ABSTRACT

The change of modal parameters, including modal frequencies and mode shapes, has been used as the basis for various vibration-based damage detection methods. Under the assumption that stiffness-loss damages have occurred only at several structural members, this article develops a method for estimating the severity of those damaged members based entirely on a few measured modal frequencies. A steel offshore jacket structure model is chosen for the numerical example, where the “measured” modal frequencies are synthesized from using a finite element model. Numerical results indicate that the proposed method performs well under the noise-free situation. When only noisy measured frequencies are available, the proposed method is also able to properly estimate the damage degrees for essential structural members.

KEY WORDS: Damage assessment; Jacket structure; Modal frequency; Modal strain energy

INTRODUCTION

Widely used in offshore oil and gas exploitation have been steel jacket-type platforms, which are the most common kind of offshore structures. As always, jacket-type platforms during their service life continually accumulate damage as a result of the action of various environmental forces. Clearly the development of robust techniques for early damage detection and assessment is crucial to avoid the possible occurrence of a catastrophic structural failure. Since the cumulative damage may cause the change on the mass and/or stiffness distribution of the structural system, consequently the modal properties of the structural system, such as natural frequencies and mode shapes, may alter as well (Doebling et al., 1998).

A typical modal-based damage assessment method can be divided into two parts: (1) the modal parameters extraction algorithm to estimate modal frequencies and mode shapes; and (2) the algorithm to perform damage assessment from the estimated modal properties (Ewins, 2000). Extracting modal parameters from measurements has been a subject of constant improvement and enhancements, and the interested reader is directed to the textbooks in the area of modal analysis (Maia et al., 1997).

In civil engineering applications, because dynamic testing of large civil structures can only be performed in the field and applying energetically and artificially generated excitation is technologically and/or economically prohibited, it is often necessary to extract modal parameters exclusively from output signals (James et al., 1995; Brincker et al., 2001).

The alteration of modal parameters can be used as the basis for various vibration-based damage detection methods. In the particular application to jacket-type offshore structures, more recent publications include modal strain energy method (Kim and Stubbs, 1995), artificial neural networks method (Mangal et al., 1996; Surace and Worden, 1998), modal strain energy decomposition method (Li et al., 2006), etc. Those methods were demonstrated to be more effective on localizing damaged members, but assessing the damage severity remained problematic.

Under the assumption that the damaged members have been located, the focus of this article is on estimating the severity of those damaged members based entirely on a few measured modal frequencies. The proposed damage assessment approach is an extension of the cross-model cross-mode (CMCM) method, which was originally developed for the finite element model updating (FEMU) when one or more spatially complete vibration modes were measured (Hu, et al., 2007a; Hu, et al., 2007b). The CMCM method was so named because it involves solving a set of linear simultaneous equations in which each equation is formulated based on the product terms from two same/different modes associated with the analytical and experimental models, respectively. While the original CMCM method is a non-iterative method and very cost-effective in computational time, it also has the advantage of preserving the initial model configuration and physical connectivity of the updated model. In addition to those features, the CMCM method also has other advantages over traditional model updating methods, including: (1) it does not require the measured mode be paired with the same mode of the analytical model, and (2) the measured modes can be arbitrarily scaled.

The original CMCM method, however, has a major application restriction that the measured modes must meet the spatial completeness requirement. In the literature, there are two typical ways of overcoming the spatial incompleteness difficulty, namely reducing the analytical model order (model reduction) or expending the measured mode shapes (mode expansion). A common engineering approach to achieving either model reduction or mode expansion is to apply a coordinate transformation matrix between master and slave DOFs, such as the Guyan reduction/expansion scheme (Friswell and Mottershead 1995). While no rotational degrees of freedom were measured at an offshore jacket platform, Li et al. (2008) applied the CMCM method, together with the Guyan