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RESEARCH PROJECT TITLE

FE-ANN Based Modeling of 3D Simple Reinforced Concrete Girders for Objective Structural Health Evaluation

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The Midwest Transportation Center (MTC) is a regional University Transportation Center (UTC). Iowa State University, through its Institute for Transportation (InTrans), is the MTC lead institution.

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tech transfer summary

Artificial neural networks (ANNs) can be used to evaluate bridge components, such as simply supported reinforced concrete T-beams, and this quantitative approach can be used to supplement traditional structural health monitoring (SHM) systems, making them more efficient and accurate.

Background

The deterioration of transportation infrastructure is an important issue worldwide, and aging bridges are a primary concern. While transportation agency staff and the traveling public recognize the importance of repairing and maintaining infrastructure, economic pressures necessitate doing so most efficiently. Over the past several decades, the most common and cost-effective method of evaluating bridge condition has been structural health monitoring (SHM).

Problem Statement

The most commonly applied SHM technique is visual inspection and condition rating. While less expensive than many alternatives, this method relies heavily on the availability of well-trained, qualified, and experienced personnel and largely qualitative damage evaluations.

Objective

The objective of this study was to develop an objective, quantitative method for evaluating damage to bridge girders by using artificial neural networks (ANNs). This evaluation method, which is a supplement to visual inspection, requires only the results of limited field measurements to operate.

Research Description

To develop this method, simply supported three-dimensional reinforced concrete T-beams with varying geometric, material, and cracking properties were modeled using Abaqus finite element (FE) analysis software.

- The modeling databases included beam models with between one and five cracks.
- The ratios of stiffness between cracked and healthy beams with the same geometric and material parameters were measured at nine equidistant nodes along the beam.

- Two feedforward ANNs utilizing backpropagation learning algorithms were then trained on the FE model database, with beam properties serving as inputs for both ANNs.
- The outputs for the first network consisted of the nodal stiffness ratios, and the sole output for the second ANN was a health index parameter, computed by normalizing the area under the stiffness ratio profile over the span length of the beam.
- With these databases in place, a practitioner can enter the measurements of cracks found in an actual beam in situ and the computer program can predict the health and stiffness of that beam.
- An extra step was taken to account for the reverse problem, where a practitioner inputs the geometric, material, and nodal stiffness ratios to come up with a prediction of the damage a girder suffers.
- One ANN was trained to predict the crack parameters using the full database developed to model the forward problem.
- A touch-enabled user interface was developed to allow the ANN models to be utilized for on-site damage evaluations.

Key Findings

- The ANNs displayed good prediction accuracies ($R^2 > 0.8$) even when predicting damage levels in beams with geometric, material, and cracking parameters dissimilar from those found in the training database.
- The damage prediction ANN achieved poor prediction accuracies with coefficients of determination (R^2) equal to 0.42.

Implementation Readiness and Benefits

Utilizing the two top-performing network architectures, the researchers developed a touch-enabled software application for use as an on-site bridge member damage evaluation tool in the field. The application was given the acronym BRIDGES, for Bridge Rating for Induced Damage in Girders: Evaluation Software. The application's outputs were validated as matching the ANN predictions.

The researchers developed a similar software application for the reverse problem/damage detection and use as an on-site damage prediction tool. This application tries to predict the crack configurations using ANN, based on the geometrical and material parameters, as well as the nine nodal stiffness ratios. This touch-enabled application was given the acronym DRY BEAM, for Damage Recognition Yielding Bridge Evaluation After Monitoring.

These applications will become even more useful with further development and the addition of more robust data.

For example, to make the applications more widely applicable and useful, researchers could investigate the effects that different beam widths have on crack prediction and add that data to the database. Additionally, researchers could add data from beams with more cracks, expand the data sets for beams with two through five cracks, and add angled cracks and additional beam configurations to the database.

The use of the ANN method for bridge health determination will require a paradigm shift, time, and resources; however, this technology can expand the number of people able to perform bridge health inspections, leading to more bridges being evaluated more quickly. Ultimately, increased numbers of inspections can lead to safer bridges.