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A framework to efficiently calculate the probability of failure of dynamically sensitive structures in a random sea

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ABSTRACT

The growing interest in the use of offshore platforms in deeper waters and harsher environments, as well as the desire to extend the operation of existing structures beyond their design lives, is increasing attention on the assessment of the response and failure of these units under extreme storm loading. Such assessments of dynamically sensitive structures are complicated by their dynamic response combined with the random nature of extreme waves. This paper proposes a practical method for the estimation of (i) the extreme response statistics and (ii) the probability of failure of dynamically sensitive offshore structures in a given sea-state. The proposed method accounts for the random nature of a sea-state by the structured use of multiple Constrained NewWaves in combination with the Monte Carlo method. Analyses of a sample mobile jack-up structure show that the probability of failure can be efficiently calculated for even the most nonlinear and dynamically responsive offshore structures.

1. Introduction

The underlying philosophy of conventional methods for the design of offshore structures that are subjected to environmental loads is to assure that they can safely withstand a load level that represents a certain return interval (e.g., 100-year event). These methods provide criteria for acceptance or rejection; however, they do not quantify the reliability under extreme loadings. In recent years, there has been an increasing demand for quantitative predictions of the failure rate of offshore structures. This is mainly due to two reasons: the desire to employ these structures in deeper waters and more hostile environmental conditions and the requirement to extend the operation of existing offshore structures beyond their design lives.

Failure occurs when the extreme response of the structure exceeds the threshold of the overall ultimate limit state(s). Therefore, assessing the probability of failure requires a precise estimate of the "extreme response" as well as the "ultimate limit state" of the structure. These are difficult to determine for offshore structures because of the large number of associated uncertainties.

The inherent randomness of waves in the ocean is one of the main sources of uncertainty. Deterministic regular wave theories that are widely used to calculate wave loading, such as the Airy wave theory, assume that all of the wave energy is concentrated in one frequency component rather than across the broad spectrum of the ocean environment. This assumption provides an unrepresentative response. To achieve more realistic simulations of the wave loads, it is essential to incorporate all of the frequency components and therefore the randomness of the water surface. On the other hand, simulating many hours of a random storm in real time is a computationally time consuming process, particularly because only a few of the waves in each time series are capable of producing the extreme result. In this case, a shorter time period with a logical combination of crest elevations can be used to simulate the extreme responses for the expected wave size within the sea-state. This can be done using the NewWave (Tromans et al., 1991) and Constrained NewWave (CNW) (Taylor et al., 1997) theories for the calculation of wave loads on offshore structures (Cassidy et al., 2001 and Cassidy et al., 2002).

The environmental loads that are applied on offshore structures, and particularly the forces exerted by waves across the structure, are dynamic. For offshore structures with natural periods that approach the peak wave periods of the sea-state, referred to as dynamic sensitive platforms, such as jack-ups or slender jackets, the contribution of the dynamically amplified environmental loads to the total response of the structure is significant. For these dynamically sensitive structures, the extreme response may either occur from an extreme sea-state or lower sea-states where significant dynamic amplification of the structural response occurs (Karunakaran, 1993). Furthermore, the extreme response is

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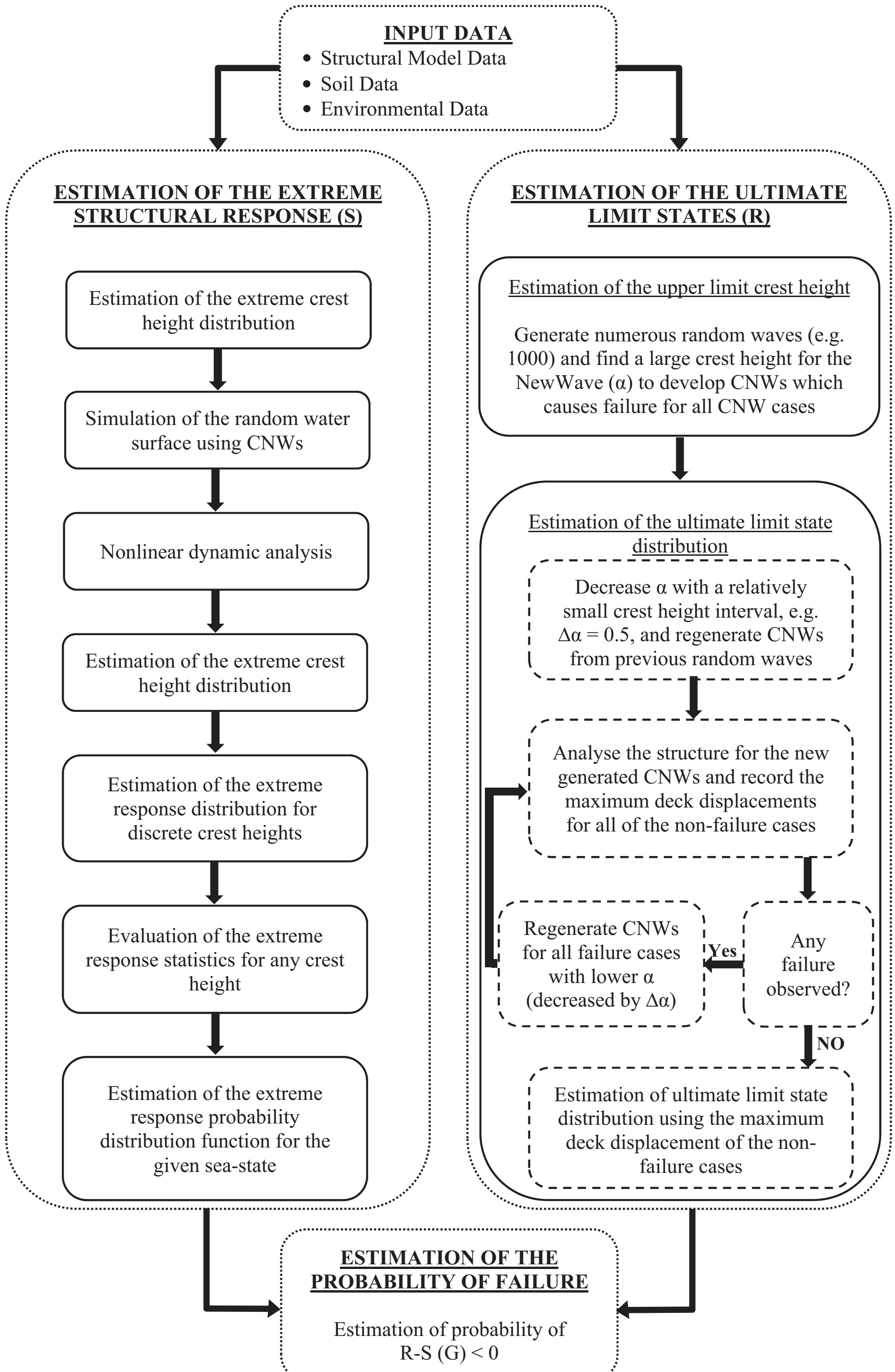

Fig. 1. Logical scheme for the estimation of the probability of failure.

not necessarily dictated by the extreme crest elevation event within a given sea-state.

Relatively few methods have been presented in the literature to calculate the probability of failure of dynamically responding offshore structures in extreme storms, and these methods usually use simplifications in the wave modelling as well as in the estimation of the failure criteria. Most previous studies have used regular wave theories and failure thresholds that are defined based on the maximum base shear to evaluate the probability of failure of offshore platforms through static pushover analyses. For example, based on this approach, Sigurdsson et al. (1994) estimated the probability of failure of a jacket platform using the fifth-order Stokes wave theory, and Van de Graaf et al. (1996) estimated the failure probability of a jack-up platform using the NewWave theory. These methods include neither the randomness of the sea-state nor dynamic effects in the estimation of the response and failure of the structure.

Cassidy et al. (2003) used CNW theory and the dynamic time history analysis method to calculate the statistical response of a sample jack-up platform. In their study, the exceedence of the