

Silesian University of Technology
Faculty of Mechanical Engineering
Department of Fundamentals of Machinery Design

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**BRIDGE HEALTH
MONITORING
USING AUTOMATED FE
MODEL UPDATING,
SIGNAL PROCESSING,
AND MACHINE LEARNING**

Gliwice 2024

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BibTeX

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@BOOK{, title = {Bridge health monitoring using automated FE model updating, signal processing, and machine learning}, publisher = {Politechnika Śląska, Katedra Podstaw Konstrukcji Maszyn}, year = {2024, author = {Duc Cong Nguyen}, volume = {163}, series = {Zeszyty Naukowe}, address = {Gliwice}}
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ISBN 978-83-60759-38-7

Publisher

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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.

I would like to express my deepest thanks and sincere appreciation to Dr. Grzegorz Poprawa for sharing and supporting field experimental data sets from the long-term vibration-based structural health monitoring system of Dębica railway steel arch bridge in Poland, and for his assistance and contributions in my conferences and papers as co-author.

I also would like to thank all the technicians in SUT's Lab and CADmost for their industrial projects of some bridge diagnostic load tests in Poland. I wish to extend my thanks to the whole "family" of the Department of Mechanics and Bridges (RB5), for having made my research journey.

I would like to thank the accredited national laboratory LASXD-162 of the Mien Trung University of Civil Engineering managed by the Ministry of Construction of Vietnam for providing data sets from field diagnostic load testing of some bridges, where I have been working as a lecturer and field engineer since 2010.

I am sincerely grateful to the reviewers: Prof. Krzysztof Dragan, Prof. Phong Ba Dao, and Prof. Mieszko Kuźawa for their positive, valuable, and constructive comments on my doctoral dissertation.

My gratitude is extended to Doctoral School of Silesian University of Technology; NAWA-Polish Government under PPN/FRC/2020/1/00034 for Polish language course at Cracow University of Technology and BPN/FRC/2021/1/00048 for the doctoral program at the Silesian University of Technology; as part of bilateral agreements and cooperation with the Vietnamese government for more financial support given to this work under 3416/QĐ-BGDĐT 04/11/2020; 4534/QĐ-BGDĐT 30/11/2021; Nr145/21-NG-LHS 21/6/2021; MienTrung University of Civil Engineering for salary support of the lecturer resource training program given to my study abroad.

Finally, a special thanks is extended to my wife, Nguyen Thi Ai Nuong, whose patience has remained steadfast for four years of my research work. Therefore, this doctoral thesis is dedicated to her; to my children: Nguyen Minh Phu and Nguyen Minh Nhat, who received less attention and love than they deserve; to my wife's mother Le Thi Xuan and father Nguyen Ngoc Anh, who have been taking care of my two sons; particularly to my mother Nguyen Thi Hoang and father Nguyen Van Hong, who are Vietnamese rice farmers with no scientific background but have always encouraged me, as well as my young sister and brother.

Nguyen Cong Duc

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