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PROCEEDINGS

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Preface

Shells, plates and beams have always appeared as fundamental components for civil, mechanical, aerospace and naval engineering. The increase in the use of these structures in different engineering practices justify the present international meeting where researches from every part of the globe can share and discuss the recent advancements regarding the use of standard structural components within advanced applications such as buckling, vibrations, repair, reinforcements, concrete, composite laminated materials and more recent metamaterials. In particular, the computational and experimental methods for shells, plates, beams and arches are the general topics of this conference. The importance of the present topics is justified also by the number of journal papers and technical notes that have been published extensively over the last seventy years in international scientific journals of different engineering fields.

This fact attests that there has been a major effort to develop experimental and theoretical models for the study of shells, plates and beams systems in engineering. Studies about shells, plates and beams are truly multidisciplinary and the given contributions can help other researches and professional engineers in their own field. This Conference is suitable as a reference for engineers and scientists working in the professional field, in the industry and the academia and it gives the possibility to share recent advancements in different engineering practices to the outside world.

This book aims to collect selected plenary and key-note lectures of this International Conference.

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PLENARY LECTURES

Static-kinematic duality in beams, plates, shells and its central role in the finite element method

Alberto Carpinteri (Polytechnic of Turin, Italy)

Static and kinematic operator matrix equations are revisited for one-, two-, and three-dimensional deformable bodies. In particular, the elastic problem is formulated in the details in the case of arches, circular plates, cylinders, thin domes, and, through an inductive process, shells of revolution. It is emphasized how the static and kinematic operator matrices are one the adjoint of the other and then demonstrated through the definition of stiffness matrix and the application of virtual work principle. From the operator matrix formulation it clearly emerges the coincidence of the usual Finite Element Method definition of elastic stiffness matrix with the classical definition of Ritz-Galerkin matrix.

Third-order thermomechanically coupled laminated plates: modeling and analysis in a unified reduced framework

Rega, Giuseppe (Sapienza University Rome, Italy)
Saetta, Eduardo (Sapienza University, Rome, Italy)

Nonlinear multiphysics analyses tailored to reliably account for the involved coupling effects ensuing from embedding the system in a multifield environment are cutting edge topics in mechanical and structural engineering. In the present paper, nonlinear dynamics of the fully coupled thermomechanical laminated plate is addressed from the modeling and analysis viewpoint. A continuous model with von Karman nonlinearities and third order shear deformability and temperature distribution is presented, embedding the mechanical and thermal variables/equations into a unified 2D formulation of the thermomechanical problem. Consistent with the assumption made in the purely mechanical third-order plate theories, the temperature is considered as a cubic function of the thickness coordinate. The associated four thermal variables are reduced to two, by imposing the convective boundary conditions on the upper and lower surfaces of the plate. The attention is then focused on symmetric cross-ply laminates, for which an effective minimal dimension reduction of the continuous model, useful to catch some basic phenomena of the dynamics, can be pursued via a Galerkin procedure. Indeed, expressing both the in-plane displacement components and the shear angles in terms of the transverse displacement and of the two thermal variables via kinematic condensations performed at the continuum and discrete level, respectively, allows us to end up with a system of three thermomechanically coupled ordinary differential equations. The resulting 0D unified framework enables (i) to identify all terms of the reduced model by referring to the underlying continuous one, and (ii) to possibly consider further models variably simplified by consciously disregarding some terms. Finally, comparative analyses of the free and forced nonlinear dynamics are carried out to get some hints on the influence of various concurrent mechanical and thermal assumptions made at the modeling level on the response obtained under (transverse) mechanical and/or (membrane, bending) thermal excitations, thus possibly paving the way to more systematic parametric investigations.

Virtual element methods for plates and shells.

Claudia Chinosi (University of Piemonte Orientale, Italy)

The Virtual Element Methods (VEM) have been introduced very recently as an extension of Finite Element Methods to general polygonal and polyhedral elements. However many of their aspects are closely connected with Nodal Mimetic Finite Differences (MFD) so that VEM could be viewed as an evolution of MFD. In their more recent presentation, Mimetic Finite Differences could be considered as a form of approximations by Finite Element methods in which only the degrees of freedom are used (since the trial functions are not available in the interior of the elements). This allowed them to mimic most types of Finite Element spaces of lowest order on rather general element geometries. Further developments included the use of higher order approximation in order to gain better accuracy in the numerical results. Still the lack of trial and test functions inside the elements (or even inside the faces) was making the presentation and the analysis rather complicated. Very recently it became clear that it would be much simpler if the MFD unknowns were attached to trial functions suitably defined inside the elements, as is commonly done in Finite Elements Methods, thus motivating the birth of Virtual Element Methods. In order to preserve the great generality that MFD allow for the geometry of the elements, the Virtual Element Methods use local spaces of test and trial functions that, in addition to all the polynomials of the chosen degree, contain some non-polynomial functions that are solution of suitable PDE problems inside each element. In this respect the VEM are getting closer to other attempts to generalize Finite Elements on polygon, like the use of rational functions, the Polygonal Finite Element Methods (PFEM) or the Extended Finite Element Methods. The novelty of the Virtual Element Methods is that the non-polynomial part of the trial functions does not need to be known in detail but only through their degrees of freedom. The Virtual Element Method first has been applied to the simple case of Laplace operator in two dimensions, to some two-dimensional elasticity problems and to plate problems. Later the basic idea of Virtual Element Methods has been extended to the discretization of H(div) and H(curl) conforming vector fields and to the approximation of the Laplace equation in three dimensions with variable coefficients. Moreover, the range of applicability of VEM seems to be very wide, then leading to the extension of the method to other types of problems such as shells problems. Here we analyze this new method for the approximation of the plate bending problem in the Kirchhoff-Love formulation. In particular we show the capability of the Virtual Elements to satisfy the C1 continuity requirement in a much easier way than the Finite Elements. The core idea of the VEM for plates can be summarized as follows: the trial functions contain a certain number of polynomials sufficient to guarantee the accuracy plus other additional functions; the construction of the local stiffness matrix is carried out (ensuring the necessary consistency and stability) without knowing the non-polynomial functions but by using only their degrees of freedom, carefully chosen; in the case of C1 elements the basic idea consists in choosing some degrees of freedom at the interelement boundaries to identify in a unique way the traces of globally C1 functions that are polynomials of degree less than or equal to r on each edge, with normal derivative of degree less than or equal to s on each edge. Then, when needed, we add a suitable amount of internal degrees of freedom and we define the discrete subspace inside the elements by means of a local plate bending problem, without that its solution should be computed. Finally, for the construction of a family of the approximation spaces for plates we shall: choose the degree r of our shape functions, and the degree s of their normal derivative on each edge; suitably choose the degrees of freedom at the interelement boundaries; fix a polynomial degree k, with $k \leq r$, $k-1 \leq s$, which will be our order of accuracy; add a suitable amount of internal degrees of freedom for k greater or equal to 4. The performance of the Virtual Element Method is tested solving some benchmark problems for plates by means of the first two elements of the family previously described, namely the elements with r=3, s=1 and r=3, s=2, respectively. The degrees of freedom, chosen according to the previous steps, are: the values of the displacement and its first derivatives at the vertices for the first element; the same degrees of freedom plus the moment of order zero of the normal derivative for the second element. The two elements are the extensions to polygonal domains of two finite elements for plate: the Hsieh-Clough-Tocher reduced triangle and the Hsieh-Clough-Tocher triangle, respectively. We compare the results obtained using VEM with the ones obtained using these Finite Elements on a sequence of uniform meshes. As expected, the results are in agreement with the theoretical predictions. Moreover, problems involving general domains with irregular decomposition are considered, showing the capability of this method to treat very general geometries.

Theories and computational models for beams, plates and shells in unified form.

Erasmo Carrera (Polytechnic of Turin, Italy)

Most of known theories for the analysis of beam-, plate- and shell-type structures have been originated by intuitions of eminent Scientists such as Leonardo Da Vinci, Euler, Bernoulli, De Saint Venant, Poisson, Cauchy, Kirchhoff, Love, Reissner, Mindlin, Vlasov, etc…. In most cases these “axiomatic” intuitions leads to a simplified kinematic of the true three-dimensional deformation state of the considered structure: the section remain plane, section/thickness deformation can be discarded, shear strains are negligible, etc…. As alternative to that axiomatic approach, approximated theories have been introduced by employing asymptotic type expansions of unknown variables over the section (beam case) or thickness (plate/beam geometries) as well. In the latter case the order of magnitude of significant terms is evaluated by referring to geometrical parameters (thickness to length in case of plates/shells, section dimension to length in case of beams). Both axiomatic and asymptotic methods have been historically motivated by the need of working with simplified theories capable of leading to the simple formulas and simple equations that could be solved by hand calculation. Nowadays that limitation is not mandatory. Of course, the formulation of more complicated problems would hardly be made without the introduction of appropriate technique suitable for computer implementation. The “modern” approach discussed in this lecture introduces the latter “suitable” technique: enhanced beam/plate/shell formulations are constructed, in fact, by a condensed notation technique suitable for computer implementation.

That approach has been referred to as Carrera Unified Formulation CUF for beams, plates and shell structures. Governing equations, in both strong and weak form, are given in term of a few "fundamental nuclei" whose form do not depend on the order of the introduced approximations neither by the choices made for the base functions in the thickness direction (for plates/shells) or over the section (for beams). The Principle of Virtual Displacements PVD is used to formulate the problems in the case of only displacements variables. Related computer codes only use 9 FORTRAN statements to implement a large variety of theories that permits hierarchical evaluations of any type of approximations. This seminar shows how CUF is used to build refined beam/plate/shell theories and related computational methods by encompassing recent results obtained by Carrera and co-workers at Mul2 group of Polito (www.mul2.com).

Smart shells: sensing, actuation and control.

Horn-Sen (H.S.) Tzou (University of ZheJiang, China)

The synergistic integration of smart materials, structures, machines, sensors, actuators, and control electronics can transform conventional passive structures and machines to active, adaptive, and "smart" structronic (structure + electronic) or mechatronic systems with inherent self-sensing, diagnosis, and control capabilities. Research and development of the emerging technology of smart structures and structronic systems have been evolving for nearly three decades. Sophisticated multi-field/control coupling theories have been developed and numerous practical applications have also been proposed. This report focuses on histories, smart materials (e.g., piezoelectrics, electro-/magneto-/photo-strictive materials, shape memory materials, electro- and magneto-rheological fluids, polyelectrolyte gels, pyroelectric materials, magneto-optical materials, superconductors, etc.), precision devices (sensors and actuators), micro-/nano-actuations, smart structures, mechatronic and structronic systems, and photo-thermo-electro-magneto-mechanical systems encompassing elastic, temperature, electric, magnetic, light, and control interactions. Modern research issues are also discussed.

Precasting of large span shells and plates.

Gian Carlo Giuliani (Redesco, Research-Design-Consulting, Italy)

Large span concrete shells and plates are alternative to composite solutions with steel elements and, within some conditions of use and of the superimposed loads intensity, feature a more elevated efficiency. The resistance of the shells is mainly obtained by the spatial behavior given by a proper form and therefore the relevant thickness can be reduced to a minimum, which, in many cases, is determined by the manufacturing process. Another advantage of the shells is given by the solid surface, which can be directly covered by the insulation and the waterproofing layers. Plates, with ribs or is some cases of the sandwich type, are very efficient for carrying heavy loads over large spans. The construction of concrete shells is currently hindered in most parts of the world due to the constraints of the expensive formwork and labor costs; at the present time pre-casting, which could raise a new interest for these very efficient structures, is not given due consideration by designers and construction firms. However, the opportunities to gain and implement considerable skill and mastery in the field of concrete shell and plate construction are becoming scarcer, and those companies operating in the field of pre-casting are often the safe-keepers of the remaining experience and the necessary aptitudes. The following examples of prefabricated shells will be illustrated: north light cylindrical shells for an industrial building on site cast and erected; folded plates for industrial buildings on site cast and erected; double curvature shells on site cast and erected; truncated conical shells on site cast and erected; barrel vaults for industrial buildings in plant cast, on site assembled and erected; U shaped shells in plant cast as tower supporting legs; 3D units in plant cast for modular houses. The following examples of prefabricated plates will be illustrated: ribbed plates for multistory industrial buildings on site cast and erected; composite steel concrete sandwich plates for exhibition buildings on site cast and erected.

Whole composite structures: between research and normative.

Luigi Ascione (University of Salerno, Italy)

Over the last twenty years, several innovative solutions, both within and outside Europe have confirmed the usefulness of whole composite structures realized with FRPs (Fiber Reinforced Polymers or Plastics). These solutions are often imposed by specific needs such as requirement for speed of assembly on site or for enhanced resistance to aggressive environments, which in turn reduces maintenance costs. In addition, the lightweight of the FRP composite makes the assembly and the launch of the structure easier, besides offering a geotechnical advantage for all structures that have to rest on deformable soils. In all the world, and in particular in Europe, there are many examples of such structures: buildings for industrial or residential purposes, lock doors, and mainly bridges and bridge decks, both pedestrian as well as traffic bridges carrying all classes of wheel loads. The most representative of them will be presented in the course of the lecture. The availability of Guidelines will facilitate the free movement of FRP materials and contractors in the field building and construction within the European Community. This field offers all the prospects for a progressive expansion, with substantial positive consequences of economic nature. Such a development would undoubtedly be favored by the existence of a body of shared rules able to ensure a uniform level of safety in the production and the use of FRP structures. To achieve this outcome, CEN-TC 250 – the European committee responsible for the implementation of the Structural Euro codes - has appointed a specific Working Group (WG4: Fiber Reinforced Polymer Structures) charged to draw up, as first goal, a scientific and technical report on this subject. The author of the summary is the convener of this WG. Recently, the report has been approved by CEN-TC 250 and is being published by the Joint Research Centre (Ispra). The report represents the first step toward a Structural Euro code on the subject of FRP structures. The aim of the lecture is to summarize the main features of the report, but mainly emphasize the mechanical issues, which need further study by the scientific community. The essential references are also given.

On non linear analysis of masonry shells.

Antonio Tralli (University of Ferrara, Italy)
Gabriele Milani (Polytechnic of Milan, Italy)
Andrea Chiozzi (University of Ferrara, Italy)

Masonry curved structures – such as domes and vaults – represent one of the most widespread typologies in the historical buildings of both Eastern and Western architecture. The interest for their preservation and rehabilitation has always been growing over time along with the need for developing new efficient tools to analyze their load-bearing capacity. The lecture concisely reviews the available numerical methods to study masonry vaults up to collapse, putting in evidence pros and limitations of each approach. To be reliable, any procedure adopted should take into account the distinctive aspects of masonry behavior, namely the negligible tensile strength, the good compressive resistance and the observed formation of failure mechanisms constituted by macro-blocks. The modern theory of limit analysis of masonry structures, developed mainly by Heyman, is the most effective tool for a fast and reliable evaluation of their load carrying capacity. Computational approaches stem out from lower bound formulations, e.g. the so-called Thrust Network Method, or upper bound formulations, like finite-element based methods. A new Kinematic approach has been recently presented by the Authors, where generic masonry vault geometry is represented by a NURBS (Non-Uniform Rational B-Spline) parametric surface. The approach is able of well predicting the load bearing capacity by using a NURBS mesh constituted by very few elements provided that the initial mesh is adjusted by means of a meta-heuristic approach (i.e. genetic algorithms) in order to accurately approximate the actual failure mechanism. An alternative to limit analysis is obviously represented by traditional FEM combined with either elasto-plastic or damaging models with softening which are capable of providing a large set of information but that still remain very demanding.

KEY-NOTE LECTURES

12 | A new concept of sampling surfaces and its implementation for layered and functionally graded doubly-curved shells

Kulikov, Gennady M. (Tambov State Technical University, Russia)
Plotnikova, Svetlana V. (Tambov State Technical University, Russia)

In a present work, we utilize a new concept of sampling surfaces (SaS) implemented recently by the authors for layered and functionally graded plates and cylindrical shells subjected to thermal, electric and mechanical loading, and extend it to doubly-curved shells. As SaS, we choose inner surfaces inside each layer and introduce temperatures, electric potentials and displacements of these surfaces as basic shell variables. Such choice of unknowns with the consequent use of Lagrange polynomials in the thickness direction permits the presentation of governing equations of the SaS shell formulation in a very compact form. It is important that the developed shell formulation with equally spaced SaS does not work properly with Lagrange polynomials of high degree because of the Runge's phenomenon, which yields the wild oscillation at the edges of the interval when the user deals with specific shell metric functions. If the number of equally spaced nodes is increased then the oscillations become even larger. However, the use of Chebyshev polynomial nodes as SaS coordinates allows one to minimize uniformly the error due to Lagrange interpolation. As a result, the SaS formulation can be applied efficiently to the solution of 3D static problems for layered and functionally graded doubly-curved shells with a specified accuracy utilizing the sufficient number of SaS. This is due to the fact that analytical solutions based on the SaS formulation asymptotically approach the 3D exact solutions of elasticity, thermoelasticity and thermoelectroelasticity as the number of SaS goes to infinity.

15 | Challengers for designing a wooden beam of composed section

Wahrhaftig, Alexandre (Federal University of Bahia, Brazil)
Carvalho, Ricardo (Federal University of Bahia, Brazil)

One describes in this work, the challenges and solutions for the design of the beam of a timber structure used to replace another of steel that collapsed. The choice by wood is due to the fact that is a material better suited to environments with high salinity and, in this context, to reduce maintenance costs. The most important challenger of this project lives in the fact that the beam should surpass a long span. The principal question was what kind of cross section would be able to attend the Ultimate Limit State and Service in wood to the dimensions in project. The answer was clear; it would have to have composed section. The collapsed structure was situated in an environmental condition of high aggressiveness level. The ceramic tile roof had a total area of approximately 300 m2 and a steel frame supported it. The original steel structure collapsed after only seven years of use, destroying completely the superstructure. The metallic structure had to be replaced as well, considering, especially, the high cost of maintenance for which would be submitted. However, the roof that would be designed depended directly on the main structural components: the wooden beams. The whole roof was supported by only four columns, that impose to the laterals and frontal beams to overcome spans upper to 16 meters without intermediate supports. A mathematic computational model was constructed using the finite element method, with plate elements to simulate the group formed by roof tiles, common rafters, battens and purlins along with bar elements to simulate trusses, beams, hip rafters, ridge broad and columns. The efforts on the structural elements were extracted from the computational model and the cross sections of the beams were calculated by observing the established resistance and stability, finding a particular solution. The dimensioning followed the criteria recommended by NBR 7190 - Design of timber structures, from The Brazilian Association of Technical Standards (ABNT). An important existent limitation was the commercial unavailability of laminated timber. After dimensioned, the beam was drawn and detailed forming the drawing boards that were sent to the implementation. An important consideration about implementation and assembly of structure deserve to be highlighted given the important differences that appeared during the realization of the project. Initially planned as box beams of composed section, the beams were executed differently from the originally the designed, being necessary to reinforce it, because of the risk of lateral buckling. To conclude, it is important to emphasize that the design of a wood structure requires not only knowledge as well as creativity to overcome the challenges posed by the typical necessities common to the detailing of this material as well as require a special attention during the execution of construction due the difficulty in reading the detailing of the plans found by the carpenters.

22 | Experimental and analytical study of an RC dome under vertical vibrations

Iskhakov, Iakov (Ariel University, Israel)
Ribakov, Yuri (Ariel University, Israel)

The influence of vertical vibrations of an RC dome is investigated. Such vibrations appear due to membrane effect in shell structures under usual horizontal dynamic excitations. Therefore it is required to carry out health monitoring of such structures, first of all under dynamic loadings. Typical dynamic loadings that can be used for monitoring the above mentioned structures are vibration, impact, micro-seismic, wave excitation, and so on. The monitoring allows obtaining the dynamic characteristics, required for further analysis and proper design of the investigated structures. This paper is focused on experimental and analytical investigations of an RC dome under dynamic loadings. Dynamic behavior of a spherical RC shell is tested and analyzed. A vibration machine was used to apply the vertical dynamic load. Theoretical equations for dynamic analysis of the experimentally investigated dome are proposed. The obtained numerical results are in good correlation with the experimental data. The proposed equations form a basis to develop corresponding provisions for design and monitoring of RC domes subjected to vertical dynamic loads.

23 | Description of a design method for cryogenic concrete tanks based on a comparison between 2D and 3D numerical models

Mergny, Elke (Université catholique de Louvain, Belgium)
Poncin, Pierre (Université catholique de Louvain, Belgium)
Latteur, Pierre (Université catholique de Louvain, Belgium)

Ammonia is used in the industry for the manufacture of fertilizers, explosives and polymers and is stored at -33°C in refrigerated tanks. In most cases, tanks are cylindrical and are composed of a steel liner that contains the ammonia, with the liner itself being protected by an outer reinforced concrete tank. The function of the concrete tank is to keep the ammonia safe in case of a leak in the liner. If a leak happens, the concrete wall will be suddenly subjected to a thermal shock, with a large temperature gradient between its internal and external faces (20°C to -33°C). These thermal effects lead to cracks in concrete that allow the ammonia to escape. The junctions between walls and the base slab and, walls and the roof are particularly

sensitive to this cracking phenomenon. The aim of this paper is to present a method for the design of concrete ammonia tanks, especially taking into account thermal effects. Firstly, a 2D finite element model based on a plane frame is developed. The advantage of this approach, compared to 3D modeling, is that it requires little computing power and engineering time. Then, a 3D model is used to validate the 2D approach, and to identify its limitations. Particular attention is paid to the modeling of the weakest parts of the structure. Lastly, the paper will give the results of a parametric study based on the above 2D and 3D finite element modeling, in order to establish general guidelines for the design of ammonia tanks.

26 | Mathematical model of micropolar multilayered elastic bars and features of their strength and stiffness characteristics

Alvajyan, Shushanik I (Gyumri State Pedagogical Institute, Armenia)
Farmanyan, Anahit J (Gyumri State Pedagogical Institute, Armenia)
Sargsyan, Samvel H (Gyumri State Pedagogical Institute, Armenia)

Thin bars collected from micropolar elastic orthotropic layers with constant thickness are considered. It is assumed that the layers of the bar are rigidly connected with each other and work as a package without sliding and lift-off. It is also assumed that kinematic and static hypotheses, accepted in the paper (Journal of Materials Science and Engineering, 2 (2012) 98-108) in case of single-layered micropolar bars, are true for the whole package of the bar as a whole. These assumptions allow to reduce the problem of the stress state of thin multilayered bars to the problem of deformation of initial line, which has certain micropolar stiffness properties. On the basis of this approach applied model of micropolar elastic orthotropic multilayered bars is constructed. Particularly, model of two-layered bar is obtained when the material of lower layer is classic elastic and the material of upper layer is micropolar. Model of three-layered bar of symmetric structure is also obtained, when the material of middle layer is classic, and the material of upper and lower layers is micropolar. Micropolar materials symbolize nanomaterials (nanobars). On the basis of large volume of numerical computations following important conclusion can be done: very thin micropolar layer substantially increases stiffness and strength properties of the multilayered bar, compared with the case when the material of the bar layers are classical.

27 | Global geometric aspects of shell deformation

Sun, Bohua (Cape Peninsula University of Technology, South Africa)

The shell structures have been widely used in the construction, car, aircraft and industries. The shell deformation has been formulated using differential geometry, which can be considered as the local formulation. The global prospects of the deformation and stress are becoming more important when you fabricate the shell structures. Unfortunately the global formulation of the shells has never studied. In this paper we will use global theory geometry and Gauss-Bonnet theorem to formulate the shells and establish a linkage between Gauss curvature and moments that is an important relationship between geometry and force. The research may open a new avenue on the structural analysis.

28 | Semi-analytical solutions for electro-mechanical loading of an all-round simply supported smart plate

Sawarkar Sameer (Indian Institute of Technology, India)
Pendhari Sandeep (Veermata Jeejabai Technological Institute, India)
Desai Yogesh (Indian Institute of Technology, India)

3 Dimensional (3D) static analysis of an all-round simply supported smart plate has been performed with mixed semi-analytical model developed by Kant et.al. (2007). The plate is subjected to transverse mechanical and electric loads. In-plane displacements, transverse displacement, transverse normal stress, transverse shear stresses, electric potential and transverse electric displacement are considered as primary variables. The mathematical model consists of defining a two-point boundary value problem (BVP) governed by a set of coupled first order ordinary differential equations (ODEs). The accuracy and efficiency of the proposed model are assessed by comparing the numerical results from the present formulation with available elasticity solutions. Effects of various parameters on transverse displacement of mid-plane of the plate are investigated.

29 | Thin-walled tubes with a local sharp cut under cyclic bending

Kuo-Long Lee (Far East University, Taiwan)
Yung-Ju Tseng (National Cheng Kung University, Taiwan)
Wen-Fung Pan (National Cheng Kung University, Taiwan)

In this paper, the response of 6061-T6 aluminum alloy thin-walled tubes with a local sharp cut subjected to cyclic bending was experimentally investigated. The tube bending machine and curvature-ovalization measurement apparatus were used for conducting the curvature-controlled experiments. It was observed that the moment-curvature relationship showed an almost steady loop from the beginning of the first cycle. However, the ovalization-curvature relationship exhibited an increasing and ratcheting manner with the number of the bending cycles. In addition, deeper cut depth of a tube led to a more severe unsymmetrical trend of the ovalization-curvature relationship. It has been demonstrated that the cut depth has small influence on the moment-curvature relationship. But, it has a strong influence on the ovalization-curvature relationship. Finally, a theoretical model was also proposed in this study for simulating the controlled curvature-number of cycles to failure relationship. Through comparison with the experimental data, the theoretical model can properly simulate the experimental findings.

30 | Analysis of material-related instability problems for cylindrical shells

Kobayashi, Takaya (Mechanical Design & Analysis Corporation, Japan)
Mihara, Yasuko (Mechanical Design & Analysis Corporation, Japan)
Fujii, Fumio (Gifu University, Japan)

Geometrically nonlinear static problems sometimes involve buckling or collapse behavior, in which the load-displacement response shows a negative stiffness. If the analysis process traces unstable paths under the global load-displacement response with negative stiffness, the arc-length method is effectively usable. However, if the instability is localized (e.g., surface wrinkling, material instability, or local buckling), there will be a local transfer of strain energy from one part of the model to the neighboring parts, and global solution methods may not work. This class of problems must be solved either dynamically or with the aid of artificial damping. This paper describes the application of the artificial damping technique for the

generation of singularities in large-deformed viscoelastic shells, which is expected to be utilized in the blow-forming of plastic containers or the formation of polymer thin films. We performed experimental and analytical investigations of viscoelastic cylindrical shells under axial compression. In general, a change in elastic modulus due to viscoelastic relaxation has a range of ten to the third power or more. The study accomplished a fully automatic and seamless simulation in the deep post-buckling region and showed good agreement with the experimental results. This paper also describes the application of the technique for the generation of wrinkling during elastoplastic cup drawing.

33 | Parameters affecting the reduction factor in pedestrian load models based on pulsating stationary force

Štimac Grandić, Ivana (Univeristy of Rijeka, Croatia)
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All dynamic pedestrian load models for serviceability control on pedestrian bridges, that can be found in Euro codes (EC) or guides to EC, are based on dynamic load model of single pedestrian. Single pedestrian load model is defined, in general, in two ways: as a pulsating force moving over the bridge deck with a certain constant speed, or as a pulsating stationary force acting at the most adverse position of the bridge deck. Although it is easier to obtain the maximum acceleration due to pulsating stationary force it is necessary to establish the stationary load model that produces the same dynamic response of a structure as the moving load model. In this paper, the reduction factor is determined as the ratio of maximum accelerations due to the same model of moving pulsating force and stationary pulsating force. The reduction factors are calculated for bridge structural system of simple supported and fixed beam, span length of 15 m and 20 m, structural natural vertical frequency form 1 Hz to 5 Hz (in steps of 0.4 Hz), structural damping of 0,5%, 1%, 1,5%, 2%. From conducted analyses it can be concluded that changes in structural frequency does not affect the reduction factor, while changes in structural damping, structural system and span length affect the reduction factor as follows: the reduction factor increases with increasing in structural damping, the reduction factor is greater for longer spans, the reduction factors for fixed beam are smaller than the corresponding values for simply supported beam. Also, it can be seen that

constant value of the reduction factor that can be found in some codes or guides can greatly overestimate or underestimate the maximum deck acceleration due to single pedestrian load model.

34 | Experimental behavior of slag concrete-filled steel tubular reinforced with shear connectors

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This experimental work focuses on the study of the behavior of hollow steel tubes reinforced with angle shear connectors. The hollow tubes are made of two parallel flange channel sections which are cold rolled and welded together, with some shear connectors welded along the longitudinal fiber of the web of each C-section. The aim of this communication is to confirm the enhancement of the compressive strength by filling these hollow tubes with sand concrete with addition of fillers. Uniaxial compressive tests are performed on 10 hollow tubes of dimensions 100 x 70 x 2 mm where two specimens are empty, four specimens are filled with Ordinary Concrete and the last four specimens are filled with Sand Concrete. The influence of shear connectors and nature of filling concrete are examined regarding the kinematic behavior of tubular sections. The results show that empty hollow tubes suffered from local and global buckling of webs and flanges and full tubes reached the failure by partial crush of concrete and buckling of steel flanges. A significant increase in the compression strength of the tubes is allowed by filling the tubular section with concrete. Indeed an increase of 187% is reached for full tubes, compared to empty tubes. Finally experimental results are compared to the prediction of Euro Code Rules for both empty and full tubular sections. Euro Code 3 overestimates the load bearing capacity of empty tubes about 65% and Euro Code 4 leads to a difference near +13% for the compressive strength of full tubes.

36 | Semi-analytic analysis of composite beams using the scaled boundary finite element method

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The scaled boundary finite element method (SBFEM) is a semi-analytical method in which only the boundary is discretized. The results on the boundary are scaled into the domain with respect to a scaling center that must be "visible" from the whole boundary. For beam-like problems the scaling center can be selected at infinity and only the cross-section is discretized. Some elements for thin-walled beams have been developed on the basis of the first order shear deformation theory. The beam sections are considered to be multilayered laminate plates with arbitrary layup. The arbitrary cross-section is discretized with beam-like elements of Timoshenko type. Using the virtual work principle gives the SBFEM equation, which is a system of differential equations of a gyroscopic type. The solution is calculated using the matrix exponential function. Knowing the deformation of the beam, the stresses, strains and curvatures can be calculated and a failure criteria can be used to evaluate the laminate. The elements have been tested and compared with a finite element model and they give good results.

40 | Theories and analyses thick hyperbolic paraboloidal composite shells

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This paper presents the stress resultants of Hyperbolic paraboloidal shells is determined by deriving the dynamic stiffness matrix from the equilibrium equations of motion using Hamilton's minimum energy principle for a simply supported cross-ply structure by Zannon (TSDTZ). Composite materials offered for real applications in the automotive industry vary from thermo-plastics to laminated and fiber-reinforced structures. The results are calculated for orthotropic, two-ply unsymmetrical [90/0] shells. The extensional, bending and coupling stiffness parameters is calculated using MATLAB algorithm for laminated composite hyperbolic paraboloidal shells. A comparison of the present study with other researchers in the literature is given, and is in good agreement.

43 | Distortion of GLARE panels due to cut-outs

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A predictive model is needed to adapt the mold to produce accurate integrated Fiber metal laminates (FMLs) and also estimate the residual stresses. Primary modeling and experiments are already performed on simple FMLs and the epoxy adhesive FM-94. In this paper, the focus is on the investigation and prediction of the re-distribution of residual stresses due to making cut-outs and consequently the probable distortions. After cure and removal from mold, the panel is trimmed and cut-outs are made in the FML panel using methods like water-jet cutting and milling. This will or re-distribute residual stresses and induce some additional distortions. Simulation with finite element method should be used together with some experimental validation. Specimens' curvature is measured by digital image correlation (DIC) before and after making the cut-outs. Element birth and death approach in finite element method is used in ANSYS to predict the distortions due to cut-outs. Different panel dimensions with some kinds of cut-outs used in a fuselage, are considered in both modeling and experiments. The distortion before and after making cut-outs are predicted. Comparisons are made with experiments and the effects on the distribution of residual stresses are studied.

44 | Coupling effects of pressure and plastic folding on the buckling morphologies of thin films on substrate

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Finite element simulations of the formation of donut and croissant-like buckles observed onto the free surface of stressed gold thin films deposited on silicon substrates have been

performed. The coupling effect between the atmospheric pressure acting on the free surface and the plastic folding of the ductile film has been found to be responsible for the circular blister destabilization and the formation of the donut and croissant-like buckling patterns. A stability diagram of the buckling film is provided as a function of the internal stress and applied pressure. The effect of an overpressure resulting from the difference between an external pressure applied onto the free surface of a delaminated thin film on its substrate and the vacuum existing in the delaminated region between the film and the substrate has been also theoretically investigated on the unilateral buckling of the film. In the framework of the Föppl-von Karman theory of thin plates, it is found that depending on the initial stress in the film and overpressure, two scenarios of evolution may occur for a one-dimensional buckle. For low values of the initial stress, the snap-through of the buckle leading to the full re-deposition should occur. When the initial stress exceeds a critical value, a partial re-deposition of the buckle should take place as the overpressure increases. A snap-through while the re-deposition mechanism has been also characterized for higher values of the overpressure.

45 | Experimental investigations of thin-walled GFRP beams subjected to pure bending

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The papers deals with experimental investigations of thin-walled composite laminate beams subjected to pure bending. Profiles have been manufactured in autoclaving technique from unidirectional tape prepregs (SE70/EGL/300/400/35%/PoPa) - GFRP laminate. The nominal volume fraction of the reinforcing fibers in the composite was about 60%. Six different layer arrangement were considered: [(-45/+45)2]S; [45/-45/0/0]S; [45/-45/45/0]S; [45/-45/45/0/0/-45/45/-45]T; [0/45/-45/45/-45/45/-45/0]T and [-45/45/45/45/-45/-45/-45/45]T. Part of the beams under consideration have a length of 275 mm and square cross-section with following dimension (width × height × thickness of the wall): 82 × 82 × 1.8 mm. In order to provide pure bending, special grip have been designed. A specimens have been mounted into a grip and the four-point bending tests have been performed. The Instron tensile test machine with

Zwick-Roell modernization has been employed. The strain gauge bridge HBM Spider 8 was used to collect the strains and the measuring system ARAMIS have been employed to visualized deflection of the beams under consideration. The main aim of experimental investigation has been to determine the buckling load, to observe post buckling behavior and determine failure load. A well-known methods (e.g. P-w2 method, Koiter's method and ""inflection point"" method) of determining buckling load have been used. The results obtained using both measure techniques (i.e. strain-gauges technique and stereographic transformations technique) allows to make better comparison of buckling load and post buckling behavior for compressed composite columns with different layer arrangement. The influence of layer arrangements on post buckling stiffness and the failure mode have been checked.

50 | Comparison of two shell theories of composite materials

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The asymptotic method is used to reduce the exact three dimensional elasticity theory of composite materials, which are anisotropic and non-homogeneous, and obtaining approximate theories governing circular cylindrical shells. A choice of characteristic length scale in the asymptotic expansion of various variables will guide to different shell theories. For the case of equivalent isotropic homogeneous material, we will introduce and compare two classical shell theories, membrane and bending theories, which can be useful for practical designs. The stress resultants and radial deformation are computed for different angle ply of composites.

51 | The effect of current types on the microstructure and tribological properties of Ni/nanoAl2O3 composite coatings

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The paper describes an investigation of the nickel and nickel-alumina coatings. The layers was obtained from Watts bath with presence of nickel grain growth inhibitors by direct (DC), pulse (PC) and pulsed reverse (PRC) current plating. The study included the composite coatings of microcrystalline and nanocrystalline Ni matrix and nanometric Al2O3 particles. In order to ensure uniform co-embedding of disperse phase particles with nickel matrix and producing a stable suspension, the mechanical agitation was also used. It was proved in our previous investigations that the mechanical agitation is the best way of embedding of nano-alumina particles in nickel matrix. The effect of the electroplating techniques on the microstructure (SEM, TEM, XRD) and tribological properties of Ni/Al2O3 composite coatings was investigated. The SEM studies on the worn surfaces were also conducted. The examined coatings exhibited different values of the friction coefficients depending on the applied plating current. Scanning electron microscopy studies of the worn surface reveal different delamination process of all examined coatings. The completed studies have shown that the type of current significantly affects the structure of nickel and composite coatings, as well as its tribological properties.

52 | Analytical and numerical analysis of composite impact attenuators

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Recently automotive crashworthiness trend is the use of thin-walled composite impact attenuators in specific vehicle zones, ensuring the greater quantity of kinetic energy absorption. The paper aims at developing an analytical procedure in order to capture the

energy absorption capability of impact attenuators with a square frusta geometry to adopt in the front of a car. An energetic approach is addressed taking into account the energy contributions responsible for the absorption during crushing. Comparison between analytical and numerical data, using an explicit dynamic code as LS-DYNA, shows the efficiency of the proposed relatively simple model for predicting energy absorption of axially collapsing composite shells.

53 | Elastodynamics of FGM plates by a mesh-free method

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The paper deals with the transient dynamic analysis of plates considered within three plate bending theories such as the Kirchhoff-Love theory (KLT), the 1st order shear deformation plate theory (FSDPT) and the 3rd order shear deformation plate theory (TSDPT). The Young modulus and the mass density are allowed to be functionally graded either in the transversal direction or in the in-plane directions. Moreover, the thickness of the plate can be variable on the in-plane coordinates. The material coefficients as well as the thickness of the plate are assumed to be graded according to the prescribed power-law functional dependences. The transversal gradation of the Young modulus gives rise to coupling between the bending and in-plane modes of deformation. The mesh-free approximation for spatial variations of field variables and a strong formulation are employed in numerical solution together with the Wilson-θ method for time stepping method. The functional gradation of each material coefficient is controlled by two parameters, such as the level of gradation and the exponent of the power-law gradation. The influence the levels of gradations on the frequency of vibrations (for both the bending and in-plane modes) in a plate subjected to an impact pulse load can be expected qualitatively. However, it is much more complicated in the case of influence of the exponents of gradations on the vibration frequency. Therefore it could be interesting to examine numerically the response of the FGM plate on changing parameters of gradation of material coefficients.

54 | An equilibrium approach to finite element modeling of plates and shells

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It is well known that conventional conforming Mindlin-type elements for modeling shallow beams, thin plates, and shells can suffer from unrealistic locking and oscillations of stress resultants. Such properties have lead to much research to develop better types of element in the general framework of a displacement based approach. In this presentation we will focus on recent experience with the dual approach of using stress based hybrid equilibrium elements in the context of plates and shells. These elements are designed to provide a much stronger form of equilibrium without the defects of locking and associated oscillation problems. Currently these hybrid elements are based on flat triangular "primitive" elements assembled in such a way as to form stable facetted models free from spurious kinematic modes. Despite the facetted nature of the models, they nevertheless appear to converge well towards solutions based on curved conforming elements. A quadrilateral macro-element will be briefly described along with the nature of the equilibrium enforced at interfaces where adjacent elements lie in different planes of a shell model. Numerical results will be presented and discussed in particular for the Scordelis-Lo cylindrical shell, covering both linear elastic and geometric non-linear forms of behavior. This problem has previously been used as a benchmark problem for linear analysis, although certain aspects of behavior appear to have been reported in the past without very clear agreement!

55 | Development of in-plane fracture criteria for fiber-reinforced composite materials

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Composite material, also shortened to be composite, is the material made of two or more constituent materials. The composite is classified in accordance with specific matrix and reinforcement material. One typical employment in engineering applications is the fiber-reinforced composite (FRC). When compared with traditional engineering materials, e.g., steel or alloy, the FRC generally has merits of higher stiffness, higher strength, lighter weight, stronger resistance against corrosion, etc. Contributed to these benefits, the FRC is nowadays increasingly popularly used in engineering structures, such as the composite tube in construction, the riser pipeline in deep water drilling, the fuselage of commercial airliner, the rotor blade of helicopter, and the wind turbine blade in wind power industry, etc. Since the widely accepted situation of FRC in engineering applications, as well as numerous reports concern failure of FRC caused accidents in real cases, a thorough understanding on fracture mechanisms of this material is of significance, i.e., to provide guidelines of structural optimization to engineers. While general knowledge explains that the fracture mechanisms of FRC consist of in-plane fracture and delamination, and interaction between the intra-laminar and inter-laminar damages. Study on the in-plane fracture of FRC, especially, has been carried out for a few decades and is still on the way. Owing to many pioneering works, various in-plane fracture criteria were put forward. This paper intends to give an general overview on various in-plane fracture criteria for FRC in recent decades. Firstly, the development of in-plane fracture criteria is presented following timeline, the characteristic of each criterion is analyzed based upon its particular application. A comparative study on these criteria is performed in order to investigate the advantage and limitation of each criterion. Finally, the orientation of future work and potential breakthrough is discussed.

57 | Effect of geometric imperfection on the mechanical behavior of PFRP profiles

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Pre-buckling imperfection sensitivity of pultruded Fiber Reinforced Polymer (FRP) beams is analyzed in this contribution. The study is performed on the basis of a non-linear mechanical model recently proposed by the authors, accounting for the effect of manufacturing imperfections. The kinematic model is developed under the assumptions of small strains and moderately large rotations of the cross-sections, and taking into account the contributions of shear strains and warping displacements. Several case studies representing different pultruded beams utilized in Civil Engineering field are presented. The effects of the imperfection geometry and the mechanical behavior in flexure of analyzed beams are discussed.

58 | Buckling analysis of a simply supported rectangular orthotropic composite plate with delamination

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The main failure mode of layered composites is the delamination, which modifies the buckling behavior of these structures. In this work we analyze the buckling process of composite plates with trough-the-width delamination, using uniaxial compression. Because of the delamination the buckling process of the plate is complex, as the crack is able to open. This can lead to, that the plate can buckle either locally or globally, or mixed-mode-buckling can occur. For determining the behavior of the delaminated plate with respect of the external compression, a progressive method is introduced. First a constrained model is created, where the transverse deflection of the delaminated top and bottom parts are coupled, to avoid the intersection of the layers. The governing equations are derived using the system of exact kinematic conditions (SEKC). Next the local buckling is determined using a built-in end FEM model on the delaminated plate portions. The analysis is carried out using the method of harmonic balance because of the distribution of the in-plane forces along the crack tip. The novel part of the local stability analysis is, that in mixed-mode case the force distribution resulting from the global buckling was taken into consideration. Finally the local and global modes are superimposed using a static displacement controlled model. Using this model the progressive buckling of a delaminated plate can be determined with respect of the axial displacement.

60 | On asymptotic theory of beams, plates and shells

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Thin wall bodies of beams, bars, plates and shells type are characteristic as one of their dimensions is sharply different from the others. This circumstance permits us, by means of passing to dimensionless coordinates and dimensionless displacements, to create small geometric parameter in the equations of statics and dynamics of elasticity theory. The corresponding system of the equations turns out to be singularly perturbed by small

parameters, which does not allow, by one decomposition by small parameter, to solve the boundary-value problem. The solution of similar systems is combined of two, principally different, types of solution-outer (inner) solution I(out) and solution I(b) for the boundary layer problem. These solutions can be found by the help of specific decompositions by small parameter. For each desired value of a parameter the noncontradictory system of equations for determining the coefficients could be obtained. The noncontradictory values strictly depend on the type of the boundary-value problems. In the plane problem for the anisotropic strip (bar, beam), the solution is brought to the defined the displacements. The original approach in the space problem for plates coincides with the solution by Kirchhoff classical theory for plates. Therefore, classical theory of beams and plates neglects the approaches in the outer and boundary layer problems. The solution for the boundary layer is localized near the end-wall of the beams and lateral surface of plates and shells. Classical theory of beams, plates and shells considers only one class of problems; it is considered that on their facial surfaces the values of the corresponding components of the stresses tensor are given. In case when on the facial surfaces other conditions, the displacement vector or mixed conditions are given, it is proved that Bernoulli-Euler or Kirchhoff-Love hypotheses are not applicable. For the solution of similar problems the asymptotic method turned out to be effective. This turned out to be also effective for the solution of plane and space problems of thermoelasticity for layered bodies. Cases, when the solution of outer problem becomes mathematically exact are established. New classes of dynamic problems according to forced and own vibrations of thin one-layered and multi-layered bodies are solved. The asymptotic method can be successfully applied for the solution of interaction of beams, plates and shells with different physical fields, particularly, for the problems of electroelasticity, connected thermoelasticity.

61 | Generalized plate model-application to laminated glass

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This article deals with the behavior of sandwich plates, composed by stiff elastic layers and a thin soft viscoelastic core. By assuming a small scale ratio ε between the plate thicknesses and the characteristic size of the plate, the macro-behavior is derived by an asymptotic approach. The model considers the mechanical contrast between the Young modulus of the layers and

the shear modulus of the core, and the geometric contrast between the thickness of each layer. A two-order mechanical contrast (ε^2) and a zero-order geometric contrast (ε^0) lead to a generalized plate model, governed by a differential equation of 6th degree. This model degenerates into usual plate models. Varying the contrast allows to observe the transition from a monolithic behavior (low contrast) involving a global inertia, to a two-layer behavior (high contrast) showing the inertia of each layer. This model is applied to laminated glass plates, composed by two external glass layers, and a PVB core. As the shear modulus of his latter significantly depends on temperature and frequency, the mechanical contrast vary according to these parameters. These analytical results are experimentally validated by 3 points bending tests conducted at several temperatures. The relaxation response to a Heaviside loading evidences the evolution from the short term (monolithic behavior) to the long term (two-layer behavior). The time scale is shown to be strongly temperature dependent. Direct applications concern the design of glass structures.

62 | A multifiber beam model coupling damage and warping for reinforced concrete structures under multiaxial loads

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To determine the seismic vulnerability of existing reinforced concrete structures, computations at the structural scale accounting for material non-linearity are needed. The multifiber finite element method has proved its accuracy for slender frame structures subject to bending and/or axial loading, but fails to deal with large shear stresses. Indeed, the plane cross section assumption in the strain computation is not precise enough to convey the effect of shear. The present research proposes to include shear warping in the formulation by the mean of additional axial displacements, resulting in additional shear strains in the cross-section. Stresses are obtained from the axial and shear strains using a 3D damage model. Warping is computed by solving the cross section equilibrium accounting for the current state of damage. The behavior of beams subjected to multiaxial loads is computed with the classical and enhanced methods. The comparison of the global response to experimental

results highlights the importance of warping, both in the linear and nonlinear ranges. For example, taking torsional warping into account for a rectangular beam decreases the initial stiffness by about 40% and the peak torque by about 30%. Consequently, the seismic behavior of the structural elements is greatly affected. Warping also considerably influences the damage profiles.

63 | Model development and comparisons for light shell structures in textile reinforced concrete

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As part of the research project "product and process development of light-bearing ceiling elements made of textile reinforced concrete", the Institute of Concrete Structures is involved in the task to develop new simulation and design models for shell structures. The filigree precast ceiling elements are made of the innovative composites: textile reinforced concrete and fleece-concrete. For this bearing structure, different material models are developed further, implemented in the structural model shell and are compared with each other. The simulation models are validated through experimental studies. The initial draft of such elements shows a barrel-like curved element cross-section with lateral vertical up stands. This design is strictly based on the force behavior in the material and therefor it follows the principle of minimum cost of materials. FEM calculation is necessary for structural calculation, because nonlinear material laws and geometrically nonlinear analysis algorithms are used. The material models for the contemplated novel composite materials arise from the results of the material tests of the textile reinforced concrete respectively fleeces in a cement-bound matrix. So with these models a mapping of the special stress-strain behaviors is possible. Subsequently these various models for each composite material form the basis for parametric studies.

66 | Detection of damage in RC beams with NSM CFRP by frequency measures

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The use of the near surface mounted (NSM) carbon fiber reinforced polymer (CFRP) technique is increasing in civil engineering for the strengthening of RC beams to improve their capacity. This method consists in the use of FRP rods inserted into grooves, usually in the cover of concrete sections. NSM technique represents a more convenient method if compared to externally bonded (EB) FRP strengthening with strips or sheets for many reasons: FRP debonding and concrete cover delamination; damage from collision, high temperature and fire. NSM reinforcement is bonded inside the concrete cover and, hence, relative high FRP strains can be achieved before failure. The bond between concrete-resin-rods is decisive in this type of strengthening; the availability of this technique also depends on the effects of beams' cracking concrete under static loads. Static tests, such as bending tests, may be adequate to control the availability, but unfortunately they are destructive methods.
The authors combined static and dynamic tests to detect damage in strengthened RC beams. A number of experimental tests measuring frequency values under free vibration was developed to detect damage due to lack of adhesion and cracking diffusion on RC beams with NSM CFRP circular and rectangular rods strengthening. Six RC beams have been investigated: three beams were strengthened using NSM CFRP circular rods and one with rectangular rods. The dynamic tests were carried out through free vibration inflicted by an impact hammer recording the response of the structure with an accelerometer at different points. A Fast Fourier Transformation (FFT) two-channel analyzer and PULSE software were used for dynamic tests and for experimental data acquisition.

67 | Usage of IPN water-based resins in the execution of reinforcements of RC beams with composite materials

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For over 20 years composite materials have been used for the reinforcement and/or structural adjustment of individual element or complete reinforced concrete buildings. The composite materials most widely used in construction are based on carbon fibers and/ or aramid fibers and/or glass fibers and epoxy matrix. As known, the poor fire resistance of epoxy resins restricts the use of composite materials in building construction. Indeed, for temperatures above the Tg of the matrix occurs a rapid decrease of the composite elastic modulus. Usually for the epoxy resins laminated on site, the Tg value is less than 100°C.The article presents the result of an experiment conduct on RC beams reinforced with water-based IPN resins and unidirectional tapes carbon. As these IPN resins have a microcrystalline structure consisting of a polymer phase and a crystalline interpenetrated, they are material with class 1 reaction to fire (according to UNI 9177). Particularly, the beams have been reinforced with different configurations of strengthening to shear stress and bending. By comparing the results of load test applied on IPN resins and on epoxy resins, it has been proved that non only IPN resins have a better fire resistance, but also excellent properties of the reinforcements applied with the IPN matrix, showing similar values to the one obtainable with epoxy reinforcements.

68 | Finite element for hinged multi-stepped beams and beams with linearly-varying heights having an arbitrary number of cracks

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Simple, but nevertheless efficient representation of transversely-cracked slender Euler-Bernoulli beams subjected to small deflections can be achieved by modeling the cracks by means of internal hinges endowed by rotational springs connecting non-cracked beam's sections. Numerous examples have proven that this model provides reliable results when

compared to detailed 2D models even if the basic linear moment-rotation constitutive law is adopted. Recently, the derivations of a closed-form stiffness matrix and a load vector for slender multi-stepped beams and beams with linearly-varying heights were presented for clamped boundary conditions. The principle of virtual work further allowed for the inclusion of an arbitrary number of transverse cracks. This paper extends the utilization of this model for element's hinged boundary conditions as it presents two stiffness matrices and load vectors for each height variation. The presented matrices and load vectors (given in the closed-form) define an 'exact' finite element for the utilized simplified computational model. The derived elements can be implemented for analyzing multi-cracked beams by using just one finite element per structural beam member. The presented expressions for a stepped-beam are not exclusively limited to this kind of height variation, as by proper discretization an arbitrary variation of a cross-section's height can be adequately modeled. Numerical examples conclude the paper and show that, although with considerably less computational effort than with 2D finite element meshes, the presented beam finite elements yield results that exhibit excellent agreement with the results from the huge 2D FE meshes.

70 | Mode I energy release rate variability along delamination front in laminated composite structures with general fiber orientation

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The compression-buckling tests performed so far have indicated, that along the loading path different kinds of defects can initiate and propagate. The most common type of defects is laminated composite structures is delamination. On the other hand, understanding the nature of general layups (neither symmetrical, nor asymmetrical) seems to be advantageous from the point of view of more effective tailoring the properties of composite structural members. The advance of delamination front can be described in terms of the strain energy release rate. The common experimental schemes, such as Double Cantilever Beam (DCB) test by assumption give information on a single fracture mode characteristic – GIc for Mode I. This is true for unidirectional specimens, but not for angle-ply ones, especially those with general layups, exhibiting mechanical couplings. In such cases the mode mixity along delamination front should be expected rather than the single fracture mode. This demands a definition of the circumstances of delamination initiation and propagation concerning the actual stress state in compressed composite columns at any stage of the loading and buckling process, as any defect can additionally weaken the load-bearing capacity of the column. Thus, numerical analyses preceding the experimental tests were performed in the ABAQUS Finite Element (FE) software environment in order to determine the variability of GIc along delamination front in DCB specimens with various general ply layups.

71 | Investigation of fracture toughness of cracked concrete beam repaired by epoxy

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This paper attempts to investigate the fracture toughness of the cracked concrete repaired by epoxy - a thermo-set polymer resin. A single-edged beam in three-point bending test was conducted in an MTS system to examine the performance of concrete beam after being repaired. Each beam was completely broken into two pieces and then reassembled as the original beam with a designated crack. Three concrete crack widths of 1 mm, 5 mm, 10 mm were designed to be repaired. The fracture properties including load capacity, fracture toughness were observed. The fracture toughness, in terms of critical stress intensity factor KIC by Jenq and Shah and fracture energy GF by Hillerburg, were evaluated for the concrete before cracking and after reparation. Four sand contents of 0%, 10%, 20% and 40% by volume was used in the resin mixture. From the testing results, it appears that the strength and fracture toughness of repaired concrete increased with the increasing sand content. And the pure epoxy resin made repaired concrete better strength and fracture toughness as well.

72 | Interlaminar stresses in curved sections of composite box beams

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In regard of lightweight potential it is promising to employ box beams where the sections are fiber reinforced laminates, made e.g. from CFRP. An effect unaware from metallic beam cross-sections is the occurrence of localized interlaminar stresses in those parts of the profile where there is large curvature. The present work is devoted to the analysis of these interlaminar stresses. For that purpose the stress function based model for semicircular curved

transverse isotropic multilayered bars subjected to bending by William L. Ko and Raymond H. Jackson [NASA Technical Memorandum 4139, September 1989] is rewritten in such a way as to take into account strain in third dimension. This gives an exact solution for semicircular arches, subjected to in-plane forces and moments and out of plane strain. This solution is further used to examine stresses and deformations in composite box beams with trapezoid cross sections under tension in general, and occurrence of interlaminar stresses in particular, where extra attention is given to structures that are thick walled and have strong curvature. Comparison with the results obtained from finite element method is given for both, the semicircular structure and full trapezoid box beam.

73 | Post-buckling behavior of thin-walled columns made of in-plane coupled composite laminates

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In general, the layers of a laminate may be arranged in any way. This type of non-symmetric laminate exhibits different types of coupling between the extension, shearing, bending and twisting. On the other hand, there are some known arrangement laminate layers, e.g. [60/-602/03/602/0/-60/602/-603/02/60]T, where it is possible to fully uncouple the in-plane and out-of-plane response to mechanical and/or thermal loading. It is possible to observe isolated coupling effects. The relationship between forces/moments and deformations/curvature describes the stiffness matrix consisting of three sub matrices: extensional (A), coupling (B) and bending (D). The coupling behavior depends on the form of the elements in each of the sub matrices. When elements: A16 and A26 are not equal to 0, the coupling between in-plane shearing and extension take place. For practical reasons, it is a particularly interesting case of coupling. The in-plane coupled laminates can be produced with modern technology at elevated temperatures. The elements are not warping in the cooling process. An example of the in-plane coupled laminate is [45/0/-45/45/-455/(0/-45)3/452/-45/]T. Detailed calculations were performed for a column of square cross-section made of in-plane coupled and fully uncoupled laminate. In these cases, the lowest forms of buckling differed both quantitatively and qualitatively. The designated equilibrium path was stable and symmetrical.

75 | FE analysis of mode II delamination in laminated composite structures with general fiber orientation

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The presented paper is a part of the buckling analysis research of the compressed composite elements with general ply layup. In such structures the risk of premature failure due to local defect is high. Delamination is the most probable damage observed in the stand tests performed by the authors so far for symmetrical laminates. The next step in the research is testing a more advanced – general layups towards fuller utilization of design possibilities offered by laminated composites. The Mode II loading scheme was analyzed in terms of the Finite Element Method (FEM) using the commercial ABAQUS code. The analyses had in target analysis of the real Mode II proportion along the delamination front in general laminates having a form of the End Nothed Flexure (ENF) specimen. These simulations were a necessary step in elaboration of the most advantageous general layups allowing to evade defect occurrence with respect to the actual stress field taking place in the compressed profiles along the whole post-buckling path. The GIIc value ratio was found and indications for the physical test specimens were given.

76 | Dynamic equations for a micropolar cylinder

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This work considers the analysis and derivation of dynamical equations of a solid cylinder governed by micropolar continuum theory. The proposed method is based on a power series expansion of the displacement field and micro-rotation field in the radial coordinate of the cylinder. This assumption results in sets of equations of motion together with sets of boundary conditions that are variationally consistent. These derived equations are hyperbolic and can be constructed in a systematic fashion to any order desired where the equations are asymptotically correct to all studied orders. The construction of the equations are systematized by the introduction of recursion relations that relate higher order displacement and micro-rotation terms to the lower order terms. Results are obtained for cylinders using different truncations orders of the present theory including higher order benchmark solutions. Numerical examples are presented for dispersion curves, eigenfrequencies with stress and displacement distribution plots for simply supported cylinders.

77 | Effect of welding induced imperfections on the buckling load capacity of shells

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The buckling load capacity of shells is well known to be highly dependent on geometrical imperfections but otherwise generally no appropriate equivalent imperfection can be named. The designer therefore faces the task to find appropriate imperfection shapes that are both leading to lowest likely buckling load as well as representing the specific peculiarity of the structure. Equivalent imperfections obtained from eigenmodes, failure shapes and others are not suitable to cover the specifics of the real structure as production induced deformations or residual stresses. Using the example of a wind energy tubular steel tower section the paper presents how a simplified method to analyze welding distortions can be used to determine realistic production induced imperfections that are later on used to determine a close to reality buckling load capacity of the shell section. On base of instrumented welding tests on simple, flat metal sheets, experimental data has been used to verify the local distortion modeling. Afterwards, this analyzing method is transferred to large-scale cylindrical shell sections. Following the welding distortion simulation the buckling behavior of the imperfect structure is investigated and compared firstly to the results of the geometrically perfect shell. Furthermore, the standardized equivalent imperfections are included in this comparison as well. Finally, the different assumptions are evaluated regarding their application in the buckling shell design.

78 | Simulating the warping of thin coated Si wafers using ansys layered shell elements

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The possibilities to simulate the thin-film-on-substrates behavior of large thin coated wafers using Ansys layered shell elements is investigated and the results are compared to phenomena known from literature and to experimental findings. Wafer fabrication is a first step in a process chain towards an integrated circuit device. Due to different requirements, the wafers are often thinned by grinding and subsequently coated with metallic layers what induces stresses in the wafer's surface. Already in absence of other loads the wafers warp from the stress mismatches over the wafer thickness. The warping shape depends, amongst others, on the thickness ratios and the crystal orientations. A fundamental prerequisite for further numerical analyses of the mechanical behavior of these wafers is the ability to reliably calculate their stress and deformation state. A thin wafer is a circular plate with a diameter to thickness ratio in the order of 1000:1. The coating is again three orders smaller than the thickness of the composite wafer. The wafer has a distinct crystal orientation and, thus, an anisotropic material behavior. The deflections to be dealt with range up to a size of 10 times of the wafer thickness. Simulation approaches suggested in literature for the thin-film-on-substrates problem use a combination of solid and shell elements. For compact specimens it works fine, but here it does not work properly due to the extreme diameter to thickness ratio of a whole wafer. The Finite Element Program Ansys knows shell elements based on Mindlin-plate theory with coupled interior layers that can be used in conjunction with an update Lagrange algorithm (NLGEOM). We investigate the use of these elements for the presented problem.

86 | A solution for the superabundant unknown problem in the boundary element analysis of plates

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In the analysis by the Boundary Element Method (BEM), a well-known problem, which is called the superabundant unknown problem will occur at a point such as a corner where the traction or the flux is discontinuous. In that case, the number of unknown value is more than that of the equations. The situation is caused by the shape of the boundary and may occur in various fields. It is very troublesome to solve this problem and may be one of the factors obstructing the wide application of the BEM. In order to solve this problem, several techniques were proposed. However, they either reduce the precision or complicate the calculation due to the hyper singularity. In this study, we propose a method using a new kernel function that is comprised of the solution of a semi-infinite media at the discontinuous point of traction or flux. By this way, equations with necessary number can be constructed without any drop of precision, since the source point keeps at the original position, and the order of singularity does not be increased. We examined the present method for solving the superabundant unknown problem through a number of simple analysis examples and compared the numerical results with those by several conventional methods. The results from the present method were in the best precision. It is expectable to extend this technique to the three-dimensional analysis, as well as to fields other than the elastic plate problem.

90 | Free vibration analysis of rotating FGM beams using the p-FEM

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The functionally graded materials (FGMs) are inhomogeneous composite materials where the properties of FGM constituents vary gradually and smoothly. The smooth variation of the material properties overcomes the adverse effect of the laminate and sandwich composites structure such as the delamination mode of failure caused by the large interlaminar stresses. In this study, the free vibration of the lead-lag motion of a rotating functionally graded beam (RFGB) is investigated. From Hamilton's principle, the linear partial differential equations are derived for coupled stretching and bending motion. The governing equations based on Euler–Bernoulli beam theory accounts for centrifugal forces field, the centripetal acceleration and the gyroscopic effect. A p-version of the finite element method in conjunction with the modeling dynamic method using the arc-length stretch deformation is applied to find natural frequencies and modes shape of the cantilever beam. The displacements are expressed as the combination of the in-plane and out-of-plane shape functions, enriched with trigonometric hierarchical shape functions used generally to give additional degrees of freedom (dof) to the interior of the element. The convergence properties of the rotating beam Fourier p-element is examined, the results are compared with those of the literature where excellent agreements are observed. The influence of angular speed, Young's modulus ratio and power-law exponent on the natural frequencies and mode shapes is investigated. The tuned rotating speeds at which the beam will vibrate violently are determined for stainless steel-silicon nitride RFGB versus the power-law exponent.

92 | Crack propagation effect at the interface of a composite beam

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In this research work, crack propagation at the interface of a composite beam is considered. The behavior of composite beams (CB) depends upon a law based on relationship between tangential or normal efforts with inelastic propagation. Throughout this study, composite beams are classified like composite beams with partial connection or sandwich beams of three layers. These structural systems are controlled by the same nature of differential equations regarding their behavior in the plane, as well as out-of-plane. Multi-layer elements with partial connection are typically met in the field of timber construction where the elements are assembled by joining. The formalism of the behavior in the plane and out-of-plane of these composite beams is obtained and their results concerning the engineering aspect or simple of interpretation are proposed for the case of composite beams made up of rectangular section and simply supported section. An apparent analytical peculiarity or paradox in the bending

behavior of elastic–composite beams with interlayer slip, sandwich beam or other similar problems subjected to boundary moments exists. For a fully composite beam subjected to end moments, the partial composite model will render a non-vanishing uniform value for the normal force in the individual sub-element. Obtained results are similar to those for the case of vibrations in the plane as well for the composite beams as for the sandwich beams where eigen-frequencies increase with related rigidity.

96 | Load-bearing capability of composite cylindrical stiffened panels with account of post-buckling failure of skin

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At development of wing or fuselage composite structures of an aircraft it is necessary even at a stage of preliminary designing to consider a potential for the structure weight reduction by allowing local buckling of skins in the stiffened panels at a lower external loads than critical loads of the panels' global buckling, which define the load-bearing capability of the structures. The researches, which were carried out in last years in frames of some European projects, have been aimed on increase of a range of external loads at which it is possible to allow local buckling of skin in composite panels. To ascertain that this increasing is possible for composite panels, the analysis of the panels' buckling with taking into account post-buckling failure of composite skin has been carried out. The method of the "fast" analysis of the global buckling of the stiffened panels with taking into account premature local buckling of the skins is presented in the report. For the model of the stiffened panel, the buckling equations containing nonlinear coefficients were deduced. The solution was determined with use of the iterative process based on specially developed "fast" procedure for searching critical loads. The method for analysis of premature failure of the composite skin at post-buckling state is presented. It is based on nonlinear solutions obtained by means of parametrical analyses of post-buckling failure of the layered skin. The results of the analysis of load-bearing capability of the stiffened panels with use of the developed technique which considers the premature failure of the skin, have shown that the "optimistic" assumptions of possibility to receive big range of change of external loads in which composite skin of stiffened panels can work at

post-buckling state without failure, are not well substantiated to use at designing without non-linear analysis.

97 | Aspects of error estimates in quantity of interest for the FSDT laminated plate model and GFEM

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A formulation for discretization error estimation is developed for the bending problem of composite laminated plates based on the Mindlin-Reissner kinematic model discretized by the displacement based GFEM (Generalized Finite Element Method). The error estimation process starts with an upper bound in energy norm, which is obtained following the basic CRE (Constitutive Relation Error) framework of the Ladevèze formulation that is, the estimate is obtained from a statically admissible stress field computed at element level (Element Equilibrated Technique) in a Neumann problem where the element boundary forces are equilibrated. The formulation is adapted to two types of GFEM, one the usual form based on $C^0(\Omega)$ continuous partition of unity (PoU) denominated C^0-GFEM and another based on Ck(Ω) PoU, denominated Ck-GFEM, which generates stress approximations continuous at element interfaces. It has been shown previously that an accurate description of the in plane stresses in the laminate is essential to obtain accurate approximations to the transverse shear and stresses at the layers interfaces of the laminated composite. Since important failure modes in laminated composite plates, like the delamination, are linked to the transverse stresses, it is essential to develop both, accurate post-processing procedures to compute improved transverse stresses, and also estimate the errors of the approximation. The first condition is adequately satisfied by both types of GFEM, particularly by Ck-GFEM. Therefore, the aim of the present formulation is to extend the general CRE technology to develop formulations to estimation of errors in quantity of interest identified, obtaining reliable lower and upper bounds for stresses in important regions of the model. The present formulation is described only for the bending response that is, for a symmetric laminate, but can be extended to an arbitrary non-symmetric laminate, by the inclusion of the in-plane behavior and the membrane equilibrium, whose element equilibrium error formulation is well known.

99 | The influence of patch load length on the ultimate strength of longitudinally stiffened plate girder

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This paper presents the behavior of the welded girders with longitudinally stiffened web plate due to patch loading. The aims of the research are possibilities for numerical modeling of girder and comparison with experimental tests. The research is based on laboratory tests and finite element analysis. The numerical simulations are compared to results from experimental tests on welded I-shaped girders with different patch load length. Based on the experimental tests the real initial geometric imperfections are taken into account and implemented in FE model. Also, for shape of the initial imperfections eigenmodes and sinus shapes are considered. In order to investigate the effect of patch load length the post buckling response and ultimate load of plate girders are presented. This analysis is performed by nonlinear analysis using both nonlinearities, geometrical and material. The numerical tests are created using commercial FE analysis software package Abaqus. Girders were modeled in full size using different types of elements and varying element size.

101 | Simulation of optimal polarization for three-layered piezoelectric transducer using ACELAN package

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In present study the influence of non-uniform polarization on the electro-mechanical properties of a three-layered piezoelectric transducer is investigated. We suggest that non-uniform polarization field with certain disposition of electrodes can be lead to increased

efficiency of the transducer. Finite element package ACELAN was used to solve modal and harmonic problems for observed transducer. In this study two models of non-uniform polarization were observed. First model is based on splitting the body into parts with various polarization angles and same modulus. The second model includes two steps: defining exact polarization field of each active part of the multi-layered transducer and transferring those fields to finite element model of whole transducer. This approach well reflects the piezotransducers manufacturing process. Results obtained with both model were observed in this study. Various numerical examples were held with different configurations of the polarization field. In some cases the electro-mechanical coupling coefficient enlarged by 67% comparing to uniform polarization field. Some of numerical examples were repeated using ANSYS package to compare results. The electrical circuit with observed transducer and resistor was modeled in ANSYS to analyze electrical properties of piezoelement in the case of forced oscillations. Comparison with some physical experiments is discussed. Developed tools can be used to design more efficient piezoelectric devices, including energy storage devices, by selecting the most efficient electrode configuration during preliminary polarization of ceramics.

103 | Influence of locational states of submicron fibers added into matrix on mechanical properties of plain-woven carbon fiber compos

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The aim of this study was to show the influence of locational states of submicron fibers added into epoxy matrix on mechanical properties of modified plane-woven carbon fiber reinforced plastic (CFRP). To change the locational states of submicron fibers, two kinds of fabrication processes were applied in preparing specimen by hand lay-up method. Submicron fibers were simply added into epoxy resin with ethanol after they were stirred by a dispersion process using homogenizer to be located far from the interface between reinforcement and matrix. In contrast, submicron fibers were attached onto the carbon fibers by injecting from a spray nozzle accompanying with ethanol to be located near the interface, after they were tentatively contained in ethanol. The plain-woven CFRP plates were fabricated by hand lay-up method

and cured at 80 degree-C for 1 hour and then at 150 degree-C for 3 hours. After curing, the plain-woven CFRP plates were cut into the dimension of specimen. Tensile shear strength and Mode-II fracture toughness of CFRP were determined by tensile lap-shear test and End-notched flexure(ENF) test, respectively. When submicron fibers were located far from the interface between carbon fibers and epoxy resin, tensile shear strength and Mode-Ⅱ fracture toughness of CFRP were improved 30% and 18% compared with those of unmodified case. The improvement ratio in modified case was rather low (about few percentages) in the case where submicron fibers were located near the interface. The result suggested that crack propagation should be prevented when submicron fibers were existed far from the interface due to the effective stress state around the crack tip.

107 | Analysis in theory and experiment on waves propagating in a vibrating cylindrical shell

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In this paper, waves propagating in a vibrating cylindrical shell are analyzed in theory and experiment. In the theory, the assumption of thin shells allows the dispersion relation to be separated into three relations related to the propagation of flexural waves and two types of membrane waves. Those relations are used to identify the characteristics of those waves. Above the ring frequency of the cylindrical shell those waves are clearly identified to be flexural, shear and longitudinal waves. Below the ring frequency, the characteristics of waves are identified with dependence of the direction of wave propagation. Those characteristics of waves are also identified below the ring frequency as well as above the ring frequency by processing the experimental vibration data on the surface of the vibrating cylindrical shell.

108 | Large deflection analysis of shallow conical shells

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Geometrically nonlinear analysis of shallow conical shells with circular plan form is going to be investigated numerically. The edge of the shell is going to be considered to be simply supported or clamped. Due to the rotational symmetry of the shell, a system of ordinary differential equations is going to be solved. The finite difference method is going to be employed in the study. Six field variables three of which are components of deformation (i.e., displacements and rotation), and three of which are stress resultants are going to be introduced at each grid point. The grid points are going to be located along the radial coordinate on the middle surface of the shell. The influence of (i) the thickness, and (ii) the depth of the shell on the field variables are going to be examined. The results are going to be compared with the solutions of circular plates by setting the height of the apex to zero.

109 | Safety electron beam irradiated adhesion between polyurethane and metal sheets

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Polyurethane (PU) is utilized for insulation, walls, roofs, appliances, medical devices, coatings, adhesives, sealants and automotive interiors. Aluminum (Al) exhibits the high electric conductivity, shiny silver color and light specific weight, as well as high corrosion resistance due to passivation. Structural components made from Al and its alloys are utilized for the structural and electric articles. Copper (Cu) exhibits the high electric conductivity. The Cu wire is utilized for the electric motor. Homogeneous low energy electron beam irradiation (HLEBI), which safety equipment is skillfully devised for convenient use, improves the mist resistance and wetting of inorganic materials, and increases polymer adhering to glass fibers raising impact strength in GFRP. Improvements are mainly caused by the irradiation with the formation of dangling bonds in polymers. Dangling bonds enhance the surface energy, which probably causes the joining of different polymers. Thus, rapid and safety HLEBI induced adhesion between different polymers can be expected. Therefore, the effects of HLEBI prior

to hot-press lamination on the adhesive force of peeling resistance of high strength PU/metal (Al or Cu) laminated sheets of PU and metal have been investigated. The double-step treatment applying increased HLEBI dose enhances the mean adhesive force of peeling resistance at all peeling probabilities. When HLEBI cuts the chemical bonds and generates dangling bonds with nonbonding electrons in PU and metal, the created adhesion between the laminated sheets can be explained.

110 | Surrogate-based optimum design of curvilinearly stiffened panels for cutout reinforcement

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The aerospace industry increasingly relies on the use of lightweight structures to meet financial and environmental targets. Due to high specific bending stiffness, stiffened panels are widely used in aircraft and launch vehicle designs to resist buckling. However, cutouts are often inevitable in these thin-walled structures, for the purpose of easy access, inspection, electric lines and so on. The main objective of this study is to meet the requirement of cutout reinforcements in aerospace industry by utilization of the design flexibility of curvilinearly stiffened panels. The inherent superiority of such structures was examined in detail by comparison of straightly stiffened panels. The advantageous load path and tension field caused by curvilinear stiffeners can increase the load-carrying capacity of stiffened panels. Due to the large computational burden caused by post-buckling analysis, optimum designs of curvilinearly stiffened panels with cutouts were obtained based on surrogate model. On this basis, we took full advantage of the variable symmetrization and reduction methods for different design cases, aiming to reduce the number of dependent variables in the optimization. Illustrative examples show the superiority of curvilinearly stiffened panels for cutout reinforcement, and demonstrate the effectiveness of the proposed optimization framework.

111 | Adhesion created and improved by safety electron beam irradiation

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PTFE (Polytetrafluoroethylene) exhibits high strength, corrosion and heat resistance, although adhesion of PTFE with simple principal chains to others has not been easy. To create and improve the adhesion force, many sites number of chemical bonds at interface has been required. One of possible tool is the homogeneous 100 keV class low voltage electron beam irradiation (HLEBI), which safety equipment is skillfully devised for convenient use. Low potential HLEBI disorders and runs surface atoms, resulting in thermoelectric power of n-type Bi-Te-Se and thin film insulation of YBa2Cu3O7-y superconductor for Josephson contact utilized for brain wave detector. In addition, it also generates active terminated atoms with dangling bonds and adsorbed gas atoms, as well as charging with short life. Although additional dose of HLEBI induces the radiation damages, optimum dose of HLEBI induce strengthening of polymers of Polycarbonate (PC) and Epoxy and transparent ceramics glasses of carbon fiber, Silica, soda glass, Alkali-free and Borosilicate of utilized for liquid-crystal displays, as well as composite materials of C/C, CFRP, GFRP and optical fiber. Furthermore, it improves the mist-resistance with sterilization of endoscope Sapphire lens, Diamond window, Dentist mirror and polymers, as well as enhances the electric conductivity of PTFE. The mist-resistance depends on the surface activation, which predicts to improve the adhesion. Since the HLEBI induced adhesion without glue has been observed carbon or E-glass fibers/PEEK, Metals/PU, Metals/Epoxy-CFRP, Nylon-6/polymers and PFFE/polymers, they are utilized for insulation, walls, roofs, appliances, medical devices, coatings, adhesives, sealants and automotive interiors.

114 | Effective and efficient hybrid model for buckling analysis of hierarchical composite stiffened plates

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As a potential aerospace structural concept, hierarchical stiffened plates composed of the skin, major and minor stiffeners are characterized by multiple local features, which lead to the buckling analysis by Finite Element Method (FEM) suffering from heavy computational costs. Thus, an effective and efficient hybrid model is presented. In order to capture the partial overall buckling mode occurring between major stiffeners, only minor stiffeners are smeared but with major stiffeners retained. Then, the above equivalent plate and major stiffeners are combined into a hybrid model, bringing a higher computational efficiency than the detailed model significantly. Particularly, three equivalent methods are compared when smearing minor stiffeners, including Representative Volume Element (RVE), Smeared Stiffener Method (SSM) and Asymptotic Homogenization Method (AHM). Meanwhile, a straightforward numerical implementation of AHM is involved, which can be easily realized using commercial software as a black box. Results indicate that RVE and SSM make an incorrect prediction of buckling modes owing to their low prediction accuracy for bending stiffness. However, equivalent results by AHM show a good agreement with the detailed model results about buckling modes and loads, because AHM is based on the rigorous mathematical foundation. Finally, AHM is selected for applying to the hybrid model and the effectiveness is demonstrated by illustrative examples under various loading conditions.

118 | Evaluation of the dynamic properties of composite laminate under flexural vibration

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This study was aimed at investigating the effect of orientation fiber reinforced on dynamic properties of laminate composite FRP. An experimental investigation is implemented using an impulse technique. The various specimens are excited in free vibration by the use of bi-channel Analyzer. The experimental results are compared by model of finite element analysis using ANSYS. The results studies (natural frequencies measurements, vibration mode, dynamic modulus and damping ratio) show that the effects of significant parameters such as lay-up and stacking sequence, boundary conditions and excitation place of accelerometer. This results are critically examined and discussed. The accuracy of these results is demonstrated by comparing results with those available in the literature.

120 | Elastic analysis of a double side-coated circular plate with functionally graded interlayers

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In layered material systems, the presence of interfacial damages such as delaminations reduces the strength of the structure, leading to a premature failure. In order to reduce these effects, in recent years, some researchers proposed to use a new generation of composites, the so-called functionally graded material (FGM), in which the elastic properties vary continuously in the thickness of the structures. In this paper, the effect of functionally graded (FG) interlayers on the elasto-static behavior of a double-sided coated circular plate is investigated in the framework of the elasticity theory. In particular, two perfectly bonded interlayers, with an exponential variation of Young's modulus along the plate thickness (Poisson's ratio is assumed uniform), are considered between the core and the coatings of the circular plate. Furthermore, axisymmetric transversal load and boundary conditions on the

transversal displacement of the lateral surface are assumed. The elastic solution is obtained by using Plevako's representation form in cylindrical coordinates that permit us to solve the elasticity equations, also in inhomogeneous layers, in terms of a suitable potential function that satisfies a four-order partial differential equation. The elasticity equations are so written for each layer of the plate-system (core, two coatings and two interlayers) and, in order to construct the solutions of these equations, zero-order Bessel expansions with respect to the radial coordinate are adopted to write the potential functions, in according to a semi-inverse solution method. The explicit three-dimensional solution is obtained using the boundary and interface conditions and the detailed conditions on the lateral surface are determined by the solution method. The accuracy and reliability of the analysis presented is validated by comparing the numerical results obtained by the analytical solution with a three-dimensional finite element analysis. A comprehensive comparative study shows the inherent advantages of the present coating system compared to a conventional homogeneous coating system and a simple system of circular plates with FGM coating layers.

123 | Asymptotic analysis of nonlinear elastic adhesives

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Adhesive bonding plays an important role when composite materials are involved. Adhesive joints are subjected to complex states of stress with high stress concentrations and, consequently, their accurate analysis is needed. Due to the large number of elements in the thickness direction, a large number of degrees of freedom is necessary with an increase of the simulation costs. A classical alternative approach consists in modeling the adhesive as a material surface. Various methods have been proposed to identify the appropriate transmission conditions and most of the studies focus on adhesives undergoing small displacements. In this communication, we report on a recent work concerning thin adhesives made of the Saint Venant-Kirchhoff material, the simplest hyperelastic material model extending the linear elastic material to the nonlinear regime. Soft and hard cases are considered, meaning that the adhesive is assumed to be softer and harder than the adherents, and the corresponding transmission conditions are obtained. These turn out to be conditions of imperfect contact, prescribing jumps of the displacement and stress fields at the material surface modeling the adhesive.

128 | Effect of localized inertia on the vibrations of civil engineering structures by 1D component-wise models

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Non-structural masses can play a significant role in the dynamic response characteristics and earthquake performances of civil engineering structures. Mathematical models that are able to take into account the effects of those localized inertias are mandatory. 3D elasticity models or truss models made of assemblies of 1D elements are widely used in the engineering practice, especially by using FEM. Nevertheless, the former models usually require huge computational power, whereas the latter can be affected by physical inconsistencies. In the present work, we propose a refined 1D model based on the Carrera Unified Formulation (CUF). According to CUF, the accuracy of the analysis is a parameter of the formulation. The displacement field is expressed, in fact, as an arbitrary expansion of the generalized unknowns via user-defined functions. The attention is focused here to a particular class of 1D CUF models that employs Lagrange polynomials to refine the cross-sectional kinematics. The resulting models are geometrically consistent and they are referred to as Component-Wise (CW) because Lagrange polynomials can be used on the beam cross-section to model each component of the structure with arbitrary accuracy. Various numerical examples are discussed, and the accuracy and efficiency of the proposed CW models in dealing with modal analyses of buildings accounting for localized inertia effects are widely demonstrated.

131 | Anomalous and unpredictable deformation of ordinary impulsively loaded shells, plates and beams

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An unusual phenomenon in the field of nonlinear dynamics was discovered by the author of this paper in 1983. It was shown that impulsive loads of certain durations and amplitudes may induce unusual deformation behavior of elastic-plastic plates, leading to their unpredictable final shapes and failure modes. In one experiment, an axisymmetric transverse pressure was applied to a clamped circular metal plate. Unexpectedly, the plate lost its axial symmetry and formed a folded six-corner star. In similar experiments, several metal plates developed unusual cracks. In another experiment, impulsively stretched rods buckled and obtained final shapes similar to the classical shape of a slender rod buckled under static axial compression. This kind of structural behavior was called anomalous, paradoxical and counterintuitive. It was shown that commonly used finite difference and finite element models were not able to reliably predict the motion of ordinary elastic-plastic beams, plates and shells. As of today, engineering manuals contain little or no information related to this unusual structural behavior, over-predicting their load bearing capacity; little remains known to the broader interdisciplinary research community. The goal of this paper is to summarize the most interesting results produced for the past three decades, and to advance the understanding of this phenomenon. We will discuss little-known experiments, describe the phenomenon and the conditions for its occurrence, and explain the underlying physics and mathematical challenges. We will show how the structures designed using existing engineering manuals can fail under much smaller than expected "smarter loads". In addition, we will describe the concepts of post-chaotic self-organization in elastic-plastic plates, shells and beams. An emphasis will be placed on the "point of no return" and chaotic dynamics induced in various structures and systems. We believe that there is "some predictability" for their final states based on their internal geometric and material characteristics including eigenvalues and natural deformation modes. The understanding of this phenomenon may have far-reaching implications in various nonlinear systems modeled by similar equations and analyzed using the same numerical methods.

132 | Study of laminated shells by generalized differential quadrature and Murakami's theory

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Generalized differential quadrature and Murakami's Theory will be used to perform the analysis of shells. This technique combined with this theory, implemented using a unified formulation, was used before to perform the study of isotropic and cross-ply laminates. Numerical examples will be performed and compared to references available.

133 | Alternative thin plate formulation using a peridynamic approach

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Peridynamics is a recently proposed continuum theory based on a non local approach and formulated with integral equations. The theory is suitable for dealing with crack propagation in solid materials. Current peridynamic models capture tension and compression in 1D bars and 2D membranes, but these do not resist to transverse loads, in this case a complete 3-dimensional solid model should be used. A recent paper reduces a bond based 3D plate to two dimensions with an integral through the plate's thickness. This creates a model that can represent thin structures and includes a bending term, but additional equations are needed. Other authors use the state based peridynamics (that requires more computational effort with respect to the bond based version) and instead of build up new equations of motion they develop a new material constitutive model (non-ordinary bond-pair model). In the present work an alternative thin flat plate formulation for isotropic materials using the bond based peridynamics will be shown. Static analysis results will be compared with the ones obtained with the corresponding FEM model. Then a dynamic analysis of progressive damage in isotropic thin plates will be presented. Results will be evaluated taking into account different grid sizes, horizon dimensions, crack initial lengths and crack orientations.

135 | The dynamics of frames braced with functionally graded members

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In recent years several different bracing devices have been proposed, analyzed, and then applied to a number of real cases. Indeed braces, mounted as diagonal members of frames, are widely used in building structures and are designed to allow them to efficiently resist to lateral loads. However, buckling of braces compromises their strength and deformation capacities in compression. To overcome such a drawback, buckling-restrained braces (BRBs) have been introduced and studied since early Seventies. In the present contribution, a shear-type moment-resistant frame, assumed to have linear elastic behavior, is considered. The dynamic behavior of this very basic structure is compared with that of its buckling-restrained braced counterpart. The core of the brace is assumed made with a functionally graded material working in its linearly elastic phase, while the whole brace is allowed to undergo moderately large deflections. Thus, in the problem under consideration, the only source of nonlinearity is geometric. The results of a number of numerical simulations are collected in bifurcation diagrams.

136 | Analysis of laminated structures with variable number of layers by CUF shell elements

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The present work deals with the analysis of multilayered composite plates and shells with variable number of layers. Finite shell elements with different theories are employed to ensure an accurate description of the mechanical fields in the layers. One of the most interesting features of the unified formulation consists in the possibility to keep the order of the expansion of the state variables along the thickness of the plate as a parameter of the model.

In so doing, both equivalent-single-layer (ESL) and layer-wise (LW) descriptions of the variables are allowed. In this work the LW and ESL descriptions are combined, as a function of different structure laminations and loading configurations, to save degrees of freedom and preserving the same level of accuracy. The Mixed Interpolated Tensorial Components (MITC) method is employed to contrast the membrane-shear-locking phenomenon that usually affects shell finite elements. This formulation has already shown all its potentiality as a base for finite elements in the mechanical analysis of multilayered shells. Some results from the static and dynamic analysis of plates and shells under mechanical loads will be provided, in order to show the efficiency of models presented.

137 | Nondestructive testing method for curved composite surface based on twin-robot technology

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A curved surface path planning method base on twin-robot technology is proposed in this paper. Multi-Gaussian beam model for multi layers composite is introduced into the curved composite ultrasonic testing system. The mathematical model of receive beam field to composite is established to analyze the effect of different testing parameters for the receiving transducer. The simulation and experiments illustrate the validity and effectiveness of the proposed method. Imitating surface with bi-cubic B spline curves for complex curved surface. The normal vector can be calculated out to achieve transmitting transducer position and orientation. The acoustic length in water of receiving transducer is decided by the receiving beam field. By coordinate transformation, the position and orientation of receiving transducer can be achieved. Experiment results indicate the receiving signal is stronger, measuring accuracy is more accurate with the proposed method. The C-scan image results verify the effectiveness of the proposed method. It is believed that our method provides an effective solution to curved composite surface part, and it will greatly benefit industrial development.

138 | Numerical and experimental determination of natural frequencies and critical loads for compressed open thin-walled beams

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As is well known, thin-walled open profiles have an appreciable bending stiffness at least about one of the principal axes of inertia, but a low torsional stiffness. In addition, boundary effects do not have rapid extinction, and the contribution of warping stiffness may be crucial. Due to the widespread application of open thin-walled beams in engineering, vibration and stability analyses are of prime interest for this kind of elements. Since strain modes of thin-walled beams can be coupled according to the cross-section geometry, the pre-buckling equilibrium path can affect both the critical load and the natural frequencies. We have investigated on the effects of non-trivial equilibrium paths and warping constraints in thin-walled open profiles by a numerical in-house code based on a finite difference procedure, where stability is analyzed in a dynamic setting. This has provided interesting results when coupled with a direct one-dimensional model of standard beam enriched with a coarse descriptor of warping. Thus, we have undertaken an experimental campaign to verify these results, starting from the most simple cases to prepare and measure, i.e., beams with two axes of symmetry. In this contribution, we present some numerical and experimental results in terms of natural frequencies and critical loads for compressed thin-walled beams, having cruciform cross-sections with a vanishing or a remarkable warping stiffness. The specimens were subject to axial loads by means of a universal testing machine, and the natural frequencies were extracted, using piezoelectric pickups, for increasing values of the axial compressive force.

139 | Snap-through vs. Eulerian instability in arch structures affected by geometrical imperfections

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The multiple nature of structural instability problems make necessary different kinds of analytical and numerical approaches. Recently, some limiting recommendations, due to instability collapses of large-span roofs, have been proposed to reduce the effects of geometrical imperfections. The aim of the present paper is to investigate on the interaction between two different categories of structural instability. To this purpose, the snap-through phenomenon of 2D Von Mises arches is investigated by an incremental-displacement nonlinear analysis. At the same time, the equilibrium paths are considered in relation to the Eulerian buckling loads for the same structural systems. For each structural scheme, different parameters are analyzed, such as the internal and the external constraints, together with the arch depth. According to these purposes, several theoretical and numerical snap-through versus buckling interaction curves are obtained. These curves provide indications about the prevailing collapse mechanism with regards to the geometric configuration of the structure. Consequently, this innovative method is able to predict the actual instability category of a wide range of mechanical systems. According to this approach, it is possible also to establish the relation between entity of the structural imperfections and related instability behavior. The proposed procedure is capable to provide indications about the maximum tolerable imperfection.

141 | Evolutionary analysis of masonry arches: effects of aspect ratio and size scale

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Masonry arch structures can be assessed using a thorough analysis that takes into account the intermediate cracking stage that occurs when the material’s tensile strength has been

exceeded, although the collapse mechanism has not yet formed. Such assumption is based on a constitutive law providing a closer approximation to the actual behavior of the material.
In this paper, the Evolutionary Analysis for the fracturing assessment of masonry arches is presented. This method makes it possible to capture the damaging process that takes place when the conditions of linear elastic behavior in tension no longer apply, and before the achievement of the limit conditions. Furthermore, the way the thrust line is affected by the opening of cracks and the consequent redistribution of internal stresses, representing the “fracturing benefit”, can be checked numerically. Size Scale effects are considered as well as the influence of the aspect ratio of the arch.

146 | On elasto-plastic deformations in 6 parameter nonlinear shell theory with FGM

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In this paper we present geometrically and materially nonlinear analysis of functionally graded shells in the framework of 6-parameter shell theory. Drilling rotation (6th DOF) enters this theory in the natural way and the kinematic model is formally equivalent to the Cosserat surface with 3 rigidly rotating directors. It is assumed that the shell consists of two constituents: ceramic and metal, which varies their mechanical properties smoothly through the thickness. Continuous change in material mixture ratio prevents from introducing any stress concentration aroused by discontinuity of material properties, typical in laminate and fiber-reinforced composites. Reissner-Mindlin type kinematics is introduced and formulation based on 2-D Cosserat elasto-plastic J2 type constitutive model is used to derive constitutive relation for functionally graded shells. It brings some limitations, due to the fact that ceramics are brittle materials. Some observations lead to the conclusion, that limit behavior of FGM shells is mainly affected by metal flow, so regarding ceramics as elasto-plastic is justifiable simplification. Numerical results for smooth, cylindrical FGM shell under mechanical loading are presented. The influence of power-law exponent and micropolar material constants on the overall behavior is investigated.

147 | Middle Byzantine masonry domes: an investigation on the structural problems

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Domes are often present in churches. According to the Christian tradition, a dome structure supported by four pillars covers the church central area, at the intersection between the transept and the main nave. In the Byzantine churches, the two arms have the same length and form the Greek cross plan. Furthermore, four chambers are sometimes situated at the corners of the cross, forming an outer square, hence generating the so-called cross-in-square church. The specific system, which can be meant as a combination between the basilica and the central plan, has become the main structural scheme that characterized the Byzantine churches, starting from the most striking case of Saint Sophia of Constantinople. The cupola on squinches is a variation of the cross-in-square church. Specifically, it occurs in a group of Greek Middle-Byzantine churches, the so-called octagonal-plan type, where the main dome and its drum are supported by eight pendentives and eight arches (four semicircular and four embodied in the squinches of the corners), forming an octagon and achieving in this way the transition from circle to square. The aim of this work is the examination of masonry domes belonging to this specific structural scheme, which developed during the XI century mainly in Greece, starting from the church of Hosios Loukas in Phocis. These basilicas have typically shown structural problems due to their slender abutments: the main dome stands on a slight drum that through eight pendentives and four squinches is finally sustained by eight slender pillars. In several cases, these domes suffered severe damages due to both long term actions and earthquakes, so that they were demolished and subsequently reconstructed. An attempt is made to investigate the reasons for their strong exposure to seismic damage, through a comparison among the several churches that belong to this category. Attention is given to the boundary conditions as well as to the dimensional relationships of the constructive elements, in order to evaluate the weakest parts and through rehabilitation interventions, prevent the collapse of these domes, whenever another strong earthquake occurs.

148 | Buckling and geometrically nonlinear analysis of soft core sandwich plates and shells

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In this work a plate/shell finite element model is used for buckling and nonlinear analysis of sandwich plates and shells with a soft core and laminated composite face layers. The laminated composite face layers are modeled using the classical plate theory and the soft core is modeled using Reddy's third order shear deformation theory. Displacement continuity is imposed at the interfaces between the face layers and the core and a non-conforming triangular plate/shell element with 24 degrees of freedom is obtained. The model is used to obtain the solution for buckling and geometrically nonlinear analysis of several illustrative examples and the results are compared with alternative solutions found in the literature and using commercial finite element codes. For the geometrically nonlinear analysis, using the Newton-Raphson incremental-iterative method, the equilibrium path is obtained, and in case of a snap-through occurrence the automatic arc-length method is used to track the full load displacement curve. The results show the importance of using proper sandwich models when analyzing soft core sandwich structures.

149 | On some recent developments of GBT for composite beams

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Thin-walled beams are widely used in many industrial applications ranging from Civil to Aeronautical engineering. Due to the their complex kinematic behavior, which includes non-linear warping and section distortion, it is not possible to apply standard beam models for the description of their kinematic behavior. Models characterized by enriched kinematics have been developed aiming at preserving the advantage of a mono-dimensional formulation but

still retaining a three-dimensional description of the displacement field. The Generalized Beam Theory, GBT, proved to be a powerful tool for the analysis of such structural members. The fundamental idea of the GBT consists in assuming the displacement field of the beam to be a linear combination of predefined cross-section deformation modes (which are selected beforehand) multiplied by unknown functions dependent on the beam axial coordinate, called generalized displacements. In this sense, the GBT model can be viewed as a one-dimensional model deduced from a parent three-dimensional one. In such a framework, the beam is represented as an assembly of plates that deforms in cylindrical bending. It is noticed that methodologies have been developed in the literature, mainly for laminated plates elements, which allow to reconstruct the full three-dimensional stress state from the reduced model, so rendering the technique theoretically applicable even in the case of laminated beam elements within the GBT framework. Nevertheless, due to the adoption of a reduced kinematic, some three-dimensional strain components might be poorly represented or even completely disregarded so leading to an over-stiffening of the model that might seriously compromise its accuracy. Such phenomenon can be particularly insidious in the case of orthotropic and laminated plates for which the strongly coupled constitutive relations lead to complex interactions between all strain/stress components. In order to overcome these difficulties, an approach, able to automatically identify constitutive relations consistent with the adopted kinematic hypotheses, is presented. In the proposed approach, constitutive relations are obtained via complementary energy and there is no distinction between membrane and bending parts, nor isotropic and orthotropic materials.

150 | Lateral-torsional buckling of compressed and highly variable cross section beams

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Lateral-torsional balance condition may be found for beams with straight axis subject to normal compressive stress. In this study the lateral-torsional balance condition is obtained for a beam with highly variable cross section along z-axis, under the assumptions that shear centers are aligned and line of centers is bound to not deform. Flexural configuration takes place in all cases where the line of shear centers does not correspond with the line of centers of mass. Differential equations that govern the problem are obtained.

151 | Modal characteristics of rotating moderately thick composite plates

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The modeling of deformable bodies undergoing large overall rotation has been addressed by several authors due to the relevance of this topic in many engineering fields. The rotating system often consists of slender structural components with a geometrically predominant dimension, which are usually modeled as beams. However, some applications involve structures having plate-like shapes. Typical examples include spacecraft solar panels, low-pressure stage turbine blades and aircraft rotary wings with small aspect ratios. The analysis of those systems would be more accurate and reliable if plate models rather than beam models are adopted. Furthermore, since composite structures are increasingly used in many rotating systems nowadays, appropriate two-dimensional modeling methods of rotating laminated plates can be useful for the design of such structural components. Compared to the huge amount of studies available on rotating beams, only few results have been presented in the last two decades on the modal analysis of rotating plates. The literature is even more scarce for moderately thick or composite plates undergoing overall motion. The purpose of this paper is to present a modeling method for rotating moderately thick composite plates and to investigate their modal characteristics. When studying rotating flexible systems, the floating frame approach is usually employed since this choice simplifies the analysis of small vibrations about the overall rigid-body motion. However, a consistent linearization process must be carried out to correctly deal with the motion-induced gyroscopic softening and stiffening terms in the equations of motion. Furthermore, the Coriolis effect should be properly accounted for, especially at high angular velocity, due to the coupling between in-plane and out-of-plane vibrations of arbitrarily laminated composite plates. Finally, the effect of rotary inertia and transverse shear deformations should be incorporated due to their large influence on the accuracy of results for composite structures. The above issues are fully addressed in the formulation developed in this work. In particular, the present linearized model is based on the first-order shear deformation theory and can be used to study the modal characteristics of cantilever composite rectangular plates attached at different angles to a rigid rotating hub. The effect of the angle-ply orientation and the lamination sequence on the natural frequencies of the rotating plate is investigated for different values of the angular

velocity. The influence of the most relevant parameters of the system such as the aspect ratio, the thickness ratio and the hub radius ratio on the modal behavior is also discussed. The proposed method is validated by comparison with several test cases taken from the literature and new results are also presented that could be used as benchmarks for future investigations.

152 | The vk-Ritz method for bending, vibration and buckling analysis of heterogeneous multilayered plates

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Composite structures in the form of multilayered constructions made of heterogeneous materials are increasingly used in modern aerospace, mechanical, civil and marine applications. Many efforts in the literature have been devoted in particular to the analysis of thin and thick multilayered plates and shells by means of analytical and semi-analytical methods. In the past, solutions have been derived in the context of first- and higher-order shear deformation theories. Depending on the loading, the material lay-up and distribution and the boundary conditions of the problem, these solutions can be found in exact or approximate manner. This paper is aimed at reviewing the so-called variable-kinematic Ritz (vk-Ritz) method as an effective semi-analytical computational tool for refined bending, vibration and buckling analysis of heterogeneous laminated and sandwich plates. The formulation is developed within the framework of a variable-kinematic theory, offering the advantage of automatically handling theories of various order in the context of the same, unified, approach. Both layer wise and equivalent single-layer theories can be considered. Compared to analytical models, the Ritz approach allows the analysis of more complex configurations, involving quadrilateral and annular plates, arbitrary combination of classical boundary conditions, different stacking sequence and materials, and multi-axial loading conditions of bi-axial compression/tension and shear. Compared to numerical models, such as FEM models, the good spectral convergence and accuracy of a Ritz approach make the present formulation highly attractive for preliminary design studies and reliable parametric analysis. The problem is formulated referring to the Principle of Virtual Displacements, which

is expressed in terms of two-dimensional generalized kinematic variables arising from the assumed plate theory. The plate theory is written in a unified layer wise indicial notation such that the order of the theory is a free parameter of the formulation. Each layer wise kinematic unknown is expanded as the product of Chebyshev polynomials and appropriate boundary characteristic functions. Accordingly, the so-called invariant Ritz fundamental nuclei of the load and the mass, stiffness and geometric stiffness matrices of the model are derived for each layer and successively expanded at the multilayered level. From the assembled matrices of the plate, the discretized bending, vibration and buckling problem can be obtained. The potentialities of the method are assessed by presenting the results for a wide range of cases, including isotropic quadrilateral and annular plates, skew laminated composite and sandwich plates, rectangular sandwich plates with FGM core and orthotropic skins, multilayered plates embedding piezoelectric and frequency-dependent viscoelastic materials. The accuracy of the numerical predictions computed with the present vk-Ritz method is validated by comparison with 3-D and other 2-D reference solutions available in the literature.

153 | Multilayered metal panels for doubly curved freeform shell structures

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Shell structures disappeared from the architectural horizon in the last 30 years. This was mostly due to the high labor costs and the huge effort of geometrically complex scaffolding. Novel computer driven production processes and file to production technologies allow the production of building components with custom geometry at relatively contained costs, and make for this reason the building of free form structures newly affordable. In a cooperative research between the Chair of Structural Design and the Institute of Metal Forming at the RWTH-Aachen University a new concept for doubly curved multilayered metal sheet panels has been developed. These novel components can be employed in the realization of self-supporting lightweight freeform shell structures, avoiding this way any scaffolding during the erection or primary supporting structure during the service life. The manufacturing process

relies on the combination of stretch forming and incremental sheet forming and delivers a built-up panel, which is able to resist against in-plane actions, as well as bending and shear forces, thanks to conical embossments engraved on one of the layers. In this respect, the possible shell geometries that can be implemented are not limited to the strict repertoire of "compression-only" forms, but can assume also more complex shapes. As concluding case study, a building scale example is investigated to show the potential of the solution here proposed.

155 | Infrared thermography to evaluate impact damaging of thermoset- and thermoplastic-matrix composites

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This work would be an overview on the use of infrared thermography (IRT) to investigate impact damaging of composite materials. An infrared imaging device allows getting information on the impact damaging mechanisms of composites in a fast and completely non-invasive way. In particular, the same infrared camera is used with a twofold function: surface temperature mapping when the composite surface is being impacted; non destructive evaluation (NDE) technique before and after impact. NDE is performed with lock-in thermography (LT) with results shown as phase images. Different types of fiber reinforced composite materials are considered by varying either the reinforcement from glass to carbon fibers, or the matrix from a thermoset to a thermoplastic one. Specimens are first non-destructively inspected with lock-in thermography to search for manufacturing defects. Then, they are impacted at different energy values while the surface opposite to impact is monitored with the infrared camera. Each impacted specimen is again inspected with lock-in thermography. Impact tests are carried out at low energies with a modified Charpy pendulum, which allows enough room for positioning of the infrared camera. The impact energy is

varied in a certain range owing to the different type of material to reach the condition of barely visible damage without any perforation. The obtained results show that monitoring the thermal signatures induced by impact supplies useful information for the material characterization specifically for identifying initiation and propagation of the impact damage. Phase images obtained with locking thermography allows for estimation of the damage extension through the thickness and in plane.

157 | A one dimensional beam-like model for composite tubes with foam core

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Tubular composite beams are widely used in the application industry. In particular, in the automotive field, tubes constituted by a thin metallic skin and a thick soft core made of PVC foam are often used to exploit the high strength to weight ratio; there, the foam has the task of avoiding local instabilities and thwarting the ovalization of the cross section. For this kind of structure, a one-dimensional, homogeneous, beam-like planar model is proposed, taking into account the ovalization of the cross section as well as its warping due to shear. The coarse configuration variables are the displacement of the axis line, the global rotation of the cross section, as well as two variables describing the amplitudes of both ovalization and warping shape functions, as driven by the GBT idea. The constitutive law of the metallic skin is assumed elastic linear, whereas the core is considered nonlinear elastic. The elastic energy provides the response function of the beam and both static and dynamic bifurcation analysis is carried out to evaluate the critical conditions and the post-critical behavior.

158 | Verification of engineering methods of accounting post buckling deforming by the means of non-linear FE methods

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The effect of local buckling is allowed for some elements of airframes aiming to get more rational parameters of the stiffeners. In order to use of this effect, the investigation of reduction of stiffness of the elements at post buckling is required. The so-called ""method of reduction factors"" is applied in engineering practice to take into account reduction of buckled elements' stiffness. This method is based on semi-empirical approaches and it uses the approximate analytical models. Latest achievements of finite elements method (FEM) in the field of solving nonlinear problems give an opportunity to investigate these questions more precisely and to verify the analytical models that have been used. The results of a set of analytical researches are presented in this work for post buckling deformation of rectangular plates loaded with compression, shear and various combinations of these loads. A comparison of the obtained results with well-known formulas of Von Karman, Marguerr, Kuhn and other authors is given. A number of effects are noted, for example increase of shear rigidity of buckled plate for a certain ratio of shear and compression loads. The comparative analysis of analytical (FEM) and experimental results concerning post-buckling behavior of composite plates are presented. The comparative evaluations on influence of local buckling of skin on the global buckling of stiffened airframe panels obtained using analytical and numerical methods are presented. It is shown that the analytical methods not to a fully extent account some important aspects of post buckling behavior. AS an example, the effect of deformational interaction between stringer and buckled skin is described.

161 | Development of modeling techniques for unidirectional composite ribs for static and impact strength analysis of airframes

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Lattice composite structures have been successfully applied for years in rocket structures for their excellent strength and stiffness to weight ratio. The first optimistic results of successful applications of the lattice structure concept in aviation were obtained in a number of Russian and European projects. The main load-bearing element in these structures is a grid of unidirectional (UD) composite ribs. As topological and geometrical parameters of these ribs are significantly different from the corresponding parameters of conventional composite panels the new approach in FE-modeling of lattice (or another unidirectional composite rib) structures is needed to get successful results in designing such kind of structures. Simple and effective analysis technique based on special parametrical 2D FE models for simulation of three-dimensional composite UD-rib shave been developed in TsAGI. In frame of this technique, FE model of each rib is formed as a system of empty boxes where the faces of the boxes are simulated by 2D membrane elements. Strength and stiffness characteristics of these 2D elements are calculated automatically using the special algorithm in order to keep constant the stiffness characteristics of the ribs for any size of FE mesh. The considered FE modeling technique has shown good efficiency from the viewpoint of performance and accuracy of the results for static strength analysis. The technique have been successfully used in European projects FP7 ALaSCA, FP7 PoLaRBEAR and in a number of Russian projects. In this work, the considered FE modeling technique was adopted for impact strength analysis of UD-rib composite structures that allowed to reduce the time of impact strength analysis of composite ribs by replacing 3D elements by 2D elements in the FE model of ribs. The additional benefit of the technique is that the same FE model can be used for static and impact strength analyses of composite UD-rib structure. The results of validation of the modeling technique by the means of 3D-element modeling methods and experimental testing are presented in the paper.

162 | On dynamic problems of anisotropic strip-beam and plates

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Forced vibration of anisotropic strip – beam, being in the conditions of the plane problem of elasticity theory, are investigated. It is considered, that in the plane of the strip anisotropy is general. Two groups of the boundary conditions on the longitudinal edges are considered. In the first group of the boundary conditions it is considered, that normal and tangential displacements, which are changed harmonically in time, informed to the lower border of the strip, and the opposite border is free or is rigidly fastened. These problems particularly simulate seismic effects on the base of the constructions. In the second group it is considered that the lower longitudinal border of the beam is rigidly fastened, and on the opposite found normal and tangential loading, which are changed harmonically in time, act general asymptotic solutions of the formulated problems are obtained. It is shown, that in case of general anisotropy, forced vibrations are not purely shear or purely longitudinal, unlike the vibrations of the orthotropic strip. It is proved, that if the functions entering the boundary conditions are polynomials, the mathematically exact solution corresponds them. The conditions of resonance rise are established. It is shown, that the outer loading is variable along the coordinates, then one type of the vibrations gives rise to the vibrations of the opposite type. Space dynamic problems on forced vibrations of rectangular plates under the series of the boundary conditions variants, given on the facial surfaces of the plates are solved. It is considered, that anisotropy is general (21 constant of elasticity). Asymptotic solutions of space dynamic problem of elasticity theory with two sets of the boundary conditions are obtained: a) One of the facial surfaces is rigidly fastened, and on the other one the values of the tangential and normal loadings; the values of the displacement vector components; mixed conditions are given; b) oOn one facial surface the displacement vector which changes in time harmonically is given and the opposite facial surface is free, rigidly fastened or is in the conditions of the mixed problem. In case of the general anisotropy presence the solution of the space problem is reduced to the solution of the system from three ordinary differential equations relative to three displacement vector components. In case of the orthotropic plates it is proved that this system splits into three independent in the input approximation of the asymptotic decomposition equations, to which two types of shear and longitudinal vibrations correspond. The solutions, corresponding to all set boundary

conditions are found, the conditions, of the resonance rise are revealed. In case of the presence of the general anisotropy the solution of the system from three equations is reduced to the determination of one function from the ordinary differential equation of the sixth order. The solution of this equation and all the solutions of the formulated space dynamic problems are found.

164 | Thermo-mechanical modeling of photovoltaic laminates by means of unified formulation

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Photovoltaics (PV) is the direct conversion of solar radiation into electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels comprising a number of silicon solar cells embedded in laminates. Typical crystalline silicon PV laminates are multilayered structures composed of a glass superstrate, the interconnected silicon (Si) solar cells, an encapsulating polymer (ethylene vinyl acetate, EVA), and a polymeric protective backsheet. Figure below shows the schematic composition of such a PV module. The computation of thermo-elastic deformations in PV laminates is a prerequisite to propose new technical solutions that may result in innovative solar cell design. In this context, the development of kinematic models would be convenient to understand the roles played by the different materials on the global mechanical behavior. In this paper, the thermo-elastic deformations in photovoltaic laminates are investigated by developing different models based on Unified Formulation (UF). Due to the discontinuity of the mechanical and thermal properties at the layer interfaces, an accurate description of the mechanical and thermal fields in the layers is essential. For these reasons, the use of classical plate theories based on Kirchhoff and Reissner-Mindlin hypotheses can lead to inaccurate results. Since analytical models are available in few cases, the solution of these practical problems demands the use of computational methods such as the Finite Element Method. This work presents shell finite elements for the thermo-mechanical analysis of photovoltaic laminates, based on the Principle of Virtual Displacements (PVD) and the Unified Formulation. These are nine-node elements and the Mixed Interpolation of Tensorial

Components (MITC) method is employed to contrast the membrane and shear locking phenomenon. This formulation has already shown all its potentiality as a base for finite elements in the mechanical analysis of multilayered shells. Shell finite elements based on UF for the analysis of thermo-mechanical problems have been already presented in previous works. One of the most interesting features of the Unified Formulation consists in the possibility to keep the order of the expansion of the state variables along the thickness of the plate as a parameter of the model. In so doing, both equivalent single layer (ESL) and layer-wise (LW) descriptions of the variables are allowed. These last models are particularly fitting for the analysis of photovoltaic laminates. The results for the maximum deflection are compared with some solutions discussed in the literature and show good agreement with them.

165 | Bending capacity of the post-tensioned steel beam with the sandwich plate system

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Most of structural systems of the existing public parking buildings have been built by the floor planning having a module of 7 by 8 m. As a result, lots of columns were located in the parking space and it sometimes resulted in the inefficiency of the parking area. Additionally, because the structures of the parking buildings were mainly constructed using the lightweight steel members such as profiled steel sheets and channels to reduce the construction period, the systems could cause the noise and vibration problems. To improve these problems of the parking buildings, a new system was proposed. This system consists of steel beam with post-tensioned tendons and the Sandwich Plate System (SPS). To evaluate the bending capacity of this floor system, total two specimens were tested. Test results showed that the first specimen of the steel beam with the SPS slab exhibited very high ductile behavior and it was finally failed by the local buckling of the top faceplate of the SPS. The behavior and failure mode of the second specimen with post-tensioned steel beam were similar to the first specimen. However, the bending resistance improved by 14% due to the installation of the post-

tensioned tendons. Relative displacements between steel beam and the SPS slab were measured at about 3.5 mm because of the tolerance between the bolt and the hole. However, in spite of the slip occurrence by the bolted connections, full composite strength was achieved at the ultimate state.

167 | Higher-order theories for the structural analysis of doubly-curved shells and panels made of innovative materials

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The static and dynamic behavior of shell structures is influenced considerably by the use of innovative materials such as functionally graded materials and carbon nanotubes. Similarly, the manufacture of laminated shells with a soft core or reinforced by curvilinear fibers implies remarkable effects both on the free vibrations and on the stresses and strains of these structures. Nevertheless, the First-Order Shear Deformation Theory turns out to be inadequate when the exact mechanical behavior has to be gotten. Therefore, a higher-order displacement field is needed in order to study properly these structures. The present approach is based on the Carrera Unified Formulation (CUF) and allows to consider variable mechanical properties on the shell surface and variable thickness. Both Equivalent Single Layer and Layer-Wise models are taken into account since the classical theory of elasticity is too burdensome from the computational point of view. Several surface load distributions, as well as concentrated forces, can be included in the current approach. The partial differential system of governing equations for laminated composite doubly-curved shells and panels with variable radii of curvature is solved by using the Generalized Differential Quadrature (GDQ) method, whereas the geometry of these structures is described mathematically through the differential geometry. Several numerical applications are presented to show the accuracy of the current technique for the resolution of various dynamic and static problems. In particular, the recovery procedure based on the three-dimensional equilibrium equations is employed to estimate the strain and stress profiles at each point of the 3D solid when the static analysis is performed.

168 | Static and dynamic analyses of arbitrarily shaped laminated composite structures

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It is well known that many applications in several fields of engineering cannot be solved analytically due to the complexity of the governing equations. Therefore, a particular technique is needed to solve numerically the problem under consideration. As regards the structural analyses, the most common approach is the Finite Element Method (FEM), which decomposes the domain in several subdomains and finds an approximate solution evaluating the equations in their weakened form. On the other hand, the authors have developed a different approach, which solves the governing equations in their strong form using a higher order numerical scheme inside each element. The so-called collocation methods based on the distribution of points upon the physical domain is employed to discretize the partial differential system of governing equations. Since the domain decomposition in several elements characterizes both the two approach, the presented technique can be termed Strong Formulation Finite Element Method (SFEM) in order to stress the fact that it is based on the strong formulation. The SFEM expresses all its potentiality especially when an irregular domain is considered. In fact, most of the practical applications in civil, mechanical and aerospace engineering are quite hard to analyze due to the presence of irregular geometries, different kind of materials, cracks, curved boundaries and load discontinuities. Several structural applications are shown to demonstrate convergence, reliability and stability of the SFEM when it is applied to the static and dynamic analyses of arbitrarily shaped laminated composite plates, membranes and beams with geometrical and mechanical discontinuities.

169 | Bifurcational buckling of two-dimensional functionally graded beams resting on the Winkler elastic foundation

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In this study, bifurcational buckling of two-dimensional functionally graded (2D-FG) resting on the Winkler elastic foundation is studied. The material properties of the beam vary in both

axial and thickness directions, and the variation of elasticity modulus in two dimensions. Based on the Timoshenko beam theory, the critical buckling load of 2D-FG beam is obtained using the Ritz method. In order to obtain buckling load, the trial functions for axial, transverse deflections and rotation of the cross-sections are expressed in polynomial forms. Simple-simple (SS) and clamped-clamped (CC) boundary conditions are considered. The boundary conditions in the study are satisfied by adding auxiliary functions to the displacement functions. At the same time, buckling load 2D-FG beam is calculated for Euler-Bernoulli beam theory. Some numerical results are provided to examine the effects of the material gradation, aspect ratio and different boundary conditions on the buckling behavior of 2D-FG beam.

170 | Vibration of a functionally graded microplate under a moving load using neutral surface based on the modified couple stress theory

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In this study, forced vibration of a functionally graded (FG) microplate under the action of a moving load is analyzed based on Kirchhoff-Love plate theory and the modified couple stress theory. In order to reduce computational effort, the formulation of the problem is developed considering the neutral surface of the microplate. Thus, there is no need to take into account the in-plane displacements, and then stretching-bending coupling effect. The material properties of the microplate vary in the thickness directions according to the simple power-law. The equations of motion of the problem are derived using Lagrange's equations. In order to apply Lagrange's equations, the trial function for the dynamic deflection of the microplate is expressed in the polynomial form. Fully simply supported (SSSS) and fully clamped (CCCC) boundary conditions are considered. For this purpose, the boundary conditions are satisfied by adding some auxiliary functions to the trial functions. The time-dependent equations of motion are solved via implicit time integration Newmark- β method. A parametric study is conducted to study the effects of the material length scale parameter, material gradient, boundary conditions and the moving load velocity on the dynamic response of the FG microplate. Also, in order to validate the present formulation and solution method, some comparisons with those available in the literature are performed. Good agreement is

found. The results show that the dynamic deflections are significantly affected by the scale parameter and the load velocity.

171 | Revisiting the problem of vibration analysis of clamped plates

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The vibration analysis of plates is a widely researched area. Hundreds of papers were published on the topic. The problem can be divided into two groups: the first group includes cases for which an analytical solution is known (Navier and Levy solutions). These are cases with at least two opposite edges simply supported. The second group includes cases with clamped edges, free edges, and simply supported edges not included in the first group. For the second group semi analytical and numerical solutions are in use. Benchmark solutions for the cases in the second group are highly desired for validation and comparison of existing and future methods. It is well know that closed form analytic solution is not available for the problem, which is represented by partial differential equation with constant coefficients and boundary condition that prevent deflection and rotation along all four edges of the plate. Solutions in the form of series are known but have not been put in the past to a practical and comprehensive form. In this work a review is presented on the available solution methods for fully clamped plates. All these are compared with new solutions procedures that were proposed in the last year. In summary one can conclude that the recent progress in the new methods, have made a significant step forward, and can now serve as benchmark results.

172 | A complex wavenumber approach to model wave dispersive properties in phononic damped plates

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Phononic crystals, i.e. media or structural systems characterized by some form of periodicity in the material constituent/geometrical arrangement, have attracted considerable interest because of the exhibition of complete band gaps for elastic wave propagation. In this context, phononic plates have received particular attention for their potential in Lamb wave guiding

and filtering. Plates band structures are generally numerically predicted enforcing the Bloch type boundary conditions to a unit cell assuming the structure as infinite and elastic. However, absorbing phenomena might affect the nature of the band structure and thus the extension/existence of the band gaps. At such, in this work a Finite Element framework is proposed for the computation of the complex band structures in linear viscoelastic phononic plates. The approach is based on a post-processing strategy of classical global stiffness and mass matrices of the unit cell. Unit cell complex dispersive relations are obtained in terms of real band structure and attenuation. Guided wave propagation in a periodic 3D printed stubbed plate is investigated numerically, via the proposed approach. The existence of complete band gaps and well as the strong effect of damping on flat bands of elastic waves are shown.

173 | Structronic composite plates based on novel guided wave frequency steerable transducers for aeronautic structures

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Structural health monitoring (SHM) for damage detection in composite plate-like structures is an emerging field in aeronautics. Generally, guided ultrasonic waves methodologies, such wave time-of-flight based methods or tomographic approaches, driven by networks of piezoelectric transducers are exploited to this aim. The main limitation of such SHM systems is the hardware complexity and power consumption mainly related to the high number of transducers required. In this context, the proposed sensor node for guided wave detection allows drastic hardware simplification and transducers reduction. The device embeds a novel piezoelectric Frequency steerable acoustic transducer (FSAT) that thanks to its peculiar shape produces a frequency-dependent spatial filtering effect so that a direct relationship between the direction of propagation and the spectral content of the transmitted/received signal can be established, and a small footprint, low power, and light weight electronic designed to control the FSAT. In particular, transducer novelties are in the extension of FSAT directivity from 180° to 360°, and in an improved focusing capability thanks to the use of Ditering techniques

in the piezoelectric patterning process. Numerical simulations of the FSAT capabilities and an experimental test aimed at detecting damage in a plate show the effectiveness of the novel structronic technology.

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