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NON-STATIONARY PROBABILISTIC SOLUTION OF THE NONLINEAR OSCILLATOR WITH VARIOUS NONLINEARITY UNDER EXTERNAL MODULATED GAUSSIAN WHITE NOISE

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Abstract

In this paper, an improved procedure is presented to acquire the non-stationary response of the stochastic oscillator with various nonlinearity subjected to external stimulation being modulated Gaussian white noise based on the conception of the exponential-polynomial-closure (EPC) approach. Here, an exponential polynomial function with time-varying unknown parameters is adopted as the evolutionary joint probability density function (PDF) of oscillator response. Integrating the residual error with a class of weight functions being independent evolutionary base functions spanning a RN space can generate N ordinary differential equations. The unknown parameters in the polynomial can be valued by solving those ordinary differential equations numerically. The evolutionary PDF of the oscillator can be acquired by utilizing the presented procedure effectively and efficiently contrast with Monte Carlo simulation (MCS), particularly in the tails of the evolutionary PDF solution which plays a vital role in reliability analysis. Moreover, the numerical example indicates that the non-stationary PDF solution of the oscillators can be asymmetric at their nonzero means when there is even nonlinear terms. The evolutionary response performance of the oscillator is also analyzed along with the performance of modulated Gaussian white noise.

Keywords: Non-stationary, stochastic, probabilistic solution, modulation, Gaussian white noise.

BRIDGING THE GAP BETWEEN COMPUTATIONAL AND EXPERIMENTAL 3D CELL FORCE CALCULATION

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Abstract

The forces that cells exert on the extracellular matrix (ECM) play a critical role in many physiological processes, including tissue development, wound healing, and disease progression. Traction Force Microscopy (TFM) is a well-established methodology for estimating these cell-ECM forces, but it requires complex computational and experimental techniques. Our recent work covers a thorough methodological validation of all the techniques that are necessary to quantify cell forces in 3D in vitro models. Specifically, we developed a novel inverse method to calculate cell tractions from measured ECM displacements, integrated it into an open-source and user-friendly software (TFMLAB), and validated it with experiments using a 3-dimensional in vitro model of sprouting angiogenesis. Our validation results demonstrated that our technique accurately quantifies cell-ECM forces in 3D. Additionally, we provided a web-based data analysis tool (integrated within the SGABU platform) for additional data processing. Our work represents an important step forward in accurately and comprehensively quantifying cell-ECM forces in 3D, which has important implications for understanding and treating various physiological and pathological conditions.

Keywords: traction force microscopy, image analysis, cell mechanics, angiogenesis.

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FRAGMENTATION OF DROPLETS OF COAL-WATER SLURRIES CONTAINING PETROCHEMICALS UNDER DIFFERENT HEATING METHODS

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Abstract

Composite liquid fuels have a relatively high viscosity. This complicates their atomization in the power plants burning this type of fuel. Micro-explosion of composite fuel droplets holds great promise as a method of their secondary atomization. However, the necessary and sufficient conditions for these processes depend heavily on the component composition of the fuels. In this research, we studied the conditions and outcomes of micro-explosive breakup of fuel droplets with very different compositions. The ready-made vaporization centers in droplets in the form of solid particles or bubbles of air, gases, and vapors were found to be the most important factor. The droplet lifetimes and breakup delays were also determined, accounting for the impact of component composition on the droplet heating dynamics. Finally, we obtained approximations in the form of critical bubble size as a function of the ambient gas temperature for two-liquid droplets containing the dispersed phase of different quality.

Keywords: two-liquid droplets, slurries, coal-water fuels, micro-explosive breakup, bubbles, solid particles.

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EFFECTIVE DIFFUSION PROPERTIES OF CALCIFIED HYDROGELS OBTAINED BY THE ASYMPTOTIC HOMOGENISATION

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Abstract

While hydrogels can be tuned to have favourable mechanical properties (e.g. strength and toughness) when dry, in most cases these qualities are lost when the hydrogel is swollen with water. To date much work has been done to coat the hydrogels or to develop hydrophobic gels and protect them from water but the recent development of calcified hydrogels by enzymatic mineralisation of calcium into the gels has achieved impressive mechanical properties [1] approaching those of biological tissues such as skin and cartilage. These relatively new materials have a heterogeneous structure and show complex diffusion behaviour. In order to study this application-relevant property of hydrogels, the present contribution uses the homogenisation method based on a two-scale asymptotic expansion. The chosen procedure yields a homogenised diffusion tensor in terms of the volume average of its original counterpart and of solutions of auxiliary problems for unit perturbations and periodic boundary conditions. The latter are solved by using the finite element method and software library deal.II. The contribution particularly focuses on two types of microstructures. In the first case, amorphous calcium phosphate aggregates in semi-porous spheres throughout the hydrogel matrix, and in the second case the calcium forms a double inorganic-organic network. Accordingly, the representative volume elements (RVE) differ: The RVE of the first material type includes spherical, nearly impermeable obstacles that are randomly distributed over the matrix material with a higher diffusivity. The situation is opposite concerning double-network hydrogels. Here, the matrix material is impermeable, whereas, the interconnectivity of pores is decisive for the effective diffusivity of the whole composite. The presentation compares the effective diffusivities of different materials for different size of diffusing macromolecules (proteins) as the final result.

APPROACHES TO REAL-TIME FE-BASED SIMULATIONS

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Abstract

Owing to rapid development of numerical methods and hardware components, the field of structural analysis has made tremendous progress over the previous few decades. A necessary prerequisite for successful structural analysis is the reliability and accuracy of the methods used in structural computations. Beside those classical demands, a variety of applications set new ones. Possibility of preparing high fidelity, i.e. detailed models combined with high efficiency of computations based on such models belong to the standard meanwhile. The finite element method has imposed itself as a method of choice in the field of numerical structural analysis. Novel application fields of the method, such as surgery and other types of simulators, call for interactive, real-time computations. In addition, realistic simulations involving finite displacements demand the coverage of geometric and, in some cases, material nonlinearities, contact, etc. This paper gives an overview of developments done at the Institute of Mechanics, TU Berlin. The approaches range from model order reduction techniques and up to full fidelity FE models based on a co-rotational approach to cover geometric nonlinearities. Furthermore, a coupled mesh technique is presented that couples a complex geometrical model with a not too expensive FE model. Several interactive, real-time simulations illustrate the developed techniques.

MODEL-FREE DATA-DRIVEN SIMULATION OF INELASTIC MATERIALS USING STRUCTURED DATA SETS, TANGENT SPACE INFORMATION AND TRANSITION RULES

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Abstract

Model-free data-driven computational mechanics replace constitutive phenomenological functions with numerical simulations based on data sets of representative samples in stress-strain space. The method is based on the nearest neighbours approach. Precisely, in continuum mechanics, the optimization problem consists of computing the nearest point in the data set consistent with the compatibility and equilibrium condition of the problem. Thus, the data-driven scheme bypasses the empirical material modelling step providing an alternative formulation of the classical boundary-value problem. Although this method operates well for non-linear elastic problems, there are challenges dealing with history-dependent materials since the same point in stress-strain space might correspond to different material behaviour. Our recent research and publication focused on analysing non-linear elasticity and elasto-plasticity with isotropic hardening, utilizing a data-driven paradigm augmented by tangent space and transition rules based on structured data. To simulate plasticity, we augment the tangent space directly into the distance minimizing data-driven formulation and classify the underlying data structure into subsets corresponding to different material behaviours. We achieve the optimal material states through a fixed-point iteration. Incorporating tangent space results in a significantly more concise set of equations and allows for interpolation in regions with sparse data sampling, ensuring that the internal states are consistent with the data set. The classification of data subsets enables dealing with loading paths deriving from inelasticity, thereby eliminating the need to rely on models to evolve historical variables. We define transition rules to map the system's internal states to the different subsets. Consequently, the extended data-driven paradigm evaluates the closest point in the subset of transitioned material data consistent with the problem's field equations and also closest to the local tangential direction.

A NEW METHOD FOR SOLVING PLANE STRAIN PROBLEMS FOR THE GENERALIZED LINEAR YIELD CRITERION

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Abstract

The system of equations comprising the generalized yield criterion and the stress equilibrium equations under plane strain conditions form a statically determinate system. The properties of this system are consequently independent of any flow rule that may be chosen to calculate the deformation and also independent of whether elastic strains are included. The system of equations under consideration is hyperbolic for many yield criteria. It is, therefore, natural to solve it using the method of characteristics. In the classical pressure-independent metal plasticity, Mikhlin's variables are widely used for finding the orthogonal net of characteristics and the stress field. The characteristic directions of the system of equations comprising the generalized yield criterion and the stress equilibrium equations are not orthogonal. The angle between these directions depends on the yield criterion. In the present paper, Mikhlin's variables are generalized on such a non-orthogonal net of characteristics. It is shown that the generalized Mikhlin variables can be found utilizing solutions of the telegraph equation. The latter can be solved by the method of Riemann. In particular, the Green function is the Bessel function of zero order. Then, the net of characteristics is built up by means of evaluating ordinary integrals. Calculating the stress field having the net of characteristics found is straightforward. An example for calculating the stress field near an arbitrary traction-free surface is provided.

FLUID VELOCITY SLIP ON A SOLID SURFACE

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Abstract

Despite a long history of research on slip boundary conditions, most existing theoretical models of gas-solid and liquid-solid interfaces fail to provide satisfactory predictions of experimental results. Discontinuities in transport quantities at a fluid-solid interface are pronounced in micro- and nanoscale transport phenomena, but poor understanding of the actual mechanisms limits the proper use of boundary conditions. Even more puzzling is the perplexing influence of several influential factors found in the experiments. Given the uncertainties, theoretical work grounded on the fundamental behavior of fluid-solid interactions is crucial to elucidate the physics behind this phenomenon. In this paper, a new analytical model for fluid slip on solid surfaces is developed. Aspects of surface science theory are incorporated into the description of dynamical intermolecular interactions at interfaces. The novel ideas in the proposed model include the establishment of an adsorption framework for fluid-solid interactions for deriving boundary discontinuities, and the validity of the model for both gas-solid and liquid-solid interfaces. Furthermore, the new boundary conditions provide viable explanations for hitherto unobserved phenomena. In this paper, it is shown that the slip velocity in both gas and liquid originates from the dynamical adsorption process at the interface. Based on the theory of surface science, a unified analytical model valid for both gas-solid and liquid-solid slip boundary conditions is proposed. Corroboration with experimental data extracted from the literature shows that the proposed model outperforms existing analytical models. Overall, the good agreement between the newly developed model and literature data suggests that the slip at the fluid-solid interface may be attributed to the adsorption process.

Keywords: slip, fluid, surface, boundary condition, adsorption, dissipation.

DEVELOPING A MICROSTRUCTURE-SENSITIVE MACHINE LEARNING YIELD FUNCTION AND STRAIN HARDENING MODEL

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Abstract

Machine learning (ML) algorithms can provide an effective way for modeling complex material behavior, including plasticity. With their ability to analyze vast amounts of data and identify patterns, these advanced computational techniques can capture relationships between microstructure and mechanical properties and enable an accurate, yet flexible description of material behavior. The importance of high-quality training data in machine learning cannot be overstated, as it directly impacts the performance and reliability of the resulting models. Therefore, finding an optimal data generation strategy for the training of ML yield functions and strain hardening models is essential to ensure their accuracy and reliability. Our work revealed that Support Vector Machines (SVM) can be used as machine learning yield functions and can be successfully trained for materials with significant plastic anisotropy, like polycrystals with a Goss texture, using only 300 data points. The training data was carefully selected to cover a wide range of loading conditions in full 6-dimensional space. The accuracy and reliability of the trained ML yield functions were assessed using a variety of statistical measures, including mean squared error and confusion matrix. As the next step, the optimal training data strategy was employed for generating training data using micromechanical modeling. This allowed for further consideration of microstructural parameters like crystallographic texture or grain size in the input data for the training of the ML yield function. Moreover, these data also contain information of the strain hardening behavior of the material. A database containing simulation data and metadata was developed, making it easier to train and refine the ML model. From this database, a proper data-oriented formulation for strain hardening was developed, which complements the previously established yield function. This study demonstrated the potential of ML algorithms as powerful tools for modeling complex material behavior. The careful selection and generation of training data, as well as the inclusion of microstructural parameters and work hardening effects, were crucial for achieving reliable and accurate ML yield functions and strain hardening models.

Keywords: machine learning yield function, plasticity, micromechanical modeling, strain hardening.

MATERIAL MODEL OF REINFORCED CONCRETE STRENGTHENED WITH FRP

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Abstract

The application of shear walls as a primary earthquake resistant mechanism in structural design is traditionally accepted and used over the last decades. However, very often, older structures having shear walls no longer comply with the contemporary standards and codes which raise the need for their strengthening and retrofit. Many different methods of seismic strengthening and repair of shear wall structures have been developed and tested in the last thirty years. Recently, state-of-the-art strengthening and retrofit techniques increasingly utilize externally bonded fiber reinforced polymer (FRP) composites, which offer unique properties in terms of strength, lightness, chemical resistance, and ease of application. Such techniques are most attractive for their fast execution and low labor costs.
Only recently have researchers attempted to simulate the behavior of reinforced concrete strengthened with FRP composites using the finite element method. Most of the studies that included numerical modeling of FRP strengthened RC members with FEM use element overlaying, where solid or layered that represent the FRP material are superimposed over the concrete elements, either with or without interface elements that represent the influence of the adhesive material or the bond between the FRP and the concrete.
This paper presents and attempt to formulate a new material model capable of simulating the behavior of biaxially loaded reinforced concrete in plane stress state, strengthened with FRP. The proposed model is implemented into ANSYS as a user material model to test its results against the available experimental data. Based on the presented results, it can be concluded that the proposed model is able to correctly simulate the behavior of the RC members strengthened with FRP in different configurations. Its ANSYS implementation enables its use in both research and practical purposes, facilitating further research in this field as well as the practical applications in the construction industry.

Keywords: material modeling, FRP, reinforced concrete, FEM.

NUMERICAL ANALYSIS OF AN INNOVATIVE ENERGY DISSIPATION DEVICE

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Abstract

Application of systems for passive vibration control is an efficient way for seismic protection of structures. Systems for passive vibration control consist of seismic isolation devices and energy dissipation devices. Base isolation of structures is a concept where devices for passive vibration control are placed in foundations of buildings. Various energy dissipation devices have been developed and tested so far, and metallic dampers represent a significant class. Those devices dissipate energy through the yield of metal material which they are made of. The metallic dampers have often been used because of their main advantages reflected in stable hysteretic behavior and well-known models for analytical prediction of the dissipated energy and structural response. Most of the metallic dampers have been developed for application in the beam-column joints or in the bracing system. The innovative energy dissipation device named multi-gap multi-level multidirectional seismic energy absorber, intended for the application in the horizontal seismic dilatation in the system of base isolation, has been developed recently by one of the authors of this paper. The main parts of the absorber are vertical components with linearly changeable circular cross-section. Due to the lateral displacements of the isolated structure the vertical components bend and yield of steel material occurs which provides energy dissipation. According to the previous experimental and numerical study of the absorber's vertical components, three-dimensional finite element model of the absorber has been developed and presented in this paper. The aim of the numerical analysis is to determine mechanical properties of the absorber based on the lateral force-displacement diagram. Furthermore, a simplified numerical model using one-dimensional beam finite elements has been proposed. The performance of the absorber has been determined using the available semi-analytical solution for elastoplastic deflection of non-prismatic cantilever beams as well. The obtained results have been compared and it has been concluded that all three analyzing methods provide reliable mechanical properties of the absorber necessary for dynamic analysis of structures in engineering practice.

Keywords: metallic damper, finite element method, elastoplastic bending, lateral force-displacement relationship

AUTOMATING CONSTITUTIVE MODELING BY MACHINE LEARNING: A LIGHTWEIGHT ML APPROACH FOR CYCLIC PLASTICITY

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Abstract

Machine Learning (ML) methods are more and more involved in material modeling with the goal to replace analytical constitutive models by machine-learned relationships. Apart from the possible simplification of existing approaches, the application of ML is motivated by the increasing automatization of material characterization. The present talk particularly focuses on modeling of cyclic plasticity which is crucial for an accurate fatigue analysis.
The model proposed assumes von Mises flow rule and the associated plasticity framework as a basis. Moreover, it uses pseudo-experimental data and lightweight Feed Forward Neural Networks to completely replace assumptions on the mixed kinematic and isotropic hardening. The approach is strongly motivated by the fact that the existing analytical assumptions even with the introduction of several internal hardening parameters are only partially able to represent the complex stress-strain dependency typical of realistic cyclic behavior.
The numerical investigations performed with different network architectures indicate that a direct training of a six-dimensional stress tensor is not feasible and show that the reduction of the problem complexity is key for a successful training and a low generalization error. This has been achieved by learning the plastic multiplier and the evolution of backstresses. The training data set is generated by random walks constructed by Gaussian Processes. An optimal lightweight architecture is determined by systematically varying the number of hidden layers, neurons and activation functions. In terms of computational effort necessary for training and prediction, the final configuration has shown a significant improvement compared to the alternative approaches based on the application of Recurrent Neural Networks. The validation of the model has been performed on the example of dual-phase steels.

Keywords: Machine learning, cyclic behavior, plasticity, constitutive model, mixed hardening.

TUNABLE RESONANT METAMATERIAL FOR LOW-FREQUENCY VIBRO-ACOUSTIC INSULATION

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Abstract

Vibro-acoustic metamaterials are artificial periodic structures with unique wave manipulation properties, owing to the dynamic influence of their local resonant units. The main characteristic of the resonant metamaterials is their ability of creating stop bands (band gaps) - that is frequency range in which free propagation of waves is not permitted. These stop bands can be easily detected in the dispersion diagrams of the metamaterial. Finite element method (FEM) is employed for calculation of the dispersion diagrams of the infinite metamaterial. Based on the Bloch-Floquet boundary conditions, only one unit cell is required for FEM modeling.
A decorated plate with periodic arrays of resonators is proposed for low frequency application (<150 Hz). By tunning the dynamic behavior of the resonant units, a favorable interaction between resonators and bending waves in host plate is possible, resulting in band gap creation. For the proposed decorated plate with finite dimensions, the frequency response under harmonic excitation is calculated and also the sound transmission loss under oblique and diffuse sound field. The semi-infinite air domain in the coupled vibro-acoustic FEM model is simulated using perfectly matched layers (PML). The proposed metamaterial plate can be used for vibration reduction but also for sound insulation in a specific frequency region.

Keywords: band gap, periodic resonators, metamaterial, low-frequency, sound insulation, vibration reduction, FEM.

EFFECT OF A KERR-TYPE COMPLEX MODIFIED ELASTIC FOUNDATION ON THE STOCHASTIC STABILITY OF BEAMS

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Abstract

The moment and almost-sure stochastic stability of the Timoshenko beam resting on the elastic foundation under parametric excitation of white noise are investigated through moment Lyapunov exponents and Lyapunov exponents. The foundation medium is visualized as modified Kerr-type elastic layer, which consists of, three layers of springs, with mutually different stiffness moduli, and two intermediate shear layers. The method of regular perturbation is used to determine the explicit expansions of the moment Lyapunov exponent and the Lyapunov exponent. Moment Lyapunov exponent and the Lyapunov exponent are important for determining stability of a stochastic dynamical system. Analytical results are presented for the almost sure and moment stability of a stochastic dynamical system. Finally, the effects of the damping coefficient, stiffness of the layers and the intensity of the random process on the stochastic stability of systems are considered and graphically displayed for chosen set system parameters.

Keywords: Stochastic stability, modified elastic layer, moment Lyapunov exponents, Lyapunov exponents.

STOCHASTIC MODELLING OF TENSOR FIELDS ADAPTED TO ELASTICITY CLASSES

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Abstract

Uncertain material properties are often described in probabilistic terms. And although the properties of the material may be uncertain, some relations may not be uncertain at all. One possible kind of such a relation are spatial symmetries and invariances of the material. It is well known that such symmetries and invariances play an important role in the behaviour of materials, and thus one should try to respect this in the probabilistic description and modelling of material properties. The focus is here on material properties described by the class of physically symmetric fourth order tensors, of which the elasticity tensor is a prime example. We shall concentrate on spatial point symmetries or invariances under rotations, a classical subject in deterministic elasticity, a topic which has already attracted considerable attention, e.g. [5], and offer a sketch how this can be connected to stochastic geometric symmetries or invariances in the modelling of spatial tensor fields. The culmination of a long series of works on such representations of tensors of any order in the presence of spatial symmetries or invariances is given in [7], but the additional property of physical symmetry implies a possible spectral theory and decomposition to separate scale or strength from orientation, and this will be the topic here.

The characterisation of elasticity tensors through their spectral decomposition, i.e. eigenvalues, is is an old subject, already started by Lord Kelvin (W.K. Thomson) [13, 14], but little appreciated at the time and then apparently almost forgotten, to be picked up again by [3], and later, among others, by [9, 8, 11]. A historical account in modern notation may be found in [6].

An approach on the basis of the spectral decomposition was used in [10] to model random second order symmetric tensors fields. As for second order symmetric tensors there are only three classes in 3D and two classes in 2D, this is quickly reviewed to easily explain the concepts.

The elasticity tensor is not only a physically symmetric tensor, but each realization usually has to be positive definite. Looking at random ensembles resp. probability distributions on such tensors, one wants to preserve those properties. This is achieved by constructing a mapping from a product Lie group to the positive tensors. The corresponding Lie algebra is then a direct sum of vector spaces, and the appropriate exponential map, which is easily computed in this case, guarantees positive definiteness. Additionally often one wants to prescribe certain classes of spatial symmetries and invariances for each member of the whole ensemble, while at the same time demanding that the mean or expected value of the ensemble be subject to a possibly ‘higher’ spatial invariance class.

In formulating a modelling framework which respects these requirements, one has to explore the mathematical structure of the underlying sample space of all such tensors, in the course of which it appears expedient to introduce a new distance measures or metric between such tensors. It is

shown how the proposed framework allows the random ensemble to be modelled and generated, independently in its scaling and orientational or directional aspects.
To achieve this modelling we collect for the fourth-order elasticity tensor for all eight elastic symmetry classes [4] in 3D and for the four symmetry classes [1] in 2D the invariant subspaces with appropriate Kelvin eigenvector basis and the corresponding eigen value the Kelvin stiffnesses or Kelvin elastic moduli [13, 14, 6] are introduced. In a slight deviation [8] from the traditional Voigt notation, e.g. [12], the fourth order elasticity tensor is mapped onto a 6-dimensional tensor of second order, the Kelvin notation, which will then be used for the representation. In this 6-dimensional strain-stress space one might distinguish the rotations induced by true spatial rotations from others, which are strain redistributions. The rotations induced by spatial rotations allow the well-known group theoretic reduction, e.g. [2], to the well known zero-non zero patterns resp. block diagonal forms which characterise the different elasticity classes in 2D and 3D, e.g. [1, 4]. Rotations in the 6-dimensional strain-stress space which only redistribute strains can then be used to achieve a complete diagonalisation.
On this basis a method to generate random elasticity tensors is described. The tensor is in this way modelled by one spatial vector which describes a spatial orientation through its direction and magnitude leading to a reduction of the symmetry group representation and the well-known reduced forms of the tensor-tuples of parameters to describe the logarithms of the eigenvalues resp. Kelvin moduli, plus tuples of parameters to describe the ‘strain distributors’, which furnish an orthogonal transformation in strain space to completely diagonalise the tensor from its reduced form.

ENSEMBLE MACHINE LEARNING AS AN APPROACH FOR IMPROVEMENT OF CLASSIFICATION ON VERY SMALL DATASETS

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Abstract

Machine learning is a branch of artificial intelligence most commonly used for solving problems related to classification and regression analysis through the use of supervised learning approaches. Machine learning models require high quality and a sufficient quantity of data to produce good results. This paper investigates an approach which incorporates ensemble learning to increase prediction capabilities in cases in which a very limited amount of data is available for training. The ensemble model was trained on a patient fractional flow reserve biomarker dataset and had a goal of classifying patients into risk classes based on their risk of suffering an acute myocardial infarction. The ensemble model was built by aggregating multiple random forest classification models which were trained with different combinations of training and test data to improve the prediction accuracy over the use of a single random forest model. Final ensemble achieved a prediction accuracy of approximately 71.3% which was an immense improvement over the 36% prediction accuracy of a single random forest classification model.

Keywords: machine learning, classification, risk assessment, random forest, ensemble.

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FILTER-BASED IMAGE PROCESSING OF CORONARY ANGIOGRAPHY IMAGING DATA OF THE LEFT CORONARY ARTERY

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Abstract

Ischemic heart disease (IHS) is the most common type of heart disease in the world and is characterized by plaque buildup in the walls of the arteries that supply blood to the heart (called coronary arteries). In clinical practice X-ray coronary angiography is dominant imaging diagnostic procedure, even though it produces lower quality images due to high noise, imaging artifacts, vessel overlap, etc. In this work, we propose an X-ray coronary angiography image processing methodology that combines different filters in order to improve quality of images and separate blood vessels of left coronary artery from the background. In order to suppress the noise in the image and enhance edges of the left coronary artery, angiography image is processed with CLAHE, the Wiener filter and gamma correction. Image processed in this manner is then segmented using global Otsu's thresholding technique, that binarizes the image into the region of interest (left coronary artery) and background. Otsu's thresholding successfully separated blood vessel, but also it wrongly labeled some of the background as blood vessel. These non-vessel areas have been removed using connected components analysis.

Keywords: image processing filters, left coronary artery, x-ray coronary angiography.

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SENSITIVITY OF TENSION TRANSIENTS ON THIN AND THICK FILAMENT REGULATION BY CALCIUM

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Abstract

Physiological twitch contractions in cardiac muscles are regulated by intracellular calcium transients ($[Ca^{2+}]$). The level of resting tension is low at low $[Ca^{2+}]$ and tension relaxation is accelerated after peak tension is reached and calcium levels fall to low values. To achieve the observed transient tensions, it was necessary to incorporate both thin and thick filament regulation by $[Ca^{2+}]$ into multiscale software package MUSICO. Simulations performed using MUSICO successfully matched twitch transient and force-pCa experiments [1, 2]. Simulations proved that both mechanisms are necessary for achieving the observed tensions, but their individual contributions can only be quantitatively evaluated through specifically designed experiments. In the absence of such experiments, the contribution of these mechanisms can be assessed by evaluating the calcium sensitivity of thin and thick filament activation. We have demonstrated that reducing the sensitivity of opening thin filament regulatory units (RU) to $[Ca^{2+}]$ requires adjustments in rates of transitions to and from parked state, which are the key parameters in formulating thick filament regulation.

Keywords: calcium regulation, thin and thick filament, tension transients, cardiac muscle.

Acknowledgement: Research was funded by Serbian Ministry of Science, Technological Development and Innovation through Agreement No. 451-03-47/2023-01/200378.

COMPUTATIONAL MODELING OF NEOVASCULARIZED IMPLANTABLE CELL HOMING AND ENCAPSULATION (NICHE) DEVICE

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Abstract

Conventional drug delivery systems (tablets, capsules, syrups, ointments, etc.) suffer from poor bioavailability and fluctuations in plasma drug level and are unable to achieve sustained release [1]. Inadequate drug delivery mechanism can affect whole drug delivery process and seriously reduce therapy success. Hence, significant interest is constantly present regarding development and engineering of *in-vivo* microenvironments, with ultimate goal to make advancement in delivering cell therapeutics, local immune modulation and cell transplantation. Different characteristics of the microenvironment (such as vascularization, tissue remodeling, immune cell infiltration) can be tuned to provide immune modulation and regulate oxygenation. So far, multiple platforms employed aforementioned strategies. For example, NanoLymph is an implantable device [2] that releases chemo attractant in a reservoir loaded with tumor antigen to create a microenvironment capable of attracting immune cells and to prime them to recognize and attack the tumor. Considering the novelty of the field and required *in-vitro* and *in-vivo* testing, there is appreciably lack of available studies which leads to consequential need for developing computational *in-silico* models as predictive tools to support these types of biomedical devices. Our research group developed an implantable device for local immunomodulation named Neovascularized Implantable Cell Homing and Encapsulation (NICHE), which consists from drug reservoir from which drug diffuses to the tissue space, through the permeable holes. This paper presents a developed computational model of a subcutaneous microenvironment, generated using 3D composite smeared finite elements, recently introduced in [3]. The model describes vascularization and tissue composition and is potentially capable of estimating oxygenation and drug distribution in the microenvironment, with satisfactory accuracy between experimental and computational results.

Keywords: computational models, immunomodulation, drug delivery, composite smeared finite element

COMPUTATIONAL PLATFORM FOR IN-SILICO INVESTIGATION AND OPTMIZATION OF DRUG-ELUTING BIORESORBABLE STENTS

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Abstract

Different stents made by manufacturers must meet various criteria defined by ISO standard. In-silico investigation can help in optimization and validation of prototype stent designs, and further can reduce costs and time for stent production. The InSilc platform, developed during the imeplementation of the EU project, can be used for computational analysis of standards test that has to be performed for any new stent prototype: Radial compression, Inflation, Three-point pending, Two-plates crush resistance, Longitudinal tensile strength, Local Compression, Kinking, and Flex 1-3. The InSilc platform is based on finite element program PAK and 3D graphical interphace software CAD for modeling and visualisation. The inSilc platform is further used for comparing the material charachteristics of two different stent designs (AB-BVS vs. AB-BVS-thinner, and PLLA-prot vs. PLLA-plot-slot). Using the platform, we tested these two different designs and presented the results of the comparison. The obtained results show that this platform has the potential to be used in the future for the validation and optimization of stent prototypes, but additional assumptions and analyzes must be included to make the software reliable for official use.

Keywords: bioresorbable PLLA stent, finite element analysis, in-vitro mechanical test, inSilc platform.

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DATA-DRIVEN DUCTILE DAMAGE MODEL WITH MICROSCALE-RELATED DAMAGE EVOLUTION

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Abstract

A data-driven model has been utilized to predict the evolution of ductile damage in dual-phase steel. The model is trained on experimental void area fractions, which are obtained by scanning electron microscopy. Thus, unlike conventional damage models, the damage evolution can be directly related to quantities on the microscale, i.e. void area fractions. The model is capable of predicting the void area fractions in various tensile and bending tests, enabling determination of the relationship between porosity, as expressed by void area fractions, and material softening through coupling the damage evolution to the mechanical properties. This coupling is achieved by incorporating the damage evolution into an elastoplastic material model using the homogenization approach of effective stresses. The model parameters that describe the plasticity as well as the damage coupling are identified through inverse parameter identification. Ultimately, the proposed model predicts both the void area fractions and the corresponding material properties, as demonstrated by load-displacement curves in various tensile tests.

VIBRATIONAL ANALYSIS OF PORCINE TEMPORAL BONE

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Abstract
Temporal bone provides the protection of the inner ear structures and it also contains openings and canals that allow for sound to pass through on the way to the inner ear. The aim of the study was to obtain the vibrational modes of the porcine temporal bone. The modal frequencies and mode shapes can provide important information regarding the transmission of sound. The analysis was performed on the realistic model of porcine temporal bone developed from micro CT images. The model included both cortical and trabecular segments of the bone. Material properties and mass densities were taken from the available literature. The modal analysis was performed for two combinations of the material properties in order to understand how the modal frequencies will be affected. The natural frequencies for the first ten modes were determined, and the results showed that the change in the values of trabecular bone elasticity had a significant effect on the frequency values.

Keywords: modal analysis, natural frequencies, porcine temporal bone.

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A MULTISCALE-MULTIPHYSICS MODEL FOR LUNG MECHANICS, AIRFLOW AND MOLECULAR TRANSPORT

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Abstract

Lung diseases are one of the leading causes of death worldwide. Many unknowns still exist regarding the breathing process and these mysteries have to be solved in the days to come. The lack of measurement methods or recording techniques leads to an insufficient knowledge of the processes in the lungs, but with the application of computer models new perspectives are opened. Many computer models, with varying degrees of simplification and sophistication, have been introduced to simulate this phenomenon, but a sufficiently accurate and precise model that can have real clinical use in the future has not yet been developed. In this paper we present unprecedented comprehensive computational models of the respiratory system: a 3D multiscale-multiphysics composite finite element (FE) model that includes mechanics of lung tissue coupled with the airflow and the molecular transport. By applying such a model, it is possible to carry out numerical simulation of various lung abnormalities and diseases, including acute lung injury, acute respiratory distress syndrome, or lung cancer.

Keywords: lung mechanics, airflow, molecular transport, computational modeling, finite element analysis, multiscle composite finite element, Kojic Transport Model.

OPTIMIZATION-ORIENTED EPC: A NEW APPROACH FOR INVESTIGATING THE PDF SOLUTION TO NONLINEAR RANDOM OSCILLATOR

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Abstract

In this article, a novel approach named the optimization-oriented exponential-polynomial-closure (OEPC) is proposed to solve the reduced Fokker-Planck-Kolmogorov (FPK) equation which governs the probability density function (PDF) of the nonlinear stochastic oscillator. The idea is to replace the projection procedure in conventional EPC method by an optimization procedure in eliminating the residue of FPK equation in Rn space [1-4].
To study the stochastic oscillator subjected to Gaussian white noise, an exponential function of a 6th-order polynomial is used as the approximate solution to formulate the objective function from the residual error of FPK. By introducing a weight function being the solution from equivalent linearization (EQL), the objective function of the optimization procedure is established to minimize the cumulative residual error square. With the gradient-based method, the minimal value of the objective function can be found and the values of the undetermined parameters in the 6th order exponential-polynomial function can be determined.
The PDF solutions of the oscillators obtained by the presented approach can be verified by the exact solution in some special cases or the Monte Carlo simulation (MCS) [5]. Numerical analysis indicates that the solutions obtained by the presented approach match well with MCS solutions. The advantage of the presented solution procedure is that it can provide a much more accurate solution than the EQL and it is much more efficient than MCS as demonstrated by the numerical examples. Another advantage of the presented solution procedure is that all the available methods can be adopted here for solving the formulated optimization problems.

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PROJECT RISKS DURING COVID 19 PANDEMIC AND THEIR EFFECTS ON DELAYS AND COST OVERRUNS

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Abstract

The Covid-19 pandemic has significantly impacted project costs and delays across numerous industries. We can find in the literature that project delays and higher costs have all been caused by people, material, and equipment movement restrictions, supply chain disruptions, social distancing policies, and other risk factors. In fact, the COVID-19 pandemic has seriously disrupted international supply chains in a variety of sectors, including biomedical technology. A number of variables, including travel restrictions, labor shortages, lockdown procedures, and a spike in demand for medical supplies and equipment, were the main causes of the interruptions. To confirm this assumption, a comprehensive study was conducted to understand whether these factors affected project delays and cost overruns. A multiple regression analysis was conducted to analyze the significance and the volume of the effects of specific factors on project delays and rising project costs. Contrary to the previous understanding, we found that only a few factors or project risks associated with Covid 19 pandemic have an effect. The findings show that only risk factors related to material supply and epidemic prevention methods that the company was requested to implement inside the company influenced delays of projects, while other risk factors had no influential effects on a project schedule. Additionally, it has been found that only risks associated with rising costs of material supply affected the rising costs of projects during Covid 19 pandemic, while other project risk factors had no influence. These findings can be valuable for developing risk mitigation strategies that will enable the smooth implementation of projects during similar events and long-term disruptions.

Keywords: project risks, Covid 19 pandemic, project delays, projects costs.

INVESTIGATION OF MECHANICAL AND THERMODYNAMIC CHARACTERISTICS OF SINGLE LAYER GRAPHENE SHEET USING MOLECULAR DYNAMICS SIMULATIONS

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Abstract

The investigation of mechanical and thermodynamic properties of graphene sheets is often required since they are basic elements of many nanodevices such as nano-sensors [1]. Various methods have been used to experimentally [2] and theoretically [3] investigate these properties. Here, the results of the theoretical investigation of graphene sheets are presented using molecular dynamics (MD) simulations. This research aimed to investigate the mechanical and thermodynamic characteristics of single-layer graphene sheets (SLGS) at different temperatures using MD simulations with Reactive Empirical Bond Order Potential (REBO) [4.]. Before conducting mechanical test simulations, the SLGS models must be created and equilibrated to specific temperatures. Since the SLGS were considered as building blocks of nano-sensors in real-world applications the idea was to investigate the mechanical characteristics at temperatures in the range from 233.15 K up to 313.15 K with the temperature step of 10 K. After the equilibration simulation was performed i.e. the SLGS structure was brought up to the specific temperature and the thermal expansion coefficients were calculated. Since SLGS is orthotropic material and the material is two-dimensional the tensile mechanical tests were conducted in the x and y directions, and the shear test was conducted in the xy direction, respectively. To obtain mean values of Young's modulus in the x and y direction as well as shear modulus each tensile test for each temperature was conducted 10 times. The Poisson's ratio was also calculated in the postprocessing step.
Based on the conducted investigation the mechanical parameters using MD showed that all mechanical parameters are temperature dependent and as the temperature increases the values of mechanical parameters such as Young's modulus in x and y directions decrease from 1 to 0.9 TPa. The investigation also showed that the tensile test produced different stress values in different directions. The thermal expansion coefficient was negative due to the shrinking of the graphene sheet during the equilibration simulation.

Keywords: Molecular Dynamics, REBO, SLGS, Young's modulus, Shear modulus, Thermal expansion coefficient, Poisson ratio

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A NONLINEAR DYNAMICS MODEL OF ANTIBIOTIC PERSISTER FORMATION BY TYPE I TOXIN-ANTITOXIN SYSTEMS

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Abstract

Antibiotic persisters are a subpopulation of genetically identical bacterial cells that are in a dormant state, which allows them to survive antibiotics. Persisters may lead to chronic and recurrent bacterial infections. Toxin-antitoxin (TA) systems, which consist of a pair of toxin and antitoxin genes, have been implicated in persister cell formation. TA regulation in the context of persister cell formation involves multiple feedback loops and regulatory mechanisms (some of which are highly non-linear). We develop a mathematical/biophysical model of a persister formation by a group of Type I toxin-antitoxin systems (where the antitoxin is RNA) that share very similar regulations. We performed analytical and numerical analysis of the model stability and bifurcations, and show that the system is bistable for a wide range of parameters, where the high toxin state may correspond to the persister state. We directly relate the two bifurcation parameters with the system regulatory mechanism: two distinct steps of toxin repression, cell division rate, and increase in toxin transcription due to antibiotic action. Based on this, we relate the two toxin repression steps with the modulation of high and low toxin states in the bistability regime. We also show that antibiotic application, or slow cell growth, promotes persister formation. Finally, modifying biochemical parameters related to two toxin repression steps (either in an experiment by mutations or by evolution in different TA implementations) may qualitatively change the system properties, which we relate to the bifurcation diagrams.
The well-recognized mechanism of bistability emergence is through positive feedback with high non-linearity - e.g., by highly cooperative binding of transcription regulator to its promoter. However, we obtained an unintuitive result that more extensive negative feedback (commonly viewed to stabilize monostable states) is necessary for bistability. Specifically, we showed that toxin inhibition of its translation is insufficient to achieve bistability, i.e., that additional negative feedback through inhibition of antitoxin degradation is necessary. This difference from the classical mechanism is due to an unusual positive feedback exhibited by toxin-antitoxin systems, exhibited by the toxin inhibition of the bacterial cell growth that in turn decreases the toxin dilution (effective degradation).
Biologically, the model indicates that Type I toxin-antitoxin systems may not be able to produce persisters under standard conditions. However, antibiotic application or slow cell division (or both) promotes entry into the bistable region and consequently persister generation. This model result is consistent with experimental observations that TA system deletion only leads to a difference in persister cell generation when the antibiotic is applied for an extended time. The model also explains why two apparently redundant mechanisms of toxin expression inhibition exist in Type I TA systems by predicting that they have almost entirely distinct roles in modulating the low and the high toxin states in the bistable region. The low toxin state directly

relates to persister production. The high toxin state likely distinguishes between cell dormancy and death (for too high a toxin amount), so it has to be tightly regulated. These model predictions can be directly experimentally tested by mutating the control/regulatory elements for a given TA system or by comparison of different natural implementations of Type I TA systems. Overall, this is (to our knowledge) the first quantitative model of Type I TA systems that can explain existing experimental observations and provide predictions to be tested by further experiments.

Keywords: antibiotic persistence, non-linear dynamics modelling, bistability, bifurcations, type I toxin-antitoxin.

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DYNAMICS OF A TYPE-II TOXIN-ANTITOXIN SYSTEM RESPONSE TO ANTIBIOTIC STRESS

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Abstract

Bacterial toxin-antitoxin (TA) systems of Type-II, in which toxin is a protein, respond to various stressful conditions, such as antibiotic exposure. Specifically the kacAT Type-II TA system is involved in the antibiotic persistence of *Klebsiella pneumoniae*. We present the results of a joint experimental and theoretical study of kacAT [1]. Antibiotic persistence refers to a phenomenon in which a small subpopulation of bacterial cells survives exposure to antibiotics despite being genetically identical to the majority of cells that are susceptible to drugs. Spontaneous persistence presents the natural ability of a small fraction of bacterial cells to enter a dormant or non-replicative state, regardless of antibiotic exposure. On the other hand, antibiotic-induced persistence refers to the phenomenon where a subset of bacterial cells enters a persistent state, specifically in response to antibiotic exposure. Experiments show that antibiotic application results in a strong increase in transcription of the antitoxin (kacA) and toxin (kacT) genes. This increase is due to antibiotic-induced KacA degradation and a decrease in the KacA:KacT ratio, relieving the KacAT complex repression of its promoter region. Since KacAT complex formation is highly cooperative (formed by four antitoxin and two toxin molecules), the system dynamics is characterized by highly non-linear feedback loops, for which we develop a quantitative model [1]. Our model reproduces the experimentally observed reduction of the [KacA]:[KacT] ratio and a large increase in kacAT transcript levels under strong promoter autorepression by the KacAT complex. Moreover, under the same conditions, the model explains the somewhat perplexing observation that KacAT overexpression induces antibiotic stress tolerance, whereas kacAT deletion does not affect this tolerance.
The observation that kacAT deletion does not affect antibiotic tolerance also implies that this system does not lead to spontaneous persister formation. This is consistent with recent experimental results on other Type II TA systems but contradicts earlier experimental and theoretical studies that implied Type II systems in spontaneous persister formation. However, a crucial assumption of these theoretical studies is the cooperative (joint) action of several TA systems, which are often present in several instances in the genome. To test this assumption, we performed a bioinformatics analysis of TA systems similar to kacAT in completely sequenced genomes of *K. pneumoniae* [2]. Statistical analysis of the bioinformatically predicted loci shows pronounced deviation from random distribution within the same clades, where multiple system instances are strongly disfavored. Moreover, we also obtain statistically significant correlations between different clades, which shows their cross-talk is disfavored. The analysis shows that (at

least for kacAT) the assumption of cooperativity in TA action is unrealistic and may explain why spontaneous persister generation is not observed for kacAT.

Keywords: type II toxin-antitoxin systems, antibiotic persistence, systems biology, non-lienar dynamics, gene expression regulation, bioinformatics.

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BISTABILITY IN THE REGULATORY DYNAMICS OF BACTERIAL RESTRICTION-MODIFICATION SYSTEMS

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Abstract

Restriction-modification (R-M) systems include genes for restriction enzyme and methyltransferase. A specialized regulator (C protein) is often co-expressed with the restriction enzyme, which tightly regulates the system through a complex regulation that involves cooperative (nonlinear) positive and negative feedback loops. R-M systems defend bacterial cells from invasion by foreign DNA, such as plasmids and bacteriophages (bacterial viruses). By this, R-M systems modulate horizontal gene transfer, including the transmission of pathogenic genes, such as determinants of antibiotic resistance or virulence. Most recent experimental results directly confirm this possibility by showing that the ratio of R and M significantly modulates the efficiency of bacteriophage infection, making a subpopulation of cells susceptible to horizontal gene transfer. We develop a mathematical model of a restriction-modification system regulation, which we tightly constrain by numerous biophysical measurements of the system interaction parameters. We further provide a nonlinear dynamics analysis of this model, which is technically complicated due to the C protein forming dimer and tetramer complex in the solution and on DNA. We, however, analytically derive the system stability diagram, which is applicable (straightforward to modify) to R-M systems with diverse architectures. A single free parameter determines if the system is bistable. We infer this parameter from experimental measurements in the case of three systems with different architectures. Surprisingly, the system dynamics is monostable for one system class and bistable for the other two system classes. We show that our model can explain the experimental data very well. More importantly, we obtain that modulation of the barrier to horizontal gene transfer may be achieved through qualitatively substantially different mechanisms: i) bistability, which leads to long-living states susceptible to acquiring pathogenic genes, ii) stochastic fluctuations, which can only transiently lower the barrier to horizontal gene transfer. The exact implications of these differences for bacterial pathogenicity and evolution remain to be determined. We, however, hypothesize that the systems capable of bistable R-M gene expression can lead to a genetically distinct bacterial population with potentially different phenotypes in terms of pathogenicity and antibiotic resistance.

Keywords: restriction-modification systems, nonlinear dynamics modeling, biophysical modeling, bistability, antibiotic resistance.

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DAAD COOPERATION ON THE APPLICATION OF THE NEURAL FEM AND NEURONAL OPERATOR METHODS IN SOLID MECHANICS

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Abstract

Machine Learning methods belong to the group of most up-to-date approaches for solving partial differential equations. The current work investigates two classes, Neural FEM and Neural Operator Methods, for the use in elastostatics by means of numerical experiments. The Neural Operator methods require expensive training but then allow for solving multiple boundary value problems with the same partial differential equation. Main differences between the two classes are the computational effort and accuracy. Especially the accuracy requires more research for practical applications.

Keywords: machine learning, neuronal FEM, neuronal operator, solid mechanics.

DEEP LEARNING AND COMPUTATIONAL FLUID DYNAMICS APPLIED ON 3D INTRACRANIAL ANEURISM

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Abstract

Intracranial aneurism is expansion or ballooning in blood vessel in the brain. Treatment options are very well established, like surgical clipping or endovascular treatment with its various forms. Still, there is a dilemma that is yet to be solved. Approximately 50–80% of intracranial aneurysm do not rupture in the individual's lifetime. Hemodynamics for sure plays significant role in understanding of growing and rupture of intracranial aneurism. Before calculation of blood flow 3D geometry reconstruction from magnetic resonance imaging is necessary.
In this study we use an open dataset that consists of 3D aneurysm segments with segmentation annotations, automatically generated blood vessel segments, and complete models of scanned blood vessels of the brains [2]. Three-dimensional model of blood vessel segments from complete models and annotated a 3D aneurysm model was build. Datasets consist of 103 3D models of entire brain vessels which are collected by reconstructing scanned 2D MRA images of patients. Furthermore, geodesic distance matrices are computed and included for each annotated 3D segment, because the expression of the geodesic distance is more accurate than Euclidean distance according to the shape of vessels. The non-watertight mesh with PyMeshFix was fixed and voxelize the watertight mesh with trimesh into 28 × 28 × 28 voxels. The source dataset was divided in ratio of 7:1:2 into training, validation and test set. We implement ResNet-18/ResNet-50 [3] with 2.5D/3D/ACS convolutions with a simple early-stopping strategy on validation set as baseline methods, using the one-line 2D neural network converters provided in the official ACS code repository [4]. When loading the datasets, we copy the single channel into 3 channels to make it compatible. For all model training, we use cross-entropy loss and set the batch size as 32.
After 3D surface mesh was created, we generated 3D full mesh in order to implement computational fluid dynamics (CFD) calculation of hemodynamics characteristics of intracranial aneurysm. That analysis has been shown blood flow velocity, pressure and shear stress as well as forces on the aneurism wall. Finally, some results using full 3D finite element solver [5] are presented.
This study combines state of the art of machine learning algorithm and CFD to better understand complex phenomena of intracranial aneurysm.

Keywords: intracranial aneurysms, deep learning, 3D reconstruction, CFD calculation.

DETERMINATION OF YIELD LOAD FOR FEMORAL PART OF TOTAL HIP ENDOPROSTHESIS

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Abstract

The focus point of this research is to provide initial input data for structural integrity assessment through SINTAP procedure applied to neck of total hip endoprosthesis femoral part in order to compare the scope of application for wrought and selective laser melted Ti-6Al-7Nb alloy used for hip implant. Final goal is to implement failure assessment diagram (FAD) approach for both production methods. Input data for SINTAP procedure are tensile test results, fracture toughness values and limit load for each crack depth. These data are necessary for both production methods. A part of the data will be obtained experimentally, while the other part will be gathered through numerical calculations. The numerical part of the research refers to fracture mechanics parameters calculation using finite element method implemented into Ansys software. The neck of the femoral part of total hip endoprosthesis is modelled and used for numerical simulations. For the purposes of this research, dimensions of a realistic implant that suffered a failure and was removed from the patient is used as a base in scientific research.

Keywords: Ti-6Al-7Nb, total hip endoprosthesis, selective laser melting, yield load, finite element method.

NUMERICAL ANALYSIS OF TEMPERATURE DISTRIBUTION IN SHELL AND TUBE HEAT EXCHANGERS

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Abstract

This research presents numerical simulation of heat transfer using finite element method (FEM) implemented in Ansys software. Numerical analysis was performed on the example of a shell and tube heat exchanger. The shell and tube heat exchanger are among the most prevalent exchangers extensively employed in industrial applications. Heat exchangers are incorporated in all process and energy facilities.
The aim of this study is to examine the influence of insulation on temperature distribution in shell and tube heat exchangers. The case will be considered where the exchanger is uninsulated, perfectly insulated, and insulated with a 20-millimeter-thick polyethylene insulator. Considering that in the case of a heat exchanger, the proportion of heat transferred by radiation is small, only heat transfer through conduction and convection will be analyzed.
Since this case involves a relatively large model geometry, the shell diameter is 640 mm, and the length of the tube is 3200 mm. The tubes are made of copper, while the shell is made of stainless steel. Due to the limitations of the processor in numerical analysis, to use a mesh with a higher number of elements and nodes that provides more accurate results, only a quarter of the model will be analyzed. Therefore, the influence of individual parts that have a small impact on the overall results will be neglected.

Keywords: FEM simulation, thermal analysis, shell and tube heat exchanger.

FORMULATION AND RESULTS OF THE OPTIMUM 3 AND 4 NODES PLATE BENDING ELEMENTS WITH SHEAR EFFECTS

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Abstract

This paper deals with the presentation of a general, variational principle as theoretical support for the development of two simple and efficient triangular and quadrilateral finite elements having only one displacement and two rotations at the corner nodes to model very thin to very thick plates based on the first order Reissner- Mindlin plate theory. The functional is a modified Hellinger-Reissner mixed expression in terms of the kinematic variables (transverse displacement w and rotations β_x and β_y), and independent transverse shear strains (γ_x and γ_y). The approximations of the five independent variables of the mixed formulation take into account the accumulated knowledge on existing performing 2D Timoshenko beams, triangular elements such as T3γ, DKT, DST, DKMT, DSTK and quadrilateral elements such as such as Q4γ, DKQ, DSQ, DKMQ, DSQK developed by the senior authors and collaborators during the last 40 years. The present mixed variational support is useful, not only to give a unique theoretical support to the above existing elements, usually based on assumed natural strain formulations, but it allows also to propose two new simple and efficient triangular and quadrilateral elements. The new elements are a generalization of the 2D Timoshenko beam element leading to an exact stiffness matrix. Hence in our elements we consider quadratic rotations as in DKT or DKQ, linear independent shear strains with constant tangential shear strains on sides, as in MITC3 or MITC4 elements. The quadratic rotation components and the independent (mixed) shear strain components at mid-side points are eliminated by static condensation. The resulting stiffness matrices are of dimensions 3 and 4. Then the orthogonality conditions between the linear and quadratic bending modes is considered as for the Bergan free formulation in order to avoid "bending locking" for thick plates and exactly satisfy the constant curvature kinematical patch tests for any aspect ratio. Our elements are using full integration (3 Hammer points or 2x2 Gauss points) for a proper rank and without any adjustable parameters. The paper includes a detailed presentation of results of patch tests for very thin and very thick plates, for convergence of displacements, bending moments and shear forces for circular, square and skew plates and for s-norm convergence tests considering regular and irregular meshes. Shear force distributions are also considered for situations with boundary layer effects. The new elements appear to be the optimum ones in terms of efficiency and robustness.

Keywords: modified mixed Hellinger-Reissner functional, nine and twelve dof plate bending elements, s-norm convergence tests, displacements and stress resultants, square/ circular and skew plates.

COST ACTION HISTRATE: SIMULATION METHODS AND BEST PRACTICES FOR COMPOSITES UNDER HIGH STRAIN RATES

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Abstract

HISTRATE aims to define scientific and technological foundations for development of a robust framework for the certification-by analysis of advanced composite structures, which undergo high strain rate loading, including impact and blast loading. The framework consists of validated simulation tools integrated with the state of the art of material characterisation and smart sensing techniques, and is designed to replace a number of segments of the time consuming and complex building block protocols currently used for validation and product certification. The approach accelerates the design and certification process and allows for design upgrades of the structures without recertification. Direct measure of success of the framework is accuracy and efficiency of the modelling tools. Consequently, our objectives are to gather the state-of-the-art in the numerical modelling and design of safety-critical structures under high strain rate dynamic loading; identify challenges and limitations in design of lightweight composites, including safety structures undergoing extreme loading conditions, establish the best practice for numerical modelling and select the case studies relevant to industrial applications and future research areas; identify challenges in modelling composite structures related to multiscale modelling of composite materials (including novel composite materials).
The core of the Action work plan are working groups developed around novel simulation methods and best practices for composites under high strain rates, which is closely linked to the groupings for multi-modal sensing for impact detection, including damage characterisation, and advanced testing and instrumentation for composites under high strain rates.
HISTRATE has established a good communication practice and has built a strong knowledge base, which consists of over 100 European and non-European, academic and industrial experts working in the wide field of composites. Our ambition is to keep the network open and inclusive and develop it further, by establishing regular workshops for training of early career investigators and young researchers.

Keywords: composite materials, modelling, high strain rate loading, certification by analysis

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