Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 54(9) (2022) 671-674
DOI: 10.22060/ceej.2022.19812.7262

Identifying Damages in girders of Bridges Using Square Time-Frequency Distribution and Neural Network

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ABSTRACT: The detection of damage to structures has received much attention, especially in recent years. In this research paper, a new method for detecting damage in concrete girders of bridge decks is presented. Ease of use, high accuracy, and reduction of monitoring costs are the requirements for the new method. In this research, signal processing tools and artificial intelligence were used to extract damage-sensitive features so that the presence of damage, its intensity, and its location can be determined with very high accuracy based solely on the vibration signals received from a sensor. The accuracy is about 99%, and the error percentage is less than 1. Based on the proposed method, firstly, using the time-frequency function, the response signals from the structure were processed. The neural network was trained, using the processed data. To evaluate, validate and ensure the performance of the proposed method, the numerical model of the concrete girder and the numerical model of the Shahid Madani bridge in Tabriz under normal and disturbed conditions were used. The results show the high diagnostic accuracy of this method and the lowest error rate in determining the condition of the structure and the location of the damaged element.

Review History:

Received: Apr. 03. 2021
Revised: Oct. 16, 2021
Accepted: Oct. 17, 2021
Available Online: Feb. 28, 2022

Keywords:

Damage Detection
Health Monitoring
Neural Network
Square Time-Frequency Distribution
Bridge

1- Introduction

One of the most significant goals of existing bridges is to determine the characteristics of the bridge and identify possible damage [1, 2]. Nowadays, the repairing and maintenance of bridges and especially their structural components are more researched. However, many of the existing bridges designed in the past cannot withstand seismic loads and need to be evaluated and improved according to the new codes [3]. To strengthen the bridge against earthquakes, it is necessary to determine and identify the existing condition of the structure. Based on the existing conditions, the necessary analyzes are then performed, and needed solutions are presented [4]. Common and older methods of identifying damage, including observation methods and local nondestructive testing, have problems, risks, and shortcomings. For these cases, researchers have proposed other methods for monitoring the condition of structures, one of which is the basis for using vibration data. In general, health assessment and damage diagnosis methods include the two main processes of system identification and pattern recognition. The purpose of monitoring the health of bridges is to perform non-destructive field tests and analyze the response of the structure or part of it to detect the presence of structural damage or deterioration, its location, extent, and impact on the bridge performance before the bridge becomes inefficient [5-7]. Since bridge responses are nonstationary and their dynamic response to earthquakes is usually characterized by nonlinear behavior, the use of square time-frequency functions for signal processing and feature extraction has been used in this research [8].

In this study, the condition monitoring and control of bridges and their structural components are carried out in the shortest time and without affecting the operation. To identify damage in concrete girders of bridge decks, a new methodology was proposed.

2- Materials and Methods

In the research, an intelligent system that uses vibration data for damage detection is presented. In developing this system, every effort has been made to detect damage at the lowest cost and with the highest possible accuracy, as well as to provide the convenient and practical implementation. The proposed system consists of these three stages:

Data Collection: In this stage, vibration data are collected in the healthy and damaged states of the structure.

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Data Processing: in this stage, time-frequency plans are extracted and collected using the reduced interference distribution method (RID). The equation of RID for analytical signal x(t) is defined as follows [9]:

$$RID(t,\omega) = \int_{-\infty}^{+\infty} h(\tau) R_x(t,\tau) e^{-i\omega\tau} d\tau \quad (1)$$

where, t and τ are time and time lag, respectively. In addition, h(τ) is time smoothing window and $R_x(t,\tau)$ is the kernel defined as below:

$$R_x(t,\tau) = \int_{-\frac{\tau}{2}}^{\frac{\tau}{2}} \frac{g(\nu)}{|\tau|}(1+\mathrm{Cos}\frac{2\pi\nu}{\tau}) x(t+\nu+\frac{\tau}{2})x^*(t+\nu-\frac{\tau}{2})d\nu \quad (2)$$

in which, g(ν) is the frequency smoothing window and indicates the complex conjugate. In this research, the Hanning window was used to estimate the spectrum in the time-frequency functions.

Making Decision: In this phase, also known as the classification phase, the neural network is trained, and the state of the structure is identified.

In this study, square time-frequency functions are used together with a neural network to detect damage to concrete girders of bridge decks. For this purpose, a concrete beam is modeled, and its vibrations are recorded under the effect of the applied load. Then the model is damaged, the load is reapplied, and the response signals are recorded. It is worth noting that in addition to the desired damage in one area of the beam, the damage is also caused in different parts of the numerical model, and the above steps are performed for them. The response signals of the concrete beams are processed before and after the damage with a reduced interference distribution function, and the dynamic properties of the beams are extracted. The obtained properties are used to train the neural network. The neural network is trained to identify the damage and determine its position by introducing a new feature derived from processing the response signals of the concrete beam. To validate the above method, the structural results of Shahid Madani Bridge in Tabriz, which was studied for noise-free and noise-affected responses, were used. The capability, innovation, and possibilities of this method are underlined by the fact that although it is easy to use, it can only detect damage if the data from a sensor is used accurately and with an error rate close to zero.

3- Case Study and Dataset

Two numerical models were used to evaluate the proposed damage detection method. First, a simple concrete beam was studied. Then, to evaluate the proposed method comprehensively, the numerical model of the Shahid Madani Bridge in Tabriz was also used. The modeling of the Shahid Madani Bridge was done based on the as-built details prepared by the first author.

3- 1- Damage Scenarios

To study the damage detection method in the concrete deck of the bridge deck and the Shahid Madani Bridge, a different single damage scenario is considered for the failure of the numerical model. These failures are considered by reducing the stiffness of the elements in the numerical models. In this study, the number of elements is considered as the location of failure.

3- 2- Processing of The Response Signals

The response signals were recorded under the stimulus load before and after the damage. For signal processing, the reduced interference distribution was used as the desired function. Using this function, the processed response signals and time-frequency matrices are obtained. After processing and calculating time-frequency plans, the dynamic characteristics of the system were extracted.

3- 3- Determining The Severity and Location of The Damage in The Structure

In this phase, the training of the neural network starts using the time-frequency matrices. The search method was used to select the appropriate network, and the neural networks that minimize the error function were selected. Therefore, after training 25 networks at each stage, the network that had the least error was selected. Of all the neural networks created, the results of the network whose numbers are closer to 1 in the data control columns or closer to zero in the mean square error columns are considered the best-trained networks. This process is performed based on the number of neurons and the number of repetitions.

4- Conclusions

In this research, a new method for identifying damage in concrete beams of bridge decks was proposed. The proposed method uses the dynamic response of the bridge structure to detect damage. This method is based on using a quadratic time-frequency distribution and a neural network. Considering the existing experience in monitoring the condition of structures and the superiority of output-only methods, an approach that does not require measurement of the input force was chosen. In other words: In this study, based on the measured response of the bridge structure, its dynamic characteristics were extracted, and the damage was determined. Furthermore, since the approach used is based on output signals, it is unnecessary to build a numerical model of the bridge. In this study, a new method was proposed to determine the extent and location of damage to structures by minimizing the number of sensors used. To reduce the cost of monitoring, the responses of the structures were recorded using only one sensor. As the number of sensors decreases, the cost of software and hardware for condition monitoring is significantly reduced. A numerical model of a concrete girder and deck of the Shahid Madani Bridge in Tabriz was used to evaluate the proposed method. The obtained results indicate the optimal suitability of the proposed method and show its accuracy in diagnosing the extent of the health condition and localizing the damage. Due to its simplicity and performance, as well as its practicality, the proposed method can be used for measuring the condition of concrete girders of bridge decks.

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HOW TO CITE THIS ARTICLE
H. R. Ahmadi, A. M. Allahyari, H. M. Allahyari, Identifying Damages in girders of Bridges Using Square Time-Frequency Distribution and Neural Network , Amirkabir J. Civil Eng., 54(9) (2022) 671-674.

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