Chapter 13

Infrastructure Sustainability: Damage Assessment in Multiple-Girder Composite Bridges Using Vibration Characteristics

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ABSTRACT

Assessing the structural health state of urban infrastructure is crucial in terms of infrastructure sustainability. This chapter uses dynamic computer simulation techniques to apply a procedure using vibration-based methods for damage assessment in multiple-girder composite bridges. In addition to changes in natural frequencies, this multi-criteria procedure incorporates two methods, namely, the modal flexibility and the modal strain energy method. Using the numerically simulated modal data obtained through finite element analysis software, algorithms based on modal flexibility and modal strain energy change, before and after damage, are obtained and used as the indices for the assessment of structural health state. The feasibility and capability of the approach is demonstrated through numerical studies of a proposed structure with six damage scenarios. It is concluded that the modal strain energy method is capable of application to multiple-girder composite bridges, as evidenced through the example treated in this chapter.

INTRODUCTION

Bridges are normally designed to have long life spans. Changes in load characteristics, deterioration with age, environmental influences and random actions may cause local or global damage to these structures. Continuous health monitoring of structures will enable the early identification of distress and allow appropriate retrofitting to prevent potential catastrophic structural failures.

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In recent times, structural health monitoring (SHM) has attracted much attention in both research and development. SHM, as defined by Housner et al. (1997), refers to the use of in-situ, continuous or regular (routine) measurement and analyses of key structural and environmental parameters under operating conditions. Its purposes are to warn of impending abnormal states or accidents at an early stage so as to avoid casualties, as well as to give maintenance and rehabilitation advice. SHM encompasses both local and global methods of damage identification (Zapico & Gonzalez, 2006). In the local case, the assessment of the state of a structure is done either by direct visual inspection or by using experimental techniques such as those using acoustic emission; ultrasonic, magnetic particle inspection; radiography, and eddy current. A characteristic of all these techniques is that their application requires a prior localization of the damaged zones.

The limitations of the local methodologies can be overcome by using vibration-based (VB) methods, which give a global damage assessment. Health monitoring techniques based on processing vibration measurements basically relate to two types of characteristics: the structural parameters (mass, stiffness, damping) and the modal parameters (modal frequencies, associated damping values and mode shapes). As the dynamic characteristics of a structure—namely, natural frequencies and mode shapes—are known to be functions of its stiffness and mass distribution, variations in modal frequencies and mode shapes can be an effective indication of structural deterioration. Deterioration of a structure results in a reduction of its stiffness which causes the change in its dynamic characteristics. Thus, damage state of a structure can be inferred from the changes in its vibration characteristics (Doebling et al., 1996). Usually, there are four different levels of damage assessment (Rytter, 1993): damage detection (Level 1), damage localization (Level 2), damage quantification (Level 3), and predication of the acceptable load level and of the remaining service life of the damaged structure (Level 4).

The amount of literature is quite large for treating single damage scenarios, especially in simple structural elements, but limited for multiple damage scenarios. Also, most existing methods are based on a single criterion and only a few authors demonstrate these methods in slab-on-girder bridges. These methods, depending only on changes in frequencies and mode shapes, are limited in scope and may not be useful in several realistic situations. It is observed that changes in natural frequencies alone may not provide enough information for integrity monitoring. It is common to have more than one damage case giving a similar frequency-change characteristic ensemble. In the case of symmetric structures, the changes in natural frequency due to damage at two different symmetric locations are exactly the same. Alternatively, no changes in the mode shapes could be detected if the mode had a node point at the location of damage (Farrar & Cone, 1995). There is thus a need for a more comprehensive method of damage assessment in structures.

Fast computers and sophisticated finite element programs have enabled the possibility of analyzing hitherto intractable problems in structural engineering, while also simplifying the analyses of other problems. Dynamic computer simulation techniques are used to develop and apply two non-destructive damage detection parameters, along with changes in natural frequencies, for damage identification in slab-on-girder bridges. These parameters—the modal flexibility and the modal strain energy—are based on the vibration characteristics of natural frequencies and mode shapes, and their variations with the health of the structure. The application of the approach is demonstrated through numerical simulation studies of a single-span, simply supported truss bridge with eight damage scenarios corresponding to different types of deck and truss damage.
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