International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 16, No. 2, June 2006, pp. 138–145

Reliability Calculation of RC Offshore Structures Under Extreme Wave Loading

H. Karadeniz*
Department of Civil Engineering, Delft University of Technology, Delft, The Netherlands

In this paper, a general formulation of the section capacities of a circular RC tubular cross-section is first presented assuming that the strain-stress relation of the concrete in the compression zone is simply modelled as a bilinear function with ultimate values given in Eurocode 2. It is also assumed that the concrete works only in the compression zone. In the cross-section, tension stresses are carried by the reinforcement. Having presented a general formulation of the extreme bending moment and normal force of an RC monopod offshore tower subjected to wave loading, uncertainties in both section capacities and loading terms are presented. Then, a reliability calculation of the cross-section is performed to find out the reliability index. In this calculation, the balance of the normal force is used to determine the concrete compression zone during the reliability iteration, and the failure function is defined on the basis of the section capacity and applied bending moments on the cross-section. Variation of the reliability index with various parameters is investigated, and most sensitive uncertainty variables are determined.

INTRODUCTION

Reinforced concrete (RC) structures have been alternatively used at early stages of offshore structural engineering in moderately deep-water environments (Watt, 1978; Huslid et al., 1982) and may still be used for gas and oil production, and perhaps for observation purposes. Even for deep-water environments, RC structural components or systems are an alternative solution for a stable structural configuration, such as a floating concrete platform's hulls and pontoons (Haug and Fjeld, 1996), in harsh weather conditions. The concept of a mobile offshore base (Rognaas et al., 2001) is another application of RC in offshore environments. Beyond these uses, concrete piles have also been commonly used as foundation elements to support offshore structures such as bridges, oil rigs and floating airports (Eicher et al., 2003). A concrete gravity structure, which works in the same manner as a simple pad foundation, resisting overturning by keeping the resultant load, may be used when seabed conditions are not suitable for piling, and their large cellular base may also be used as a storage facility for recovered oil or gas. Long RC pontoons and columns, which have circular cross-sections, behave more or less as beams carrying mainly bending moments, normal and shear forces, which are produced from wave loading as internal member forces. Since loading in offshore environments is continuously time-dependent, the fatigue phenomenon in the long term becomes a major design criterion, and consequently the fatigue reliability has been an important research topic (Karadeniz et al., 1982; Tricklebank et al., 1982). In this case, the structural behavior is dynamic, which is predicted by numerical analysis for the design purpose. It may be verified with test results of the model studies (Swan et al., 1997) or, later during the service period, analytically predicted response characteristics can be compared with those obtained from observations of the response of prototype structures (Langen et al., 1998). However, under an extreme wave condition, the deformation responses and internal member forces reach high levels at a specific time so that resultant stresses (tension for the reinforcement, and compression for the concrete) must remain below ultimate allowable stresses. The extreme member forces are obtained as the largest amplitudes of the corresponding dynamic response, which can result in a collapse mode or a failure mechanism of the structural system with multiple members. This happens especially with steel offshore structures. For RC offshore structures, system failure occurs when a member cross-section fails, i.e. if the section forces (internal forces) exceed the ultimate resistance of the section. Internal member forces are calculated from applied external wave forces under an extreme sea condition, and the resistance capacity of a cross-section is calculated depending on material and cross-sectional properties. They contain various uncertainties mainly from the lack of exact wave information, loading model and member cross-sectional properties. Since RC is a complex and nonlinear structural material, there are additional uncertainties in working and allowed ultimate stresses (Kappos et al., 1999; Lu and Gu, 2004). Thus, a reliability analysis is required to find the safety measure of the member. Such an analysis is carried out from a failure function based on both compression and tension stress criteria under an eccentric normal force (bending moment and normal force). In this paper, a failure function of an RC tubular cross-section is constructed first, in which resistance of the cross-section is calculated on the base of a bilinear stress-strain relation of the concrete. Then, as an example, the calculation is made of the extreme bending moment and normal force of a monopod tower at the bottom, which constitute loading terms of the failure function. In this study, the total shear force, foundation slippage and overturning reliabilities are not considered. Only the reliability of an RC cross-section with extreme external loading terms is considered, and in the calculation of the cross-section capacity, the ultimate strains and stresses are taken from the Eurocodes. The effective height of the concrete compression zone is determined from one of the failure criteria, based either on the normal force or the bending moment equilibrium.

*ISOPE Member.

Received February 24, 2005; revised manuscript received by the editors January 11, 2006. The original version (prior to the final revised manuscript) was presented at the 15th International Offshore and Polar Engineering Conference (ISOPE-2005), Seoul, June 19–24, 2005.

KEY WORDS: RC offshore structures, reinforcement ratio, monopod tower, RC section capacity, compression zone, extreme wave forces, uncertainty modeling, reliability index.

CALCULATION OF FORCE AND MOMENT CAPACITIES OF RC TUBULAR CROSS-SECTIONS

Here we calculate the normal force and moment carrying capacities of an RC tubular cross-section assuming that the stress-strain