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INSPECTION

Damage Assessment of Bridge Structures Using Measured Acceleration Data by A System Identification Scheme (IABMAS' 02)

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ABSTRACT

Various damage assessment schemes based on system identification (SI) have been extensively investigated for bridge structures during the last few decades[1]. In the SI-based damage assessment scheme, stiffness properties of a structure is estimated by minimizing the least square errors between measured and calculated responses. Structural damage is identified based on the estimated stiffness properties. Either static or dynamic responses of a bridge have been used in the SI-based damage assessment scheme.

The modal analysis approaches have been widely adopted to detect structural damage using measured acceleration of structures[2,3]. The modal analysis approaches, however, suffer from drawbacks caused by insensitiveness of modal data to changes of structural properties. In addition, the damping properties of structures cannot be estimated by the modal analysis. To overcome the drawbacks of the modal analysis approaches, this paper presents a system identification scheme in time domain using measured acceleration data.

The proposed algorithm is based on the minimization of an error function with respect to the structural parameters. The error function is defined as the time integral of the least square errors between the measured acceleration and the calculated acceleration by a mathematical model. The structural damping is modeled by the Rayleigh damping in SI. The regularization technique is employed to overcome the ill-posedness of the SI scheme[4,5]. This paper presents a new regularization function that is defined as the time integral of the variations of system parameters with respect to time.

It is assumed that accelerations of a given structure are measured from a dynamic test at selected observation points, and that the stiffness properties and damping properties do not change during the test. The minimization problem for the proposed SI algorithm in the time domain is defined as follows.

$$\underset{\mathbf{x}}{\text{Min}}\ \Pi(t) = \frac{1}{2}\int_0^t \|\tilde{\mathbf{a}}(\mathbf{x}) - \bar{\mathbf{a}}\|^2\, dt + \frac{\lambda}{2}\int_0^t \left\|\frac{d\mathbf{x}}{dt}\right\|^2 dt \ \text{ subject to } \ \mathbf{R}(\mathbf{x}) \le 0 \qquad (1)$$

where $\mathbf{x}$, $\tilde{\mathbf{a}}$, $\bar{\mathbf{a}}$, λ and $\mathbf{R}$ are a system parameter vector, the calculated acceleration and the measured acceleration at observation points, regularization factor and constraint vector, respectively, with $\|\cdot\|$ representing the Euclidean norm of a vector. The system parameter

vector includes both stiffness and damping parameters. The first term and the second term of (1) represents the error function and the regularization function, respectively. The regularization function, which represents the variance of system parameters in time, is added to the error function to overcome ill-posedness of inverse problems. The regularization factor has critical effect on the stability of the solution of the minimization problem. The optimal regularization factor is determined by the geometric mean scheme (GMS)[6]. The recursive quadratic programming with a line search technique is employed for the optimization.

The validity and accuracy of the proposed method are demonstrated through an experimental study on a shear building model and a numerical simulation studies on a truss bridge. The numerically generated data with noise are utilized as measured acceleration for the numerical simulation. It is shown that the Rayleigh damping approximates the actual structural damping reasonably. It is confirmed that the damping characteristics should be adjusted properly according to measured acceleration data. Although it is not possible to form the exact damping matrix of a structure, it is very important to approximate the damping parameters to the real damping as closely as possible.

The proposed method can estimate the stiffness properties accurately even though the damping characteristics are approximated by the Rayleigh damping. The proposed method yields accurate solutions for numerically generated data and the experimentally measured data. It is believed the proposed method provides a very powerful engineering tool to identify dynamic characteristics of structures and to detect damage in structures using measured accelerations.

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