A Probabilistic Approach for Mud Mat Stability Analysis

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ABSTRACT

Subsea structures are typically supported on mud mat type foundation systems. Traditional approaches for mud mat foundation stability analysis consider calculating the factors of safety using the classical methods given in API RP 2A or the more recent API RP 2GEO. Due to the inherent uncertainties in soil properties and subsea structure forces, conservative factors are generally required, consequently resulting in over-designed mud mat systems. In the present study, a probabilistic response analysis of a mud mat type foundation system is conducted. The effects of uncertainties in the soil properties are evaluated and quantified. Specifically, DNV RP C207 is utilized for the statistical representation of the soil. An approximate analytical approach is proposed to solve for the response probability density function (PDF). Further, the probability of failure is derived directly from the response PDF. A numerical example is presented to illustrate the simplicity of the proposed approach and the results are compared to simulations performed using the Monte Carlo method. In addition, the importance of uncertainty modeling and stochastic-based analysis approaches in the context of subsea systems are discussed.

KEY WORDS: Probabilistic; Reliability; Mud Mat; Offshore; Shallow Foundation; Monte Carlo Simulation; Random; Stochastic.

INTRODUCTION

Offshore structural systems often exhibit random characteristics due to inherent uncertainties in offshore loading conditions (i.e. wind, wave, earthquake etc.), soil conditions, operating conditions (i.e. high pressure high temperature, HPHT) and system material properties. In order to realistically capture the system behavior the inherent randomness must be appropriately modeled. This requires a suitable uncertainty quantification methodology with concepts and methods of mathematical statistics and probability theory (e.g. Ang and Tang, 2007). Stochastic procedures have been shown to provide a sound frame work for a rational treatment of uncertainties (Schüeller 2007). Numerous probabilistic approaches have been developed that realistically capture uncertainties in the design of offshore systems (Eltaher et al. 2008; Gazis 2011; Gazis 2012). An aim of the current work is to develop a methodology to quantify the uncertainties exhibited in soil properties for mud mat foundation design. Classical foundation stability analysis approaches, as presented in the governing codes, consider deterministic methods where variations in soil properties are usually taken into account by either selecting low, average or high values. Thus, inherent uncertainties in mud mat design using the classical approaches are considered just intuitively. Soil data used as a basis for foundation design are usually burdened with uncertainty, both in terms of natural variability and in terms of limited amounts of data (aleatory and epistemic uncertainties). The classical deterministic methods do not explicitly take into account the uncertainties and consequences of failure (e.g., loss of life, cost, environmental disaster, etc.), thereby, resulting in over- or under-designed foundation systems. Stochastic based methods provide a more realistic treatment of the uncertainties inherent in foundation analysis.

Deterministic methods can easily be extended by applying statistical and probabilistic concepts. The powerful Monte Carlo simulation (MCsim) method allows for the straightforward use of deterministic analysis procedures (Spanos and Zeldin, 1998). However, a well-known disadvantage of the MCsim method is the extensive computational cost required. Therefore, it is advantageous to develop approximate analytical approaches to address the aforementioned multi-disciplinary challenges in engineering mechanics (e.g. Kougioumtzoglou and Spanos, 2009; Spanos et al. 2011; Spanos and Kougioumtzoglou, 2012; Kougioumtzoglou and Spanos 2012; Kougioumtzoglou and Spanos, 2013) in order to reduce computational time. Specifically, an analytical probabilistic approach for mud mat foundation design is proposed herein which proves to be efficient and yields results comparable to those obtained in simulations.

CLASSICAL APPROACH TO FOUNDATION STABILITY ANALYSIS

The governing design codes used for offshore foundation design, API RP 2A and the more recent API RP 2GEO, recommend the classical approach for foundation stability analysis. This approach is generally based on the bearing capacity equation for failure of a vertically loaded strip foundation on a uniform Tresca soil (Terzaghi, 1943) combined...