Silesian University of Technology
Faculty of Mechanical Engineering
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BRIDGE HEALTH MONITORING USING AUTOMATED FE MODEL UPDATING, SIGNAL PROCESSING, AND MACHINE LEARNING

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Preface

Bridge health monitoring plays an important role in ensuring the safety, reliability, and longevity of road and railway bridges. This book investigates bridge health monitoring using automated FE model updating, signal processing, and machine learning, which can be categorized as the following main points.

Intelligent data processing algorithms based on ANN and ANFIS are proposed to predict the dynamic behavior of Dębica railway steel arch bridge produced from dynamic responses of steel hangers during the passage of trains. Field data sets were collected from the vibration-based SHM system of the hangers and bridge deck over a nine-month period from December 2019 to September 2020. The input variables of the ANN and ANFIS models consist of RMS values of vibration signals installed on the hangers, and the output is RMS values of dynamic responses on each of the two bridge spans. The optimization of the ANN architecture based on the genetic algorithm is implemented to determine the number of neurons in the hidden layers of the ANN regression models. Optimized ANN prediction models have been shown to outperform ANFIS regression models among the six proposed strategies.

Data-driven applications of wavelet transforms, orbit-shaped analysis, and CNN using GoogLeNet are proposed for Dębica railway bridge health monitoring in Poland. Training and validation data sets are the dynamic behavior of the bridge deck recorded through an IEPE vibration sensor with a sampling frequency of 128 Hz from vibration-based SHM system during a nine-month period. Utilizing Morse, Morlet, and Bump wavelet, the vibration signal scalogram images are produced in the time-frequency domain as the input for CNN classification models, while the output is to predict health states based on the experimental tension force of eight hangers using label thresholds developed by the calibrated finite element model. Moreover, the vibration-based orbit-shaped image patterns, acquired through a bidirectional sensor on each hanger are processed with CNN classification models for automated hanger health diagnostic.

Diagnostic load testing refers to the use of the historical measured responses of the structure in field data to better understand its dynamic and static structural behaviors. The calibration of the full-scale FE model of the existing bridges plays an important role, in which the representative FE model of the actual structure is determined from the optimization procedures. The optimization variables are applied, including the cross-sectional and material properties calibrated through the GA and PSO methods in the MATLAB software, which interfaces with the FE modeling in the scripting of the SOFISTIK TEDDY and ANSYS APDL softwares automatically using static and dynamic responses in the field tests. The final updated FE modeling is used to apply truck or train load configurations according to bridge design standards, specifications, or codes, which can predict the load limits and overloads of the existing bridge structure more accurately and reliably. These proposed approaches can be applied to the RC bridge, steel-concrete composite bridge as well as the railway steel arch bridge.

The developed approaches of the bridge FE model calibration using field load testing and monitoring can equip the engineer with a useful tool to make evaluation decisions that require less time and improve its cost effectiveness. The SHM system of the complex heavy bridges would be tested in a more reliable way when the updated FE models are applied. The machine learning algorithms integrated into the data-driven vibration-based SHM system are useful solutions to analyze intelligent data processing as well as to predict the structural behavior under the different load events. It can keep a “remote eye” on bridge structures with the smart alarm system.

This book is based on my doctoral thesis, written under the supervision of Prof. Marek Salamak and Prof. Andrzej Katunin. The public defense of the doctoral dissertation took place on 29 October 2024 before the Doctoral Committee, which was appointed by the Discipline Council of Civil Engineering, Geodesy, and Transport.

I would like to thank my supervisors: Prof. Marek Salamak and Prof. Andrzej Katunin for their excellent guidance, encouragement, and patience throughout these studies.

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Nguyen Cong Duc

Contents