Wavelet Ridge Analysis of Nonlinear Dynamic Spar Responses

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ABSTRACT

In this work it is demonstrated that the wavelet ridge technique is applicable for tracking the time-dependent frequencies and corresponding amplitude envelopes of natural modes of spar platforms. This preliminary study examines the case where nonlinear mooring line stiffness induces time-dependent frequency behavior for a numerically modeled spar platform. Free decay tests of the spar are performed and the wavelet ridge technique is applied to track the instantaneous frequencies of the surge and pitch modes. Finally, frequency tracking of the natural modes of a spar platform subject to irregular wave loading is considered.

KEY WORDS: Wavelet Analysis, Spar Platform, Nonlinear Oscillator

INTRODUCTION

In recent years, significant research has been directed toward the numerical prediction of spar responses and in determining the importance of various nonlinearities. Early contributions to the understanding of the modern spar concept are contained in the literature; Van Santen and DeWerk (1976), Glanville et al. (1991), and Horton and Halkyard (1992) are examples. Since the early ’90s, a significant body of work has been performed at the Offshore Technology Research Center (OTRC). Kim et al. (1998) provide a good summary of the research conducted over the past decade at the OTRC. Coupled time domain simulations (Ran and Kim (1996)), frequency domain simulations (Weggel (1997)), experimental testing of scale models in the OTRC wave basin (Spar Model Test Joint Industry Project (1995)), and system identification techniques (Yoo et al. (1997)) have all been applied in the pursuit of understanding the linear/nonlinear behavior of spar platforms. This work has added to the knowledge of spar behavior and has shown the importance of various associated nonlinearities. Typically the prediction of spar responses at steady state were sought (even if time domain simulations were conducted). However, relatively little effort has been made to directly quantify how nonlinearities affect the spar’s behavior with respect to time.

The approach in this paper is to model a typical spar for use in the Gulf of Mexico. Nonlinearity of spar responses is observed based on a change in the spar’s natural frequencies with respect to its linear natural frequencies. (Linear natural frequencies can be estimated by observing the natural frequencies of the structure under low level excitation using traditional spectral techniques or by observing the frequencies of oscillation at the end of a free decay test where the amplitudes of oscillation are sufficiently low). The change in natural frequencies of a spar is important for several reasons:

1. It provides an indication of the presence of nonlinear behavior with respect to time.
2. It is useful for the accurate prediction of VIV responses where the natural frequency of a particular response mode must be known with sufficient accuracy so that reasonable comparisons to the Strouhal number can be made.
3. It enhances frequency domain analyses where it is important to modify the natural frequency of the structure to be consistent with the level of applied loading.
4. It indicates damage due to breakage of a mooring line or localized yielding of structural members.
5. It may provide additional insight into the stability of the dynamical system.

The Fourier transform is not an effective approach for quantifying time-dependent changes in natural frequency because it eliminates all time information. However, a common approach to obtain information about time-varying frequency in a signal is to compute the Windowed Fourier Transform or Short-Time Fourier Transform (STFT) (Chui, 1992), which is to ‘split’ the fluctuation into consecutive constant size windows in time and then Fourier transform the fluctuations in the individual windows. The ‘Gabor transform’ (Chui, 1992), for example, is a STFT that applies a Gaussian for the time windowing function. A drawback to the STFT is that once the window size is chosen, the time and frequency resolutions are constants independent of frequency. According to Kaiser (1994), the STFT introduces a rather arbitrary characteristic scale into the analysis, namely, the width of the time window. Fluctuations much longer or very much shorter than this window are not well resolved by the analysis. A key advantage of the wavelet transform is that the window size, hence resolution, is adaptive (actually proportional) to the frequency range being examined. For the analysis of very low