The Effects of Wind Modeling Considerations and Wind Direction on an Accurate Fatigue Life Assessment of High Rise Tubular Structures

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ABSTRACT

The fatigue damage of a structure is much more sensitive than the stress amplitude to the variation of the load and structure modelling. An appropriate calculation method must then be carefully selected to estimate the fatigue life. By presenting a practical approach for calculating the wind induced fatigue of a typical high rise tubular structure based on the joint probability with regard to wind speed and its main direction, the current paper assesses the effects of the wind direction, across wind and wind grid size on the high cycle fatigue of the structure. In each time step of the dynamic response calculation, the large deformation effects and the wind induced drag forces due to the updated structural deformations are taken into account. It is concluded that, the directional wind effects on the fatigue damage mainly depends on the orientation of the structure, the location and the support condition of the selected joints, and the relative probability of occurrence for the high winds speed in each direction. Furthermore, the across wind components are proved to be a significant contributor on the fatigue damage and can not be ignored. The fatigue damage is also found to be rather sensitive to the wind grid size for generating the wind fields. The wind fatigue calculation procedure presented in the current paper can be widely adopted on the similar study on high rise tubular structures.

KEY WORDS: High cycle fatigue; along wind; across wind; wind direction; nonlinear dynamics; HHT-a method; industry practice.

INTRODUCTION

Wind loading is by its nature dynamic and therefore normally induces vibrations at the structure’s natural frequencies. These vibrations produce fluctuating stresses which lead to the fatigue damage accumulation and can cause the structural failure without exceeding the design wind actions. At the global level the lateral wind load comprises in order of 10% and 25% of the total lateral load for fixed and floating platforms, respectively. While only very few researchers have studied the individual module contribution to the overall wind load for the design of offshore platforms (Gomathinayagam, Vendhan and Shanmugasundaram, 2000). Under extreme wind loading, the structure may reach ultimate strength and lead to the local or global structural failure. This requires substantial repairing or even replacement. Damage to the deck structures due to extreme wind loads has been reported by Kareem and Smith (1993).

Quite a few pieces of research work have been reported concerning the wind induced fatigue. Repetto (2005) proposed a method that is applied to several different bimodal processes which are usual in dynamic response of structures. Based on a bimodal representation of the alongwind induced stress power spectral density functions, Repetto and Solari (2006) formulated a counting method to estimate the fatigue damage for only alongwind actions on structures. Since the wind-induced fatigue is sensitive to moderate wind velocities for which stable or unstable atmospheric conditions can occurs (Panofsky and Durton, 1984), Repetto and Solari (2007) evaluated the wind-induced fatigue by taking the stable, unstable and neutral condition of wind field into account and applying this approach to the fatigue calculation of a steel chimney. By including the viscoelastic dampers in the modelling, Palmeri and Ricciardelli (2006) had studied the fatigue life of structural components of tall buildings due to the buffeting response.

Since the directional effects of wind on the structural response may give engineer with better understanding of the structural response with regard to wind resistance, their influences on the dynamic structural response have been studied by Davenport (1977), Simiu and Filliben (1981), and Wen (1983) using simplified structure models. The later two pieces of articles conclude that the worst direction approach used for evaluating the wind induced response may significantly overestimate the response. It should be noted that for a complex structure like a high rise flare boom, a simplified structural modelling may lead to an inaccurate estimation of the fatigue damage.

Because the frequency domain analysis can not properly take the nonlinear load effects, large deformation as well as the plasticity into account, and also because the power spectrum of the critical stress due to the dynamic wind loading may not be narrow banded initiated from the influence of the background components of incident turbulence (Gu, Xu, Chen and Xiang, 1999), crosswind induced vibrations, wind directional effects and structural damping etc, the inappropriate use of frequency domain based spectral methods developed for Gaussian processes may then significantly underestimate the fatigue damage contribution (Sarkani, Kihl and Beach, 1994). However, the spectral methods based on non-Gaussian process are still under development. This is because that if stress time history cherish a greater probability of occurrence, the worst direction approach used for evaluating the wind induced response may significantly overestimate the response. It should be noted that for a complex structure like a high rise flare boom, a simplified structural modelling may lead to an inaccurate estimation of the fatigue damage.

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