A Novel Lumping Block Method for Fatigue Damage Assessment of Mooring Chain

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ABSTRACT
Fatigue damage assessment of mooring chains applied by long-term wave loads is of great importance. This paper explores a new lumping block strategy to give an assessable guideline on the calculation of equivalent significant wave height and spectral peak period in each block of the wave scatter diagram. The fatigue damage of mooring chains is then computed in time-domain method using these wave parameters, which has a benefit to the improvement of computational efficiency by simplifying the sea states. The effectiveness and accuracy are validated by conducting a numerical model of the mooring system of a semi-submersible platform.

KEY WORDS: Fatigue damage; lumping block method; mooring chain; wave scatter; equivalent code.

INTRODUCTION
For an offshore mooring/riser system which is exposed to a multitude of sea states during its service life, fatigue damage is one of the main damage styles and the fatigue damage assessment is of great importance during the engineering design. However, the coupled response of the offshore platform and mooring/riser system in the harsh ocean environment is strongly nonlinear. As a result, the fatigue damage assessment of mooring chains or risers is very difficult. The fatigue damage is accumulated over a prolonged duration from numerous sea states described by a scatter diagram which delineates the joint statistics between the wave height and a characteristic period (Low and Cheung, 2012). The spectral method and the time-domain analysis method are commonly used during the fatigue damage analysis.

The spectral method is a stochastic approach which is based on some assumptions. For example, load analysis and the associated structural analysis are linear, and the short-term stress variation in a given sea state should follow the Rayleigh distribution. The Rayleigh distribution method only relates to the narrow band random process whose bandwidth parameter is less than 0.5 (Gao and Moan, 2008). However, for the mooring and riser system under the combined action of wind, wave and current, the nonlinearities of the wave frequency (WF) and low frequency (LF) line tensions are significant and the response spectra are always wide-band random processes (Hu et al., 2009). For a simple wide-band random process, the Rayleigh distribution for the response peak values will result in a conservative estimation of the fatigue damage (Low, 2011). Therefore, many scientists, including Wirsching (1980), Rice (1944), Kim (2007), Benasciutti (2005) and Braccesi et al (2005) and so on, have done much work to calculate the cycle counting correction factor for a wide-band process to modify the spectral method. For bimodal and trimodal Gaussian processes, several frequency-domain combination rules (Jiao and Moan, 1990, Fu and Cebon, 2000, Gao and Moan, 2006, 2007, Low and Cheung, 2012) are available and Benasciutti and Tovo (2005) discussed and compared some of them.

In the time-domain analysis method, coupled dynamic analysis in time domain is performed for each given combination of wave height and period and it can consider the effect of non-linearity. Therefore, the fatigue damage can be accurately estimated from the total WF and LF time series of mooring line tensions in a straightforward manner based on the rainflow cycle counting method (Matsuishi and Endo, 1968, Rychlik, 1987). The accuracy of the fatigue damage prediction is benchmarked against the result from the time-domain analysis (Low, 2011). However, its calculation procedure is pretty complicated and computationally expensive, because the coupled dynamic analysis must be executed for all the sea states in the wave scatter in principle. In order to expedite the computation, a common practice which is the lumping of sea states into blocks is recommended by DNV design code (DNV, 2005) and Sheehan et al. (2006), while there is no consensus on an effective lumping strategy and the level of discrepancy arising from blocking has not been investigated so far (Low and Cheung 2012).

The primary objective of the present paper is to develop a new strategy based on the spectral method to make the time-domain analysis process of offshore structure fatigue life assessment more efficient. This present method adapts a new lumping strategy to give an assessable guideline on the calculation of equivalent significant wave heights and spectral peak periods in each wave scatter block. To this end, the remainder of this paper is organized as follows. At first, preliminaries and the traditional methods of fatigue analysis are described. Then, the new lumping block method of simplifying the sea states based on the spectral method is proposed. At last, a case study is conducted to verify the new developed method via the comparison with the full scatter method and another method recommended by DNV (2005).

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