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Editorial

Automated Operational Modal Analysis and Its Applications in Structural Health Monitoring

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Research in operational modal analysis (OMA) and its applications in structural health monitoring (SHM) have experienced significant efforts in the last decade. The development of methods able to provide, eventually in a fully automated way, accurate estimates of the modal parameters from structural response only measurements opened new applicative perspectives in the field of structural condition assessment. In fact, while visual inspections, typically in combination with destructive and nondestructive investigations on selected portions of the structure, and scheduled maintenance are the conventional approaches to damage detection and management, the local nature of tests, the subjectivity of the expert judgment, and the costs and very limited frequency of inspections have solicited strong research efforts to change the paradigm, leading to the development of innovative structural health monitoring strategies relying on the analysis of the global, continuously measured, response of the structure. Among the developed approaches, modal-based damage detection is probably one of the most popular for SHM of civil structures. The recent developments in the field of OMA, including in particular several robust automated OMA algorithms, make modal-based SHM an attractive and fairly mature technology. However, in spite of the significant advantages and proved effectiveness of the technique, limitations to its extensive application still come from the accuracy and reliability of the (automated) OMA results, which can affect the damage-detection performance. Moreover, extending the potentialities of the technique to deal with time-varying structures or to support the setting and refinement of numerical models is also a significant research challenge.

This special issue collects five original research contributions that present recent advances in OMA as well as important applications in the context of SHM. In particular, the papers address the following relevant research issues: improving the quality of estimates, dealing with nonstationarities and/or time-varying systems, on-line identification of modal parameters from strong motion records, enhancing FE models by reducing epistemic uncertainties. The collection of papers focused on different aspects and applications of OMA clearly remarks that, even if the technology is mature for applications, several aspects can still be improved, and they are worthy of additional research efforts. It is the hope of the editors that this special issue will contribute to the development of the discipline and the enhancement of its already promising applicative perspectives in SHM.

The paper by B. Zhou et al., entitled "The tunnel structural mode frequency characteristics identification and analysis based on a modified Stochastic Subspace Identification method," deals with a challenging modal-identification problem, that is the modal identification of underground tunnels based on processing of ambient responses as well as of hammer test records. The challenging nature of the investigated problem is related to the coupling between structural and soil vibrations and to the need of selecting the appropriate eigenproperties for condition monitoring. The topic is highly relevant in view of continuous SHM applications of underground tunnels to detect faults, damages, and the effects of nearby soil excavations. To effectively identify the fundamental natural frequencies of underground tunnels, a combined method based on the natural excitation technique (NExT) and the stochastic subspace identification (SSI) method is proposed. After the introduction, the paper presents the mathematical formulation of the new proposed identification method. Afterwards, the efficacy of the method is demonstrated in application to real data acquired on a concrete power tunnel having a 3.2 m external diameter and on a subway tunnel where each ring is made of six different concrete segments resulting in an external diameter of 6.2 m. The proposed NExT-SSI method results in quite clear stabilization diagrams, whereby the same stabilization diagrams based on covariance-driven SSI (SSI-COV) are quite poor and fail to provide evidence of eigenfrequency stability with increasing model order. The paper ends with an elegant model-based validation using dispersion analysis based on the so-called pipe-in-pipe analytical model, where dispersion analysis is the analysis of the relationship between wave number and frequencies of propagating waves. The results demonstrate that the first natural frequency of the underground tunnels can be effectively identified by the proposed method, although daytime traffic may lead to wrong estimates. Hammer test also allows higher-order modal identification with good consistency against dispersion analysis, and its use is therefore recommended for providing additional information for condition assessment.

The paper by F. Liu et al., entitled "An introduction of a robust OMA method: CoS-SSI and its performance evaluation through the simulation and a case study," addresses the challenge of nonstationarity. Most of the OMA techniques have been developed under the assumption of linear and stationary system. However, the monitoring data are often nonstationary, as shown in the paper for the cases of platforms under wave excitations, and bridges under time-varying traffic loading. As a result of nonstationarity, the identified modal parameters might be unreliable, or part of the modes could be missed. An improved OMA method based on SSI is therefore proposed to analyze the dynamic response of nonstationary systems. The proposed method is denoted as correlation signal subset-based SSI (CoS-SSI) as it divides correlation signals from the system responses into several subsets based on their magnitudes; then, the average correlation signals with respect to each subset are used as the inputs of the SSI method. The performance of CoS-SSI has been evaluated first against simulated data, considering also different levels of noise, and it has been validated afterwards through an experimental study. Both simulation analysis and the experimental results remark the promising performance of CoS-SSI method in dealing with nonstationary systems and noisy signals, thus overcoming some inherent limitations of the traditional SSI-COV as well as of the average correlation signal based SSI (ACS-SSI) method, which is another variant of the SSI method specifically developed to deal with nonstationary data. The CoS-SSI method seems to be able to provide more accurate and reliable modal identification results with respect to the latter reference methods, thus resulting in a promising solution for reliable SHM.

The paper by H. Jin et al., entitled "Modal Parameters Identification Method Based on Symplectic Geometry Model Decomposition," proposes a novel method for operational modal analysis with the ability to identify the modal parameters of time-invariant structures and also track the evolution of the dominant frequencies of time-variant systems. This is achieved with the use of symplectic geometric model decomposition (SGMD). The authors advocate that compared with other decomposition methods, SGMD does not need user-defined parameters, has better robustness and suppresses modal aliasing. The methodology is validated with both simulated and measured data. Simulation studies are performed on a time-variant multi-DOFs shear-type structure, considering periodical and smooth variations on the springs that connect the vibrating masses, to explore the effectiveness of the proposed method for time-variant system identification. The validation with measured data encompasses a laboratory experiment with a dissected vehicle underframe crossbeam of high-speed train tested under time-invariant conditions and a time-variant wheel-rail coupling system. In the latter the moving vehicle vibrations were monitored during a field braking test and the instantaneous frequencies of the system were tracked during 9 seconds. The authors concluded that experiments using simulated and real data show that the proposed method can make good use of the limited bandwidth of each model for signal decomposition, and it can also accurately extract the instantaneous frequency of the time-variant system.

The paper by L. Cheng et al., entitled "Online Modal Identification of Concrete Dams using the Subspace Tracking based Method," proposes an online modal identification procedure based on strong-motion records to investigate the time-varying dynamic characteristics of concrete dams under the excitation of earthquakes. The online modal identification is expressed as a subspace tracking problem, and a newly developed recursive stochastic subspace identification (RSSI) method based on the "Generalized Yet Another Subspace Tracker" (GYAST) algorithm, which exploits both the accuracy of the subspace identification and fast computational capability, is used to extract the time-varying modal parameters of concrete dams during earthquakes. Firstly, the method is validated with numerically simulated vibration response records to verify its accuracy, robustness, and efficiency. Then, several strong-motion records collected at the Pacoima arch dam are analysed using the proposed modal-identification procedure, and the time-varying characteristics of the concrete arch dam during three different earthquakes are analysed. The authors conclude that the GYAST is a good tool to track different modes, since it shows good identification accuracy, robustness, and computation efficiency. They also report that the identification accuracy of the frequencies and modal shape vectors is sufficient, while for the damping ratios, the performance of the proposed online modal identification method still needs to be improved.

The paper by M. Juul et al., entitled "One-step updating using local correspondence and mode shape orthogonality," deals with the topic of FE model updating based on results of OMA aimed at improving an FE model in order to enhance its agreement with test results and reduce modeling errors (epistemic uncertainties). Particularly, the paper proposes a one step updating technique where mass and stiffness matrices are corrected using experimentally identified mode shapes. These last are appropriately smoothed and are initially mass normalized to the first guess mass matrix through a fixed-point iteration procedure that is also illustrated in the paper. The one-step principle is based on expressing the inverse of the mass matrix as a sum of the contributions of lower order modes (those that are actually identified by OMA) and of higher-order modes (those that are not identified), with the same being done also for stiffness matrix. After the introduction, the paper illustrates the mathematical formulation of the proposed one step updating procedure, which exploits the circumstance that the mode shape matrix of a perturbed system can always be expressed as a linear transformation of the mode-shape matrix of the unperturbed system. The second part of the paper contains a validation of the proposed method considering both simulated and real test data on a T steel frame structure arranged in the lab and a section presenting the discussion of the obtained results. The discussion covers two main aspects. First of all, it comments on the fact that the proposed one step method assumes small distributed perturbations. This implies that when perturbations are localized and significant, the method may fail in handling epistemic uncertainties. Furthermore, the discussion contains very useful computational hints when dealing with applications of the proposed method to systems having a large number of degrees of freedom, where the inversion of very large dimensional matrices is required. The results show that, after mass scaling with respect to the updated mass matrix, the eigenvalue analysis using the updated FE model provides the "correct" (identified) undamped modal frequencies. A notable result of the paper is that in the case of perturbations distributed along the structure, the updating procedure is effective even when experimental information is limited to lower-order modes, while keeping higher-order modes unchanged.

In conclusion, it is clear that the above papers address relevant research issues in the field of OMA and its application to SHM, contributing to the development of the discipline and the enhancement of its already promising applicative perspectives. These editors, therefore, are confident that this special issue will be useful for researchers and practitioners working in the field.

Conflicts of Interest

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

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