Hindawi
Shock and Vibration
Volume 2019, Article ID 2380616, 5 pages
https://doi.org/10.1155/2019/2380616

Editorial

Structural Health Monitoring through Vibration-Based Approaches

Giosuè Boscato,[1] **Luca Zanotti Fragonara**,[2] **Antonella Cecchi**,[1] **Emanuele Reccia**,[3] **and Daniele Baraldi**[1]

[1]*Iuav University of Venice, Venice, Italy*
[2]*Cranfield University, Cranfield, UK*
[3]*Sapienza University of Rome, Rome, Italy*

Correspondence should be addressed to Giosuè Boscato; gboscato@iuav.it

Received 11 December 2018; Accepted 12 December 2018; Published 17 February 2019

A promising method of assessing the safety of vulnerable structures is the application of vibration-based monitoring (VBM) systems. These allow observation of the global response for a structure, including damage detection, classification, and progressive development. In fact, dynamic monitoring systems have proven to be particularly suited for systems whose structural behaviours are strongly influenced by their geometric complexity or the inhomogeneity of their constituent materials. Moreover, because of its nondestructive and noninvasive nature, vibration-based monitoring can be safely applied to historical or damaged structures, which are potentially dangerous under other test conditions. Thus, the analysis of the modal behaviour can reveal structural weaknesses or deficiencies amplified or induced by unforeseen events. In fact, the monitoring of a set of appropriately chosen features jointly with the identification of the local and global structural weaknesses may reveal the effectiveness of safety and retrofitting interventions, as well as any progression of structural damage. Thanks to their noninvasive characteristics, VBM procedures are widely used, and several studies have addressed structural identification through the vibration data.

This special issue aims to explore structural health monitoring via vibration-based approaches, especially for complex systems. In welcoming interdisciplinary studies from across several scientific communities—including engineering, numerical modelling, seismology, and geotechnics—we hope to present studies from the breadth of the field and provide insights into its future development.

The main areas are covered by the special issue: (1) dynamic identification for model and data-driven approaches, (2) local and global damage detection, and (3) numerical, experimental, and physical modeling.

Among the 41 researches, which constitute this special issue, the main research topics addressed were damage identification, data-driven approaches applied to relevant case studies, and the operational-experimental modal analysis for the SHM. In detail, the researches carried out through procedures based only on statistical analysis of experimental dynamic parameters outline a new trend based on fast and reliable procedures for structural identification.

P. Zhang et al. study the fracture process of rock with acoustic emission related to sudden inelastic deformations. In detail, the rock stability assessment approach is established based on the chronological order of the characteristic acoustic emission phenomena, and then the rock stability was assessed using the proposed approach.

The study of Q. Xiong et al. proposes a method of integrating the vibration monitoring system of the axle box bearing with the underfloor wheelset lathe, where the integration scheme and work flow of the system are introduced followed by the detailed fault diagnosis method and application examples. Firstly, the band-pass filter and envelope analysis are successively performed on the original signal acquired by an accelerometer. Secondly, the alpha-stable distribution (ASD) and multifractal detrended fluctuation analysis (MFDFA) of the envelope signal are performed, and five characteristic parameters with significant stability and sensitivity are extracted and then brought into the least-squares support vectors machine based on particle swarm optimization to determine the state of the bearing quantitatively. The effectiveness of the method is finally validated by bench test data.

The work of P. G. Golanó et al. focuses on the structural design and performances of a unique optical test system (OTS) used for measuring metre-scale optical surfaces. The investigation was carried out using modal identification procedures. Two sets of results are presented, and both modal analysis of the entire OTS and the transmissibility function related to its use as an optical system are carried out and analysed. The results of the modal analysis highlight the natural modes of the entire OTS. Both numerical and experimental modal analyses were applied to the case study, and a model updating procedure was also proposed.

The energy transmission of the guided waves propagating in composite sandwich structures is investigated in a wide range of frequencies using numerical simulations by S. Shoja et al. The effects of different potential defects on the guided wave energy transmission are explored in such structures. Furthermore, the accuracy of homogenization methods for finite element modelling of guided wave propagation in sandwich structures is studied with the aim of reducing the computational burden of the simulations in the low range of frequencies.

A. Tessler et al. apply the inverse finite element method (iFEM) to reconstruct the displacement field of a shell structure, which undergoes large deformations using discrete strain measurements as the prescribed data. The iFEM computations are carried out using an incremental procedure where, at each load step, the incremental strains are used to evaluate the incremental displacements, which in turn update the geometry of the deformed structure. The incremental iFEM procedure is demonstrated to be sufficiently accurate in terms of reproducing the correct nonlinear character of the load-displacement curve even when a reduced number of strain sensors are used.

Z. Li and B. Shi propose the stochastic resonance (SR) to extract the weak fault characteristics, which are able to utilize the noise to amplify weak fault characteristics. Although classical bistable stochastic resonance (CBSR) can enhance the weak characteristics by adjusting the parameters of the potential model, when potential barrier height is adjusted, potential well width is also changed, and vice versa. With the simultaneous change of both potential well width and barrier height is difficult to obtain a suitable potential model for better weak fault characteristic extraction and further fault diagnosis of machinery. For this reason, the output signal-to-noise ratio (SNR) of CBSR is greatly reduced, and the corresponding enhancement ability of weak fault characteristics is limited. In order to avoid the shortcomings, a new SR method is proposed to extract weak fault characteristics and further diagnose the faults of rotating machinery, where the classical bistable potential is replaced with a bistable confining potential to get the optimal SR.

M. B. Bağbanc and Ö. K. Bağbanc study six historic two-storied timber-framed masonry structures dating from the nineteenth century in Bursa City. The physical, mechanical, and dynamic parameters of the studied structures are investigated, and the results are comparatively discussed showing that the use of different infill materials affects the dynamic behaviours of these structures.

F. Li et al. address the difficulty of fault feature extraction when multiple failures occur in the reducer through the variational mode decomposition that can be performed to decompose the vibration signal according to frequency, enabling separation of the vibration signals of the spur and planetary gears. The common fault features of these gears can be extracted from the spectrum of the amplitude demodulation envelope. To verify the effectiveness of this method, the authors first analysed a simulation signal and then utilized the experimental signals from a laboratory multistage reducer for verification.

The work of D. Wang et al. propose a new method to identify crack parameters in a rotor-bearing system based on a Kriging surrogate model and an improved nondominated sorting genetic algorithm-III (NSGA-III).

The goal of the paper of S.-Y. Ok et al. is to expand the multiobjective optimization approach developed for robust damage identification in order to facilitate its applications to more realistic bridge damage identification problems. Specifically, a benchmark problem on highway bridges, developed under the auspices of International Association for Bridge Maintenance and Safety (IABMAS), is investigated. Various issues regarding sensor noises, multiple measurements, and loading scenarios are addressed to improve the robustness of bridge damage identification.

W. Wan et al. propose a compound risk assessment by combining probabilistic analysis with a computational fluid dynamics (CFD) technique to numerically predict the potential cavitation of a high-speed flow in a chute spillway. Based on the local pressure and flow velocity of the nodes, the traditional cavitation number is introduced to characterize the possibility of cavitation. The distribution of cavitation numbers was obtained according to the numerical simulation of the flow field in an open spillway. The proposed numerical approach is economical and saves time; moreover, it can provide greater information about the potential cavitation region.

M. T. Kashani and S. M. Hashemi apply the Galerkin-weighted residual method to convert the coupled differential equations of motion of delamination beams to a discrete problem, where, in addition to the conventional mass and stiffness matrices, a delamination stiffness matrix, representing the extra stiffening effects at the delamination tips, is introduced. The linear eigenvalue problem resulting from the discretization along the length of the beam is solved to determine the frequencies and modes of free vibration. Both "free mode" and "constrained mode" delamination models are considered in formulation, and it is shown that the continuity (both kinematic and force) conditions at the beam spanwise locations corresponding to the extremities of the delaminated region, in particular, play a great role in "free mode" model formulation.

D. Tao et al. detect seismic damage of moment-resisting frame (MRF) structures through a data-driven method using the fractal dimension (FD) of time-frequency feature (TFF) of structural seismic dynamic responses at measured stories. The TFF is defined as the real part of Gabor wavelet transform of translational interstory displacement, and FD is used to give a quantitative value to describe the calculated TFF. Static condensation method is first used to reduce the degrees of freedom (DOFs) of MRF and to express the rotational displacements using translational displacements. For linear MRF, the FDs of TFFs at all stories are the same using the definition of TFF and modal superposition principle. For damaged MRF with plastic hinges at the ends of beams and columns, the force analogy method is implemented to establish the transformation matrix from plastic hinge rotations to translational interstory inelastic displacements.

G. Boscato et al. identify the intrinsic discontinuity and the damage of multileaf masonry walls through the vibration-based approach. In the first step, the characterization of initial conditions based on the investigation of the intrinsic discontinuity and the manufacturing imperfections has been done. In the second step, starting from the identification of the undamaged condition, the damage effects on changes of the dynamic parameters have been recorded. The incoherent response between the leaves affects the dynamic parameters.

In the work of M. B. Bağbancı and Ö. K. Bağbancı, five historic timber minarets in Sakarya City are experimentally and computationally examined to determine the effects of the construction techniques and geometrical properties on the dynamic behaviour of the minarets. Ambient vibration tests of timber minarets are performed, and the construction techniques and geometrical features are examined. An empirical formula is derived from the relationships for a rapid estimation of the fundamental period of timber minarets.

X. Guan et al. investigate the effects of snow load to the modal parameters of the steel structure roof of the Harbin Railway Station. A single-span simply supported beam is analysed from the theoretical perspective to study the principles. FEM-based analyses are conducted for the steel structure roof to illustrate the significance of the snow load effects to modal parameters.

In the F. Jiang et al. study, the improved permutation entropy (IPE) is defined as a feature for bearing fault diagnosis. In this method, the ensemble empirical mode decomposition (EEMD), a self-adaptive time-frequency analysis method, is used to process the vibration signals, and a set of intrinsic mode functions (IMFs) can thus be obtained. A feature extraction strategy based on statistical analysis is then presented for IPE, where the so-called optimal number of permutation entropy (PE) values used for an IPE is adaptively selected.

The work of Q. Zhang and Z. Xiong proposes a new sensing system combining BOFDA (Brillouin optical frequency-domain analysis) and FBG (fiber Bragg grating) technology, which are used to detect internal and surface cracks and their development in reinforced concrete structures, and an attempt is made to estimate the width of surface cracks.

P. Guéguen and A. Tiganescu, after analyzing the correlation of resonance frequency values with temperature for one building, used a data mining procedure called "association rule learning" (ARL) to predict future frequencies according to temperature measurements. The study then proposes an anomaly interpretation strategy using the "traffic light" method.

J. Tian et al. propose a new method for the fault diagnosis of intershaft bearings. The fusion information exergy distance method (FIEDM) is proposed by fusing four information exergies, such as singular spectrum exergy, power spectrum exergy, wavelet energy spectrum exergy, and wavelet space spectrum exergy, which are extracted from acoustic emission (AE) signals under multiple rotational speeds and multimeasuring points.

The work of M. Romero et al. shows operational modal analysis (OMA) capabilities for evaluating the effectiveness of intervention works on the health state of a historical masonry structure. In detail, this work reports the evaluation of the effects that the strengthening intervention has on the structural health state of the Jura Chapel, in Jerez de la Frontera (Spain), using nondestructive techniques based on ambient vibration tests (AVT) and operational modal analysis (OMA). The AVT are performed for both prerestored and restored states and under environmental loads. A discussion about the validity of doing AVT from extrados when a vault presents disconnection between ribs and web is included in the paper.

S. R. Borneman and S. M. Hashemi present a method for detection of multiple cracks present in laminated composite bending-torsion coupled cantilevered beams using natural frequency data. This methodology relies on both experimentally collected natural frequencies and frequencies calculated using a mathematical model. An algorithm is devised based on the Adam–Cawley criterion and extended to laminated composites with multiple cracks. This method has shown exceptional convergence on the size and location of cracks using a number of modes of free vibration with and without errors in measured frequencies.

The research of X. Fukun et al. adopts the French ROCK600-50 three-axis experiment instrument and SH-II system to evaluate the acoustic emission (AE) peak of the rear axle of yellow sandstone by carrying out the confining pressure synchronous unloading experiment and evolution of mechanical properties and characteristics of energy transformation and damage of a yellow sandstone.

E. Lenticchia et al. propose a seismic assessment of the structures of Hall B of Turin Exhibition Centre, considering the potential seismic damage and the related consequences to global behaviour of nonstructural elements. The application of an optimal sensor placement strategy is described with reference to two different scenarios: the first one corresponding to the undamaged structure and the second one that considers a possible damage to the infill walls. A novel damage-scenario-driven sensor placement strategy based on a combination of the two abovementioned scenarios is proposed and discussed.

In the research of S. Tashakori et al., two different SHM methods are used to evaluate the strength of composite bonds by using two separate experimental setups. First, the heterodyne effect method is used for assessing the separation in the composite joint. Then, the surface response to excitation (SuRE) method is used for studying various simulated contamination levels.

A. Concha and L. Alvarez-Icaza propose a parameter identification method and a high gain observer to identify the model and to recover the state of a seismically excited shear building using acceleration responses of the ground and instrumented floors levels, as well as the responses at noninstrumented floors, which are reconstructed by means of cubic spline shape functions.

X. Zhang et al. present a novel fault diagnosis approach for rotating machinery by combining improved local mean decomposition (LMD) with support vector machine-recursive feature elimination with minimum redundancy maximum relevance (SVM-RFE-MRMR). Firstly, an improved LMD method is developed to decompose vibration signals into a subset of amplitude modulation/frequency modulation (AM-FM) product functions (PFs). Then, time- and frequency-domain features are extracted from the selected PFs, and the complicated faults can be thus identified efficiently.

M. Regni et al. analyze the effect of temperature and wind velocity on the natural frequencies and modal damping ratios of the Faculty of Engineering Tower at the Università Politecnica delle Marche, a 10-story reinforced concrete frame building, permanently monitored with low-noise accelerometers. The data recorded over the first 5 months of monitoring demonstrate that temperature variations and wind intensity have a clear effect on the first three natural frequencies and the corresponding damping ratios. A mechanical explanation of these phenomena is offered, based on a critical review of literature case studies.

M. R. Kaloop et al. develop and apply four advanced heuristic regression methods to estimate raft foundations' settlement, namely, multivariate adaptive regression splines (MARS), M5 model tree (M5Tree), generalized regression neural networks (GRNN), and support vector regression (SVR) techniques. Simulation of raft pile foundations is utilized to calculate the settlements of piles under the effect of static and dynamic loads. The results show that the four models can be used to accurately predict foundations' settlements in the training stage.

X. Wang et al. address the damping identification with acceleration measurements based on the sensitivity enhancement method. To reduce the measurement noise effect and enhance the effectiveness of the response sensitivity method, an enhanced sensitivity analysis method is proposed to identify the structural damping based on the principal component analysis (PCA) method. The proposed damping identification method is numerically validated with a planar truss structure at first, and then the experimental study is conducted with a steel planar frame structure.

Br. Joyce et al. outline the design of an experimental test bed with user-selectable parameters that can change rapidly during the system's response to external forces. The test bed consists of a cantilever beam with electronically detachable added masses and roller constraints that move along the beam. Both controllable system changes can simulate system damage. Experimental results from the test bed are shown in both fixed and changing configurations.

A. Malekjafarian et al. investigate the feasibility of detecting local damage in a bridge using laser Doppler vibrometer (LDV) measurements taken from a vehicle as it passes over the bridge. It is shown that instantaneous curvature (IC) at a moving reference, which is the curvature of the bridge at an instant in time, is sensitive to local damage. The vehicle measures the rate of instantaneous curvature (RIC), defined as the first derivative of IC with respect to time. A comparison of filtered RIC measurements in healthy and damaged bridges shows that local damage can be detected well with noise-free measurements and can still be detected in the presence of noise.

D. Han et al. propose a new method to solve detection problems of multifrequency weak signals in noisy background; a novel weak signal detection method based on variational mode decomposition (VMD) and rescaling frequency-shifted multistable stochastic resonance (RFMSR) with analytical mode decomposition (AMD) is proposed. In this method, different signal frequency bands are processed by rescaling subsampling compression to make each frequency band meet the conditions of stochastic resonance.

S. Yang et al. investigate the damage evolution of sandstone specimens under two types of cyclic loading by monitoring and analyzing changes in the elastic moduli and the ultrasonic velocities during loading. A crack density parameter is introduced in order to interpret the changes in the tangential modulus and the ultrasonic velocities.

J. Gai and Y. Hu propose a method based on singular value decomposition (SVD) and fuzzy neural network (FNN) to extract and diagnose the fault features of diesel engine crankshaft bearings efficiently and accurately.

J. Qian et al. analyze a method to identify strand tensions based on scale energy entropy spectra of ultrasonic-guided waves (UGWs).

S. Quqa et al. investigate the usability of easily obtainable parameters instead of the modal traditional ones, in the context of a flexibility-based damage detection procedure, under the assumption of unknown structural masses. To this aim, a comparison is made between two different approaches: the first involves the calculation of the flexibility matrix by using traditional modal parameters, while the second involves the use of singular vectors, obtained through a simple matrix factorization. The modal parameters and the singular vectors necessary for the implementation of the damage detection procedure are evaluated through two different techniques: the eigensystem realization algorithm and a wavelet-based procedure, for which a variant is proposed by introducing the energy reassignment concept into the original algorithm.

W. Shan et al. study a procedure to eliminate the temperature effect on modal frequency, an effective method to construct quantitative models which accurately predict the modal frequency corresponding to temperature variation. In this paper, principal component analysis (PCA) is conducted on the temperatures taken from all embedded thermocouples for extracting input parameters of regression models. Three regression-based numerical models using multiple linear regression (MLR), backpropagation neural network (BPNN), and support vector regression (SVR) techniques are constructed to capture the relationships between modal frequencies and temperature distributions from measurements of a concrete beam during a period of 40 days of monitoring.

The paper of H. Kordestani et al. provides a simple and direct output-only baseline-free method to detect damage from the noisy acceleration data by using moving average filter (MAF). MAF is a convolution approach based on a simple filter kernel (rectangular shape) that works as an averaging method to smooth signal and remove incorporated noise. In this paper, a method is proposed to employ MAF to smooth acceleration signals obtained from a series of accelerometers and determine the damage location along a steel beam.

L. Gang et al. investigate the acoustic emission (AE) characteristics of dry and saturated columnar joints basalt under uniaxial compression and tensile damage process by using the TAW-2000 rock experiment system and SH-IIAE system for the whole loading. Dry sample of uniaxial compression in the process at the beginning of loading produces a large number of AE signals, and the AE signal has shown steady growth along with the load increase, but the sample destroy appears during the blank period that can be used as a precursor of instability. From the amplitude-time-energy diagram, it can be found that when amplitude increases with hit, the related energy decreases.

The paper of Marco Buzzoni et al. focuses on the development of a novel condition indicator specifically designed for the damage assessment in rolling elements bearings. The proposed indicator allows to track the bearing degradation process taking into account three different possible positions: outer race, inner race, and rolling element. The validation of the proposed indicator has been carried out by means of both simulated signal and a run-to-failure experiment. The results highlight that the proposed indicator is able to detect more efficiently the fault occurrence and, most importantly, earlier than other established techniques.

We hope that this special issue updates scientific evidences in SHM integrative research based on vibrational data contributing to a scientific and practical improvement of the SHM topic.

Conflicts of Interest

The editors declare that they have no conflicts of interest regarding the publication of this special issue.

Acknowledgments

We express our great appreciation to all authors for their excellent contributions and reviewers for their valuable help. We express our sincere thanks to the Editorial Board of SHMV for their approval on this topic and continuous support in successful publication of this special issue. The Lead Guest Editor would like to thank the three Guest Editors for their dedicated cooperation.

Giosuè Boscato
Luca Zanotti Fragonara
Antonella Cecchi
Emanuele Reccia
Daniele Baraldi

Structural health monitoring through vibration-based approaches

Boscato, Giosuè

2019-02-17

Giosuè Boscato, Luca Zanotti Fragonara, Antonella Cecchi, et al., Structural health monitoring through vibration-based approaches. Volume 2019, Article number 2380616

https://doi.org/10.1155/2019/2380616