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Editorial

Editorial

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Abstract. This Special Issue in honor of Prof. Fabio Casciati and Prof. Lucia Faravelli, both retired Professors from the University of Pavia (Italy), proposes papers in the spirit of their activity, with a strong scientific interaction between researchers from different backgrounds, operating in the fields of Applied and Computational Mechanics by analytical, computational and experimental works. It is, therefore, devoted to disseminate the current developments and trends in the area of structural mechanics and control and in the related fields as auspicated by the International Association for Structural Control and Monitoring (IASCM) and the European Association for the Control of Structures (EACS). During their Academic careers, Professor Fabio Casciati and Professor Lucia Faravelli deeply contributed to the spread and development of the discipline by acting as members and high representative of both these two Associations.

Special Issue Title: Special Issue in honor of Prof. Casciati and Prof. Faravelli retirement.

1. Introduction

This special issue celebrates the scholarly contributions of Professor Fabio Casciati and Professor Lucia Faravelli who have each dedicated 45 years of their academic careers to students, the global scientific community, and their colleagues in the fields of structural dynamics, stochastic mechanics, materials science, computational mechanics, soft computing, nonlinear random vibrations, smart structures, and mechatronics within the discipline of civil engineering. In an effort to protect human lives by advancing the safety and reliability of infrastructure systems and hazard mitigation strategies, their work has elevated the state-of-the-art in the areas of durability, protection of the built environment, material degradation, nonlinear dynamics, structural safety and reliability in response to extreme loading, man-made or natural hazard environment. Furthermore, Professors Casciati and Faravelli have made novel and seminal contributions in the areas of vibration mitigation, including computational and experimental validation. They have also carried out pioneering and original work in the treatment of uncertainties in modelling, design and in measurements.

Professors Casciati and Faravelli's research and extensive studies in the aforementioned fields have resulted in numerous international scientific collaborations that have significantly supported the advancement, growth, development, prosperity, and fruition of the disciplines of smart structures, structural control and health monitoring, as partially demonstrated by the contributions collected in this Special Issue.

Several milestones which outline the development, and original contributions, of these colleagues' research are summarized as follows:

- They were among the first leading scholars who confronted the challenging problems of "Scienza delle Costruzioni" with a particular focus on the problems of numerical solution aiming to determine the ultimate behavior of complex structural systems at their incipient collapse. They succeeded to implement the constitutive laws of materials, ranging from the classical to smart materials, such a shape memory alloys.
- Next, they focused their research efforts on the treatment of uncertainties and uncertainty quantification, by the development and utilization of methodologies for the reliability assessment of structural systems. In particular, they proposed the adoption of the response surface methodology to evaluate important structures, such as nuclear power plants, and to address the impact problems.
- Subsequently, they pursued the tasks of risk assessment and analysis in the field of earthquake engineering by the introduction of artificial intelligence methods, neural networks and expert systems.
- Throughout their entire career span, they have pioneered the introduction of structural control strategies, which initially coupled with and further extended to the development of structural monitoring techniques. They devoted particular attention to the design and experimental evaluation of controllers and sensors, with emphasis on their wireless use.

- They have also always collaborated with research centers and agencies worldwide to foster important exchanges of knowledge with the scientific community. These scientific collaborations, and the innovations that have resulted, have been visionary, quite rewarding, fruitful and often ahead of their times making them a source of motivation and a stimulus for the new generations.

Since 1993, Fabio and Lucia have provided valuable guidance and support to both the International Association for Structural Control and Monitoring (IASCM) and the European Association for the Control of Structures (EACS). Under the auspices of these two Associations, the World Conference on Structural Control and Monitoring and the European Conference on Structural Control have been alternatively held every four years with the aims of promoting advanced structural control and monitoring technologies and enabling these fields to stay abreast of contemporary standards in the workflow and new developments in the discipline. Their editorial work has also provided a valuable resource for the researchers in the general areas of structural control, structural health monitoring theory and smart materials and structures.

For 22 years, Professor Fabio Casciati and Professor Lucia Faravelli provided a leadership role in the Ph.D. School in Civil and Environmental Engineering at the University of Pavia, Italy (http://www.dipmec.it/dott/obiettivi_en.php). They co-founded the School in 1994 and promoted, with continuity in time, the scientific rigor, the internationalization, and the up to date versions of its curricula. To support the research and the teaching activities, they setup and conducted both a Laboratory for the analysis of vibrations and material characterization, and an educational facility for the study of computational mechanics. Their International cooperation with other Universities and Research Institutes enabled the exchange of both Ph.D. students and the members of the teaching staff involved in joint research activities and in the offering of the Ph. D. courses. They personally supervised more than 20 Ph.D. students and doctoral projects on the following research topics: numerical and experimental techniques for the studies of the non-linear dynamics of structures; structural systems identification; soft computing, expert systems, neural networks, and artificial intelligence methods for solving optimization problems in structural engineering; structural health monitoring with contactless methods, terrestrial systems (accelerometers, displacement sensors) and satellite-controlled systems (GPS), and wireless communication; numerical and experimental aspects of passive, active, and semi-active structural control; numerical modeling of aeroelastic forces and aerodynamic instability in huge span bridge design and cable vibration control; numerical and experimental study of smart materials (Shape Memory Alloys) and their applications in monumental buildings rehabilitation; characterization tests for the mechanical and fatigue behavior of shape memory alloys and plastic materials for hydraulic and structural engineering applications; probabilistic analysis and simulation methods for structural safety; environmental, industrial and territorial risk analysis; probabilistic analysis and simulation methods for seismic vulnerability evaluation; seismic risk analysis and risk mitigation methods; numerical techniques for the simulation of the ground-structure interaction.

As an addendum to this Preface, a brief biography of Fabio and Lucia is provided below.

2. Authors and Abstracts

1. Temperature Dependent Damping in Additively Manufactured Polymer Structures

Katherine K. Reichl, Onur Avci, Daniel J. Inman

Temperature effects are predominantly ignored when computing the dynamic response of structures. Yet, in applications where large changes in temperature occur, the dynamic response can drastically change. This is particularly true for polymers. While the temperature effects on modulus and loss factor are often available for most polymers, this change is not addressed or corrected for. Meanwhile, the recent research on additively manufactured polymer metastructures has yet to consider the effects of temperature change on their ability to suppress vibrations. In order to fill this gap, the study presented in this paper focuses on the effects of temperature change on additively manufactured structures.

2. Natural frequencies and internal resonance of beams with arbitrarily distributed axial loads

Stefano Lenci, Francesco Clementi

An exact analytical solution for transversal free vibrations of a beam subjected to an arbitrary distributed axial load and a tip tension is obtained by means of a power series representation, whose coefficients are determined recursively in an easy way. The dependence on the natural frequencies on the load is then investigated, and the buckling load (corresponding to vanishing frequency) is also discussed. Next, the 1:3 internal resonance between the first and the second mode is deeply studied, and an interesting (and unexpected) property is found for linearly distributed axial loads

3. Modeling beam-like planar structures by a one-dimensional continuum: an analytical-numerical method

Manuel Ferretti, Francesco D'Annibale, Angelo Luongo

In this paper, beam-like structures, macroscopically behaving as planar Timoshenko beams, are considered. Planar frames, made by periodic assemblies of micro-beams and columns, are taken as examples of these structures and the effectiveness of the equivalent beam model in describing their mechanical behavior, is investigated. The Timoshenko beam (coarse model) is formulated via the direct one-dimensional approach, by considering rigid cross-sections and flexible axis-line, while its constitutive laws is determined through a homogenization procedure. An identification algorithm for evaluation of the constitutive constants is illustrated, based on Finite Element analyses of the cell of the periodic system. The inertial properties of the equivalent model are instead analytically identified under the hypothesis the masses are lumped at the joints. The advantages in using the equivalent model are discussed with reference to the linear static and dynamic responses of some planar frames, taken as case-studies, for which both analytical and numerical tools are used. Numerical results, obtained by the equivalent model, are compared with Finite Element analyses on planar frames (fine models), considering both symmetric and not-symmetric layouts, in order to show to effectiveness of the proposed algorithm. A comparison with analytical results is carried out to validate the limits of applicability of the method.

4. Nonlinear dynamics and stability of a homogeneous model of tall buildings under resonant action

Daniele Zulli, Angelo Luongo

A homogeneous model of beam-like structure, roughly portraying the mechanical behavior of a tall building, is considered to address nonlinear dynamic response in case of external resonant excitation. A symmetric layout of the building is considered, so as to allow the existence of an in-plane response, whose features are evaluated by means of the Multiple Scale Method and accounting for internal resonance, necessarily occurring in the model. Furthermore, to take into account the three-dimensional nature of the problem, stability of the in-plane response to out-of-plane disturbances is addressed, solving the associated parametrically excited linear system.

5. Flexural-Torsional Galloping of Prismatic Structures with Double-Symmetric Cross-Section
Angelo Luongo, Francesca Pancella, Giuseppe Piccardo
The linear galloping of prismatic structures having double-symmetric cross-section, subjected to steady wind flow acting along a symmetry axis, is investigated. The continuous system is reduced to a three degree-of-freedom system via a Galerkin approach. The quasi-steady assumption for the aerodynamic forces is applied, under the hypothesis that the galloping instability is well-separated from the vortex induced vibration phenomenon. Due to the structural symmetry conditions and accounting for the aerodynamic coupling, galloping is of flexural-torsional type, occurring in the direction orthogonal to the incident wind. Moreover, coupling is stronger close to the resonance between the flexural and torsional degrees of freedom. A linear stability diagram is built up in a two-parameter space, highlighting the role of coupling in modifying the critical wind velocity, and in producing a veering phenomenon between the two modes. The existence of points at which a double-Hopf bifurcation manifests itself is detected. Both exact and perturbation solutions are provided, these latter in the non-resonant and resonant cases, useful to throw light on the interactive mechanisms. The resonant perturbation solution permits to analytically investigate under which conditions coupling has a detrimental effect on galloping, which manifests at a wind velocity lower than the flexural and torsional critical velocities. Situations where coupling between modes leads to beneficial effect with respect to the Den Hartog's critical wind velocity are also highlighted. As an application, galloping of a family of multi-story tower buildings having a square cross-section is studied.

6. Modeling of Flight of the Line Thrower Projectile
Alexander K. Belyaev, Vladimir A. Piskunov, Tatiana V. Zinovieva
The actual problem of increasing the flight range of line thrower projectile which is a container with a line (thin rope) inside. The line leaves the container during the flight, i.e. the projectile has a variable mass. Mathematical model of the projectile flight is constructed using the Lagrange equations of the second kind. The projectile is considered as a material particle, the line considered as an elastic thread with the tensile Cauchy strain. An approximation of the projectile flight trajectory is introduced in terms of three generalized coordinates. The dependence of the projectile’s flight distance on the projectile departure angle is constructed for several values of the tensile rigidity of the line.

7. Long-span Suspension Bridge Flutter Analysis with Drag Force Effects
Gianfranco Piana, Alberto Carpinteri
The paper investigates the influence of the drag force on the flutter velocity and frequency of the Akashi Kaikyo Bridge. Finite element analyses were run in ANSYS by combining unsteady lift and moment actions with: (a) unsteady drag, (b) steady drag, (c) no drag. The finite element results are compared with those obtained by an in-house MATLAB code based on a semi-analytic continuum model and with others of literature. The continuum model includes flexural-torsional second-order effects induced by steady drag force into the bridge’s equations of motion, in addition to unsteady lift and moment actions. The results show that good predictions of the flutter velocity can be obtained by combining steady drag with unsteady lift and moment.

8. VIV Control Strategies Using Displacement-Based Phenomenological Model
Muhammad R. Hajj, Arshad Mehmood, Imran Akhtar, Khondokar Billah
Linear and nonlinear feedback control of vortex-induced vibrations are assessed using a single degree-of-freedom phenomenological model of the uncontrolled response. The model is based on the role of linear and nonlinear damping forces in inducing and limiting the amplitude of these vibrations. First, the model prediction is validated using data from previously published high-fidelity direct numerical simulations. Then, linear and nonlinear control are applied to the validated model over a broad range of gain values. The predicted controlled responses are also validated against previously published results from high-fidelity numerical simulations. Based on this validation, it is shown that the single degree-of-freedom model is an effective alternative, in terms of computational cost, to high fidelity simulations in assessing control strategies over broad regions of control gains.

9. Improving the linear stability of the visco-elastic Beck's beam via piezoelectric controllers
Arnaldo Casalotti, Francesco D’Annibale
Control strategies for the visco-elastic Beck's beam, equipped with distributed piezoelectric devices and suffering from Hopf bifurcation triggered by a follower force, are proposed in this paper. The equations of motion of the Piezo-Electro-Mechanical (PEM) system are derived through the Extended Hamilton Principle, under the assumption that the piezoelectric patches are shunted to the so-called zero-order network and zero-order analog electrical circuit. An exact solution for the eigenvalue problem is worked out for the PEM system, while an asymptotic analysis is carried out to define three control strategies, recently developed for discrete PEM systems that are here adapted to improve the linear stability of the visco-elastic Beck's beam. An extensive parametric study on the piezo-electrical quantities, based on an exact linear stability analysis of the PEM system, is then performed to investigate the effectiveness of the controllers.

10. Stress Control of a Piezoelectric Lumped-element Model – Theoretical Investigation and Experimental Realization
Juergen Schoeftner, Andreas Brandl, Hans Irschik
This contribution focuses on force- and stress-tracking of a multi-degree of freedom system by eigenstrain actuation. The example under consideration is an axially excited piezoelectric bar which can be modeled as a lumped parameter system. The piezoelectric effect serves as actuation source and the question is answered how to prescribe the piezoelectric actuation in order to achieve a desired stress distribution, or, in the lumped case, a desired distribution of internal forces. First, the equations of motion are set up in matrix notation where the state vector contains the displacement components. After some basic manipulations, the governing equation can be written in terms of the internal force vector. Now, if one intends to have a certain desired internal force distribution, it is straightforward to find a condition for the piezoelectric control actuation. The developed theory is first verified by using a continuous piezoelectric bar, where the motion of one end is prescribed. Then the theory is experimentally verified: a lumped two-degree of freedom system is investigated and the goal is to reduce the stress or the internal force in order to avoid mechanical damage. The force-controlled configuration is exposed to a sweep-signal excitation between 1000–4900 Hz, running for 22 minutes without any signs of damage. Then the same system is excited by the same excitation but without piezoelectric control. After some seconds the test sample is visibly damaged, going along with a significant reduction of the first eigenfrequency. This gives strong evidence for the appropriateness of the proposed stress or force control methodology.

11. On/off Nodal Reconfiguration for Global Structural Control of Smart 2D Frames

Blazej Poplawski , Grzegorz Mikułowski , Anita Orlowska , Łukasz Jankowski

This paper proposes an on/off semi-active control approach for mitigation of free structural vibrations, designed for application in 2D smart frame structures. The approach is rooted in the Prestress–Accumulation Release (PAR) control strategies. The feedback signal is the global strain energy of the structure, or its approximation in the experimental setup. The actuators take the form of on/off nodes with a controllable ability to transfer moments (blockable hinges). Effectiveness of the approach is confirmed in a numerical simulation, as well as using a laboratory experimental test stand.

12. Precision Shape Control of Ultra-thin Shells with Strain Actuators

Kainan Wang, David Alaluf, Gonçalo Rodrigues, André Preumont

This paper is part of an effort conducted at Université libre de Bruxelles (ULB) on behalf of European Space Agency (ESA) to control the shape of thin polymer shell structures with a unimorph layer of strain actuators (Polyvinylidenefluoride-co-trifluoroethylene, PVDF-TrFE), to achieve high quality light-weight foldable reflectors for space observation. The paper discusses the influence of the electrode size on the morphing capability of the system and addresses the difficulty associated with the ill-conditioning when controlling a very large set of electrodes. The final part of the paper describes a technology demonstrator currently under development and presents some simulation results fitting low order optical modes.

13. Structural Health Monitoring of Multi-Storey Frame Structures using Piezoelectric Incompatibility Filters: Theory and Numerical Verification

Michael Krommer, Markus Zellhofer, Hans Irschik

In the present paper, we develop a novel method for structural health monitoring of multi-storey frame structures with the capability to detect and localise local damage. The method uses so-called spatial incompatibility filters, which are continuously distributed strain-type sensors only sensitive to incompatibilities. In the first part of the paper the concept of incompatibility filters is introduced for multi-storey frame structures and it is shown how these filters can be used to detect and localise local cracks in frame structures. In the second part of the paper we study the use of incompatibility filters put into practice by piezoelectric sensor networks for structural health monitoring of a three-storey frame structure. The design of the piezoelectric sensor network is based on an analytical analysis of the frame structure within the framework of the method developed in the first part of the paper and a numerical verification using three-dimensional Finite Elements completes the paper.

14. Manifold Learning Algorithms Applied to Structural Damage Classification

Jersson X. Leon-Medina, Maribel Anaya, Diego A. Tibaduiza, Francesc Pozo

A comparative study of four manifold learning algorithms was carried out to perform the dimensionality reduction process within a proposed methodology for damage classification in structural health monitoring (SHM). Isomap, locally linear embedding (LLE), stochastic proximity embedding (SPE), and laplacian eigenmaps were used as manifold learning algorithms. The methodology included several stages that comprised: data normalization, dimensionality reduction, classification through K-Nearest Neighbors (KNN) machine learning model and finally holdout cross-validation with 25% of data for training and the remaining 75% of data for testing. Results evaluated in an experimental setup showed that the best classification accuracy was 100% when the methodology uses isomap algorithm with a hyperparameter k of 170 and 8 dimensions as a feature vector at the input to the KNN classification machine.

15. Direct Normal Form Analysis of Oscillators with Different Combinations of Geometric Nonlinear Stiffness Terms

Ayman Nasir, Neil Sims, David Wagg

Nonlinear oscillators with geometric stiffness terms can be used to model a range of structural elements such as cables, beams and plates. In particular, single-degree-of-freedom (SDOF) systems are commonly studied in the literature by means of different approximate analytical methods. In this work, an analytical study of nonlinear oscillators with different combinations of geometric polynomial stiffness nonlinearities is presented. To do this, the method of direct normal forms (DNF) is applied symbolically using Maple software. Closed form (approximate) expressions of the corresponding frequency-amplitude relationships (or backbone curves) are obtained for both ε and ε2 expansions, and a general pattern for ε truncation is presented in the case of odd nonlinear terms. This is extended to a system of two degrees-of-freedom, where linear and nonlinear cubic and quintic coupling terms exist. Considering the non-resonant case, an example is shown to demonstrate how the single mode backbone curves of the two degree-of-freedom system can be computed in an analogous manner to the approach used for the SDOF analysis. Numerical verifications are also presented using COCO numerical continuation toolbox in Matlab for the SDOF examples.

16. On the Active Vibration Control of Nonlinear Uncertain Structures

Vasilis K. Dertimanis, Eleni N. Chatzi, Sami F. Masri

This study proposes an active nonlinear control strategy for effective vibration mitigation in nonlinear dynamical systems characterized by uncertainty. The proposed scheme relies on the coupling of a Bayesian nonlinear observer, namely the Unscented Kalman Filter (UKF) with a two-stage control process. The UKF is implemented for adaptive joint state and parameter estimation, with the estimated states and parameters passed onto the controller. The controller comprises a first task of feedback linearization, allowing for subsequent integration of any linear control strategy, such as addition of damping, LQR control, or other, which then operates on the linearized state equations. The proposed framework is validated on a Duffing oscillator characterized by light damping and an uncertain nonlinear parameter under harmonic and stochastic disturbance. The demonstrated performance suggests that the proposed Bayesian approach offers a competitive approach for active vibration suppression in nonlinear uncertain systems.

17. A Generalized Identification of Joint Structural State and Unknown Inputs Using Data Fusion MKF-UI

Lijun Liu, Jiajia Zhu, Ying Lei

The classical Kalman filter (KF) can estimate the structural state online in real time. However, the classical KF presupposes that external excitations are known. The existing methods of Kalman filter with unknown inputs (KF-UI) have limitations that require observing the acceleration response at the excitation point or assuming the unknown force. To surmount the above defects, an innovative modal Kalman filter with unknown inputs (MKF-UI) is proposed in this paper. Modal transformation and modal truncation are used to reduce the dimensionality of the structural state, and the accelerations at the excitation positions do not need to observe. Besides, the proposed MKF-UI does not require the assumption of unknown external excitation. Therefore, the proposed approach is suitable for the generalized identification of dynamic structural states and unknown loadings. The effectiveness and feasibility of the proposed identification approach are ascertained by some numerical simulation examples.

18. Vibration Mitigation of Rail Noise Barriers by Hysteretic Absorbers
Michela Basili, Paolo Casini, Laura Morelli, Fabrizio Vestroni
A strategy is proposed to mitigate the noise barrier vibrations due to the train passage in high speed lines employing a hysteretic vibration absorber. The barrier is modelled as a generalized single degree of freedom system; the absorber consists of a light mass attached to the main structure by a hysteretic element whose restoring force is described by the Bouc-Wen model. The resulting two degrees of freedom system is studied, and it is shown that, for control purposes, beneficial conditions are obtained when the two oscillators are close to the resonance conditions (1:1). A procedure for a preliminary design of the absorber is highlighted; a parametric analysis varying the absorber characteristics is carried out and the optimal values are obtained by maximizing the barrier response performance. The absorber is then realized exploiting high damping rubber elements whose constitutive parameters have been identified through experimental tests. The effectiveness of the realized absorber is assessed by performing dynamic analysis of the two degrees of freedom system under the train excitation at a reference speed and comparing its performances with those of the designed one, observing a similar reduction of the barrier response. Finally, a sensitivity analysis of the performances varying the train speed shows that, even if the stiffness and damping of the absorber are amplitude dependent, its efficiency is confirmed in the speed range of high speed trains.

19. Variational Inference for Nonlinear Structural Identification
Alana Lund, Ilias Bilionis, Shirley J. Dyke
Research interest in predictive modeling within the structural engineering community has recently been focused on Bayesian inference methods, with particular emphasis on analytical and sampling approaches. In this study, we explore variational inference, a relatively unknown class of Bayesian inference approaches which has potential to realize the computational speed, accuracy, and scalability necessary for structural health monitoring applications. We apply this method to the predictive modeling of a simulated Bouc-Wen system subject to base vibration and compare the performance of this inference approach to that of the unscented Kalman filter. From this investigation, we find that though variational inference is more computationally intensive than the unscented Kalman filter, it exhibits superior performance and flexibility.

20. About Earthquakes in Subduction Zones with the Potential to Cause a Tsunami
V.A. Babeshko, O.V. Evdokimova, O.M. Babeshko
The problem of occurrence of starting earthquakes in subduction zones is considered. Subduction is the phenomenon of movement of the oceanic lithospheric plate under the continental one. The oceanic lithospheric plate at a certain depth melts from below and can slide. The paper considers the occurrence of starting earthquakes under the assumption that lithospheric plates have different contact conditions, being on a rigid base in the subduction zone. A molten lithospheric plate has no tangential contact stresses, while the other, oceanic, is rigidly connected to the base. The block element method is used to study the occurrence of the starting earthquake and the peculiarity of its consequences. The conditions to generate of tsunamis as a result of such earthquakes are being studied. Solutions to boundary value problems that are constructed precisely, rather than approximatively, allow us to reveal the mechanisms of destruction of the environment that were not previously known. In particular, the results obtained allowed us to detect a new type of crack that was not previously described. They destroy the environment in a different way than Griffiths cracks, which is demonstrated in this paper and is important in engineering practice.

21. Predictive Control with Dynamic Hysteresis Reference Trajectory: Application to a Structural Base-Isolation Model
Nubia Ilia Ponce de León Puig, José Rodellar, Leonardo Acho
Over the last decades, in the field of control engineering, Model Predictive Control (MPC) has been successfully employed in many industrial processes. This due to, among other aspects, its capability to include constrains within the design control formulation and also its ability to perform on-line optimization. For instance, in the civil engineering field, different MPC approaches have been well developed to formulate active control algorithms able to reduce civil structural responses to earthquakes. Thus, in this paper, a customized version of a conventional Predictive Control (PC) strategy is proposed to mitigate the displacement on a base-isolated system with a nonlinear hysteresis behavior that is excited by a seismic event. The proposal consists of including a dynamic hysteresis system into the control scheme to generate a reference trajectory that will softly drive the base-isolated structure to a rest status. The proposed control scheme is evaluated through numerical experiments, and then its performance is compared with respect to the conventional Predictive Control methodology. According to the numerical experiments, the approach here presented results more efficient than the conventional method due to the use of a suitable linear model of the structural system plus a new Driver Block with dynamic hysteresis within the Predictive Control scheme.

22. Validation of Model-Based Real-Time Hybrid Simulation for a Lightly-Damped and Highly-Nonlinear Structural System
Amirali Najafi, Billie F. Spencer Jr.
Hybrid simulation (HS) is a cost-effective alternative to shake table testing for evaluating the seismic performance of structures. HS structures are partitioned into linked physical and numerical substructures, with actuators and sensors providing the means for the interaction. Load application in conventional HS is conducted at slow rates and is sufficient when material rate-effects are negligible. Real-time hybrid simulation (RTHS) is a variation of the HS method, where no time-scaling is applied. Despite the recent strides made in RTHS research, the body of literature validating the performance of RTHS, compared to shake table testing, remains limited. In the few available studies, the tested structures and assemblies are linear or modestly nonlinear, and artificial damping is added to the numerical substructure to ensure convergence and stable execution of the simulation. The objective of this study is the validation of a recently proposed model-based RTHS framework, focusing on lightly-damped and highly-nonlinear structural systems; such structures are particularly challenging to consider using RTHS. The boundary condition in the RTHS tests are enforced via displacement and acceleration tracking. The modified Model-Based Control (mMBC) compensator is employed for the tracking action. A two-story steel frame structure with a roof-level track nonlinear energy sink (NES) device is selected due to its light damping, high nonlinearity, and repeatability. The complete structure is first tested on a shaking table, and then substructured and tested via the RTHS method. The model-based RTHS approach is shown to perform similar to the shake table method, even for lightly-damped and highly-nonlinear structures.

Guest Editors

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Addendum

Fabio Casciati was born in Naples, Italy, on January 16, 1949. He achieved a Laurea magna cum laude in Civil Engineering from the University of Pavia, Italy, on June 15, 1972. He held the following Academic positions: Research Assistant (1974–80); Lecturer (1976–80); Full Professor (1980- 2019) of Scienza delle Costruzioni at the School of Engineering of the University of Pavia, Italy. He served as the Institute and the Department Chairman from 1980 to 1983. He was a member of the Faculty of the Ph.D. Course on Structural Engineering, jointly administered by the Polytechnic of Milan and the University of Pavia during 1984 to 1994. Professor Casciati was the Chairman of the Civil Engineering Council from 1986 to 1989; and was responsible of the Infrastructure Engineering undergraduate school from 1993 to 2001. From 1994 to 2016, he served as the Coordinator of the Ph.D. School in Civil and Environmental Engineering of the University of Pavia, Italy. Within the national project CAMPUS he implemented these new curricula and he designed and realized both a numerical and an experimental laboratory.

Other noteworthy accomplishments and academic endeavours of Professor Casciati included: Visiting Researcher at Virginia Polytechnic Institute and State University, Blacksburg, Virginia (USA), in 1985; Visiting Researcher at Stanford University, Stanford (USA), in 1986; Visiting Professor at Florida Atlantic University in Boca Raton (USA) in 1992, and Visiting Researcher at Karlsruhe University Germany in 1993. Since 1999, he served as a member of the Ph.D. graduation committees of the Universities of Barcelona, Granada, Hong Kong and Rome. Since 2019, he has been an Adjunct Professor at the College of Civil Engineering and Architecture, Zhejiang University, Hangzhou, China.

He served as the President of the European Association for the Control of Structures (EACS) from 1993 to 2008, and the President of the International Association for Structural Control (IASC) from 2000 to 2004. Since 2002, he has been a Scientific Partner of the Mechatronics Excellence Centre ACCM, Linz, Austria.

Fabio Casciati is the Editor in Chief of Smart Structures and Systems, and a member of the Editorial Board of Structural Safety, J. of Structural Control and Health Monitoring, Computers and Structures, Acta Mechanica Solida Sinica, J. of Earthquake Engineering and Engineering Vibrations, and Vietnam Journal of Mechanics. He also served as member of the Editorial Boards of Probabilistic Engineering Mechanics (1986-88), Nonlinear Dynamics (1994-2009), Journal of Vibrations and Structural Control (1995-2017; Senior Editor since 2015), Earthquake Engineering and Engineering Dynamics (1996-2003).

In 2006, he was awarded a distinguished plaque in recognition of his cooperation effort from the Asian Network of Centers of Research in Smart Structures Technology, and in 2018, he was awarded the Takui Kobori Prize 2015.

He has given several plenary lectures worldwide and has chaired the organization of Euromech 250, Como, Italy, in 1989 (Proceedings published by Elsevier, with I. Elishakoff and J.B. Roberts as co-editors, ISBN 0-444-88803-9), the IUTAM Symposium on Nonlinear Stochastic Mechanics, Torino, Italy, in 1991 (Proceedings published by Springer-Verlag, Berlin, edited by N. Bellomo and F. Casciati, ISBN 3-540-55545-5.), and the 3rd International Conference on Structural Control, Como, Italy, in 2001 (Proceedings published by Wiley, edited by Casciati F., ISBN: 978-0-471-48980-1). He also co-edited the following Proceedings: Civil Infrastructure Systems: Intelligent Renewal. Proceedings of the Third International Symposium, Capri, Italy, in 1997 (Published by World Scientific Publishing Company, co-edited by F. Casciati , M.P. Singh , P. Spanos , F. Maceri, doi: https://doi.org/10.1142/3853); Structural Control for Civil and Infrastructure Engineering. Proceedings of the 3rd International Workshop on Structural Control, Paris, France, in 2000 (Published by World Scientific Publishing Company, co-edited by F. Casciati and G. Magonette, ISBN 981-02-4475-4); Structural Health Monitoring 2010, the Fifth European Workshop on Structural Health Monitoring, Sorrento, Naples, Italy, in 2010 (Proceedings published by Destech Publications Inc, co-edited by F. Casciati and M. Giordano, ISBN 978-1605950242); CIMTEC 2016, 2012, and 2008 (Proceedings published by Scientific.net, Advances in Science and Technology, Vo. 101, 83, and 56 co-edited by F. Casciati and P. Vincenzini, ISSN: 1662-0356).

From 1991 to 2007, he served as an invited lecturer and chaired several advanced courses at the International Centre for Mechanical Sciences (CISM), Udine, Italy. He edited or co-edited the following monographs of the CISM/Springer series: “Reliability Problems: General Principles and Applications in Mechanics of Solids and Structures”, 1991, ISBN 978-3-211-82319-4, and “Dynamic Motion: Chaotic and Stochastic Behaviour”, 1993, ISBN 978-3-7091-2682-0

Professor Casciati was the principle investigator in several research grants from the National Research Council (CNR) since 1976. From 1980 he acted as the Coordinator of several projects of relevant national interest. Financed by the European Commission, he also acted as the Coordinator of a FP4 Telematics project (RADATT, EN1011-96), two INTAS projects (97-1140 and 2003-51-5547), an FP5 INCOMED project (ICA3-99-06), and an FP6 INCOMED project (FP6-INCO/509085). He acted as vice-chairman of the COST action E24 (2000-2005) and served as a member of the Management Committee of the COST actions E55 and TU0601. He was director of the Cooperlink projects with Algeria, Armenia and Macedonia from 2006 to 2012.

Since 1994, Professor Casciati has been an expert reviewer of the scientific programs of the National Science Foundation (NFS), the European Science Foundation (ESF), the European framework programs FP4, 5 and 6, and the National Agencies operating in Austria, France, Italy, Luxembourg, and Romania. He has authored or co-authored more than 200 papers (more than 60 were published in ISI international journals) and three books: Augusti G., Baratta A. and Casciati F., 1984, Probabilistic Methods in Structural Engineering, CRC Press, London (ISBN: 9780412222306; translated also in Russian); Casciati F. and Faravelli L., 1991, Fragility Analysis of Complex Structural Systems, Research Studies Press, Taunton, UK (ISBN: 9780863801143); Casciati Fabio, Magonette G., Marazzi F. (2006). Technology of Semiactive Devices and Applications in Vibration Mitigation. CHICHESTER:John Wiley & Sons, ISBN: 9780470022894. He is also the co-editor, with J.B. Roberts, of Mathematical Models for Structural Reliability Analysis, CRC Boca Raton, Mathematical Modelling Series, 1996, ISBN 9780849396311.

Professor Casciati’s research fields of expertise include: stochastic mechanics, earthquake engineering, nonlinear dynamics, structural control, smart materials, and structural monitoring.

Lucia Faravelli was born in Travaco’ Siccomario (PV), Italy, on August 27, 1947. She graduated in Mathematics from the University of Pavia, Italy, on February 29, 1972. She has held the following Academic positions: Research Assistant (1972–83); Lecturer (1980–83); Associate Professor (1983–90) of Scienza delle Costruzioni at the School of Engineering of the University of Pavia, Italy. Professor at the School of Engineering of the University of Perugia, Italy, from 1990 to 1991; Full Professor at the School of Engineering of the University of Pavia, Italy, from 1991 to 2017. She served as the Chairperson of the Civil Engineering Council in the period from 1995 to 2001, and she was a co-founder and a Faculty member of the Ph.D. School in Civil and Environmental Engineering from 1994 to 2016. She is the first scholar in Italy to introduce a Structural Safety course in a Civil Engineering curriculum. She was a visiting Researcher at Virginia Polytechnic Institute and State University, Blacksburg, Virginia (USA), in 1985; Visiting Researcher at Stanford University, Stanford (USA), in 1986, with an NSF Award. Since 2000, she has served as a member of the Ph.D. graduation committees of the Universities of Bologna, Padova, Roma, Girona, Sydney, and Hong Kong. Since 2019, she has been an Adjunct Professor at the College of Civil Engineering and Architecture, Zhejiang University, Hangzhou, China.

Professor Faravelli served as a member of the Board of Directors of the European Association for the Control of Structures (EACS) from 1993 to 2012, a member of the Board of Directors of the International Civil Engineering Risk and Reliability Association (CERRA) and a member of the Italian Association of Theoretical and Applied Mechanics (AIMETA). Since 2002, she has been a Scientific Partner of the Mechatronics Excellence Centre ACCM, Linz, Austria.

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In 1986, she received the NSF Award for Distinguished Woman Scientists; in 2006, she received a distinguished plaque in recognition of her cooperation effort from the Asian Network of Centers of Research in Smart Structures Technology; in 2018, she was awarded the Takui Kobori Prize 2015.

She has given several plenary lectures worldwide, and has organized, as the European chairperson, four ESF-NSF joint workshops on Smart Structures (2002, 2003, 2005 and 2006).

She served as the Coordinator of the Human Capital Mobility program of the European Union on Stochastic Mechanics ERBCHXCT940565 (1994-97), and the Coordinator of the European Research Foundation (ESF) research program CONVIB on Innovative Control Technologies for Vibration Sensitive Civil Engineering Structures (2001-05). She was responsible of the Cooperlink project with Cyprus in 2011.

Since 1990, Professor Faravelli has been an expert reviewer of the scientific programs of the National Science Foundation (NFS), the European Science Foundation (ESF), the European framework programs FP6 and 7, and the National Agencies operating in Austria, Belgium, Italy, Romania, Chile and China.

She has authored or co-authored more than 200 papers (more than 58 were published in ISI international journals) and two books: "Sicurezza Strutturale" (in Italian), Pitagora, Bologna (ISBN: 9788837104160) and "Fragility Analysis of Complex Structural Systems", Taunton Press co-author F. Casciati (ISBN: 9780863801143). She is also a co-editor of "Shape Memory Alloys: Advances in Modelling and Applications", CIMNE, Barcelona (ISBN: 84 -89925-82-8).

Professor Faravelli’s research fields of expertise include: structural reliability, stochastic mechanics, earthquake engineering, boundary elements analysis, structural control, structural identification, and smart materials