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Sensitivity analysis of jacket-type offshore platforms under extreme waves

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ABSTRACT

Jacket-type offshore platforms play an important role in oil and gas industries in shallow and intermediate water depths such as Persian Gulf region. Such important structures need accurate considerations in analysis, design and assessment procedures. In this paper, nonlinear response of jacket-type platforms against extreme waves is examined utilizing sensitivity analyses. Results of this paper can reduce the number of random variables and consequently the computational effort in reliability analysis of jacket platforms, noticeably. Effects of foundation modeling have been neglected in majority of researches on the response of jacket platforms against wave loads. As nonlinear response of the pile foundation is one of the most important sources of potential nonlinearity in the response of offshore platforms, in this study, a powerful model which is able to consider Pile–Soil–Structure Interaction (PSSI) is employed. Therefore, PSSI parameters as well as other parameters such as uncertainties in the prediction of the wave force on jacket structure and uncertainties in structural model are utilized in sensitivity analyses. In this research, pushover methods as well as an advanced approach named "Incremental Wave Analysis (IWA)" are employed. Consequently, collapse prevention limit state of jacket platforms is investigated through different outcomes of pushover and IWA methods including Reserve Strength Ratio, ultimate capacity, collapse displacement and Collapse Wave Height indicators. In order to consider the effects of correlation between random variables, a robust method of sensitivity analysis named correlation coefficient approach is also employed.

1. Introduction

As offshore structures require more critical and complex designs, the need for accurate approaches to evaluate uncertainty and variability in computer models, loads, geometry, and material properties has increased significantly. For problems in which randomness is relatively small, it is evident that a deterministic model is adequate. However, when the level of uncertainty and importance of structure is high, probabilistic approaches should be employed for system analysis and design. One of the fundamental steps in the structural reliability analysis of structures is to determine the significance of random variables, and how they influence the structural response which can be acquired by sensitivity analyses. The sensitivity analysis can answer the basic question "which variables are the most important and should be used in probabilistic analyses?".

The topic of sensitivity analysis for jacket type offshore platforms against wave loading has been widely considered by different researchers. Sunder and Connor [1] investigated the sensitivity of steel jacket offshore platforms to environmental wave loading utilizing two simplified numerical models under rigid foundation conditions. They studied the effects of wave height, wave period, drag and inertia coefficients, mass and hysteretic structural damping. Hahn [2] used a simplified model in order to examine the effects of inertia and drag force components, current velocity, fluid–structure interaction, random phase angles and wave cancellation. Haver et al. [3] investigated the sensitivity of the annual failure probability to the selected airgap and current design profile. They demonstrated that the airgap parameter is a crucial parameter regarding the annual probability of structural failure.

With regard to sensitivity analyses of jacket type platforms, the effects of foundation modeling have been neglected in majority of researches on the response of jacket platforms against wave loads. As nonlinear response of the pile foundation is the most important source of potential nonlinearity in the response of offshore platforms, it is clear that a more powerful model, which is able to consider Pile–Soil–Structure Interaction (PSSI), should be employed. Owjnc [4] studied the sensitivity of the overall dynamic response of the deep water platforms to the variation of the soil characteristics and to the effect of the axial forces of the members utilizing a new formulation. It was illustrated that the overall dynamic responses of a deep water structure can be very sensitive to the foundation model. Kenji Kawano and Katta Venkatammana [5] also conducted dynamic analysis of large offshore structures utilizing the impedance function

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model for the soil–pile foundation system. Moreover, several studies by Makris et al. [6], Mylonakis and Gazetas [7], Guin and Banerjee [8] have focused on PSSI analyses. Bea [9] performed a series of static pushover analyses on a fixed offshore platform and found that the first nine nonlinear events were concentrated in the foundation piles. Moan et al. [10] demonstrated that the choice of pile/soil modeling method can affect the load distribution and failure mode in the structural model. HSE [11] concludes that for ductile jacket platforms, considering nonlinear foundation model results in a significant increase of the lateral displacement of the deck. The effect on the capacity to carry lateral load is, however, small. Although considerable researches on the PSSI have been conducted, most of the earlier studies are based on the assumption that the superstructures are simplified as a block mass or as a series of lumped masses. Therefore, in this paper, a 3-D model of SPD2 jacket platform located in Persian Gulf is utilized to increase the accuracy of the model.

In addition, majority of earlier studies have been conducted by means of simple approaches for sensitivity analysis which cannot consider the combined effects of random variables. Therefore, this paper aims to employ two robust methodologies of sensitivity analysis in order to obtain more reliable results. As a result, the main motivations of this study can be summarized as follows: (1) conduct sensitivity analysis of jacket type platforms against extreme wave loads to distinct the most important parameters affecting the nonlinear response of jacket platforms, (2) consider PSSI in the 3-D model of jacket, (3) utilize two robust methods of sensitivity analysis including Tornado and correlation coefficient approaches, (4) employ Incremental Wave Analysis (IWA) [12] as a newly introduced method in obtaining accurate behavior of jacket platforms against wave loading hazard and finally (6) consider both dynamic and static behavior of jacket platforms.

2. Modeling

In this research, a 3-D model of SPD2 jacket platform located in South Pars Gas Field of Persian Gulf region is employed as a case study. General configuration of SPD2 jacket platform is displayed in Fig. 1. Since the same design specifications and physical configuration are applied to the offshore platforms in other South Pars Gas Field platforms, the results of this research can be valid for jacket structures in this area of Persian Gulf.

SPD2 jacket platform located in 65 m water depth consists of six legs and three battered faces. Jacket plan dimension is about $16.00^{m} \times 27.50^{m}$ at deck level and $23.42^{m} \times 37.74^{m}$ at mud line elevation. The jacket is fixed to the ground by 6 through leg grouted piles. The 3-D model of SPD2 jacket is modeled in accordance with AS-BUILT drawings. Furthermore, boat landing, risers, caissons, conductors and conductor guides, launch truss and barge bumpers are modeled as non-structural members. A simplified elastic model of topside including main framing is assumed. All topside loadings which are about 2020 ton are applied on main joints as equivalent point loads. The natural period of SPD2 jacket platform is about 1.5 s. The design wave height and period are also 12.2 m and 11 s, respectively.

The finite element program USFOS, which has the capability to perform nonlinear static and dynamic analyses of jacket platforms against wave loadings, is selected. This software is proficient in taking into account the buckling and post buckling behavior of compression members as well as nonlinear PSSI, properly [13].

As nonlinear static and dynamic analyses against wave loading hazard are carried out in this research, both static and dynamic PSSI have to be considered. Static PSSI can be employed by means of static p–y, t–z and q–z curves described in API guidelines [14]. The vertical resistance of soil layers is modeled by means of two load-deformation curves, t–z and q–z, while lateral soil resistance is employed by nonlinear p–y curves. In this research, dynamic PSSI is considered utilizing "dynamic p–y" introduced by El Naggar and Bentley [15]. They employed the static p–y curve approach in conjunction with the plane strain assumptions in order to represent the soil resistance within the frame of a Winkler model. They introduced a nonlinear

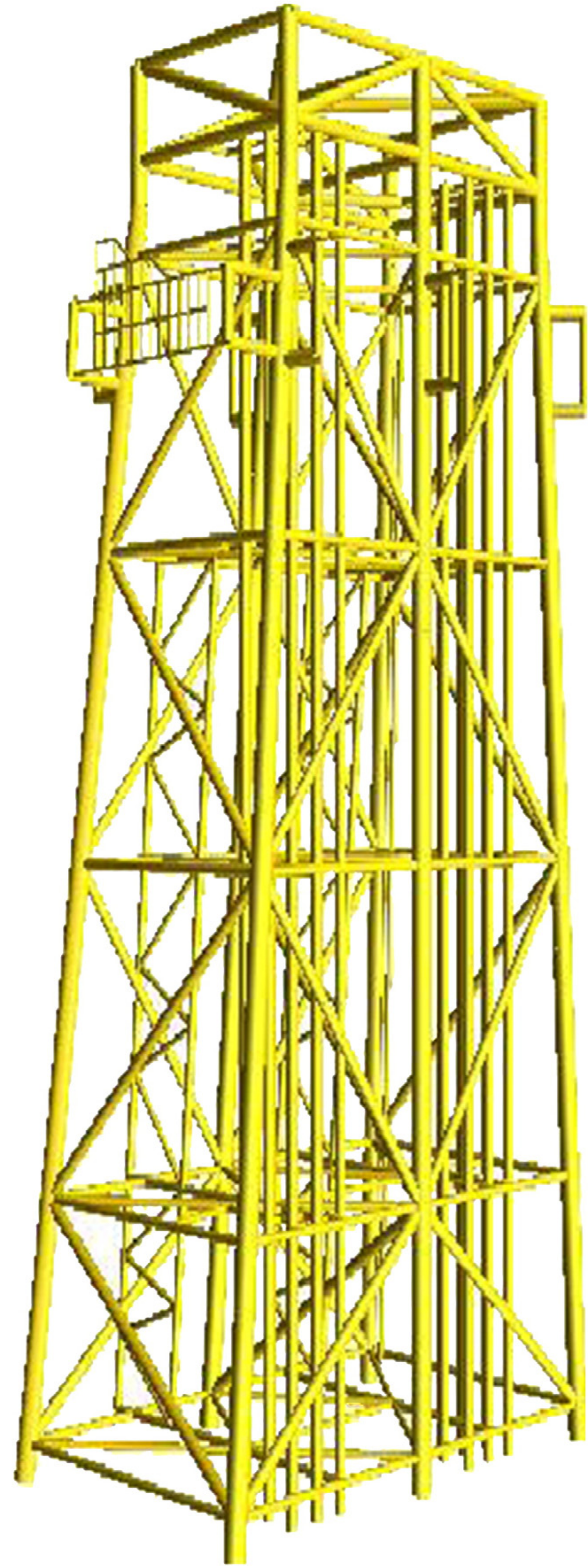

Fig. 1. General configuration of SPD2 platform located in Persian Gulf.