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A simplified method to predict fatigue damage of offshore riser subjected to vortex-induced vibration by adopting current index concept

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ABSTRACT

In the present study, an innovative method for estimating fatigue performance of risers under vortex-induced vibration (VIV) is proposed. Generally, fatigue performance is affected by the surrounding environment such as wind, wave, and current. It is well known that current is the most influential load among all for offshore risers. In structural safety aspect, strength and fatigue are the most important factors for riser design. In addition, fatigue design is affinitive to the VIV phenomenon. For the analysis of fatigue performance of riser, SHEAR7 numerical simulation code which is commonly used in offshore industry is applied. In order to identify the relation between current load and fatigue performance of riser, Fatigue damage versus Current index (F-C) diagram has been proposed. F-C diagram may cover change of current profiles and help predict the fatigue damage under VIV. In case of current profile, a total of sixty cases of current scenarios are considered based on six representative sea-states. The obtained results from this study will be a useful guideline to predict the effect of current on the fatigue performance of riser.

1. Introduction

Nowadays, Steel Catenary Risers (SCRs) have been commonly deployed in offshore oil field such as Gulf of Mexico, offshore Brazil and offshore Indonesia (Bai and Bai, 2005). Extensive studies on the behavior of SCR are needed in designing feasible and applicable SCR in deepwater operations. Challenges faced by engineers in designing a SCR are mainly related to high hang-off tensions due to the weight and bending stress of the pipe at touchdown point, as well as the high pressure and high temperature the SCR have to withstand. In addition, the environmental loads such as wave, wind and current, along with the soil condition of the seabed, introduces challenges to the operation of SCR.

One of the major issues, which is considered in Pre-FEED and FEED, is the fatigue damage experienced by the SCR over the period of operation in deepwater. Several factors contribute to fatigue damage of SCRs are mainly waves induced hull motions, vortex-induced vibrations (VIV), vortex-induced hull motion, hull heave motions and installation works. VIV is considered as a critical part in designing deepwater SCRs, especially for SCRs that operate in high current region. Several VIV mitigation methods are proposed and implemented, including VIV suppression device such as fairing and strake (Bai and Bai, 2005).

With regards to findings on VIV from previous studies, damage caused by in-line vibration due to VIV is usually disregarded in industrial practice of VIV analysis. Several numerical and experimental findings show disagreement in neglecting in-line vibration. Earlier experimental studies by Aronsen (2007) to determine the interaction between in-line and cross-flow VIV reveal that in-line oscillation will lead to cross-flow forces that cause the trigger of cross-flow VIV. Trim et al. (2005) tested the fatigue damage of a model riser in uniform and linearly sheared current profiles. Their study indicate in-line fatigue damage is as severe as cross-flow fatigue damage. Baarholm et al. (2006) further justified that in-line vibration significantly contributes to fatigue in low-modes domination cases as frequency of in-line oscillation is twice the frequency of cross-flow oscillation. Sun et al. (2014) performed numerical

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studies on the fatigue damage of a long deepwater riser using pseudo-excitation method (PEM) in two methods: by considering only cross-flow VIV and by considering both in-line and cross-flow VIV. They implied that at a location near top of the riser, is vulnerable to fatigue damage mainly due to cross-flow vibration whereas point touching bottom, has high stress ascribed to in-line VIV.

This study focuses on the effect of current profile to the fatigue performance of SCR, associated with VIV. In addition, an innovative method which represents current characteristics, is proposed for the fatigue assessment of offshore risers that are subjected to current load including VIV phenomenon. Only a limited number of reliable scenarios representing different types of current profile are selected based on obtained six types of representative current profiles. Current index (CI) for a given current profile is defined as a function of current velocity and water depth. The fatigue performance such as fatigue damage or fatigue life of a riser in any applied current profile is predicted through several analysis methods, i.e., analytical, numerical, and experimental.

In performing the above procedures for all current profiles selected, an innovative diagram representing the relationship between Fatigue damage and Current index of riser by VIV (F-C diagram) is developed. This diagram is useful for the prediction of fatigue performance of riser, especially in the stage of Pre-FEED. In the present study, applicability of a proposed method is validated through applied example of a steel catenary riser (SCR) with 2000m of water depth in Gulf Of Mexico (GOM). Several methods to develop a CI is proposed together with an F-C diagram which contributes towards the evaluation of fatigue performance of SCR in the early stages of design (Pre-FEED).

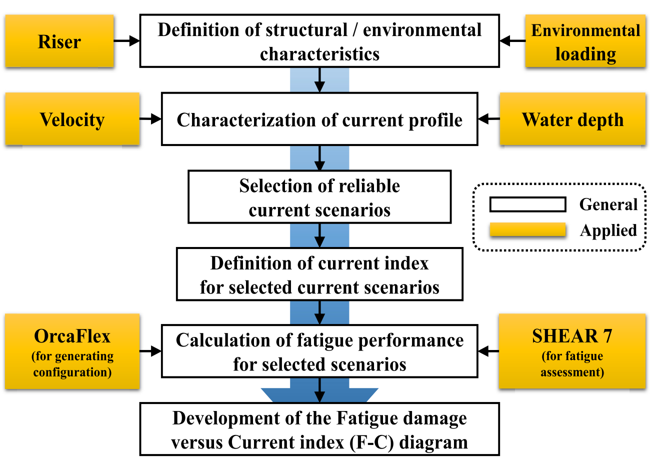

Fig. 1. Procedure of proposed method for the development of the fatigue damage versus current index diagram.

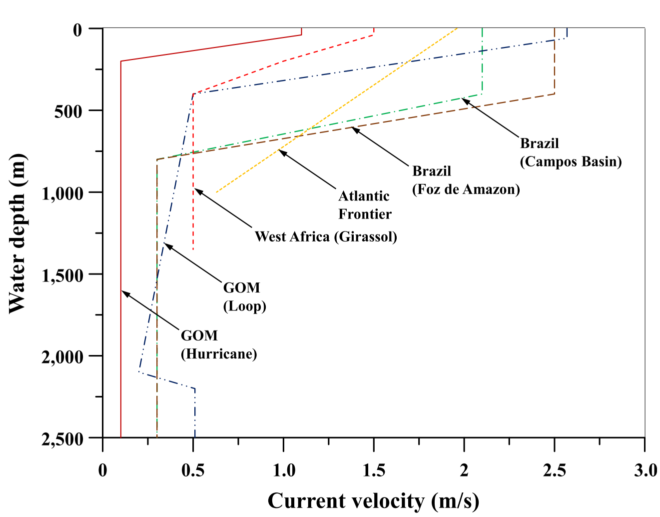

Fig. 2. Current profiles in representative offshore field (Bai and Bai, 2010).

2. Procedures for the development of fatigue damage versus current index diagram

Fig. 1 shows the development procedure in arriving at the relationship between the fatigue damage and current index (abbreviated as an F-C diagram). Once current profile is measured, including velocity of current at each water depth, several probable current profile can be regenerated and these current profiles will be used as analysis scenarios. Based on each current profiles, an innovative concept of current index, is established as a function of current velocity and water depth. In assessing the fatigue for all selected scenarios, the F-C diagram is developed and represented in an empirical formula.

Recently, an innovative method was developed by Paik et al. (2012) for the safety assessment of ships damaged by grounding. In addition, application studies were also carried out – container ships (Kim et al., 2013b), bulk carriers (Kim et al., 2013c), corrosion effect (Kim et al., 2014), and analysis methods (Kim et al., 2013a). The study herein presents the effect of current profile on fatigue performance of riser and an innovative concept of current index is proposed. This section covers a detail explanation of each step and the applicability of the proposed method is validated by applied example in the next section.

2.1. Definition of structural and environmental characteristics

First of all, structural characteristics of SCR, such as riser dimensions, riser configuration, material properties, and properties of VIV suppression device such as strake, need to be defined. Once structural characteristics are obtained, applied environmental loadings, such as wind, wave, current, and many others, will be required. The study presents only the effect of current, which is one of the significant factors to riser fatigue design due to VIV.

2.2. Characterization of current profile

In general, each offshore production field has different environmental

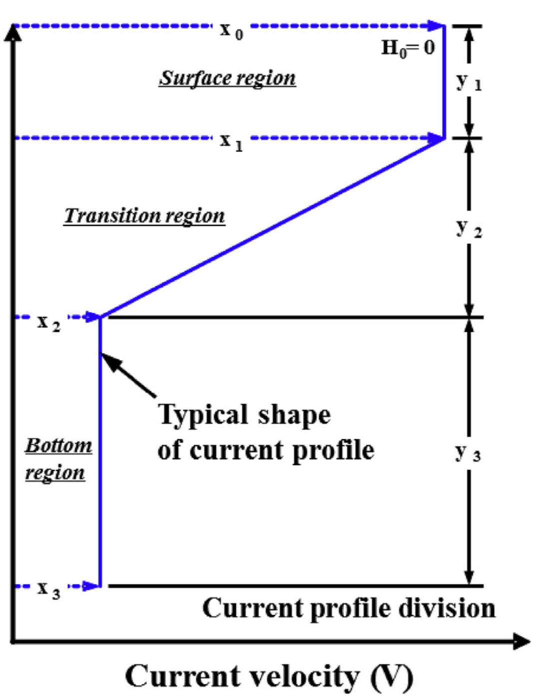

Fig. 3. Definition of current parameters.