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BOOK OF ABSTRACTS

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GADeS Aim

The aim of GADeS is to promote the scientific interaction between researchers operating in the fields of Solid and Structural Dynamics, Machine Dynamics and Dynamical Systems, as well as the opportunity for improving cooperation with researchers working on Identification and Control problems, independently from the scientific sector, thus in coherence with the AIMETA's statutory spirit. Indeed, the integration of researchers, who are studying particular and/or complementary problems, appears very important since it can enlarge the range of interests of the Group. Therefore, the AIMETA GADeS Group is specifically aimed at sharing knowledge from different sectors, through the organization of workshop, mini-symposia, special sessions in AIMETA's conferences and, last but not least, the coordinated participation to Italian and European research project.

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Effects of thermomechanical coupling in laminated plates with different thermal boundary conditions

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Keywords: laminated plates, thermomechanical coupling, global dynamics

Composite plates in thermoelastic regime have a variety of applications in mechanical, aerospace and civil engineering. Partial or full thermomechanical coupling of composite plates and shells has been addressed in the literature through models of different order and richness, and mostly finite element-based approaches, in statics as well as linear or nonlinear dynamics. In contrast, few works have referred to low-order models to numerically investigate the effects of actual coupling on the plate dynamical behavior. In the framework of the 2D modelling of geometrically nonlinear laminated plates, a von Kàrmàn plate with third-order shear deformability and consistent cubic variation of the temperature along the thickness has been formulated, accounting for the possibility to consider different thermal boundary conditions [1]. The reduced formulation, with one mechanical and two thermal time-dependent variables/equations, has shown to preserve the main nonlinear dynamic features of the underlying continuum formulation though furnishing few, manageable, equations, crucial to enable a comprehensive description of their dynamics. Yet, when dealing with multiphysics problems, characterized by contemporary presence of slow and fast dynamics, the classical numerical tools used for investigating the nonlinear dynamical response of a system, i.e. bifurcation diagrams and stability charts, prove to be inadequate to grasp its actual behavior, since they neglect the possible decisive effects of the transient dynamics [2,3]. Conversely, global dynamics analysis, carried out by constructing properly selected 2D cross-sections of the 4D basins of attraction able to reliably representing/describing the multidimensional scenario of nonlinear dynamic response, allows to obtain a comprehensive description and understanding of the response behavior of the system. The results highlight the crucial role played by thermomechanical coupling in affecting the actual onset of buckled responses, with strong differences with respect to what obtained from the uncoupled mechanical system directly subjected to steady thermal excitation. Moreover, the possibility to account for different thermal boundary conditions allows to comparatively point out several dynamical regimes, determined by the activation of different physical processes.

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A homogeneous beam to model double-layered tubes

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Keywords: Beam-like structure, Ovalization, Multi-layer beam, Brazier effect

Tubes are crucial structures in many types of civil and industrial plants, and their strength represents a key point to be addressed during the design process. Furthermore, the use of composite materials typically contributes to increase their strength-to-weight ratio and service life.
In this framework, the use of beam models [1] might be significantly helpful in the design development so as to reduce computational costs in comparison with more refined models. For instance, in [2], a homogeneous macro-mechanical (or coarse) direct model of rod is introduced to address kinematics and statics of a thin-walled beam, taking into account possible ovalization of the cross-section, and an identification procedure from a companion, micro-mechanical (or refined) three-dimensional fiber-model, is used to obtain a coupled nonlinear response function.
Here, the one-dimensional, non-standard beam-like model already presented in [2] is extended to consider a double-layered pipe, where two plies are considered as glued by means of a very thin inter-layer. Differently than what it is done in [2], a nonlinear underlying model of in-plane Timoshenko beam is assumed, and different kinds of warping descriptors are used to take into account the specific characteristics of the pipe, constituted by hyper-elastic materials and under the action of external forces inducing bending. The identification procedure of the response law, coming from a micro-mechanical model, is consistently extended as well, and the effect of the nonlinear coupling among bending, ovalization and warping in the constitutive law is analyzed, in view of the occurrence of instability phenomena. Comparison with Finite Element Models for specific case studies is provided, showing the reliability of the proposed model.

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Structural vibration control through Tuned Liquid Column Dampers: theoretical and experimental analysis

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Keywords: TLCD, Optimization, Mathematical formulation, Stochastic response, Experimental analysis.

In recent years passive structural vibration control has been a flourishing research area in civil and mechanical engineering. In fact, passive control systems can be used to prevent structural elements from damage or increase human comfort due to reduced accelerations.

In this regard, several types of devices have been proposed in order to mitigate the dynamic response of different kind of structural systems. Among them, Tuned Mass Dampers are undoubtedly the most widely used vibration control devices for buildings exposed to earthquake and wind loads.

Nevertheless, Tuned Liquid Column Dampers (TLCDs) represent now an interesting alternative for some of their particular characteristics as low cost, easy installation, lack of required maintenance, and no need to add mass to the main structure. The TLCD simply consists of a U-shaped container partially filled with water. It dissipates structural vibrations by means of a combined action which involves the motion of the liquid mass within the container. Specifically, the restoring force is produced by the force of gravity acting on the liquid while the damping effect is generated by the hydrodynamic head losses which arise during the motion of the liquid inside the TLCD. For analytical investigations, this device is generally modeled as a nonlinear single-degree-of-freedom system rigidly attached to the main structure to be controlled. Its control performance principally depends on an appropriate choice of the tuning and dissipation parameters. However, since TLCD response is generally nonlinear, the determination of its optimal design parameters may be demanding.

On this base, in this work the behavior and main characteristics of this device will be investigated and its effect on the response of vibration sensitive systems will be studied, both from a theoretical and an experimental perspective.

Three main aspects will be dealt with. Firstly, an investigation on the optimal choice of TLCD parameters will be presented, with the intent of a more reliable and efficient design procedure of these devices for real damped structures. Secondly, aiming at more carefully matching experimentally obtained data, an innovative mathematical formulation for the liquid motion within the TLCD will be proposed, as well as its extension to TLCD controlled structures. Finally, the stochastic response of these devices will be developed in details resorting to a recently proposed novel technique. Specifically, results obtained from the research undertaken at the Department of Civil and Environmental Engineering at Rice University (Houston, USA) will be discussed.

In order to validate all the proposed theoretical results, numerous experimental tests have been performed in the Laboratory of Experimental Dynamics at University of Palermo, and experimental vis-à-vis numerical results will be presented for each proposed development throughout the dissertation.

Hysteretic vibration absorber for seismic control of nonlinear structures

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Keywords: Nonlinear vibration absorber, TMD, hysteresis, pinching, seismic control, optimization

Several strategies are available to mitigate structural resonance vibrations, among which Tuned Mass Dampers (TMD). In the past decades, several studies aimed to find optimal TMD parameters for undamped or lightly damped structures under harmonic and white noise random excitations.

In the context of civil structures, TMDs are recognized as effective devices to mitigate wind-induced vibrations whereas their seismic protection capability still represents an open challenge. Generally, TMDs are not as effective for earthquake excitations as they are for wind loading due to several reasons. First, the frequency bandwidth of an earthquake is richer in high frequency content whereas the duration is much shorter. Moreover, structural modes other than the fundamental one are also often excited. The soil-structure interaction is also recognized as a potential issue for the seismic effectiveness of TMDs. Finally, structural damages due to seismic loads can cause a significant frequency shift that might detune the TMD. The performances of linear TMDs were found particularly vulnerable to such issues, and sometimes can even worsen the seismic behavior of the structural system onto which they are installed.

Therefore, many attempts have been made to improve the absorber performances, and the implementation of TMDs with nonlinear restoring forces (e.g., cubic, cubic plus a hyperbolic sine friction forces, etc.) has been proven quite promising in this regard. The concept of hysteretic TMD was originally proposed in [1] while TMDs featuring several types of hysteretic nonlinear restoring forces were tackled in [2,3,4]. Within this framework, the main goal of the present work is to study the performance of a nonlinear TMD mounted on a nonlinear structure by taking into account structural frequency changes during seismic excitation events. To this end, the nonlinear behavior of a reduced-scale steel structure is first described by means of the Bouc-Wen model, whose parameters are identified from experimental dynamic tests. The optimal TMD constitutive parameters are then derived using a Differential Evolution algorithm. Finally, a comparison with a conventional linear damped absorber is discussed.

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Symmetry breaking in planetary gearbox vibrations

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Keywords: gears, vibration, chaos

Planetary or epicyclic gear trains are widely used in many automotive, aerospace and marine applications; they are effective power transmission systems when high torque to weight ratios, large speed reductions in compact volumes, co-axial shaft arrangements, high reliability and superior efficiency are required [1]. Gear vibrations are primary concerns in most planetary gear transmission applications, where the manifest problem may be noise or dynamic forces. The most important source of vibration in planetary gears is the parametric excitation due to the periodically time-varying mesh stiffness of each sun-planet and ring-planet gear, because the number of tooth pairs in contact changes during gear rotation. This mesh stiffness variation parametrically excites the planetary gear system, causing severe vibrations when a harmonic component approaches one of the natural frequencies (or their linear combinations). Under certain near resonant operating conditions, gear systems can experience a teeth separation that induces nonlinear effects such as jump phenomena and subharmonic and superharmonic resonances with dramatic effects on the dynamic response [2]. These phenomena have been deeply investigated in geared systems during the last 20 years [3-5].

This paper presents a dynamic model to simulate the dynamic behavior of a single-stage planetary gear system with time varying mesh stiffness and backlash. The complex dynamic scenario of a three-planets gearbox is investigated in detail. A bifurcation analysis is performed to explore the dynamic scenario (periodic, quasiperiodic and chaotic), with a special attention to symmetry breaking phenomena that are extremely interesting in planetary gears as they can cause additional imbalance-induced-stresses. Numerical analyses are carried out over meaningful mesh frequency ranges. The analysis is completed with time histories, spectra, phase portraits and Poincaré maps of the most interesting regimes. It was proven in the past that chaos induced symmetry breaking in symmetric planetary gearboxes can generate unexpected and undesirable loads on the sun supports, which are not predictable using the classical design tools. The present study shows that tooth profile modifications on sun and planet gears can positively affect the dynamic response of the system and minimize the possibility of failure caused by symmetry breaking and unexpected loads on sun bearings.

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Modal parameters identification with environmental tests and advanced numerical analyses for masonry bell towers: a meaningful case study

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Keywords: Masonry towers, Dynamic Identification, Non-Smooth Contact Dynamics method

Bell and Medieval masonry towers are very widespread, and they belong to the built heritage that must be preserved, especially in high-seismicity regions [1]. Because of their geometrical features, different masonry textures and mechanical properties, they exhibit quite different structural behaviours under horizontal loads. For this reason, an accurate knowledge of dynamical parameters of such structures is paramount for any numerical advanced non-linear dynamic analysis. In the first part of this paper, a dynamic identification technique for non-destructive evaluation of heritage structures [2] is discussed with reference to a case study, namely the Pomposa Abbey bell tower, located in the Ferrara Province (Italy). Despite the fact that the positioning of the instrumentation of the monitoring system was conditioned by quite common operative problems, due to the limited accessibility of the structure, it was in any case possible to identify with a certain confidence the first four frequencies of the tower and their corresponding mode shapes.

The dynamic identification results are used to define harmonic oscillations to be applied at the basement of an advanced numerical models, discussed in the second part, based on the so-called Non-Smooth Contact Dynamics (NSCD) method [3]. A full 3D detailed discretization was adopted to take into account all details and irregularities. With NSCD model, the bell tower was schematized with rigid blocks and rigid/contact friction interfaces. Such approach is quite realistic to carry out full non-linear dynamic analyses. Furthermore, a study of the tower stability against seismic excitations has been addressed and 3D simulations have been performed with a real earthquake. With a correct identification of geometries and mechanical properties, advanced non- linear dynamic simulations resulted useful to predict with accuracy the expected behavior under a strong seismic excitation, providing information on the most vulnerable parts to strengthen, probable active failure mechanisms and expected state of damage.

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Homogenization of masonry walls for static and dynamic analyses

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Keywords: Masonry, Homogenization, Elasticity, Macroscopic moduli, Modal analyses.

Masonry is a composite material characterized by an overall anisotropic behaviour, due to the composite and heterogeneous structure reflecting the particular geometrical arrangement of units and mortar joints. Several researchers have provided macro-modelling techniques for the analysis of masonry, considered as a homogeneous, isotropic or anisotropic continuum. In this class of models, closed-form macroscopic constitutive laws are formulated for an equivalent homogeneous continuum trough homogenization techniques. Limited to the linear elasticity, several authors have derived expressions for the effective properties of masonry, by defining macroscopic elastic constants. This was done e.g., by [1], that assumed masonry to be represented by an equivalent transversely isotropic material. Later, [2] proposed approximated displacement (and stress) fields and prescribed approximate equilibrium and compatibility conditions at the boundaries of a Representative Volume Element (RVE). More recently, [3] both used a Method of Cells-type approach both minimized the potential energy of a RVE subjected to any given macroscopic stress; the FE solution is also used as a benchmark.

This paper aims at deriving analytical expressions for the macroscopic elastic coefficients of in-plane loaded masonry with regular brick pattern. The proposed approach, believed original and very simple, consists in modelling a RVE through spring models opportunely combined in series and in parallel. In particular, first, the RVE is defined and all macroscopic elastic constants of a orthotropic material are determined by introducing specific spring systems. Then, the accuracy of the derived analytical expressions is assessed through comparisons with refined finite element analyses and with the closed-form expressions available in the literature, provided by [3]. This approach is able to deal with the (most simple and efficient) analytical expressions of all the in-plane elastic constants: Young's moduli, Poisson ratios and shear modulus. Finally modal analyses are also performed on a (in scale) masonry wall model: discrete and homogenized models of wall are analysed and compared. This approach is found to accurately match the macroscopic constitutive law in linear elasticity.

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Reinforced Concrete Beams Under Blast and Impact Load

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Keywords: Blast Load, Strain rate, Impact Load, Reinforced Concrete

In this paper, the structural responses of reinforced concrete (RC) beams subjected to blast loading are investigated. In particular, RC beams with a low reinforcement ratio are examined, which are more likely to fail in flexure than in shear.
In order to assess the response of the beam, two analytical approaches are developed. In the first one, the beam is modelled as a continuous element by means of Euler-Bernoulli's theory, which neglects the contributions of shear deformation and rotary inertia. The nonlinear behavior of the beam in the elastic-plastic range is approximated by a single smooth relationship between bending moment and curvature, which allows to derive an original expression of the differential equation of motion of the beam. The parameters appearing in the latter are easily determined from the geometric and constitutive properties of the beam.
The second approach described in this paper consists, instead, in evaluating the response of the beam through an equivalent single degree of freedom (SDOF) system. The latter is a mass-spring oscillator, its constitutive behavior is expressed through a bilateral relationship between force and displacement. The main drawback of this simplified approach is the need to introduce empirical quantities, such as the equivalent mass and the length of the plastic hinge.
In both approaches, strain rate effects are taken into account. In fact, these effects should not be ignored in problems concerning blast loads, since the mechanical properties of both concrete and steel strongly depend on the rate of de-formation. In this paper, strain rate effects are considered by changing the parameters related to the material proper-ties during time, in accordance with the rules provided by the international standards.
Finally, in order to test the validity of the two approaches, the theoretical results produced by the latter ones are compared with some experimental data found in literature. In particular, the time-histories of the maximum deflections of several simply supported RC beams under uniformly distributed loads generated by explosions are analysed. It is shown that the first approach is capable of predicting both the maximum displacement time-history and the deflection at collapse of any beam accurately. On the other hand, the second approach gives a less precise assessment of the structural response of the beam; nonetheless, the method based on the equivalent SDOF model is simpler to use and its differential equation of motion is faster to integrate.

Buckling modes in pantographic lattices

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We study buckling patterns in pantographic sheets, regarded as two-dimensional continua consisting of lattices of continuously distributed fibers. The fibers are modeled as beams endowed with elastic resistance to stretching, shearing, bending and twist. Included in the theory is a non-standard elasticity due to geodesic bending of the fibers relative to the lattice surface.

Perturbation solutions of nonlinear taut strings traveled by a moving force

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Keywords: Moving-load problems, Nonlinear dynamics, Perturbation techniques

Moving-load problems are very important in several engineering systems such as bridges traveled by vehicles or pedestrians, machine tools, pantograph collectors in railways, guide-ways in robotic solutions. The moving force model is still widely used in both scientific and technical field for its relevance and ease of use; it is often sufficient to deal with problems of practical interest. The nonlinear behavior induced by moving loads has been addressed in several areas (e.g, [1], [2]) but rarely for nonlinear taut strings.

The taut string is an idealized model of cable with evanescent sag. It is quite accurate when the natural length of the cable is smaller than the distance between the suspension points (i.e., prestressed cables). In engineering problems the geometric non-linearity of taut strings is usually addressed for specific objectives such as the possibility of overcoming the critical velocity (e.g., [3]), otherwise it is usually neglected. On the other hand, the dynamics of nonlinear strings seems important to applied mathematics (e.g., [4]). Similar problems are dealt with in the field of traveling tensioned strings.

This paper concerns the study of the combined effects induced by moving loads and nonlinear- ities on Kirchhoff taut strings, paying special attention to the dynamic change of tension, not con- sidered in the linear model. If the moving force can be considered sufficiently small in value (i.e., weakly nonlinear dynamics of taut strings) the behavior for load speeds below the string celerity can be evaluated through the use of standard semi-analytical techniques [5]. Fulfilling the hypothesis of loading velocity far from the critical value, the dynamic behavior of the system under a generic load can be interpreted from a perturbation point of view, through different time scales (as, e.g., in the Multiple Scale Methods). A perturbation solution is being developed; comparisons with numerical solutions are performing using literature values for the model parameters.

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Dynamics and vibration stability analysis of a rotating thin-walled composite beam subjected to harmonic base excitation

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Keywords: rotating beam, base excitation, parametric vibrations, stability analysis

Rotating beams are used as models for studying the dynamic properties of rotating blades in turbomachinery, helicopter rotors or lightweight satellite structures appendages. Most of these systems can be considered as on-board machines. Typical examples are ship and aircraft turbines, helicopter rotors, locomotive electrical generators or wind turbines subjected to earthquake shocks. In most of these applications the in-plane base excitation takes the form of a translational acceleration and affects the overall performance of the rotating structure as exhibited by the increased lateral blade vibrations. In limit states large responses and the dynamic instability phenomenon might occur.

This study considers the stability of vibration of a rotating structure consisting of a rigid hub and a flexible thin-walled laminated composite beam performing the additional to-and-fro motion. The assumed Circumferentially Asymmetric Stiffness (CAS) profile lamination scheme results in complex deformation of the blade revealing the mutual twist/in-plane bending/in-plane shear motion coupling.

The partial differential equations of motion representing an elastic deformation of the blade have been derived by the Hamilton least action principle [1]. Next, these equations have been transformed to a single dimensionless ordinary differential equation by adopting the Galerkin method and an orthogonality condition for CAS lamination scheme [2].

It is shown the final equation of motion includes time-varying coefficients that depend on the system angular velocity as well as on the base excitation frequency. Due to the doubly periodic external excitation terms this form of the governing equation is different from the typical Mathieu-Hill equation as often met in other engineering problems – e.g. column buckling under time periodic compression or pendulums systems with support periodic motion.

The derived equation of motion is solved to determine the instability boundaries of the system. To this aim the method of multiple scales [3] is adopted and the uniformly valid expansion up to the second order is assumed. The numerical examples are presented to illustrate the influence of selected model parameters on the dynamic stability of the system.

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Flexural torsional buckling of not-uniformly compressed tower buildings

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Keywords: Equivalent beam model, Timoshenko beam, Buckling analysis

The buckling analysis of not-uniformly compressed tower buildings is addressed. To this end an equivalent 3D Timoshenko beam model is introduced through a homogenization procedure. The proposed model is formulated in the framework of a direct approach, and, therefore, a suitable constitutive law, accounting for prestress forces, is introduced. This is obtained by generalizing the results shown in [1] for the case of uniform compression. The bifurcation analysis is then carried out, also taking into account for the interaction with a Winkler soil, by means of a finite difference discretization. The numerical results concerning the equivalent model are compared with 3D finite element analyses, showing a good agreement. Finally, some conclusions and perspectives are drawn.

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Flexural torsional buckling of uniformly compressed beam-like structures

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Keywords: Beam-like structures, Homogenization procedure, Buckling analysis

A Timoshenko beam model embedded in a 3D space is introduced for buckling analysis of multistore buildings, made by rigid floors connected by elastic columns. The beam model is developed via a direct approach, and the constitutive law, accounting for prestress forces, is deduced via a suitable homogenization procedure. The bifurcation analysis for the case of uniformly compressed buildings is then addressed and numerical results concerning the Timoshenko model are compared with 3D finite element analyses. Finally, some conclusions and perspectives are drawn.

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Nonlinear planar response of massive taut strings travelled by a force-driven point-mass

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Keywords: Traveling mass, Taut string, Discontinuity trajectory paradox

The planar response of horizontal massive taut strings, travelled by a heavy point-mass, either driven by an assigned force, or moving with an assigned law, is studied. A kinematically exact model is derived for the free boundary problem via a variational approach, accounting for the singularity in the slope of the deflected string. Reactive forces exchanged between the point-mass and the string are taken into account via Lagrange multipliers. The exact model is consistently simplified via asymptotic analysis, which leads to condense the horizontal displacement as a passive variable. The dynamic increment of tension, with respect the static one, is neglected in the governing equations, but evaluated a posteriori, as a higher-order quantity in a perturbation perspective. Several simplified models are also discussed. The equations are solved and rearranged in the form of an integral equation coupled with an ordinary differential equation, thus extending a procedure already introduced in the literature. Numerical results, showing the importance of the horizontal reactive force on the quality of motion, are discussed, generalizing those relevant to massless strings.

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Synchronized solutions of wake-oscillator model equations for galloping and vortex-induced vibration

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Keywords: wake-oscillator model, galloping, vortex-induced vibration, method of averaging

Many slender bluff bodies immersed in a cross-flow are prone to both vortex-induced excitation and the purely self-excited instability known as galloping. In the ideal case, the two phenomena occur in different flow-speed ranges and do not interact with each other. Nevertheless, it has been shown in [1] that in many practical situations the two excitation mechanisms interfere giving rise to the so-called unsteady galloping instability, showing peculiar features, which cannot be captured by the theories of vortex-induced vibration and galloping taken separately.

For this reason, a wake-oscillator model has been applied to the paradigmatic case study of a rectangular cylinder [2]. The model is a modified version of the one proposed in [3], and it relies on the simple idea of the linear superposition of unsteady wake forces producing vortex-induced vibration and quasi-steady forces responsible for galloping. Mathematically speaking, the model represents an autonomous system of two coupled nonlinear equations: the transverse vibrations of the body are described by a linear oscillator subjected to a nonlinear force, while a van-der-Pol- type equation is employed to mimic the motion of the equivalent wake lamina. The major contribution of the work in [2] was the removal of a crucial assumption to estimate one of the model's parameters, increasing significantly the amount of nonlinearity in the wake equation and promoting the tendency of body and wake oscillators to synchronize. This allowed overcoming the major drawbacks of previous results obtained for an oscillating square cylinder in cross flow [3].

The equations were solved numerically in [2], adopting the flow speed as control parameter, and the results were compared to experimental data. A rich nonlinear behaviour of the equations was revealed, with supercritical and subcritical bifurcations, periodic and quasi-periodic solutions, and hysteresis loops.

In order to better understand the complicated behaviour of the model and shed some light on a few important features of the unsteady galloping phenomenon, it is useful to search for analytical approximate synchronized solutions of the equations through asymptotic methods. As a first step in this direction, the Krylov-Bogolyubov averaging method is employed in the present work, keeping in mind that this analysis is limited in certain flow-speed ranges by the fact that the wake equation does not exhibit a weakly nonlinear behaviour.

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Dynamic modelling of a gyroscopic stabilizer for the flutter performances of a long span bridge deck

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Keywords: Gyroscopic stabilizer, long span bridges, flutter performances.

Long span suspended bridges are challenging structures which are generally sensitive to wind effects and to wind-induced instabilities: it is well known that torsional rotation of the bridge deck plays an important role for the dynamic stability of the structure [1].

The paper focuses the attention on a gyroscopic device conceived as an active stabilizer of the long span bridge: the proposed method has been applied to a 3 degrees-of-freedom (dofs) section-model of the bridge deck.

A mathematical model of the gyroscopic device taken form [2] has been adopted by the authors in the present paper; the main component of the system is a rotating mass, with a horizontal angular momentum **Ω,** which is parallel to the section-model; the mass is connected to the deck by a rotational spring. The system allows relative rotations between the section-model and the rotating mass in the bridge deck plane. The gyroscopic system reacts to torsional vibrations of the deck by coupling torsional vibrations with the other dofs of the system, thus transferring the energy from the torsional mode to the others frequencies of the system [3, 4].

Free vibrations of the section-model were analyzed in order to assess the effectiveness of the proposed apparatus.

Results show that the use of a gyroscopic stabilizer allows, as expected, for an effective reduction of torsional rotation amplitude of the section-model.

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Uncertainty propagation in serviceability assessment of footbridges

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Keywords: Footbridges, Human-induced vibrations, Serviceability, Spectral model, Uncertainties.

Modern footbridges can be very sensitive to human-induced vibrations and their serviceability assessment is a central issue in their design. Recent guidelines provide straightforward procedures to deal with their serviceability analyses, based on simplified expressions of pedestrian-induced forces. The Equivalent Spectral Model is an alternative loading model that expresses the power spectral density function of the model force as proportional to the probabilistic distribution of step frequency [1]. Based on this model, a simple expression is provided for the approximate estimate of the standard deviation and of the maximum value of the footbridge acceleration as a function of the structural dynamic parameters and of the loading parameters. Monte Carlo simulations have demonstrated the accuracy of the model [2].
However, the estimate of several loading and structural parameters is uncertain. Dealing with pedestrians loading, uncertainties characterize the parameters of the distribution of the step frequency, the dynamic loading factor and pedestrian weight. Dealing with the structural dynamic parameters, the damping ratio is very uncertain, but also the natural frequency may be affected by some variations. Many procedures allow propagating the uncertainties. In this paper, Taylor series expansion technique is adopted (e.g. [3]) due to its efficiency and its ability to provide closed-form solutions.
The aim of the present contribution is to quantify the propagation of uncertainties in both the structural and the loading parameters on the serviceability assessment of footbridges. A detailed analysis of the literature concerning the experimental measurements of walking-induced forces aimed at the characterization of the main loading parameters and footbridge dynamic properties is carried out; thus, the uncertainties in the loading modelling and structural dynamic parameters are quantified. At a second step, based on the Taylor series expansion technique, the uncertain parameters having large influence on the maximum acceleration are identified. Based on the quantification of the mean values and standard deviations of all the involved parameters, the propagation of uncertainties on the serviceability analysis of an ideal and a real footbridge is carried out and the main parameters governing the uncertainty in the estimate of the standard deviation of the footbridge acceleration are identified. Furthermore, the reliability of Taylor series expansion is validated through Monte Carlo simulations. Finally, results are compared with conventional guideline verifications and the reliability of simplified assessment procedures is analysed.

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