the capability of the implemented non-linear seabed interaction model in creating a trench beneath the riser is used to study the trench impact on fatigue performance throughout a novel methodology. The details of this method will be discussed in the coming sections but shortly introduced here. Upon starting the fatigue analysis, an extreme value is adopted for the re-penetration offset parameter of the seabed model to create a trench with desired depth. Then the parameter is switched to the normal value and the deterministic fatigue analysis is proceeded by applying a full package of waves, and the fatigue damage profile is then obtained using post-processing macros coded by authors. In reality, the riser dynamics has definitely an important contribution to the system behavior, but in order to facilitate tracing the core of model response, the analyses were initially performed using quasi-static scheme. However, in the second stage of the study, the model was re-constructed again in AQUA module of ABAQUS, where the buoyancy force is automatically applied on the system and the riser dynamics including drag force, inertia and added mass were implemented through full dynamic analyses. The SCR configuration in this paper is selected from the study reported by Shiri and Randolph (2010) [10] and shown in Fig. 1. The proposed methodology is obviously mitigate the risk of enforcing inconvenient pressure hot spots between the natural riser catenary and the theoretical trench profile and this in turn can lead to more reliable and robust conclusion. However, more accurate and organised field surveys along with further research works are needed to deeply explore the nature and the mechanism of trench development beneath the riser. The exact position of the mean touchdown point (TDP) relative to the developed trench is also an area needing further investigation. This can be more illustrative if accompanied by simultaneous capturing and study of the environmental loads, vessel motions and TDP fluctuations etc.

2. Fatigue analysis

The practical fatigue analysis of SCRs considers the contribution of the various damage sources including first order wave action, second order slow drifts and vortex induced vibrations (VIV). The fatigue performance is usually assessed throughout the time domain or frequency domain analysis [1]. Depending on the system configuration and the area of interest, the contribution of various damage sources can be different. However, the fatigue damage under the first order wave action has normally a big share in the overall fatigue performance. In this study, we do not emphasize on accurate evaluation of actual fatigue damage in TDZ. Instead, we are more interested in tracing the relative influence of the seabed trench formation on fatigue performance. Therefore, first, the deterministic fatigue analysis under the wave action has been conducted using a quasi-static system and then the impact of the riser