Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia Computer Science 8 (2012) 461 – 466
Procedia
Computer Science

New Challenges in Systems Engineering and Architecting
Conference on Systems Engineering Research (CSER)
2012 – St. Louis, MO
Cihan H. Dagli, Editor in Chief
Organized by Missouri University of Science and Technology

A combined soft computing-mechanics approach to inversely predict damage in bridges.

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Abstract

This study aims to facilitate damage detection in concrete bridge girders without the need for visual inspection while minimizing field measurements. Beams with different material parameters and cracking patterns are modeled using mechanics-based ABAQUS finite element analysis software program in order to obtain stiffness values at specified nodes. The resulting database is then used to train an Artificial Neural Network (ANN) model to inversely predict the most probable cracking pattern. The aim is to use ANN approach to solve an inverse problem where a unique analytical solution is not attainable. Accordingly, simple span beams with 3, 5, 7 and 9 stiffness nodes and a single crack were modeled in this work. To confirm that the ANN approach can characterize the logic within the databases, networks with geometric material and cracking parameters as inputs and stiffness values as outputs were created. These networks provided excellent prediction accuracy measures (R^2 values > 99%). For the inverse problem, the noted trend shows that better prediction accuracy measures are achieved when more stiffness nodes are utilized in the ANN modeling process. It was observed that decreasing the number of required outputs immensely improves the quality of predictions provided by the ANN.

Keywords: Damage detection; Finite element analysis; Artificial neural network.

1. Introduction

Damage detection and structural health monitoring is a topic that has been receiving an increased attention from researchers around the world. A structure can accumulate damage during its service life,

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doi:10.1016/j.procs.2012.01.086

which in turn can impair the structure's safety. Damage detection techniques can be divided into local and global methods. Local methods require local measurements and provide information about a small region of the structure, while global methods use dispersed sensors to report the condition of the structure.

A promising approach to damage detection utilizes Artificial Neural Networks (ANNs) in solving this inverse problem. Masri et al. [1] proposed a method that relies on using vibration measurements from a healthy system to train the neural network for identification purposes. This network is then fed comparable vibration measurements from the same structure under different episodes of response in order to monitor the health of the structure. The network then delivers an indicator of damage in the structure.

Liu et al. [2] utilized back-propagation neural networks and computational mechanics to simulate the A-scan ultrasonic nondestructive testing. Neural networks were trained with the characteristic parameters extracted from surface responses. These networks were then used to classify and identify the type, location and length of the crack.

Xu and Humar [3] proposed a two-step algorithm that uses the modal energy-based damage index to determine the location of damage and an ANN to determine the extent or magnitude of the damage. This method depends on the fact that any damage in an element results in the reduction of its stiffness and affects the measured vibration modes. The location is first determined from the plots of damage indices for the elements in the model, then the damage extent is predicted with an ANN trained on simulated damage in elements and their corresponding damage indices.

In this study, a damage database for concrete beams with different parameters was generated using finite element modeling software ABAQUS. This paper investigates the viability of training a static Artificial Neural Network (ANN) with back-propagation learning algorithm on the generated databases to inversely predict a crack's depth, width and location in a simply supported concrete beam given the beam's geometric and material parameters.

2. Finite Element Modeling of a Concrete Beam with a Single Crack

For this study, a crack is modeled by a change in the cross-section of the simply supported beam as shown in Figure 1. The finite element mesh developed for this model is shown in Figure 2. A 2-node cubic beam in a plane element (B23) was chosen to model the beam segments in ABAQUS FEA. Additionally, a specified number of stiffness nodes was added to the model as shown in Figure 3. A defined load was applied to each stiffness node and the resulting displacement was obtained, then the stiffness at that node could be calculated. This was done for both the healthy and the damaged beams to determine the ratio of stiffness reduction at each node.

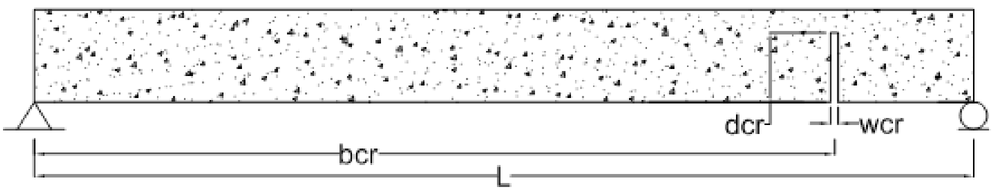

Figure 1. Actual concrete beam elevation