Damage Diagnosis of Steel Truss Bridges under Varying Environmental And Loading Conditions

Kundan Kumar and Prabir Kumar Biswas
Department of Electronics and Electrical Communication Engineering, Indian Institute of Technology Kharagpur, Kharagpur-721302, India.

Nirjhar Dhang
Department of Civil Engineering, Indian Institute of Technology Kharagpur, Kharagpur-721302, India.

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In this paper, we propose a damage detection and localization algorithm for steel truss bridges using a data-driven approach under varying environmental and loading conditions. A typical steel truss bridge is simulated in ANSYS for data generation. Damage is introduced by reducing the stiffness of one or more members of the truss bridge. The simulated acceleration time-history signals are used for the purpose of damage diagnosis purpose. Vibration data collected from healthy bridges are processed through principal component analysis (PCA) to find the reduced size weighted feature vectors in model space. Unknown test vibration data (healthy or damaged) finds the closest match of its reduced size model from the training database containing only healthy vibration data. The residual error between the spread of closest healthy vibration data and unknown test vibration data is processed to determine damage location and severity of the damage to the structure. A comparative study between a proper orthogonal decomposition (POD) based damage detection algorithm and proposed algorithm is presented. The results show that the proposed algorithm is efficient to identify the damage location and assess the severity of damage, called as the Damage Index (DI), under varying environmental and moving load conditions.

1. INTRODUCTION

Many infrastructures that have reached or are the end of approaching their design life are still under excessive repetitive use. These structures require continuous monitoring over their remaining service life. In general, the physical properties of the structure like mass, stiffness, damping coefficient, etc. change over time due to various factors such as aging effect, cracks, excessive load and other types of damage. This results in changes in modal properties and other structural behaviour.\(^1\) The vibration responses of the structure capture the effect of the changes in these properties. Bridge health monitoring attracted the researchers to the development of a vibration based health monitoring system to identify the damage on the bridge at the earliest possible stage using its dynamic behaviour analysis.\(^2\)–\(^5\) Doebling et al. have reviewed several strategies for vibration-based damage detection for bridges.\(^6\) A detailed study on different approaches implemented for Structure Health Monitoring (SHM) can be found in the literature.\(^7\),\(^8\)

In SHM, many researchers have addressed the damage detection problem as outlier detection/novelty detection in varying operational and environmental conditions.\(^9\)–\(^13\) Meruane and Heylen proposed a model-based damage detection approach to detect, locate and quantify the damage on a three span bridge under varying environmental conditions.\(^14\) In these methods, operational and environmental variabilities are considered as implicitly embedded in structural responses. Kim et al. have investigated the feasibility of traffic-induced vibration signals for damage detection in real steel truss bridges.\(^12\) Recently, train-induced vibrations of a simplified railway bridge model were used by Shu et al. to detect damage based on statistical properties of structural dynamic responses such as variances and covariances.\(^15\) However, operational and environmental variabilities are not considered, and they should be considered. Yarnold and Moon have established a relationship between temperature change and the resulting strains and displacement of the structure.\(^16\) They have evaluated their approach using long-term monitoring data from a long-span steel tied arch bridge. Li and Hao have successfully detected joint damage in a laboratory scaled steel truss bridge based on the time-frequency analysis of free vibration data.\(^17\) There is very limited work on damage diagnosis of steel truss bridges using traffic-induced vibration data under varying environmental conditions. In this paper, a damage detection approach is presented for steel truss bridges using the moving load response of the structure in varying environmental temperature and loading conditions.

In the last few decades, many bridge health monitoring systems have been implemented based on vibration signal analysis wherein the vibration signals are collected from more than 100 sensors placed on the bridge.\(^18\) These sensors produce a significant amount of vibration data. The analysis of all the vibration data together is a very crucial task. According to Cavadas et al., a data-driven approach is suitable to handle all these vibration signals simultaneously.\(^19\) The data-driven approach tracks the change in signal only; hence, it is well suited to capture the relevant information for continuous monitoring of bridge structures. They have applied a data-driven approach to the problem of detecting damage under varying load conditions and moving load measurements. They have used moving principal component analysis (MPCA) to find the discrimination between eigenvectors of the covariance matrices of the data corresponding to the undamaged and damaged structure for damage detection and severity measurement. However, they have not considered the change in vibration characteristics due to varying environmental conditions.