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Consideration of Freak Waves for Design of a Jack-Up Structure

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Abstract

To ensure adequate safety of marine structures in extreme weather, it is conceivable that standards are needed that account for the characteristics of ultimate limit seastates based on wave conditions with a return period higher than 100 years. Such standards must include an analysis of the reserve strength available when a marine structure is subject to an extreme event of a freak wave. For the generation of freak waves traditional potential flow methods are not well suited to accurately predict wave loads, because phenomena such as wave run-up on the structure's legs and impact-related loads on the hull are not accounted for. Therefore, wave effects were predicted with advanced computational fluid dynamics techniques. The purpose here was to determine the safety level under freak wave conditions. We selected a typical mobile self-elevating drilling unit stationed the North Sea and investigated its structural response under survival conditions and, in addition, under two extreme wave conditions representing freak waves. Based on a comparison of the resulting stresses with the structure's rule based design capability, we assessed the reserve strength capacity still available under freak wave conditions.

Introduction

Marine structures, such as mobile offshore drilling units, are designed to operate at different locations throughout the world under varying environmental conditions. To assess their structural strength and design safety, two loading conditions are generally investigated, namely, the operating condition and the survival condition. For both loading conditions, the unit's operating manual generally specifies limiting environmental parameters, such as maximum wave height, current velocity, and wind speed for the given water depth. It is assumed that these environmental parameters are known for the operating location of the rig and that weather forecasts are reliable enough to allow sufficient reaction time to prepare for worsening weather conditions.

Weather forecasts do not give notice of freak waves arising under extreme weather conditions; that is, such waves occur unexpectedly. The occurrence of a freak wave could be treated as an accident, similar to an earthquake. From this point of view, it would be rational to require the structure to remain standing and that critical structural components remain intact to prevent global failure. Under these circumstances, with all safety factors equal to 1.0, plastic deformation may be acceptable to avoid failure (ultimate strength).

A global loss of the structural integrity or collapse of the platform can be caused by different failure mechanisms, such as overstressing of the legs or the leg supporting elements in the hull structure, buckling of the legs, exceeding the maximum holding capacity of the jacking system, or even overturning of the platform.

An extremely high (freak) wave attacking a marine structure not only increases wave loads on legs and, hence, base sheer dramatically. In connection with limited available airgap, this wave also induces high loads to the hull of the structure. While loads on the hull increase the leg bending loads and, consequently, the overturning moment, wave-induced impact loads on the hull bottom, apart from local effects, reduce the righting moment of the structure as they act against gravity loads. Our objective was to investigate whether the safety margin of a typical marine structure operating in the North Sea is adequate to withstand a freak wave.

As a first approach, we selected conditions that led to increased wave loads acting primarily on the legs, while loads on the hull were small. This jacking height was consistent with standard operating conditions for this unit.

It may be necessary to supplement present design guidelines [1, 2] and rules, e.g. [3], by survival design procedures that include wave parameters leading to freak waves with extremely high and steep crests. Recorded wave data with maximum wave heights greater than 2.5 times the significant wave height suggest that freak waves are serious events that should be considered in the design process [4]. Although their probability of occurrence is small, they are physically possible [5, 6]. In the context of design safety, we analyzed the reserve strength available when a marine structure is subject to an extreme event of a freak wave.

In this paper we investigated a typical self-elevating (jack-up) drilling unit subject to freak waves of varying height. We determined the structure's stress level under these conditions, compared the results with the structure's rule based design