CMM-SolMech 2022 conference

S09 Nonlinear dynamics, vibrations and control

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REFINED ZIG-ZAG THEORY FOR DYNAMIC CHARACTERISTICS OF LAMINATE PLATES WITH VISCOELASTIC LAYERS

Przemysław Litewka[1], **Roman Lewandowski**[1]

[1] Institute of Structural Analysis, Poznan University of Technology, Poland

przemyslaw.litewka@gmail.com

The laminate structural elements - beams, plates and shells, including viscoelastic (VE) layers attached to or inserted between elastic panels, are very often used in various engineering applications, like aerospace, machine or car industry. Such structures possess very desirable mechanical properties combining light weight with high load capacity. The VE layers are applied to dissipate significant amounts of energy and thus vibrations and noise can be significantly mitigated also allowing to avoid fatigue failure.
In this paper the refined zig-zag theory (RZT) is used to carry out the dynamic analysis of composite sandwich plates including the VE layers. RZT allows to introduce the different physical properties of layers while preserving the stress continuity on the layer interfaces. The application of RZT to such type of problem leads to the frequency-dependent complex-valued character of the zig-zag function unlike in the case of static analysis.
The linear constitutive relations written down separately for volumetric and deviatoric strains are used to model the material. It is worth to note that such an approach allows for a clear physical interpretation whereas the corresponding relaxation and creep functions can be determined from experiments. It also introduces naturally the frequency-dependence of the Poisson's ratio postulated in some recent papers on viscoelasticity.
The fractional Zener model is used in the formulation of VE material. It is already well known that the application of fractional calculus is a very efficient tool allowing for description of all important rheological phenomena while utilizing a few material parameters. The Laplace transformation and the finite element method are used to derive the discretized nonlinear eigenvalue problem.
The fundamental properties of the plates required for design of structural elements in many fields of engineering, i.e. their dynamic characteristics - the frequency and the damping ratio, can be obtained using the specially developed numerical procedure. It is based on the continuation method. In the iterative part of each continuation step either the full Newton or the quasi-Newton iterative procedure is used.
Several numerical examples are solved to verify accuracy, efficiency and versatility of the proposed formulation. Numerous parametric studies were carried out to determine the influence of various variants of solution methods, combinations of material parameters and layers layout onto the damping properties of plates. These results will be presented and discussed at the conference.

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CHAOTIC DYNAMICS OF SIZE-DEPENDENT FLEXIBLE RECTANGULAR IN PLAN FLAT SHELLS

Vadim Krysko-jr[1], **Jan Awrejcewicz**[1]

[1] Department of Automation, Biomechanics and Mechatronics, Lodz University of Technology, Poland

vadimakrysko@gmail.com

Introduction

Nowadays, the development of structures and their elements with new unique properties - MEMS/NEMS, for various branches of science and technology: instrumentation, medical equipment, aviation and engineering, construction, space exploration is going intensively.
This paper presents a mathematical model of nonlinear dynamics of isotropic elastic structures in the form of rectangular in plan Kirchhoff-Love shells based on the modified couple stress theory under the action of transverse, alternating load. The equations, boundary and initial conditions are obtained from the Hamilton-Ostrogradsky principle. Structures are considered as systems with an "almost" infinite number of degrees of freedom. Reliability of the results is ensured by obtaining solutions by fundamentally different methods: the method of finite differences (FDM) of the second order of accuracy and the Faedo-Galerkin method (FGM) [1]. The convergence of these methods was investigated.
The mathematical model was based on the following hypotheses: the shell material is isotropic, elastic and obeys Hooke's law; the kinematic model is the Kirchhoff-Love model; geometric nonlinearity is taken into account by the von Karman; nanostructures are described by modified couple stress theory.

Scheme

Nonlinear partial differential equations taking into account modified couple stress theory -> Reduction to the Cauchy problem: Second-order finite difference method (FDM) and by the Fayedo-Galerkin method (FGM) -> Solving the Cauchy problem by Runge-Kutta type methods (from 2 to 8 orders of accuracy) using the Newmark method -> Solving the Cauchy problem by Runge-Kutta type methods (from 2 to 8 orders of accuracy) using the Newmark method -> Analysis of numerical results

Results

For a square in plan shell, we provide numerical results of the character of vibrations obtained BGM and FDM. In our research below, we will follow Gulick's definition of chaos. The largest Lyapunov exponents (LLEs) was determined using three methods: Wolf , Kantz and Rosenstein. To prove the truth of chaos, maps of the character of vibrations (Poincaré's idea) were constructed and and it was necessary to solve and analyze 9*104 problems according to the given scheme

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STOCHASTIC VIBRATIONS OF PLATES WITH VISCOELASTIC DAMPERS

Marcin Kamiński[1], Agnieszka Lenartowicz[2], Michał Guminiak[3], Maciej Przychodzki[3]

[1] Faculty of Civil Engineering, Architecture & Environmental Engineering, Łódź University of Technology, Poland
[2] Doctoral School of Poznan University of Technology, Poland
[3] Institute of Structural Analysis, Poznan University of Technology, Poland

michal.guminiak@put.poznan.pl

The main objective in this work is to study of the probabilistic structural response for the free damped vibrations of thin elastic and isotropic plates supported on boundary and resting on viscoelastic supports. Temperature sensitivity of the viscoelastic supports has been quantified and discussed here. Probabilistic mechanics is a topic that has been intensively studied, i.e. [1,2], so that the Stochastic Finite Element Method has been applied in this case study to describe and to solve the thin plate bending. The problem of eigen-vibrations of such a system is solved by the method of continuation [3,4]. The single damper contains one Kelvin element and one Maxwell element with the parameters determined at the reference temperature [5]. Probabilistic design variables in this study are as follows: the plate thickness, the material properties, the temperature influencing the characteristics of the viscoelastic supports, and the values of which can change randomly, regardless of the operating temperature. Numerical investigations include eigenfrequencies and coefficients of damping and, particularly, their first four probabilistic characteristics. Structural response containing values of eigen-frequencies or coefficients of damping will be approximated using polynomial and B-spline functions. Stochastic response has been analyzed using three independent probabilistic techniques: Monte-Carlo simulation method, iterative generalized stochastic perturbation technique as well as by the semi-analytical approach. Probabilistic entropy of structural responses has been quantified. The advantage of this approach is that the resulting expected values and standard deviations of structural response are obtained using analytical calculus of probability integrals.

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STEADY VIBRATION PROBLEMS IN THE THEORY OF ELASTICITY FOR MATERIALS WITH TRIPLE VOIDS

Merab Svanadze[1]

[1] Ilia State University, Georgia

svanadze@gmail.com

In the last two decades, intensive research has been carried out in the theory of materials with triple porosity (voids), which has led to the widespread use of such materials in civil and geotechnical engineering, technology, hydrology, geomechanics and biomechanics. Elastic materials with triple voids are solids with pores on the macro scale, pores on a much smaller meso scale, and pores at an altogether smaller scale known as micro pores.

In this talk, the linear theory of elasticity for materials with triple voids is considered. The internal and external boundary value problems (BVPs) of steady vibrations are investigated. Namely, on the basis of Green's identity the uniqueness theorems for external BVPs are proved. By virtue of Green's tensors, the internal BVPs are reduced to the equivalent Fredholm's integral equations of the second kind with symmetrical kernel. The existence of eigenfrequencies of the internal BVPs of steady vibrations is proved. Then, the formula of the asymptotic distribution of these eigenfrequencies is obtained. Finally, the existence theorems for classical solutions of the above mentioned boundary value problems of steady vibrations are proved by means of the potential method (boundary integral equation method) and the theory of singular integral equations.

RESISTANCE OF AUXETIC SANDWICH PLATE TO PROJECTILE PENETRATION UNDER DIFFERENT IMPACT CONDITIONS

Jakub Michalski[1], **Tomasz Stręk**[1]

[1] Division of Technical Mechanics, Poznan University of Technology, Poland

jakub.ja.michalski@doctorate.put.poznan.pl

Materials and structures with a negative Poisson's ratio are called auxetics. Their deformation under tensile or compressive loading is counter-intuitive but they also exhibit unusual behavior in other operating conditions. They are known to be superior to materials with a positive Poisson's ratio in many cases. It was already proven that auxetics can be used in various applications involving dynamic loads. Improved fracture and fatigue resistance of auxetics was confirmed by authors in previous studies. It was also verified that these structures can serve as protective components in cases where blast or impact loading may occur. In this study, the authors performed numerical simulations involving sandwich plates with auxetic anti-tetrachiral core compared with regular hexagonal honeycomb core. Various impact conditions were taken into account to prove that such auxetic plates may be used in place of standard sandwich structures for protective purposes regardless of how the projectile hits the structure. For this purpose, different impact angles and locations were checked. The initial velocity of the impactor was also varied. The simulations were performed using Abaqus software. Each plate was made of two outer skins modeled with solid elements and a core modeled with shell elements. Explicit dynamics simulations were carried out and a general contact algorithm was used to account for the contact between the projectile and parts of the plate but also for the self-contact of plate's surfaces. Aluminum material properties were used for a Johnson-Cook plasticity model with strain rate dependency and shear failure included. Thanks to the last option and element deletion feature it was possible to remove failed elements from mesh and model the actual penetration of the plate. Other assumptions of the analyses included a permanent connection between the skins and core of each plate and a perfect rigidity of the projectile. Plates were clamped on their sides. Evaluation of resistance of each plate to puncture was based on velocity, displacement and plastic dissipation energy plots. Results of the performed analyses clearly indicate superior resistance of auxetic plate to various impact conditions.

EIGENVIBRATION OF PLATES WITH VE SUPPORTS IN TERMS OF CONTINUATION AND SUBSPACE ITERATION METHODS

Agnieszka Lenartowicz[1], Maciej Przychodzki[2], Magdalena Łasecka-Plura[2], Michał Guminiak[2]

[1] Doctoral School, Poznan University of Technology, Poland
[2] Institute of Structural Analysis, Poznan University of Technology, Poland

maciej.przychodzki@put.poznan.pl

Keywords: thin plates, free damped vibrations, viscoelastic dampers, Finite Element Method, subspace iteration method, continuation method, frequency-temperature correspondence principle.

The free damped vibrations of thin (Kirchhoff-Love) plates supported on boundary and resting on viscoelastic supports are considered in the paper. The set of viscoelastic supports are established according to the generalized rheological model and the fractional model presented in e.g. [1-6]. The Finite Element Method was applied to describe and solve the thin plate bending problem. The rectangular four-node finite elements are used for the discretization of the plate surface in accordance with the principles of the FEM. Influence of temperature on the parameters of dampers is considered by the use of frequency-temperature correspondence principle. The natural frequencies and non-dimensional damping ratios are determined for these plates by solving the non-linear eigenproblem using the continuation and subspace iteration methods which have already been used in similar tasks, e.g. [1-6].

In the considered examples the models of VE dampers are the generalized Maxwell model and the fractional Zener model with the following parameters determined at the reference temperature according to [5]. The present results of calculation obtained by the subspace iteration method were related to the results coming from the approach based on continuation method previously presented in [6]. A square plate with support conditions was analyzed as in the example from [6]. All calculations were performed with the use of original numerical programs.

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RHEOLOGICAL PROPERTIES OF VISCOELASTIC MATERIAL IDENTIFIED IN SHEAR TESTS AND UNIAXIAL TESTS

Zdzisław Pawlak[1]

[1] Institute of Structural Analysis, Poznan University of Technology, Poland

zdzislaw.pawlak@put.poznan.pl

Viscoelastic (VE) materials that have the ability to dissipate energy are often used to reduce excessive vibration in building structures. They are most often used in the so-called passive damping systems in building structures exposed to earthquakes or wind action. Passive dampers usually work effectively only in a relatively small frequency range, therefore they must be precisely designed and their rheological parameters must be properly determined. The dynamic behavior of most of the viscoelastic materials used in vibration dampers depends on the temperature, frequency and amplitudes of the forcing vibrations. It is difficult to create a rheological model for a viscoelastic material that covers a wide range of temperature and frequency variations. In this work, the so-called fractional rheological models were used to describe the dynamic behavior of the tested material, which means that non-integer derivatives are used in the equations of motion. The use of fractional model enables a good fit of the model to the real properties of the material, with a relatively small number of model parameters, which in turn facilitates the identification process. The model parameters were identified on the basis of laboratory tests performed at different temperatures and for different vibration frequencies. In addition, the rheological properties of the viscoelastic material were identified in two different load configurations, during the shear test and the uniaxial compression / tensile test. After proving that the material is thermoreologically simple, the so-called master curves were created, where a horizontal shift factor was used. The Williams-Landel-Ferry formula was applied to create the graphs of the master curves, and the constants in the formula were determined for the selected temperature. As a result, the functions of the storage and loss module were derived for a frequency range several times larger than that which was available in the experiment. The parameters of the fractional rheological model were identified by simultaneously fitting both master curves (i.e. storage and loss modulus) obtained from shear test, as well as from uniaxial tension / compression test. In this way, a comprehensive description of the rheological properties of the viscoelastic material was obtained. On the basis of the obtained results, it can be concluded how much the rheological properties of the tested material differ in different load configurations.

OPTIMIZATION OF MTMD PARAMETERS BASED ON THE H2 AND HINF NORM ON THE EXAMPLE OF A TALL BUILDING

Piotr Wielgos[1]

[1] Department of Structural Mechanics, Lublin University of Technology, Poland

p.wielgos@pollub.pl

The work presents an innovative approach to constructing equations of motion for structures with attached MTMD. The basic system with MDOF (multiple dynamic degrees of freedom) was reduced to the equivalent system with SDOF (single degree of freedom) by a modal approach, and the equations from additional MTMD were added to the system thus created. The adopted innovative method of creating equations of motion enables the addition of single TMD or MTMD to completely different degrees of freedom of the basic system. The equation system allows easy MTMD tuning for complex vibration modes, with MTMD located at local vibration maxima, while analyzing the SDOF system with attached MTMD.
The main stage of the research was the optimization of MTMD parameters in the complex structure, but still the analysis as an SDOF system. The analysis was based on a reinforced concrete structure in the form of a tall building called Gray Office 'A' located in the city of Lublin in Poland. The building is set on a foundation slab with two underground storeys and 13 above-ground storeys with a total height of 56m. The analysis adopted the problem of MTMD tuning to the first natural frequency f1 = 0.8431 Hz. The optimization analysis covered the parameters of a single TMD, double TMD, 4 TMD and 6 TMD, which were located in selected nodes of the system. Optimization based on H2 and Hinf for the transfer function associated with the generalized displacement of an SDOF system was applied. In the research work, optimization algorithms GA (genetic algorithms) and SA (simulated annealing method) were used to determine the stiffness and damping parameters for individual TMDs. As a result of the calculations, optimal MTMD parameters were obtained, which were presented as graphs of FRF modules (frequency response function) in selected nodes of the system.
The influence of the damping and stiffness distribution (MTMD tuning) depending on the number of TMDs was also analyzed. The impact of changing the primary system weight on the performance of optimized MTMD was also reviewed, and the results of other authors regarding the greater effectiveness of MTMD in relation to a single TMD were confirmed.

IDENTIFICATION OF DYNAMIC CHARACTERISTICS OF UNCERTAIN BOLTED CONNECTIONS IN A FRAME STRUCTURE

Mariusz Ostrowski[1], **Bartłomiej Błachowski**[1], **Grzegorz Mikułowski**[1], **Łukasz Jankowski**[1]

[1] Department of Intelligent Technologies, Institute of Fundamental Technological Research, Polish Academy of Sciences, Poland

mostr@ippt.pan.pl

Parametric identification of structures and their components can be encountered in many engineering problems such as damage assessment or model updating for the control purposes. In the present study the attention is on two approaches to model updating. The first approach is the classical penalty function that minimizes the square norm of the error between experimental and numerical modal data. The second one is a probabilistic Bayesian framework that maximizes the a posteriori probability density function of the unknown parameters based on the experimental data. The main difference between these two approaches is related to the fact that the penalty function methods requires matching of the numerical data with those obtained experimentally. The Bayesian approach is not vulnerable to this problem, but it requires more weighting parameters to be selected. An improper selection of these parameters leads to a worse identification accuracy. In this work, the two approaches are compared using data obtained from experiments on a laboratory-scale frame with highly uncertain bolted connections. 17 uncertain stiffness parameters are to be identified: 16 of them correspond to the bolted connections and one to the Young modulus of the beams. 82 degrees of freedom are measured with the aid of 4 bidirectional accelerometers and roving sensor technique. Experimental modal data used for model updating contain nine mode shapes and the corresponding natural frequencies within the frequency range from 0 to 1 kHz. The research is divided into three steps: (1) model class selection, (2) assessment of the parameter identifiability and (3) updating of the selected model with the aid of both examined model updating methods.

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SEMI-ACTIVE MITIGATION OF FREE AND FORCED VIBRATIONS BY MEANS OF TRUSS-FRAME NODES

Łukasz Jankowski[1], Błażej Popławski[1], Martiusz Ostrowski[1], Aleksandra Jedlińska[1], Grzegorz Mikułowski[1], Bartłomiej Błachowski[1], Dominik Pisarski[1], Rafał Wiszowaty[1], Arkadiusz Mróz[2], Anita Orłowska[1], Jilin Hou[3], Jan Holnicki-Szulc[1]

[1] Institute of Fundamental Technological Research, Polish Academy of Sciences, Poland
[2] Adaptronica Sp. z o.o., Poland
[3] School of Civil Engineering & State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, China

ljank@ippt.pan.pl

This contribution reviews a recently proposed control strategy for mitigation of vibrations based on the Prestress-Accumulation Release (PAR) approach [1]. The control is executed by means of semi-actively controllable truss-frame nodes. Such nodes have an on/off ability to transfer bending moments: they are able to temporary switch their operational characteristics between the truss-like and the frame-like behaviors. The focus is not on local energy dissipation in the nodes treated as friction dampers, but rather on stimulating the global transfer of vibration energy to high-order modes. Such modes are high-frequency and thus highly dissipative by means of the standard mechanisms of material damping. The transfer is triggered by temporary switches to the truss-like state performed at the moments of a high local bending strain. A sudden removal of a kinematic constraint releases the locally accumulated strain energy into high-frequency and quickly damped vibrations.

The first formulation investigated global control laws [1]. Recent approaches generalized it to decentralized control with a local-only feedback, which was tested in damping of free vibrations [2] as well as forced vibrations [3]. Recently, a global formulation was proposed that aims at a targeted energy transfer between specific vibration modes [4], and attempts were made to go beyond skeletal structures [5]. Numerical and experimental results will be presented to confirm the high effectiveness of the approach in mitigation of free, forced random and forced harmonic vibrations.

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TWO COUPLED BODIES REFLECTION BY DRY FRICTION ON A HORIZONTAL PLANE

Alexander Prokopenya[1]

[1] Institute of Information Technology, Warsaw University of Life Sciences - SGGW, Poland

alexander_prokopenya@sggw.edu.pl

Two bodies of the same mass m attached to opposite ends of a massless spring of natural length l_0 move on a smooth semi-plane ($x<0$) of a horizontal plane with the same velocity $v_0>0$, and the spring is not deformed. Assume that at the initial instant of time the second body starts to slide on the rough semi-plane ($x>=0$) while the first body continues to move on a smooth semi-plane. According to the Amontons-Coulomb law, the second body is acted on by the dry friction force $F_{fr}=mu*N$ that does not depend on the area of contact of the body and the plane and is proportional to the normal reaction force $N=mg$, where mu is a coefficient of friction, and g is a gravity acceleration. As the friction force is directed opposite the second body velocity $v_2>0$ the string is compressed and the bodies are acted on by the elastic force $F_2=-k(x_2-x_1-l_0)=-F_1$, where k is a stiffness of the spring, and x_1,x_2 are the x-coordinates of the bodies. Analyzing equations of motion of the system, one can show that if the initial velocity v_0 is sufficiently small the second body stops at some instant of time t_1 and the first body starts to oscillate near equilibrium position corresponding to non-deformed state of the spring.

However, the spring may be asymmetric and its stiffness $k_1=Beta*k$ for extension may be greater than its stiffness k for compression ($Beta>1$). In such a case it may happen that the first body moving to the left ($v_1<0$) starts to pull the second body and the system moves to the left. This phenomenon may be interpreted as reflection of the bodies by friction, and the main purpose of this paper is to prove that such phenomenon is possible.

MODAL ANALYSIS OF BAR STRUCTURES WITH SEMI-RIGID AND VISCOELASTIC CONNECTIONS

Magdalena Łasecka-Plura[1], Zdzisław Pawlak[1], Martyna Żak-Sawiak[1]

[1] Institute of Structural Analysis, Poznan University of Technology, Poland

martyna.zak-sawiak@put.poznan.pl

The subject of the analysis are dynamically loaded bar systems, which are often used as building structures. Steel moment resisting frames are designed as load-bearing systems of buildings exposed to wind, as well as in high seismic risk areas in buildings of low and medium height. The theoretical assumption that the connections between elements are either perfectly rigid or perfectly pinned in practice is seldom fulfilled. In fact, most joints are semi-rigid because there is a rotational discontinuity between the parts to be joined.

In this study, it was assumed that elastomeric materials were introduced into the joints of semi-rigid steel frames in order to reduce their dynamic response. This means that in the joint, in addition to the rotational stiffness, the damping properties of the material used should also be taken into account. It was assumed that there is a hinge on the axis of the connected profile, which transfers axial forces and shear forces, and the rotation is limited by viscoelastic layers attached to the outer edges of the profile.

In the first stage of research, the stiffness matrix and the mass matrix for a finite element were determined, in which the rotational constraints in the nodes have a given stiffness. Two-node finite element with three degrees of freedom at each node were used. Polynomial shape functions were adopted to derive the stiffness and mass matrices, but they were modified by introducing rotational stiffness in the boundary supports. The determined finite element matrices were used for the numerical analysis of the selected structures to determine its dynamic properties. The influence of changes in the rotational stiffness in nodes on the value of the natural frequency of vibrations was determined.

In the second stage of calculations, the viscosity parameters of the material used in the joints were additionally taken into account. It was assumed that the layer of viscoelastic material attached to the profile flanges is arranged in such a way that the rotation of the cross-section causes shear forces in it. Accordingly, the forces generated in the viscoelastic layer act at the respective arm to provide resistance to restrict rotation. Well-known rheological models (e.g. Kelvin-Voigt, Maxwell) were used to describe the dynamic behavior of the viscoelastic layer. The equations of motion were formulated in the state-space, and their solution allowed to determine the dynamic characteristics of systems with viscoelastic connections.

A STUDY ON EFFECTIVENESS OF MACRO FIBER COMPOSITE ACTUATOR IN VIBRATION REDUCTION OF COMPOSITE BEAM

Ali Raza[1], Ruta Rimašauskiene[1], Swarup Mahato[2]

[1] Faculty of Mechanical Engineering and Design, Department of Production Engineering, Kaunas University of Technology, Lithuania

[2] Department of Mechanical Engineering, Kaunas University of Technology, Lithuania

ali.raza@ktu.edu

Undesirable vibration is very common in most of the mechanical systems. The occurrence of vibrations is unavoidable because these are influenced by various factors. However, to obtain efficient performance of mechanical system, these vibrations must be kept within the permissible limit. These additional vibrations can be reduced by employing various vibration reduction techniques. Active vibration control (AVC) technique is most efficient among them. AVC methodology can be commonly applied to reduce vibrations in vehicle interiors, fans, machinery cabin, combustion engine, helicopter blades, flexible robot arms, aerospace engineering, and have a large number of applications in other industries. In recent time, use of smart materials becomes a popular choice in application of AVC. The current study demonstrates a methodology for limiting the dynamics amplitudes of a rectangular composite beam. The beam is vibrated by an external source, and the Macro Fiber Composite (MFC) actuator delivers the controlling force. The finite element (FE) model is created and it is integrated with the MFC-8507 actuator (d33 P1 type) in the ANSYS platform. For comparative analysis and actuation performance of MFC-8507 actuator on various materials, beam is modeled with three different material properties, i.e., Polylactic acid (PLA), PLA with short carbon fibers (PLA-SCF composite) and PLA with continuous carbon fibers (PLA-CCF composite) independently. The MFC patch is placed at a suitable location of each beam (PLA, PLA-SCF and PLA-CCF) to suppress the vibration due to initial fundamental modes. The modal analysis is performed to determine the contribution of each mode in total response. To find the optimal voltage requirement to obtain the targeted reduction in amplitude, transient response analysis is carried out with a different combination of voltage range. After that, frequency response analysis is performed to investigate the effect on each individual mode. The presented methodology produces the optimal range of voltage requirement for the targeted amount of amplitude reduction.

DYNAMIC RESPONSE OF STRUCTURE CONTAINING VISCOELASTIC ELEMENTS WITH UNCERTAIN PARAMETERS

Magdalena Łasecka-Plura[1]

[1] Poznan University of Technology, Poland

magdalena.lasecka-plura@put.poznan.pl

In the process of engineering design, it is assumed that the design parameters are precisely defined, but it is important to be aware that their real values often differ from the assumed ones. These differences, called uncertainties, result from imperfections of the manufacturing process, performance of the elements, or their assembly. Failure to take these effects into account can lead to relatively large differences between the calculated and real response of the structure.
A number of methods have been proposed in the literature to take into account effects of uncertainties. Some of them assume a random distribution of parameters and some assume that the parameters only change within specified range. In the second case, the interval analysis can be used. When considering the dynamic response of structure in the design process, frequency response function (FRF) is one of the most important tools for its evaluation. The paper presents the calculation of FRF assuming that the design parameters change within defined limits. Then, the interval analysis can be used to determine the lower and upper limits of the FRF. Various approaches to this problem can be found in [1-3]. In this work, the method presented in [2] was extended to systems with viscoelastic elements.
In the first step, the equations of motion for system with uncertainties are written using the interval analysis. Then the Fourier transform is applied to convert the interval equation into a system of linear equations. The solution to the system of equations is FRF, which is obtained using Brower's fixed point theorem.
A shear frame with built-in viscoelastic dampers was considered. The behaviour of dampers is described by rheological models. The parameters related to the construction as well as the parameters of the dampers may change independently. Various changes of parameters were considered to determine the effectiveness of the proposed method. The results obtained are compared with the vertex method that contains calculations of end-point combinations of interval parameters.

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MULTIMODAL STOCHASTIC INTERACTIONS IN A CABLE-MASS-HOST STRUCTURE SYSTEM UNDER SEISMIC EXCITATION

Hanna Weber[1], **Stefan Kaczmarczyk**[2], **Radosław Iwankiewicz**[1]

[1] Faculty of Civil and Environmental Engineering, West Pomeranian University of Technology in Szczecin, Poland
[2] Faculty of Arts, Science and Technology, University of Northampton, United Kingdom

weber@zut.edu.pl

Earthquake ground motions, even if they occur at a considerable distance from a tall building, may induce the vibrations of the base structure (foundation). Therefore, they lead to bending deformations of the building, which, due to its slenderness, may result in significant dynamic displacements at the top of the structure. As the result long slender continua such as steel wire cables used in vertical transportation systems deployed in the building are subjected to dynamic excitations.

In this paper a simplified model of a vertical cable with concentrated mass attached at its lower end moving slowly in the vertical direction, is considered. In the model proposed, horizontal displacements of the mass are constrained by a spring-viscous damper. An idealized model of a high-rise building in the form of cantilever structure with stochastic ground motion is then used. The seismic excitation at the base of the building is modelled as a filtered Gaussian white noise stochastic process and the non-linear responses of the cable-mass system is determined. The response is represented in terms of cable lateral vibrations and vertical motion of the concentrated mass.

In the previous research the stochastic responses of the cable-mass system under wind or earthquake excitations were considered by using a single-mode approximation of the system obtained for a given r-th mode. In the present paper the vector of the random state variables has been extended to accommodate selected modal forms. This gives an opportunity to consider not only the results for a single mode separately but also to analyze the nonlinear interactions and their impact on the behavior of the entire system.

In this approach the non-linear set of equations is replaced with a linear one by using equivalent linearization technique. The coefficients of equivalent linear system in the form of expectations of the non-linear functions of the response process are obtained from condition of minimization the mean-square error between both systems. The set of linear differential equations is then solved by the application of numerical methods. As the results the expected values, variances and covariances of particular random state variables are obtained. The expected values of vertical displacements of the main mass and the generalized coordinates are compared with the response of the non-linear system to the equivalent harmonic process. The variances of the particular random state variables are then verified by the Monte Carlo simulation. The results obtained for the multimodal system are compared with the solution from the single-mode approximation. It is evident that the multi-modal nonlinear interactions take place in the system.

DYNAMIC RESPONSE OF A GUY LINE OF A GUYED TOWER TO STOCHASTIC WIND EXCITATION

Anna Jabłonka[1], Hanna Weber[1], Radosław Iwankiewicz[1]

[1] Faculty of Civil and Environmental Engineering, West Pomeranian University of Technology in Szczecin, Poland

ajablonka@zut.edu.pl

In the present paper the behaviour of the guy line of a guyed tower regarded as an isolated taut string is considered. The point of attachment of the guy line to the tower is subjected to the stochastic base motion, which is the displacement response of the tower to the stochastic wind excitation. Under strong wind excitation the transverse displacements of the tower may be large, hence the resulting transverse displacements of the guy line are also large causing the geometrical non-linear effects. Therefore the partial differential equations governing the coupled axial and transverse non-linear vibrations of the string are assumed [1]. The Galerkin method is used to convert a problem into the one governed by ordinary differential equations. The response of a tower to a wide-band stochastic wind excitation is a narrow-band stochastic process. Consequently the base motion excitation for the string vibrations is a narrow-band stochastic process. This process is idealized as a response of an auxiliary linear filter to a Gaussian white noise excitation [2]. As a result, the state vector of the system consisting of original state variables augmented by state variables of a filter is a diffusive Markov process. The differential equations governing the response statistical moments are derived from the Ito's differential rule. The equations are solved with the aid of closure approximations such as cumulant-neglect closure and quasi-moment closure. The approximate analytical results are verified against direct numerical Monte Carlo simulations.

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SOLUTION FOR A RANDOM RESPONSE OF A NONLINEAR 'BEAM INSIDE BEAM' MODEL BY USING A HYBRID APPROACH BASED ON A SEMI-ANALYTICAL WAVELET APPROXIMATION

Piotr Koziol[1]

[1] Faculty of Civil Engineering, Cracow University of Technology, Poland

piotr.koziol@pk.edu.pl

A previously developed and solved linear 'beam inside beam' model [1, 2] used for a rail head vibrations analysis can be extended by additional assumptions leading to a more realistic representation of rail track behaviour. Nonlinear factors can be introduced for a better description of track components, including fastening systems, or track foundation [3]. The coupled system of dynamic fourth order partial differential equations describes the multi beam structure representing rail with its foundation. This multilayer system is subjected to a random load arising from rail rolling surface imperfections generating additional vibrations during train passage. The upper beam, although arbitrarily distinguished, is not separated from the whole beam. This layer, representing a rail head, works as a vibration generator for the whole beam longitudinal axis. A specially developed generator of random geometrical irregularities of the beam surface [4] is applied in order to analyse the system behaviour in terms of stochastic features important for the model dynamics.
The nonlinear system is solved by using a hybrid method supported by a wavelet based approximation using coiflet filters [3], combined with the Adomian's decomposition [2, 3]. The new solution for a random load moving along the upper beam is an important novelty, compared to existing results. The theoretical parameters used in the paper are taken from the literature and computational examples show an importance of the 'head on web' effect.
One should mention that existing rail models do not give good enough results when one deals with the dynamic stress analysis of rails. Therefore seeking of new models is of importance for railway engineering. Before application to real rail track structure analysis, the described model of rail based on double-beam system [3, 5] should be theoretically investigated in order to determine its applicability and solution convergence. The aim of the presented study is to develop an efficient algorithm allowing parametrical analysis of the system. The model will be applied to the investigations of real engineering systems after a detailed study of its dynamic behaviour conditioned by influence of several crucial factors such as e.g. randomness and nonlinearity.

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