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Performance and System Identification of Deepwater Offshore Platform During Extreme Events Based on Field-Measured Data

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As a first try in the offshore industry, this paper introduces a spectrum estimation method, called the Thomson spectrum estimation method, to effectively identify the structural system and the period of an offshore platform based on recorded topsides acceleration time histories. This method uses several leakage-resistant orthogonal windows, and the centered discrete-time Fourier transforms of these orthogonal windows appear in the solution of a particular form of a prolate spheroidal differential equation of the first order. Also investigated and presented is the performance of a deepwater platform in the Gulf of Mexico under major hurricane conditions (i.e., Hurricanes Ivan, Katrina, Rita and Ike) in terms of estimated displacement trajectories and recorded accelerations of the topsides.

INTRODUCTION

For the dynamic analysis and structural design of deepwater offshore platforms, the most critical structural dynamic characteristics are the natural periods of the platform. The Thomson spectrum estimation method, which consists of an approximate solution to the fundamental equation (i.e., a linear Fredholm's integral equation of the first kind) of spectrum estimation, is introduced in this paper to effectively identify the structural system and period of the offshore platform based on the recorded topsides acceleration time histories. Thomson's method has the advantage of being consistent, having high resolution and high estimation capacity, and of not being hampered by the usual tradeoff between leakage and variance. This method uses several leakage-resistant orthogonal windows that are discrete prolate spheroidal sequences (DPSS). The centered discrete-time Fourier transform of DPSS is called a discrete prolate spheroidal wave function (DPSWF), which appears in the solution of a particular form of the Sturm-Liouville problem, or the prolate spheroidal differential equation of the first order.

The typical platform motion monitoring system, back in the 1990s, was based on accelerometers instead of the GPS systems used today to record the displacement trajectories of platforms under hurricane conditions. A base-line correction method is used to assess the performance of a deepwater platform in the Gulf of Mexico under major hurricane conditions (i.e., Hurricanes Ivan, Katrina, Rita and Ike) in terms of estimated displacement trajectories and recorded accelerations of the topsides. The estimated nonlinear correlation between the maximum topsides' displacements and accelerations of the deepwater platform will be addressed and emphasized as well.

SHORT-TIME THOMSON'S MULTIPLE WINDOW SPECTRUM ESTIMATION

The dynamic response time history of an offshore platform under hurricane wave conditions is typically considered to be a stationary random process, and the corresponding hurricane wave amplitude is also described mathematically by a stationary wave amplitude spectrum (e.g., a PM or JONSWAP spectrum in the Gulf of Mexico). However, under hurricane conditions, the recorded time history data of the offshore platform's responses and the wave amplitude have shown time-varying or nonstationary characteristics in terms of intensity and period. In order to identify the time-varying characteristics of the platform's response or the structural system, the time-varying or evolutionary power spectral density of the platform's response would be required and essential. A method called short-time Thomson's multiple window spectrum estimation is introduced here to successfully estimate the time-varying power spectrum density of the recorded platform topsides' acceleration time history.

The short-time Thomson's spectrum estimation method (Conte and Peng, 1997) is briefly outlined as follows. First, a time-moving window of size $N \cdot \Delta t$, $[w(n),\ n = 0, 1, \ldots, N-1]$, where Δt denotes the sampling time interval, is used to extract the local time series centered at time t_i, from the target platform topsides acceleration record, $[A(t_i),\ t_i = i \cdot \Delta t,\ i = 0, 1, \ldots, M-1]$. Thus, the local time series centered at t_i is:

$$\{S(t_i, n) = A[t_{i+n-(N-1)/2}]w(n), n = 0, 1, \ldots, N-1\} \qquad \text{(for } N \text{ odd)} \quad (1)$$

$$\{S(t_i, n) = A[t_{i+n-(N)/2}]w(n), n = 0, 1, \ldots, N-1\} \qquad \text{(for } N \text{ even)} \quad (2)$$

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KEY WORDS: DPSS, DPSWF, offshore, structure, hurricanes, spectrum estimation; system identification.