Fatigue analysis of structural members due to wind action

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The classical fatigue analysis of structural elements relates a constant amplitude load to the number of cycles to failure following an empirical relationship, such as the Whöler curve. This theory originates from the mechanical industry, where regular loading events on structural elements are common. For structural systems exposed to wind loading, failure mechanisms of structural members or connections due to fatigue are related just as much to the turbulent properties of the wind than to the wind intensity. Consequently, predictions of fatigue failure from the classical constant amplitude loading analysis may differ significantly from random vibrations induced by wind action.

Following the procedure recommended by the Eurocode design of steel structures, an estimation of the number of cycles to failure for dynamic loading is determined according to the Miner Rule. The methodology is centered on a rainflow analysis of the loading time series, where a histogram of the complete range of amplitudes is compiled and applied individually to the Whöler curve. The sum of the damage ratio for each individual loading cycle gives an estimate of the total number of cycles to failure. This methodology assumes each loading cycle can be considered as an independent event and fatigue damage accumulation is linearly related to the load cycle ratio. However, experimental studies suggest the linear damage rule may give an overly conservative prediction of the fatigue life of materials when subjected to random loading (Fatemi & Yang, 1998).

This article presents an alternative approach to fatigue analysis of structural materials subjected to dynamic wind loading. The methodology follows the Manson and Halford theory, which assumes a non-linear damage behavior, given that crack growth is a two-stage process, by treating loading cycles during crack initiation and crack propagation as separate events and applying a non-linear relation to the damage curve approximation. The cumulative damage is consequently determined by considering the sequence of the loading history.

Comparisons of the proposed methodology with predictions according to Miners Rule will be presented based on wind tunnel pressure measurements recorded on the Bicentenario Towers, Mexico. Simultaneous pressure measurements at 77 locations on the North Tower are integrated to a climate model of the site to obtain an estimate of the full-scale spatial and temporal correlation between measurements at each tap. A representative time series of an axial load on a structural member is derived based on applying a representative influence coefficient and tributary area to each of the pressure tap measurements on the tower.

Given that the proposed methodology considers that the turbulent component of the wind governs the total number of cycles to failure, special consideration must be given to the correct simulation of the turbulence in the wind tunnel and correct implementation of the wind climate analysis in the methodology. The uncertainties associated to these two aspects will also be discussed.

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