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Practical Fatigue Calculation for Offshore Structures Based on Efficient Wave Spectrum Inputs

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ABSTRACT

By adopting different numbers discrete frequencies as well as making the frequency spacing with uneven distances as the wave energy inputs and calculating the nonlinear dynamic response in time domain, the current paper presents a procedure for calculating the fatigue damage of offshore structures due to wave loading. By applying this approach into the fatigue calculation of a typical jacket structure, the directional effects and the peak enhancement of waves on the fatigue damage of the jacket structure were first identified. Furthermore, the parameters such as the number of sample points of the adopted wave spectrum, and, the length of time steps in the HHT-α time integration algorithm were also investigated. It is found that, in the reasonable range of wave peak enhancement, both the total and directional wave induced fatigue damage are not sensitive to the variation of wave enhancement amplitude in JONSWAP wave spectrum. The fatigue damage of selected positions on the jacket structure is mainly caused by the waves from certain directions. It is not sensitive to the variation of the number of wave spectrum input as well as the time step length below certain limits. It is not only dominated by the wave height, but also highly influenced by the waves with low modal period and the locations of the members relative to the sea surface. The free vibration of the jacket contributes significantly to the fatigue damage. The time step length should be carefully chosen to save the computation time as well as the computer memory without losing sufficient accuracy. Compare to the traditional wave energy spectrum input (the frequency spacing $\Delta\omega$ in the wave energy spectrum has equal distance), the new wave spectrum input approach is more efficient for calculating the fatigue damage. The nonlinear dynamic analysis approach presented in the current paper has been successfully applied in several industry projects for the life time extension of offshore installations subject to dynamic wave and wind loads.

KEYWORDS: Fatigue; jacket structure; directional effects; wave spectrum; wave peak enhancement; nonlinear dynamics.

INTRODUCTION

Offshore structures are designed to resist continued wave loading which may lead to significant fatigue damage on individual structural members, and other types of loads due to severe storms, corrosion, fire and explosion etc. The fatigue life is one of the major concerns for the offshore tubular structures since the utilization of tubular members give rise to significantly high stress concentrations in the joints. Most steel offshore support structures are three dimensional frames fabricated from tubular steel members. This gives the best compromise in satisfying the requirements of low drag coefficients, high buoyancy and high strength to weight ratio (Narayanan and Robert, 1991). The most common used offshore structure is jacket structure, which comprises a prefabricated steel support structure (jacket) extended from the sea bed (connected with piles at sea bed) to some height above the water surface level, and a steel deck (topside) on the top of the jacket. It is reported by Stacey and Sharp (2007) that fatigue cracking has been a principal cause of damage to North Sea structure and in service experience has shown that there have been several incidents of fatigue cracking requiring repair. In some cases, fatigue cracking has led to member severance, resulting in a consequent reduction in overall structural integrity.

By modelling a rotationally symmetric structure as a vertical circular cylinder, Vugts (2005) studied the influence of the wave directions on the fatigue life of this simplified cylinder. He shows that the reduction in fatigue damage is 50% for unidirectional seas and 40% for spread sea conditions. However, for a realistic structure and data of wave environment, this conclusion is unlikely to be representive.

In the current study, by adopting different number of inputs at discrete frequency of the wave spectrum, and making the frequency spacing with uneven distance, the effects of wave directions, parameters in the wave spectrum, the significant wave height, and the modal wave period on the fatigue damage of a jacket structure are identified. Note the fact that the frequency domain analysis can hardly properly take the non-linear load effects induced from the Morison's equation, the variation of the water surface causing the intermittency of the wave loading on members in the splash zone, and large structural deformation into account, and also because the power spectrum of the critical stress due to the dynamic wave loading may not be narrow banded, in the current study, the stress history in time domain is calculated for each wave load cases with respect of direction, period and wave height. The number of cycles presented in the simulated time histories is then obtained by rainflow counting algorithm. The Miner's rule is therefore adopted to calculate the fatigue damage under each wave loading case.

DESCRIPTION OF THE ADOPTED WAVE SPECTRUM

The wave environment comprises sea states, which are random processes described by random wave model using wave spectrum. The model may be visualized as the summation of a large number of periodic wavelets, each of these wavelets has its own direction, amplitude and frequency.

In shallow waters with limited fetch and for extreme wave conditions, JONSWAP spectrum developed by the Joint North Sea Wave Project