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Compact finite difference schemes, a higher-order discretisation for fluid flow simulation

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Over the last few decades, numerical simulation in mechanics has become an essential approach for the detailed characterisation of complex non-linear phenomena such as turbulence and the triggering of instabilities. Despite the ongoing development of supercomputers, numerical simulation remains costly in terms of computing resources, with the simulation of multi-scale flows still a challenge. In practice, reducing simulation time is usually achieved through the efficient use of High-Performance Computing environments, or more marginally, through the use of high-order spatial discretisations. However, the combination of these two aspects is still an open problem. The work presented here concerns parallelization techniques for a class of high order finite differences, the "compact schemes" and their application to fluid mechanics.

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Chemical, physical, and mechanical properties of old concrete – an example

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The paper describes an example of the determination of the selected mechanical, physical, and chemical properties of old concrete. The laboratory testing program to determine old concrete properties consists of the following set of tests: measurements of the depth of carbonated zone and dry density, water absorption tests, determination of concrete compressive strength and frost resistance, determination of modulus of elasticity, measurement of the pH value, determination of water-soluble chloride salt and sulfate ion content, and X-ray diffraction analyses. The properties of the old concrete are compared with the present and previous standard requirements and guidelines.
Due to concrete degradation old concrete and reinforced concrete structures require improvement, repair, and reconstruction. Before taking any action and starting the design process, it is necessary to form an expert opinion by carrying out a detailed examination and laboratory tests of the construction materials used in the old structure. A proper assessment of the properties of old concrete helps determine the range of repair or reconstruction required as well as the load capacity of the investigated structure, which is needed for ensuring extended working life and the safe use of old facilities. This paper provides scientists, engineers, and designers with a basis in the field of experimental determination of old concrete properties.

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Two-phase flows in deformable porous media with frictional contact at matrix–fracture interfaces

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We address the discretization of two-phase Darcy flows in a fractured and deformable porous medium, including frictional contact between the matrix–fracture interfaces. Fractures are described as a network of planar surfaces leading to the so-called mixed- or hybrid-dimensional models. Small displacements and a linear elastic behawior are considered for the matrix. Phase pressures are supposed to be discontinuous at matrix–fracture interfaces, as they provide a better accuracy than continuous pressure models even for high fracture permeabilities. The general Gradient Discretization framework is employed for the numerical analysis, allowing for a generic stability analysis and including several conforming and nonconforming discretizations. We establish Energy estimates for the discretization, and prove existence of a solution. To simulate the coupled model, we employ a Two-Point Flux Approximation (TPFA) finite volume scheme for the flow and second-order (P2) finite elements for the mechanical displacement coupled with face-wise constant (P0) Lagrange multipliers on fractures, representing normal and tangential stresses, to discretize the frictional contact conditions. This choice allows to circumvent possible singularities at tips, corners, and intersections between fractures, and provides a local expression of the contact conditions. We present numerical simulations of two benchmark examples and one realistic test case based on a drying model in a radioactive waste geological storage structure. This is a joint work with Jérôme Droniou (Monash University, Melbourne, Australia), Roland Masson (Inria & Université Cote d'Azur, Nice) and Antoine Pasteau (Andra).

*Speaker

Application of the design study to search for the optimal bell shape

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Bells belong to a group of instruments called idiophones, in which the sound is created during the vibration caused by the impact. After hitting by the clapper, one of the rings (the bell consists of a series of overlapping rings of different diameter and thickness depending on the profile) slightly initiates vibrations, which are transmitted to the next rings. In a short time, each of them vibrates with a slightly different frequency and intensity, producing a different tone. The tones induced in different parts of the bell overlap and combine to create harmony. The tone that is heard as the most striking is called the "main tone" and is joined by others that merge into one. The most important sound components are: hum, fundamental, tierce, quint and nominal. In order for the tones to form a sound that is pleasant to the ear, the mutual distances between the sounds must be kept in the appropriate proportions: 1, 1:2, 1:2.4, 1:3, 1:4. The most important stage in assessing the quality of the bells is the evaluation of their acoustic properties, which are affected by the material from which the bell is made, manufacturing technology, weight and the profile/shape/rib. This work shows the use of SolidWorks and the so-called Design Study (optimization method) that can contribute to obtaining an optimal profile (cross-section of the bell). To this, it was assumed that only the internal part of the rib will be optimized so as not to change the characteristic external shape, and also because the bell is tuned inside (machining). For this purpose, the profile of the bell described on dozen circles whose centers strictly defined on the plane. The four selected circles were the control circles and the diameters of the remaining were determined from them. The values of these four diameters and the radius of the bell (the fifth control parameter) were sought in the design study so as to obtain a shape for which the vibration frequencies were as close as possible to those required. During the analyses, the diameters and radius were searched in a certain range, and the weights of the first five tones in the objective function assumed that were the same. The obtained results confirm the possibility of using the proposed method to search the optimal rib shape, while the certainty that the profile is correct can be obtained only after casting the designed bell.

*Speaker

Implementation of a model to simulate plastic flow through a spiral mandrel by Chris Rauwendaal and its verification for thickness uniformity of the extruded blown film

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The blown film extrusion process is one of the most widely used film production methods. Extrusion dies are used in this process, the geometric parameters of which have a key impact on the quality of the finished product. Due to the increasing requirements for film quality, it is necessary to design extrusion dies consciously, as well as to constantly develop designs in order to optimize them and continuously develop this type of solution. In order to improve the physical properties and the quality of the extruded blown film, it is necessary to optimize the geometric parameters of the die. This is possible using one of the proposed mathematical models of polymeric material flow during the die design process. This work will present the implementation of the model by Chris Rauwendaal and its verification on the example of a selected blown extrusion die. The physical properties of the extruded film will be analyzed.

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Structural damage detection considering uncertain modal data

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Structural damage detection techniques based on vibration data have been developed for decades. The vast majority of the approaches consider measured data as deterministic, neglecting fact that accelerations recorded within a certain time period in the field conditions include noise due to environmental factors like wind, water waving or traffic, but also due to hardware limitations, which introduces uncertainty into modal identification results. The identified modal parameters, i.e., natural frequencies and corresponding mode shapes are the estimates calculated from measured vibration data. However, the literature in the field exceptionally considers the uncertainty of modal identification results in the damage detection analysis. The aim of the present study is to assess the efficacy of the structural damage detection using mode shape based damage detection approach by defining and incorporating the estimation of uncertain modal data into the analysis.
The case studies of a cantilever steel beam and a lighthouse are presented to provide a closure in the results assessment of modal identification, when its undamaged state is unknown and accessibility to convenient measurement points is limited. Two modal identification methods are presented i.e. Eigensystem Realization Algorithm and Covariance-Driven Stochastic Subspace Identification. Damage detection procedure based on mode shape curvature (MSC-DI) is considered. The modal curvature is sensitive to stiffness change in the area of damage. MSC-DI relies on mode shapes determined for actual (current measurements) and initial (usually estimated numerically) state of the structure.

In order to compare MSC-DI effectiveness in deterministic and stochastic simulation approach (without and with uncertainties consideration, respectively), MSC-DI was first calculated for individual mode shapes in relation to different initial state data (deterministic approach). Then, the stochastic simulation analysis was introduced, in which multiple realizations of the random mode shape were included within the ascertained uncertainty bounds related to each modal identification method. MSC-DI was calculated in each case. The deterministic analysis did not provide proper damage localization for all considered cases. The stochastic analysis, however, revealed an improvement of damage detection efficacy by accurate indication of damage location.

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Since experimentally identified modal parameters are estimates, their error should be taken into account in damage detection problem. The conducted study proved that neglecting modal characteristics uncertainties can lead to inadequate or false conclusions about the damage position. The stochastic simulation approach improved damage detection efficacy and may be recommended for damage detection in real constructions.

Modelling the twin-screw extrusion process - a case study of a poly(lactic acid) biodegradable composite with flame retardant fillers

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Co-rotating twin-screw extrusion is the most common and the most widely used method in the production of thermoplastic composites and obtaining polymer mixtures with fillers, functional additives and modifiers. Modelling the twin-screw polymer extrusion process is challenging due to the many variables relating to both the polymer matrix and filler and the geometric parameters of the screws. In the processing of polymeric materials, high temperatures and friction lead to material degradation, which can cause problems on finished polymer products. This is particularly true of poly(lactic acid) (PLA) composites, which are particularly sensitive to processing parameters. In this study, we show that the Hartley experimental scheme is an effective tool for optimizing extrusion parameters of PLA matrix composites. To find the best settable parameters for extrusion process, such as process temperature, screws speed and throughput, a three-level Hartley plan for three input factors on three levels of variation was proposed. Results show that, in extrusion processing window, this model is suitable for experimental prediction of best parameters of process.

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Dynamic stability of damped elements modeled with Bernoulli-Euler beams

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The study analyzed the influence of different types of damping on the dynamic stability elements modeled with Bernoulli-Euler beam. Using the mode summation method and applying an orthogonal condition of eigenfunctions and describing the analyzed system with the Mathieu equation, the problem of dynamic stability was solved. By examining the influence of internal and external damping and damping in the beam supports, their influence on the regions of stability and instability of the solution to the Mathieu equation was determined.

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Mechanical wave propagation in dynamic phononic structures

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Phononic structures are characterized by the lack of mechanical wave transmission for given frequency ranges. This phenomenon is called the occurrence of bandgaps and occurs due to diffraction and interference at the boundaries of metaatom centers and the environment or layer boundaries in quasi-one-dimensional structures. The properties of modern smart materials can be controlled by the manipulation of magnetic and mechanical fields, making it possible to periodically change material properties over time. The paper analyzes the influence of the frequency of change of material properties on the propagation of a mechanical wave both in the passband of quasi-one-dimensional filters and in the bandgap. The transmission matrix algorithm was used to determine the transmission characteristics of the static phononic structure. The analysis of mechanical wave propagation with a given frequency for the analyzed structure was carried out using the finite difference algorithm in the time domain and the discrete Fourier transform.

*Speaker

Numerical method to propagate uncertainties on parameters with non integer order PDE

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Fractional order models are interesting for parameter identification in a transient dynamics framework. The numerical identification tool proposed in this topic is an easy-to-operate tool dedicated to fractional order based transient mechanical response derivative models. Firstly, the fractional order can more accurately simulate the dynamic behavior of the system with fewer parameters. Secondly, since it is difficult to determine the unknown parameters of the analytical solution of the fractional order governing model, it is particularly important to find an effective numerical method for this. Finally, developing and evaluating high-dimensional numerical methods is the ultimate goal of this project.

*Speaker

Application of machine learning in failure mechanics

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Machine learning (ML) has recently showcased significant potential in the field of failure analysis. In situations where analytical and empirical solutions prove challenging or impossible to apply, machine-learning models, such as decision trees (DTs), random forests (RFs), and neural networks (NNs), can offer dependable alternatives for addressing certain intricate engineering problems. Numerous researchers have recognized its applications and benefits, applying them to various models and achieving significant results. ML, as an evolving field, can also play a crucial role in structural mechanics, enabling predictions of mechanical behavior and modeling the failure patterns of bonded joints. This approach, which encompasses decision trees, random forests, and fully connected NNs, has shown its value and feasibility in accurately predicting the mechanical behavior of structures. The first part of the research provides a fundamental overview of machine learning algorithms, accompanied by background information on machine learning methodology, procedures, and modeling. The second part illustrates the application of machine learning as a predictive tool to forecast the failure mechanism and strength of structural adhesives through a case study. The case study revolved around the ML prediction of the adhesive tensile strength and classification of damage mechanisms in the adhesive during tensile experiments. A total of 6 ML algorithms: linear regression, lasso regression, ridge regression, decision trees (DTs), random forest (RFs), and multi-layer perceptron (MLPs), are considered for regression to predict the strength of adhesive. The results of analysis using ML algorithms are compared with the outcomes using deep neural networks. The evaluation metrics include the coefficient of variation (R^2) and root-mean-squared errors (RMSEs). To create robust and unbiased ML models, training and testing was performed on 75 datasets. These datasets are the accumulation of the data from the laboratory tensile testing and data extracted from published research, based on the relationships of five continuous input parameters including geometric and material properties. The geometry of the tensile specimen is according to ISO 527-2-2012. The parameters include thickness of adhesive specimen (h), modulus of elasticity of the adhesive (E), Poisson's ratio (), width of the specimen (b1), and gauge length (L0). As a result, a novel data-driven ML methodology based on comprehensive design parameters is described, paving the way for better characterizing the preliminary behavior of the adhesive. The research focuses on the cutting-edge and innovative ML methodology taking into consideration both geometric and material properties to understand and classify the failure modes and predict the failure

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strength of the adhesive. Good convergence is obtained between the coefficients of determination calculated by ML and the solutions obtained using finite element modeling (FEM).

Polymer composites based on polylactide with carbon filler - production and properties

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Polylactide, also known as poly(lactic acid), is one of the compostable thermoplastic polyesters. The use of this polymer requires modification of its properties. Composites based on polylactide with the addition of carbon filler (graphite, graphene, nanotubes) can be used in the automotive, electrical and electronic industries.
Physical/mechanical methods of obtaining PLA/carbon filler composites are based on the use of mixers and extruders.

Very good dispersion of the filler in the polymer matrix is required to obtain high-quality polymer concentrates. Obtaining it by physical methods is a big challenge. Choosing the right configuration of the plasticizing system of the extruder as well as the extrusion parameters is the key to solving this problem.

Two methods of obtaining polylactide/carbon filler concentrates were discussed in the presentation: using a closed mixer and single- and twin-screw extruders. The method using a mixer is characterized by good homogenization, but its disadvantage is low efficiency. The extruder method is more efficient, but it is more difficult to obtain a satisfactory dispersion of the filler in the polymer matrix.
The concentrates obtained by this method can be used in the production of target composites based on polylactide with increased mechanical strength and improved thermal and electrical conductivity.

*Speaker

Surgical implant for repairing hernia optimized for human torso movements.

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The study refers to topology optimised surgical implant used in the treatment of abdominal hernia. This research aims to create a surgical mesh compatible with human abdominal wall by changing thickness of different zones of the implant. The implant is optimized for physiological movements of the human torso that are simulated by forced displacements of the junctions of the implant and abdominal wall.
The implant was modelled as a decagonal membrane by means of finite element method (FEM). The forced displacements are applied in the model supports that represent the tacks connecting the implant with tissue. The material is assumed as linear elastic and isotropic. Combination of commercial finite element software (Marc Hexagon) with in-house code in Python for optimisation and control is applied in the analysis.

Within optimisation process the model thickness changes in each element. The objective function minimises the difference among the reaction forces so that we obtain reaction forces distribution closer to uniform. This way the implant may be less prone to the junction failure which would lead to hernia recurrence. Sequential Least Squares method and SciPy libraries were used to minimise the objective function.

Different thickness was obtained in different regions of the implant referring to specifically loaded zones. Average thickness of model changed from 0.6mm to 0.47 mm. Resultant optimised implant model was transformed into stereolithography file (.stl) using OpenSCAD software and printed using resin 3D printer Phrozen Mighty 8k.

This is a preliminary study towards designing implants mechanically compatible with the human abdominal wall.

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*Speaker

Experimental and numerical analysis of wood logs corner joints

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The wood logs joint of three types (dovetail, saddle-notch and hook joint) have been experimentally and numerically analyzed. The laboratory tests have been made on a 1:2 scale with five log joints using the biaxial testing machine and a specially designed experimental setup. During the test, the five logs joint has been pulled into two perpendicular directions, parallel to the logs' axes. As a result, the test of the deformation of the joint and the relation between supports displacements and force in the supports have been investigated and recorded. Using the commercial FEM software MSC.Marc/Mentat the experiments have been finite element modelled. The results on numerical and experimental and numerical analysis for saddle-notch and hook joins have given similar results. But for the dovetail joint, the force-displacement function obtained during the test and calculated using the FEM model has significant differences. Due to the good correlation between saddle-notch and hook joint results, the error in material properties identification and support system modelling have been excluded. The main difference between the dovetail joint and the other types of joints is the sophisticated way of connection creation. The saddle-notch and hook connections require only a simple way of cutting by a carpenter. In the dovetail joins the cut surfaces are not parallel and should be cut with care by a skilful carpenter. It was found that the logs for dovetail joints had some cut errors therefore the shape of the joints was not perfect. It has been decided to create the finite element model taking into account the differences in each jog dimension. The individually shaped model improved the character of the force-displacement function, but the results have not been good enough. In the following step, the friction between logs and the position on the middle support has been considered. These improvements caused a good correlation between numeric results and experiments also for the dovetail type of joint. During the presentation, the details of the experiments will be presented. The method of the test performance, which protects the biaxial testing machine against damage will be explained. Also, the details of the numeric modelling will be discussed. The influence of finite element mesh creation on the final results will be shown. The most important factors which can influence the differences between the test and calculation results will be explained.
Literature

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Analysis of the rotational stiffness of connections between selected steel profiles

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The present paper is devoted to the study of the rotational stiffness of connections between elements such as I-beam, Z-beam and rectangular pipe (perpendiclular to each other). Combinations of the above-mentioned elements are often used in real building structures, such as truss coverings of steel halls. In case of loading in the form of wind suction, the compressed bottom chords of the trusses should be protected against buckling. In this case, one of the structural solutions described in the literature is the appropriate stiffening (for rotation - out of the truss plane) of the upper chord of the truss (in tension), which has a significant impact on the increase of critical loads. The paper presents the results of experimental research on the rotational stiffness of selected joints. An experimental set up with the use of two-axis strength testing machine has been described. For selected cases, a comparison of the experimental and numerical results was presented.

*Speaker

Defects detection in the flat polyethylene and polyamide boards using air-borne ultrasound

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The study presents the application of non-contact ultrasound for the non-destructive detection of defects in two kinds of plastic boards made from polyamide and polyethylene. Air-coupled ultrasonics is widely used to generate and detect Lamb waves in plates, pipes, or more complicated thin-walled structures. The transmission as a function of notch depth has been studied in steel plates or aluminum plates.
The study aimed to an assessment of the defect presence, size, type, and orientation on the amplitudes of ultrasonic Lamb waves measured in plates made of polyamide and polyethylene.

Studies were carried out for the boards with generated synthetic defects resembling the defects typically found in real such materials such as delamination at the board edge, cracking at the board edge, and cracking (discontinuity) in the middle part of the board.

Tests were carried out for three types of defects found in the structure of board materials: delamination at the board edge, cracking at the board edge, and cracking (discontinuity) in the middle part of the board. The synthetic defects were applied in a controlled manner and their size varied from 1mm to 15mm. _

Thanks to the use of Lamb waves, it was possible to perform tests for entire boards at relatively long distances (about 1m). The contactless nature of the method allows potentially for quality control of the boards even in motion (e.g. during the production process).

Toexcite the Lamb waves in the board material the 30 kHz probes were applied. The method is very sensitive to the slightest changes in the integrity of the material. The presence of a discontinuity of the tested material and the length of the defect, affect the fading of the signal amplitude (including edge fluctuations). The values of the signal amplitude measured in the polyethylene had almost twice the level compared to the polyamide. The higher signal amplitude resulted from its intrinsic material properties. Polyamide shows greater signal attenuation compared to polyethylene.

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The experimental tests show the sensitivity of the method to defects in the form of; (i) delamination from the edge of the material; (ii) cracks from the edge of the material; (iii) material discontinuity in the middle part of the boards. The results of the studies performed using airborne ultrasound, presented here, illustrate that for correct results, it is necessary to maintain the temperature of the material surface and environmental conditions during all measurements as similar as possible.

The findings presented in the paper for reference boards (with simulated defects) show that the non-contact measurement technique and Lamb waves are effective tools for defect detection in flat boards and will serve for the interpretation of the results obtained for other construction materials.

Energetically effective structures manufactured additively for crashworthiness - a review stud

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The purpose of the study was to analyse and find novel and original topology concepts for auxetic specimens suitable to be produced using the additive manufacturing (AM) technique. An important challenge for the literature research in this field is the loading conditions for such energetically effective structures. Especially dynamic tests represent a crucial group in the testing of cellular structures. Therefore, when performing dynamic simulations, the following interactions must be taken into account: inertia, strain rate, and shock wave propagation. In the field of numerical testing of cellular testing in dynamic tests, such tests are commonly used as the drop weight test, SHPB, and blast impact.

On the basis of the literature review, it is noticeable that various topology optimization methods have been developed to address the challenge of finding an optimal sectional configuration for energy absorption components in order to achieve the highest crash-worthiness performance. Despite numerous works dedicated to topology optimization, they are still challenging. In this work, twenty topologies with nearly identical relative densities belonging to 4 groups were examined: honeycomb, re-entrant, bioinspired, and chiral. The findings revealed the topologies with the most favorable energy absorption parameters and the main deformation mechanisms. The topologies were classified by mechanism and a parametric study of the basic properties of the material, namely the modulus of elasticity, the yield stress, and the ductility, was performed for a representative topology of each mechanism. The results indicated that the honeycomb group topologies absorbed energy more efficiently and yield stress was found to have the greatest impact on energy absorption efficiency regardless of the main deformation mechanism.

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*Speaker

Comparison of failure criteria in non-Newtonian shear-thickening fluid in multi-layer ballistic composites – ballistic studies and numerical analysis

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In this paper, the impact resistance of multi-layer sandwich composites was investigated. The outer layers consisted of aramid fabrics in a laminate with a thermoplastic polymer matrix. The middle layer contained a non-Newtonian shear-thickening fluid enclosed in hexagonal (honeycomb) cells. The fluid was produced using polypropylene glycol and colloidal silica powder with diameter of 14 μm in the proportions of 40/60. The research part focused on modelling the projectile – shield system using homogenization method with SPH particles conversion with different material destruction criterions – strain limit and stress limit. The Johnson-Cook constitutive strength model was used to describe the behavior of elastic-plastic materials constituting the elements of the projectiles. For the shear-thickening fluid, the Johnson-Cook model was also used, but without taking into account the elastic behavior of fluid. Then the samples were subjected to a ballistic test with 9x19 mm FMJ Parabellum projectile with an initial velocity of 360 $\pm$ 10 m/s in accordance with the CEN EN 1522 standard. The material arrangement of the sample was completely penetrated by the 9x19 mm FMJ projectile. Similar results were obtained during numerical simulations, although differences in the results obtained for both failure criteria were noted, which necessitates the correct analysis of the resultant strength of the material in the homogenization method. Particular attention was directed to the shearing of the layer made of non-Newtonian fluid. After a negative result, the optimization of this layer was performed using hybrid numerical methods. The result of numerical optimization was obtaining optimal parameters of the non-Newtonian fluid layer. The authors emphasize that the dominant layer, the purpose of which is to reduce trauma, is a layer made of shear-compacting liquid. These results were then compared with alternative solutions made of layers of aramid fabrics. Based on these comparisons, the systems with shear-thickened liquid layers are better at reducing sample deformation from the opposite side. This result was identified using a backface signature.

*Speaker

Modeling and simulating cellular membranes: Phases, flow and contact

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The membranes surrounding biological cells show complex mechanical behavior. They contain different material phases, and they simultaneously show solid- and fluid-like behavior. This work presents recent advances on the general theoretical and computational modeling of cellular membranes: The first is a new phase-field formulation for Cahn-Hilliard phase transitions on deforming surfaces (1). The second is a new arbitrary Lagrangian-Eulerian (ALE) formulation for incompressible Navier-Stokes flow on deforming surfaces (2). The third is a new chemo-thermo-mechanical contact bonding formulation that applies to cell adhesion (3). The description is based on the general framework of curvilinear coordinates and isogeometric finite elements (4). It is illustrated by several numerical examples.

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*Speaker

Modelling, analysis and numerical simulation of a Spring-Rods system with unilateral constraints

Mircea Sofonea * [1]

[1] Université de Perpignan Via Domitia – Université de Perignan Via Domitia – France

We consider a mathematical model which describes the equilibrium of a two elastic rods attached to a nonlinear spring. We derive the variational formulation of the model which is in a form of an elliptic quasivariational inequality for the displacement field. We prove the unique weak solvability of the model, then we state and prove some convergence results, for which we provide the corresponding mechanical interpretation. Next, we turn to the numerical approximation of the problem, based on a finite element scheme. We use a relaxation method to solve the discrete problems that we implement in the computer. Using this method we provide numerical simulations which validate our convergence results.

*Speaker

Self leveling terrain rover with an active rocker - bogie suspension

Krzysztof Sokół * [1], Paweł Kwiatoń [1], Maciej Pierzgalski [1]

[1] Politechnika Czestochowska – Poland

Terrain rovers are getting more popular and are often used by the special rescue/reconnaissance teams or by the scientific teams during expiration of hardly accessible areas. During those tasks the key feature is passing the terrain obstacles. The presented an this conference solution consists of a modified rocker – bogie suspension unit. The design focuses on an idea according to which each wheel is connected to the expandable section. The advantage of this design above standard one can be found in a fact that the wheel base can be dynamically adapted to the situation as well as during passing great inclines, one can manipulate the level of a main frame in order control to the center of gravity what results in more stable drive as well as allows one to transport different types of materials without losing them on the way. The results of this study are focused on leveling of the base platform during traveling on uneven terrain and on stability of suspension members.

*Speaker

Uncertainty quantification for human abdominal wall mechanics

Katarzyna Szepietowska * [1], Izabela Lubowiecka

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The work concerns modelling of the human abdominal wall under uncertainties related to the material properties of the human tissue. Computational model of the abdominal wall is needed to improve understanding of human abdominal wall mechanical behaviour and facilitate *in silico* trials, for instance, of surgical implant used in the ventral hernia repair. However, high natural variability of properties of tissues in biomechanics and uncertainties related to identification of properties of living human tissues are challenging in constructing credible computational model of the human abdominal wall. The aim of this study is to include uncertainties of the material of various component of the abdominal wall in the numerical modelling.
Finite element model with realistic geometry of the abdominal wall imaging is constructed based on medical imaging. Nonlinear analysis of the abdominal wall imposed to the intraabdominal pressure is conducted. Non-intrusive polynomial chaos expansion method is used to construct meta-model and propagate uncertainties with relatively low computational cost. Sobol indices are calculated to study global sensitivity of the model output to uncertainty of considered material model parameters of the human abdominal components. The distribution of the quantities of interest will be shown together with ranking of random variables that contributed the most to the output variance.
Acknowledgments: This work was supported by the National Science Centre (Poland) (grant No. UMO-2017/27/B/ST8/02518). Calculations were carried out partially at the Academic Computer Centre in Gdansk.

*Speaker

Strain datasets of human abdominal wall and its clustering with self-organising maps

Mateusz Troka * [1], Katarzyna Szepietowska [1], Izabela Lubowiecka [1]

[1] Gdańsk University of Technology – Poland

Hernia is a pathological displacement of the contents of the body cavity through some of the layers of the abdominal wall (AW). The surgical procedure is conventionally done using an implant. Despite being operated, 30% of patients experience recurrences of this medical condition. Developing an implant mechanically compatible with the AW, may reduce number of recurrences. Thus, the knowledge of mechanical properties of AW is important. Having in mind that AW is non- homogeneous, the designing of implants is non-trivial. To address this problem our study aims to identify mechanically similar regions of human anterior AW.
To extract such an information we conducted *in vivo* experiment where information of mechanical behaviour of human AW under changing pressure load were acquired. 22 patients underwent peritoneal dialysis (PD), a medical procedure where a dialysis fluid is introduced into the abdominal cavity. During this procedure AW deformation data were gathered with the use of Digital Image Correlation (DIC) system. The introduction of dialysis fluid caused an increase of intraperitoneal pressure and deformation of the AW. DIC was able to register movements of pattern applied on the surface of human abdomen. Following measurements served for calculation of the fields of strains and displacements.

Then, we applied this data to an unsupervised machine learning model called Self-Organising Maps (SOM). This method of analysis of large datasets is able to identify and create clusters of experimental data based on their similarity. Therefore, it is providing first piece of information to recognise and classify regions of AW which may have similar mechanical performance under pressure load. After processing, the obtained experimental data was used as the input for SOM analysis. Input for SOM analysis were principal strains 1 calculated for the tested subjects on the basis of experimental data for all time steps of PD. In one example, 2048 time steps were needed to cover around 10 minutes of the experiment duration. Therefore, the input vector for SOM contained 2048 variables corresponding to all the time steps variables. Each variable is 493-dimensional vector corresponding to the grid points on the AW surface. SOM were able to reduce the dimensionality of such a multivariate dataset and visualise it for the further analysis.

The visualisation of results can be presented on U-matrix (unified distance matrix) maps, where clusters of data can be identified. Further analysis, consisted of reverse mapping of data points onto the surface of the abdomen of the patient, where clusters of data showed areas of similar mechanical behaviour under pressure.
Application of SOM in this study enabled simultaneous analysis of large range of deformation states of the whole AW surface during loading. This type of analysis provides more information than an observation of a single mechanical quantity in a single chosen moment of time. The

*Speaker

presented methodology may assist the designing of hernia implants in terms of its mechanical compatibility with specific regions of the human AW.

Guiding the end of the column loaded by the jet engine in aspect of instability type

Sebastian Uzny * [1], Krzysztof Sokół [1], Paweł Waryś [1]

[1] Czestochowa University of Technology – Poland

The paper presents a system of rigid transoms affecting the displacement of the loaded end of the column. Mutual rotation of the transoms was limited by a rotational spring with a linear characteristic. The column was loaded with a jet engine. The direction of the compressive force from the thrust of the jet engine was tangential to the loaded end. The kinetic stability criterion was used to determine the critical load. The boundary problem of free vibrations of the system was formulated on the basis of Hamilton's principle, taking into account Bernoulli Euler's theory. Based on the mathematical model, the critical load of the column was determined depending on the parameters of the system such as: the length of the transoms, the stiffness of the rotational springs limiting the mutual rotation of the transoms, the transnational inertia of the transom system and the rotational inertia of the transom system. In the work, as part of numerical calculations, characteristic curves were determined on the plane external load - natural frequency. The considered system is a hybrid one which, depending on the parameter values, may lose stability as a result of buckling or flutter. Areas of parameter values where the system is of the divergence or flutter type have been determined. At the limit values of parameters at which there is a change of instability type, the flutter critical force may be greater or smaller than the divergence critical force. The correctness of the mathematical model was confirmed by experimental research. Two types of experimental studies were carried out. The first consisted in recording the behavior of the system with a high-speed camera, in particular in the case of flutter type instability. The second type of research was aimed at verifying the model by determining the frequency of natural vibrations depending on the system load. In addition, the characteristic of the jet engine (rotational speed - thrust force relationship) was experimentally determined at the appropriate stand. There was also a discussion on the influence of the gyroscopic effect on the behavior of the system during experimental research.

*Speaker

Identification of material properties using physics-informed neural networks

Yi Wei * [1], Quentin Serra [1], Eric Florentin† [1]

[1] INSA CVL – INSA Centre Val de Loire, Laboratoire de Mécanique Gabriel Lamé – France

Identification of material model parameters using full-field measurement is a common process both in industry and research. Techniques such as digital image correlation allow greater flexibility and provide very rich experimental data when applied to tests conducted under heterogeneous conditions. Hence, effective inverse strategies are required to identify material parameters from the full-field measurements. The constitutive equation gap method (CEGM) is a very powerful strategy for developing dedicated inverse methods, but suffers from the difficulty of building the admissible stress field. In this work, we present a new technique based on physics-informed neural networks (PINNs) to implement a CEGM optimization process. The main interest is to easily construct the admissible stress thanks to automatic differentiation (AD) associated with PINNs. This new method combines the high quality of the CEGM with the numerical effectivity of the PINNs and realizes the identification of material properties in a more concise way. We compare the developed method with the classical identification strategies on simple two-dimensional (2D) cases and illustrate its effectiveness in three-dimensional (3D) problems, which is of interest when dealing with tomographic images. The results indicate that the proposed method has good performance while avoiding complex calculation procedures, showing its great potential for practical applications.

*Speaker

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Polynomial Chaos : basis, extensions and applications.

Yi Wei , Quentin Serra , Eric Florentin * [1]

[1] INSA CVL – INSA Centre Val de Loire, Laboratoire de Mécanique Gabriel Lamé – France

Polynomial Chaos : basis, extensions and applications.

Exploring the stochastic space is typically computationally expensive and represents the main challenge in stochastic approaches. Monte Carlo simulations are often regarded as a benchmark approach, involving the evaluation of system results across a large sample of realizations. While relatively easy to implement, a substantial number of realizations is required to achieve reliable outcomes. Different variants, such as Latin Hypercube sampling and quasi Monte Carlo, have been introduced to enhance convergence.

To address the computational cost associated with sampling methods, several methodologies based on spectral expansion have been developed. Perturbation methods rely on a Taylor series expansion around the mean value of parameters. However, they are limited to scenarios with small variations in the random field around its mean value and cannot be applied to non-smooth functions. On the other hand, the Polynomial Chaos expansion is a spectral method that seeks an approximation of the stochastic response within the space defined by a finite basis of orthonormal polynomials.

This presentation provides an introduction to Polynomial Chaos Expansion and demonstrates various results obtained using this tool to analyze the response of models affected by parametric uncertainties. The tool is known for its non-intrusive nature and user-friendly implementation. The presentation emphasizes the importance of both the quality and cost considerations associated with this tool.

*Speaker

Influence of honeycomb printing pattern density and thickness of cortical layer on mechanical response of proximal end of 3D printed femur

Krzysztof Zerdzicki * [1], Aleksander Znaczko *

2

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Additive manufacturing is willingly used to fabricate artificial bones used in biomechanical testing. In this work, the proximal end of the human femur was replicated by the fused-filament-fabrication (FFF) method using a Zortrax M300 Plus printer. Firstly, the geometry of the femur was prepared based on the CT scan of the artificial femur manufactured commercially by the SAWBONE producer. Then, for simplicity purposes and due to the limitation of the printer, the outer layer, corresponding to the femur cortical tissue, was assumed to be constant throughout the whole bone. Three levels of cortical layer thickness of full solid infill were assumed: 1.2 mm, 2.1 mm, and 3.0 mm. The inner part of the femur, corresponding to trabecular femur tissue, was mimicked by a pattern resembling honey plaster. Four different infill densities of the honeycomb pattern were selected: 10 %, 20%, 30 %, and 40%, resulting in various geometry of the inner part of the femur. The polylactic acid (PLA) material was used for printing, as it was proven before that in some ranges of density it approximates the human tissue properties quite well. All the printed types of artificial femur were tested in Zwick/Roell testing machine. For a start, the femurs were uniaxial compressed 10 times in the range 100N - 500 N in a cyclic load-unload manner. Next, the specimens were cyclically compressed with a loading increase of 100 N in each step up to 2000 N. Finally, the femurs were unloaded and compressed continuously till fracture. It was observed that both the thickness of the outer layer and the density of the honeycomb filling had a great impact on the stiffness, ultimate force, and fracture mechanism of the tested artificial femurs.

*Speaker

Flexible material with variable stiffness zone to reduce high-rate excitation

Dai Zhao *† [1], Bartlomiej Dyniewicz‡ [1], Czesław Bajer *

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The crucial significance of mechanical properties in practical applications has made it one of the most fundamental and extensively researched areas in materials science. Sudden impacts cause significant harm to lives and devices. Thus the development of crash-resistant devices plays an essential role in engineering applications such as aircraft, vessels, and automobiles. Hence the demand for the safety of structures against severe loading is increasing day by day as structure safety is generally associated with the materials used for construction.
In practical applications, materials that absorb impact energy using the phenomenon of plastic deformations are most often selected. The use of aluminum or steel enables achieving desired properties such as lightweight, strength, and the ability for controlled deformation, which is crucial for the effective absorption of kinetic energy in the case of impacts. During plastic deformation, the material experiences tensile, shear, compressive, or torsional stresses, depending on the type of loading conditions. Consequently, the kinetic energy is dissipated internally through mechanisms such as grain boundary sliding, dislocation motion, or fracture propagation within the material's microstructure. This energy absorption process mitigates accelerations and forces exerted on the structure, thereby minimizing the risk of injuries or structural damage.

In the work the elastic material properties change momentarily and locally under the high deformation rate due to the movement of a wavefront. The work contains mathematical formulation, semi-analytical results, numerical formulations, and simulation results demonstrating the effectiveness of modifying the rheological properties of the elastic material upon shock load or contact with a rigid obstacle. While the semi-analytical solutions can be obtained in a narrow time interval, numerical solutions allow us to track the process of wavefront reflections from edges. The effectiveness of reducing the physical quantities significant for impact in the presented examples reaches 30-70% of forces or accelerations, depending on the adopted criteria.
This research has been supported within the projects UMO-2017/26/E/ST8/ 00532 and UMO-2019/33/B/ST8/02686 funded by the Polish National Science Centre.

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Application of variational methods in analysis of contact problems including wear profiles and wear debris

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Classical differential and variational formulations used in contact problems are extended by including a gradual removal of material from contacting and rubbing solids due to abrasive wear, and by taking into account generation and circulation of loose wear debris detached from the rubbing surfaces. The wear debris create an intermediate layer which separates the contacting bodies and transmit loads and displacements. They affect friction and wear processes significantly.
Differential forms of governing equations for two contacting solids and the intermediate layer of wear debris are constructed from general balance laws: mass, momentum, moment of momentum, energy and entropy. The layer is considered as a two-dimensional continuum with own morphology, kinematics and constitutive models (micropolar thermoelastic layer). Two motion equations define displacements and micro-rotations in the layer. Additional terms in the governing equations of the layer define a mass of wear debris supplied to the layer during the course of abrasion.

For numerical solutions of contact problems with the aid of the finite element method one needs variational forms of governing equations (principles of stationary total potential energy, virtual work, and other). To fulfil the kinematic contact constraints are used: Lagrange multiplier method, penalty method, and their generalizations.
Variational descriptions of deformations of the wearing out bodies are presented with the aid of the principle of stationary total potential energy. The total potential energy is defined in deformed configurations of two contacting solids and the thin intermediate layer of wear debris. Furthermore, variational settings of the heat conduction (in the contacting bodies) and the mass continuity problem (in the layer) are discussed. Incremental formulations, iteration techniques and loading step-by-step are applied. We search such fields of displacements, temperatures and the mass intensity (in the layer) which guarantee the stationarity of the variational functionals at the given step of incremental approach and the iteration process. The stationarity condition of the total potential energy for any finite element leads to equations of displacements in the bodies and in the layer, and to equations of micro-rotations in the layer. Evolutions of boundary geometries of the wearing out solids (irreversible changes in bodies contours) are formulated as a sequence of problems solved for large number of loading and sliding processes. Updating process of the boundary geometry can be taken by repositioning of the boundary nodes or remeshing techniques. The variational formulations can be used in numerical analysis of bearings, prostheses of human joints and fretting processes in machinery.

*Speaker

Effect of composite shield deformation on blunt chest injuries from impact loading of 7.62×51mm FMJ Ball projectile

Bożena Zwarztko *† 1, Dariusz Pyka‡ 2, Adam Kurzawa§ 3, Mirosław Bocian¶ 2, Eryk Babej 2, Krzysztof Jamroziak‖ 4, Maksymilian Stepczak** 1

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In field conditions, the human body is repeatedly exposed to the possibility of gunshot hazards. It is estimated that the surface area of the human body exposed to gunfire is 0.5m2 and up to 40% of this surface area includes sensitive areas, including the thorax. The effect of a bullet hitting a person's thorax can be represented by the amount of kinetic energy acting on the body surface. When personal protection is used, the amount of absorbable kinetic energy increases, which also translates into the creation of deformations in personal protection, which leads to BABT(1-2). Increasing requirements for designed personal protection, are driving the need for innovative applications and implementation of new materials and ways to test them.In most modern research work, surrogate models such as dummies or animal surrogates are used to study the effects of kinetic energy on the body using both analytical and numerical-experimental methods (3).In the presented work, the authors studied the deformation of an artificial thorax formed from 7075 aluminum and a sternum bone under the deformation of a composite shield formed from Dyneema (UHMWPE) subjected to impact loading. Ballistics tests used 7.62×51 mm FMJ Ball projectile with an initial velocity of 830 ± 10m/s in accordance with CEN EN1522 to study the correlation of composite casing deformation with thorax deformation and to observe possible damage to thorax tissues. In addition, the developers conducted numerical analysis in the ABAQUS/Explicit environment using hybrid numerical methods based on the transition of the FEM method describing continuous structures to the SPH method describing structural discontinuities (4). The observed deformations were then compared with the effective kinetic energy absorption criteria created by other studies (5-7). The results obtained made it possible

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to determine whether the applied personal protection formed of Dyneema composite deforms adequately to be safe for surrogate made of 7075 aluminum and a sternum bone and meets the criteria for effective chest protection. REFRENCES

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Author Index

Conference program

Thuersday	Time	Event	Title
	8.30-9.30	Registration	
	9.30-10.00	Opening ceremony	
G1	10.00-10.45	Plenary lecture 1 Y. Wei, **Eric Florentin**	Polynomial chaos: basis, extensions and applications
	10.45-11.15	Coffee break	
S1	11.15-11.30	M. Drozdowska [et al.]	Structural damage detection considering uncertain modal data
	11.30-11.45	A. Zmitrowicz	Application of variational methods in analysis of contact problems including wear profiles and wear debris
	11.45-12.00	M. Roszak [et al.]	Comparison of failure criteria in non-Newtonian shear-thickening fluid in multi-layer ballistic composites – ballistic studies and numerical analysis
	12.00-12.15	D. Zhao [et al.]	Flexible material with variable stiffness zone to reduce high-rate excitation
	12.15-12.30	Y. Wei [et al.]	Identification of material properties using physics-informed neural networks
	12.30-14.30	Lunch	
G2	14.30-15.15	Plenary lecture 2 **Roger Sauer**	Modeling and simulating cellular membranes: Phases, flow and contact
P1	15.15-16.00	Poster session	*List of posters below*
	16.00 -16.45	Coffee break	
S2	16.45-17.00	P. Kłosowski [et al.]	Experimental and numerical analysis of wood logs corner joints
	17.00-17.15	K. Fiedurek [et al.]	Modelling the twin-screw extrusion process - a case study of a poly(lactic acid) biodegradable composite with flame retardant fillers
	17.15-17.30	M. Sofonea	Modelling, analysis and numerical simulation of a spring-rods system with unilateral constraints
	17.30-17.45	A. Ambroziak	Chemical, physical, and mechanical properties of old concrete – an example
	17.45-18.00	M. Troka [et al.]	Strain datasets of human abdominal wall and its clustering with self-organising maps
	19.00-22.00	Dinner	

Friday	Time	Event	Title
G3	9.00-9.45	Plenary lecture 3 **Stephane Abide**	Compact finite difference schemes, a higher-order discretisation for fluid flow simulation
G4	9.45-10.30	Plenary lecture 4 **Jerzy Małachowski** [et al.]	Energetically effective structures manufactured additively for crashworthiness - a review study
	10.30-11.00	Coffee break	
S3	11.00-11.15	B. Zwarztko [et al.]	Effect of composite shield deformation on blunt chest injuries from impact loading of 7.62×51mm FMJ Ball projectile
	11.15-11.30	D. Kaczor [et al.]	Polymer composites based on polylactide with carbon filler - production and properties
	11.30-11.45	F. Bonaldi [et al.]	Two-phase flows in deformable porous media with frictional contact at matrix – fracture interfaces
	11.45-12.00	F. Jan [et al.]	Application of machine learning in failure mechanics problems
	12.00-12.15	K. Szepietowska [et al.]	Uncertainty quantification for human abdominal wall mechanics
	12.15-12.30	Closing ceremony	
	12.30-14.00	Lunch	
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1	D. Cekus [et al.]	Application of the design study to search for the optimal bell shape
2	P. Cyprys [et al.]	Implementation of a model to simulate plastic flow through a spiral mandrel by Chris Rauwendaal and its verification for thickness uniformity of the extruded blown film
3	J. Garus [et al.]	Dynamic stability of damped elements modeled with Bernoulli-Euler beams
4	S. Garus	Mechanical wave propagation in dynamic phononic structures
5	C. Han [et al.]	Numerical method to propagate uncertainties on parameters with non integer order PDE
6	S. Kalinowski [et al.]	Surgical implant for repairing hernia optimized for human torso movements
7	M. Krajewski	Analysis of the rotational stiffness of connections between selected steel profiles
8	A. Krolik [et al.]	Defects detection in the flat polyethylene and polyamide boards using air-borne ultrsound
9	K. Sokół [et al.]	Self leveling terrain rover with an active Rocker – Bogie suspension
10	S. Uzny [et al.]	Guiding the end of the column loaded by the jet engine in aspect of instability
11	K. Zerdzicki [et al.]	Influence of honeycomb printing pattern density and thickness of cortical layer on mechanical response of proximal end of 3D printed femur

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