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Reliability Analysis of Tension Leg Platforms by Domain Crossing Approach

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ABSTRACT

This paper presents a reliability analysis model for a tension leg platform (TLP) against severe storm events by the domain crossing approach of the random tensile stress in the tendons. Two limit conditions are considered, i.e., the exceedance of ultimate tensile capacity and the occurrence of negative tension. In order to consider the correlation effects among the failure events of the tendons at four corners, the system limit state is defined in terms of the TLP motions in the vertical plane, i.e., heave, roll, and pitch. To investigate the validity of the present method, numerical analysis is carried out for two TLPs with different structural dimensions. Numerical experiments are also performed to investigate the sensitivity of the reliability to several parameters, such as the cross-sectional area of the tendons, the mean tension in the tendons, and the uncertainties of the severe storm data.

INTRODUCTION

A tension leg platform (TLP), schematically shown in Fig. 1, is a drilling and production platform developed for deep-sea applications. It is a floating platform vertically moored by tension legs at each corner of the hull structure. The tension legs, so-called tendons, are secured to the pile-anchored templates on the seafloor. The excessive buoyancy of the platform maintains tension in the tendons so that the tendons never become slack under any loading conditions the structure may encounter during its service lifetime. The tendon system seems to be the most critical element for the safety of the TLP.

From this point of view, notable works on TLP reliability have been reported by Cornell et al. (1984), Prucz and Soong (1984), and Stahl and Geyer (1985). Those efforts are of a preliminary nature aimed at developing better design insights. Particularly, Prucz and Soong presented a reliability model for the tendon system based on a level-crossing approach associated with the tension in the tendons. They assessed the probability of progressive failure of the tendons at one corner and the reliability of the tendon system for various design parameters. Other studies on the reliability problems for parallel member systems, such as TLP tendon system, have been reported by Hohenbichler and Rackwitz (1983), Grigoriu (1983), Melchers (1983), and Ryu and Yun (1991). In those studies, loads and resistance are treated as time invariant random variables.

In general, the TLP is subjected to stochastic or time-varying loading during service life. Therefore, the reliability problem may be formulated by the first passage concept (Lin, 1967; Nigam, 1984). In this case, the evaluation of the expected domain crossing rate of the system limit state surface is the most important task. Veneziano et al. (1977), Ditlevsen (1983), and Shinozuka et al. (1986) presented a method for the evaluation of the expected domain crossing rate of multidimensional Gaussian processes.

In this study, a reliability analysis model for a rectangularly shaped TLP against tendon failure is developed by using the domain crossing concept of the random tensile stress in the tendons. Two failure conditions are considered: exceedance of the ultimate tensile capacity and occurrence of negative tension. The case of the negative tension in the tendons is considered, since the high impulsive stresses may be induced after slacking of the tendons. Using those conditions, the system limit state is defined in terms of the TLP motions in the vertical plane, i.e., motions from heave, roll, and pitch. Those motions affect the tension in the tendons more significantly than surge, sway, and yaw. A severe storm event with a long duration is represented by its maximum significant wave height and its buildup and decay process, which is modeled by multiple segments of stationary sea states (Hamilton and Ward, 1974; Haring and Heideman, 1978; Anderson et al., 1982). Each sea state is represented by the wave height spectrum and its duration. The maximum significant wave height of the severe storm event is treated as a random variable with a lognormal distribution. The ultimate strength of the tendon material is treated as a random variable with a Weibull distribution.

In order to investigate the validity of the present reliability model, example analysis is carried out for two hypothetical structures: TLP-I and TLP-II. TLP-I consists of six vertical columns, and its structural properties are similar to those of the Hutton TLP (Ellis et al., 1982; Tetlow and Leece, 1982; Allen et al., 1982; Ocean Industry, 1984). TLP-II is composed of four columns, and its structural properties are similar to those of the Snorre TLP (Almeland et al., 1989; Marthinsen, 1989). Reliabilities of the two TLPs are evaluated for a hypothetical North Sea storm condition. Then, the results are compared with those of other reliability models. Numerical experiments are performed to investigate the sensi-

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