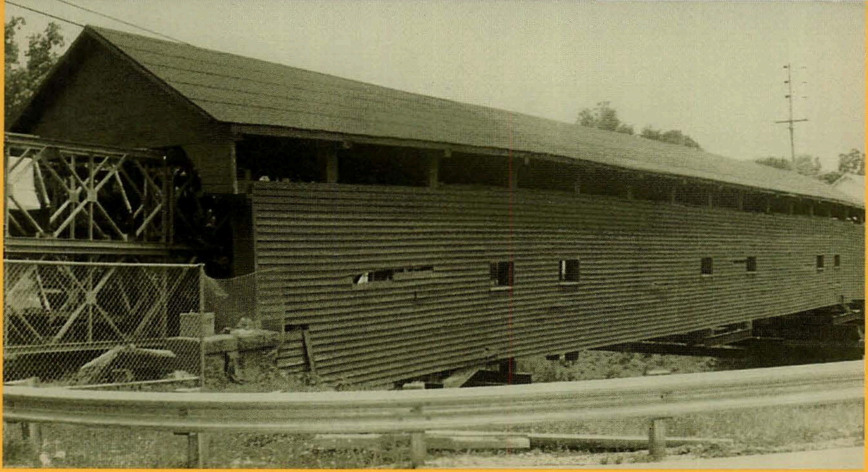

NONDESTRUCTIVE TESTING METHODS FOR CIVIL INFRASTRUCTURE

Edited by Hota V.S. GangaRao

NONDESTRUCTIVE TESTING METHODS FOR CIVIL INFRASTRUCTURE

A collection of expanded papers on nondestructive testing from Structures Congress '93

Approved for publication by the Structural Division of the American Society of Civil Engineering

Edited by Hota V.S. GangaRao

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ABSTRACT

This proceedings, Nondestructive Testing Methods for Civil Infrastructure, contains papers presented in the sessions on nondestructive testing (NDT) for the 1993 Structures Congress held in Irvine, California on April 19-21, 1993. The purpose of this proceedings is to bring the modern NDT techniques that are being used in the aerospace and medical industries into the civil infrastructure. To this purpose, these papers deal with new developments of NDT methods and experiences for testing of materials, building components, and highway structures. Some specific topics covered are vibration monitoring, acoustic emissions, and ultrasonics.

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FOREWORD

The papers included in the following proceedings are the full-length papers presented in the sessions on nondestructive testing (NDT) for the structures congress 1993 held in Irvine, California on April 19–21, 1993. Each of the papers included in these proceedings has received two positive peer reviews. All these papers are eligible for publication in the ASCE Journal of Structural Engineering.

While it is apparent that the aerospace industry has received more attention than the civil infrastructure in the application of NDT, the civil infrastructure including highway bridges and pavements require new technology or improvement of existing technology in terms of longer service-life to provide reliable quantitative information to insure the safety of our structures. Because of the neglect, infrastructure deterioration rates have led to productivity losses, user inconveniences, and severe decrease in ratings or load limitations. Hopefully, the use of modern NDT techniques can alleviate some of these problems. The purpose of these proceedings is to bring in the modern NDT techniques that are being used in the aerospace and medical industries into the civil infrastructure. To meet the above purpose, this document includes technical papers dealing with new developments of NDT methods and experiences for testing of materials, building components, and highway structures.

The focus of these proceedings is to increase the awareness of the various nondestructive evaluation methods that are now the subject of research of material science and engineering.

The research issues addressed herein are strength, deformability, chemical degradation, and fracture of structural materials, components, and systems. The goals are to predict, control, and improve the integrity of materials in service and prevent catastrophic failures.

The research challenges do occur commonly in sensor technology for making the necessary measurements (*nano and micro level*), sometimes under hostile field conditions and with limited access. Also, NDT research demands on quantification of nondestructive evaluation signals so that the information about the state of the material provided by such techniques can be used with confidence in condition assessment and remaining life estimates of a facility. The topics discussed in these proceedings include vibration monitoring, acoustic emissions, ultrasonics, and others.

Hota V. S. GangaRao, Director, Professor,
West Virginia University,
Morgantown, West Virginia

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Contributed Papers

MODAL ANALYSIS TECHNIQUE FOR BRIDGE DAMAGE DETECTION

K.C. Chang[1], A.M., Z. Shen[2], S.M., and G.C. Lee[3], M., ASCE

Abstract

The dynamic responses of a wide-flange steel beam with artificially introduced cracks were studied analytically and experimentally. Frequencies, displacement mode shapes (DMS), and strain mode shapes (SMS) are determined in both the analytical and experimental analyses. Modal damping ratios are also extracted in the experimental study. The sensitivities of the change of the modal parameters due to the damages are studied. The absolute changes in mode shapes were used to determine damage locations. Results show that the damage of a beam can be detected and located by studying the changes in its dynamic characteristics. SMS shows higher sensitivity to local damage than DMS does.

Introduction

The modal parameters of a structure are functions of its physical properties (mass, stiffness, and damping). Structural damage will result in changes of the dynamic properties [Mazurek and DeWolf 1990, M. Biswas et al. 1989, Salane and Baldwin Jr. 1990, and Yao et al. 1992]. Therefore, damages to the structure in general will result in changes of the physical properties of the structure, and hence the modal parameters. Presently, measuring and analyzing dynamic response data have been recognized as a potential method for determining structural deterioration.

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[1] Professor, Department of Civil Engineering, National Taiwan University, Taipei, Taiwan. (Formally of Department of Civil Engineering, State University of New York at Buffalo)

[2]Graduate Research Assistant, Department of Civil Engineering, State University of New York at Buffalo, Buffalo, NY 14260

[3]Professor and Dean, School of Engineering and Applied Science, State University of New York at Buffalo, Buffalo, NY 14260

Fatigue cracks constitute the most common reason for stiffness degradation of steel bridges. However, the changes in frequencies, damping ratios, and DMS associated with the development of these cracks are minimal and are difficult to distinguish from experimental noise. In this paper, SMS was used for damage detection of girder bridges. The rational for using SMS for structural diagnosis is as follows: Structural damage will always result in stress and strain redistribution. The percent of the changes in the stresses and strains will be highest in the vicinity of the damage, and hence the damage zone can be identified. An experimental study was conducted by using a model girder bridge. The changes in DMS, SMS, natural frequencies, and modal damping were recorded simultaneously as various cracks were introduced to the girder. A finite element model was also developed to obtain analytical results so that a comparison could be made with the experimentally observed data.

Theoretical Bases of Modal Analysis

The basic concept of analytical and experimental modal analyses was developed by Bishop and Gladwell [1963], Clough and Penzien [1975], Ewins [1986] and Bemasconi and Ewins [1989].

For an N-Degree-Of-Freedom system, the general equation of motion may be written as:

$$[m]\{\ddot{x}(t)\}+[c]\{\dot{x}(t)\}+[k]\{x(t)\}=\{f(t)\} \quad (1)$$

where [m], [c], and [k] are the N x N, mass, viscous damping, and stiffness matrices, respectively. {x(t)} and {f(t)} are the N x 1 vectors of time-varying displacements and forces.

Suppose a proportionally damped structure is excited at point p with the responses recorded at point q, the component of the Frequency Response Function (FRF), h_{qp} is given by:

$$h_{qp}=\sum_{r=1}^{N}[{}_rY]\,\phi_{qr}\phi_{pr}=\sum_{r=1}^{N}\frac{\phi_{qr}\phi_{pr}}{K_r-\omega^2M_r+i\omega C_r} \quad (2)$$

where Φ is the component of the mode-shape matrix $[\Phi]$ and

$$[{}_rY]=\left[\frac{1}{K_r-\omega^2M_r+i\omega C_r}\right]_{diag} \quad (3)$$

is an N x N diagonal matrix. In Eq. 3, M_r, C_r, and K_r are the components of the generalized matrices [M], [C], and [K] respectively.

The strain field may be defined as follows:

$$[\psi]=[D]\,[\phi] \quad (4)$$

where $[\psi]$ is the matrix of strain mode shapes, [D] is an N x N matrix of linear differential operator which translates the displacement field to the strain field, and

[Φ] is the DMS matrix.

The general expression for the components of the Strain Frequency Response Function (SFRF) and then be expressed as:

$$S_{\varepsilon p}(\omega)=\sum_{r=1}^{N}\frac{\Psi_{\varepsilon r}\Phi_{pr}}{K_r-\omega^2 M_r+i\omega C_r} \quad (5)$$

where

$$\Psi_{\varepsilon r}=\sum_{j=1}^{N}D_{\varepsilon j}\Phi_{jr} \quad (6)$$

It is clear from Eq. 2 and Eq. 5 that in experimental crack simulation, the displacement and strain mode shapes corresponding to different modes can be determined from the resonant magnitudes of different points on the Frequency Response Function curves.

After obtaining the FRF, the real and imaginary parts are extracted. Circle-fit analysis is then used to obtain the modal parameters. A set of measured data points around the resonance at ω_r is used for the circle fit. The modal parameters can be obtained from the modal circles.

Referring to Fig. 1, the damping of the mode can be obtained by:

$$\xi_r=(\omega_a^2-\omega_b^2)/(2\omega_r^2(\tan(\theta_a/2)+\tan(\theta_b/2))) \quad (7)$$

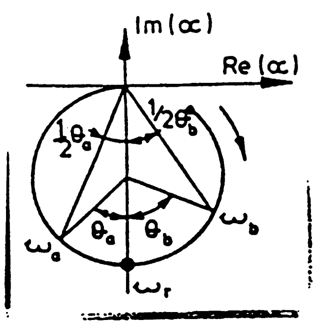

Fig.1 Fitting Circle

Where, ω_b is a frequency below the natural frequency, ω_a is a frequency above the natural frequency, and θ_b and θ_a are related phase angles.