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ABSTRACTS

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תקצירים

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PREDICTABILITY AND UNCERTAINTY IN LARGE-SCALE SIMULATIONS

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ABSTRACT

In many simulations in fluid and solid mechanics the dominant errors may come not from discretization of the PDEs but from errors associated with uncertain initial and boundary conditions, material properties, or geometric inaccuracies.

I will present a general framework based on polynomial chaos theory that allows the modeling and propagation of uncertainty through the nonlinear models. In particular, open issues such as discontinuities in parametric space, long-time integration, white noise modeling, and high-dimensionality will be addressed.

Examples will be presented for unsteady flow problems, scattering of shock waves due to random roughness, and nonlinear ocean risers.

A FICTITIOUS SOURSE METHOD FOR SOLVING AEROACOUSTICS PROBLEMS IN HALF-SPACE OVER FLAT GROUND WITH FINITE IMPEDANCE

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שיטת מקורות פיקטיביים לפתרון בעיות באוירואקוסטיקה מעל חצי מרחב שטוח עם אימפדנס סופי

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ABSTRACT

The solution of linear aeroacoustics problems, such as a point source located over a flat ground with finite impedance, is presented using a simple computational scheme of locating fictitious sources in the lower half-space domain. Such problems occur, for example, in environmental engineering, where the analysis of the Sound Pressure Level (SPL) distribution near the ground due to aircraft noise, and the resulting pollution envelope, are required by aviation regulations. Mathematically, the problem may be posed, in the frequency domain, as that of determining the Sound Pressure Level (SPL) distribution near the ground due to a point source of a given acoustic spectrum. The process of calculating the SPL distribution involves the repeated solution, for many different wave numbers, of the Helmholtz equation in the upper half-space domain with the given impedance boundary condition imposed on the ground. For flat ground with a zero or infinite impedance the Helmholtz problem is easily solved analytically using the method of images. For finite impedance (even with flat ground) the problem becomes much more complicated for analytic treatment. In recent years fictitious source schemes have been developed and applied for various acoustic and electromagnetic wave problems. It is shown here that the fictitious-source method allows efficient solution of aeroacoustics linear problems, leading to an effective SPL calculation.

COMBINED FINITE ELEMENTS & FUNCTIONAL DERIVATIVE APPROACH FOR BUCKLING OPTIMIZATION OF STRUCTURES

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גישה המשלבת אלמנטים סופיים וגזירה פונקציונלית לאופטימיזציה של מבנים בקריסה

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ABSTRACT

An analytical sensitivity (gradient) function for the buckling load is introduced for shape optimization. The gradient is derived by functional differentiation of the governing equation with respect to the structure's shape (K). Both the buckling load (P) and deflection (W) are considered as functionals of the shape. For beam-columns, an explicit analytical expression for the functional gradient ($P_{,K}$) is obtained, depending on W up to its second spatial derivative. A finite element model is used to compute $P_{,K}$ for any shape or boundary condition, and an optimization using the functional gradient projection method is performed. Results are compared with exact solutions and found to be more accurate than common FE optimization procedures. The analytical gradient expression is independent of the FE model but requires its input. The optimization produced smooth geometries with fast convergence. An example of a beam on three supports (clamped, simple, simple) is studied, with special attention to the effect of location of the middle support. The optimal cross section distribution was found to be a combination of regions having shapes identical to the basic simply supported case. The semi-analytical method is extended to the case of a circular plate under axisymmetric loading. Thickness is optimized for a variety of boundary conditions, including a central hole, where it was found that the optimal thickness distribution includes very high (singular) local stiffening near the hole. The proposed method can be generalized to other problems where the relationship between the target function and variables is implicit through a differential equation (both ordinary and Eigen value type).

APPLYING MODERN CONTROL THEORY ON NUMERICAL MODELS FOR CONTROLLER DESIGN AND REVERSE PROBLEM SOLUTION OF THERMAL SYSTEMS

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יישום שיטות מתורת הבקרה המודרנית על מודלים חישוביים לשם תכנון חוקי בקרה ופתרון הבעיה ההפוכה עבור מערכות תרמיות

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ABSTRACT

In the last few decades software that allow numerical simulation of complex thermal systems are becoming more and more available. This development is especially beneficial in the stage of design and optimization of the project. As many of these systems are closed loop controlled, a methodology for designing optimal feedback control laws based on numerical models, and for integrating these control laws in computational simulation, is of great importance. Closed loop simulation has also a pure computational aspect: calculating the heat fluxes that are required, at each moment of time, for obtaining a wanted temperature profile.

Designing a control law that is based on a large scale model is a challenging task. The basic problem is that the traditional tools of control theory produce control laws that have the same scale as the scale of the model of the system. Therefore, for large scale systems we get large scale control laws, which are inefficient in design and simulation, and impractical to implement on real time hardware.

In this work, we reduce the order of the model using Balanced Truncation or System Identification methods. Then, we design a small scale controller using standard optimal control theory procedure, and calculate the input fluxed by closed loop transient simulation with the full scale model. The Balanced Truncation approach has two main advantages. (1) It preserves as much as possible the Observability and Controllability properties of the model, which are the most important properties for controller design. Moreover, it is shown how the cost function of the optimal controller can be taken into account during the model reduction phase. (2) A reduced order estimator which allows real time estimation of process values that cannot be directly measured can be easily extracted form the numerical model.

TIME-DEPENDENT CRACK DETECTION IN FLAT MEMBRANES

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איתור סדקים תלוי-זמן בממברנות שטוחות

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ABSTRACT

A computational framework is developed for the detection of flaws in flexible structures. The framework is based on posing the detection problem as an inverse problem, which requires the solution of many forward problems. Each forward problem is associated with a known flaw; an appropriate cost functional evaluates the quality of each candidate flaw based on the solution of the corresponding forward problem. On the higher level, the inverse problem is solved by a global optimization algorithm.

The performance of the computational framework is evaluated by considering the detectability of various types of flaws. In the present context detectability is defined by introducing a measure of the distance between the sought flaw and trial flaws in the space of the parameters characterizing the configuration of the flaw.

The framework is applied to crack detection in flat membranes subjected to time-harmonic and transient excitations. The detectability of cracks is compared for these two cases.

APPLICATION OF NUMERICAL MODELS IN GEO-ENGINEERING: ACCURACY AND CHALLENGES.

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ישום מודלים ספרתיים בגיאו-הנדסה: דיוק ואתגרים

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ABSTRACT

In this paper I present a set of validation studies of two different numerical models using benchmark physical models of two typical problems in geo-engineering. First I compare between a dynamic model of a block on an incline and a prediction of implicit DEM - the Discontinuous Deformation Analysis (DDA, Shi 1993); following is a comparison between the predictions of explicit FD (FLAC, Itasca 2000) and a centrifuge model of a cracked beam (Voussoir arch). The two numerical models are tested for accuracy of prediction of stresses, displacements and correct modes of deformation.

The results of these studies show that the accuracy of prediction reduces with increasing complexity of the physical system, until only the equilibrium conditions are met. Specifically it is shown that: 1) the run-out distance of a sliding block under dynamic loading can be predicted by DDA with sufficient accuracy. However, accuracy is achieved by introducing artificial (kinetic) damping in the time integration scheme. 2) The deflection profile of a cracked beam is only partially predicted by FLAC, controlled by the stiffness value of the interfaces across the blocks. The stress distribution within the beam is predicted correctly.

It is concluded that numerical predictions of the behavior of natural, or engineered, rock structures should not rely on high numerical accuracy, but rather on capturing the essentials of the deformation process, namely: equilibrium conditions and modes of deformation.

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WHAT'S HOT IN COMPUTATIONAL MECHANICS?

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מה חם במכאניקה חישובית?

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ABSTRACT

This is the second lecture in the "What's Hot" sequence, in which the speaker describes topics in Computational Mechanics (CM) that have received a lot of attention recently, based on exposure in international CM conferences and journals in the last two years.

This time, topics which have "made waves" in the last ECCOMAS/IACM congress in Venice (June 2008) will be reviewed. In addition, five selected papers (pertaining to some of these "hot topics") that have appeared during 2007 or 2008 in the leading CM journals will be briefly described.

THE ADJOINT-WEIGHTED EQUATION FOR THE DIRECT SOLUTION OF INVERSE PROBLEMS OF INCOMPRESSIBLE PLANE STRESS ELASTICITY

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שיטת ה- adjoint-weighted equation לפתרון ישיר של בעיות הופכיות של אלסטיות בלתי דחיסה במאמץ מישורי

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ABSTRACT

Inverse problems arise in many fields of physics and often involve the recovery of the physical characteristics of a material from its response to external loads. One example is elastography, a method used for medical imaging, where recovered mechanical properties of tissues are used to create images of parts of the human body. One advantage of the method is the high contrast in shear modulus between benign and malignant tissues, providing a valuable tool for detection of tumors.

Inverse problems are usually solved by an iterative procedure. When interior data are available, simpler direct methods may be used, if sufficient measurements are provided. For the inverse problem of incompressible plane stress elasticity, a single measurement can be sufficient unless it is associated with a state of uniaxial stress.

The adjoint weighted equation (AWE) method is a variational framework that is weighted by the adjoint operator, for the direct solution of the inverse problem. The method was first devised for inverse thermal problems, and is extended here to incompressible plane stress elasticity. The method has the advantage of producing a well posed problem under relatively mild conditions, unlike the strong form where much more restrictive conditions are required. The Galerkin discretization is done in a straightforward manner and leads to a stable, convergent numerical method. Computational examples demonstrate superior performance of the AWE method compared to conventional numerical methods.

This work was done in collaboration with Assad Oberai of RPI and Paul Barbone of BU.

PATIENT-SPECIFIC SIMULATION OF THE PROXIMAL FEMUR'S MECHANICAL RESPONSE VALIDATED BY EXPERIMENTAL OBSERVATIONS

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הדמיה אינדיוידואלית לתגובה מכנית של עצם הירך מאומתת ע"י ניסויים

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ABSTRCT

The use of subject-specific FE models in clinical practice requires a high level of automation, validation and accurate evaluation of analysis prediction capabilities. Numerous studies address the generation of the femur's 3D model based on quantitative computerized tomography (QCT) scans with reasonable accuracy (but not satisfactory for clinical application). This study present a novel high-order finite element method (p-FE) for generating FE models based on CT data [1,2]. In the suggested method the geometry is represented by smooth surfaces accurately based on QCT following several steps, starting from bone borders detection at each CT slice, trough surface approximation, to solid body representation, and finally to FE mesh generation. An internal smooth surface is used to separate the cortical and trabecular regions upon which a p-FE auto-mesh is constructed within each region (cortical or trabecular). Isotropic inhomogeneous linear material representation was assigned to the FE models by a spatial function generated from the QCT data. Anisotropic material properties are also considered in the FE model and their influence will be presented. Young's modulii were evaluated by Keyak & Falkinstein [3] relations: $\rho_{EQM} = 0.682 \cdot HU - 5.5 \quad [g/cm^3]$ $(R^2 = 0.99$, For bone #2), $\rho_{Ash} = 1.22 \cdot \rho_{EQM} + 0.0523 \, [g/cm^3]$, $E_{Cort} = 10200 \cdot \rho_{Ash}^{2.01} \quad [MPa]$, $E_{Trab} = 5307 \cdot \rho_{Ash} + 469 \quad [MPa]$

To validate the FE results we performed QCT scans on 3 proximal femurs (30 years old male, 20 and 54 years old female) followed by mechanical in-vitro experiments at different inclination angles, measuring head deflection and strains at several points with a total of 77 experimental values recorded. The QCT scans were used to generate p-FE models of the three bones, and the FE results were compared to the in-vitro experiments. Excellent correspondence was obtained between computed and measured strains and displacements. The linear regression of the experiment result vs. the FE prediction demonstrates the quality of the presented methods with a slope of 0.973 and R^2=0.95, results significantly better than in previous publications known to the authors.

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DOMAIN DECOMPOSITION TECHNIQUES AS A BASE FOR A MULTI-SCALE FINITE ELEMENT ANALYSIS OF THE BONE TISSUE

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שיטות הפרדת תחומים כבסיס לאנליזת אלמנטים סופיים מרובת סקאלות של רקמות עצם

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ABSTRACT

Bones are hierarchical bio-composite materials with complex multi-scale structural geometry and complex behavior. In metabolic bone diseases, such as osteoporosis, micro-architectural deterioration of bone tissue occurs, leading to micro fractures; therefore, early diagnosis is a key to intervention.

At the micro-scale level, modern medical imaging technology allows high resolution *in-vivo* and *in-vitro* scanning of large specimens or even whole bone models. Analysis of high resolution (micro-scale) models is performed with micro Finite Element method that was developed a decade ago. The main disadvantages of the micro-FE method are: (a) micro finite element method allows solution of only a small bone volume using reasonable computational resources; (b) transition between macro-scale to micro-scale models requires re-computing of entire model at the micro-scale level; and (c) transition between micro-scale to macro-scale models by homogenizing the micro-scale model, disregarding micro-scale characteristics of bone architecture. Therefore, the current micro-FE cannot be used for robust multi-scale analysis of bone architecture.

In this lecture we present a new approach for a multi-scale finite element analysis of a trabecular structure. Two domain decomposition approaches are investigated as a basis for computational analysis at the micro-scale level, which is then applied for solving a 2D elasticity finite element problem. The proposed new multi-scale FE method has the potential to provide new insights into bone structure and behavior. Moreover, it is expected that the outcomes of this research will develop into a computerized virtual biopsy system.

DEVELOPMENT OF A NOVEL VALVELESS PUMP USING NUMERICAL INVESTIGATION

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פיתוח משאבה חסרת מסתמים חדשנית באמצעות חקירה נומרית

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ABSTRACT

Impedance pump (IP) is a valveless pump which is basically an elastic fluid-filled tube connected to tubing by an impedance mismatch. By a periodic excitation of the elastic wall, a net flow is obtained in a preferential direction. Although the principle of IP is simple and known for decades, the physical dynamics of which flow derived in a preferential direction was revealed recently using numerical investigation.

Several biomedical implementations of IP will be discussed such as IP on a coronary artery bypass graft (CABG), on the total cavapulmonary connection of the Fontan procedure, on active stents, as intra-aortic pump and as micropumps for different biomedical applications. In addition to the basic IP pump, innovative multilayered IP and multipinching IP will be introduced – both applications are used to obtain significant pumping where only small excitations are possible.

The presented work includes numerical simulations of axisymmetric and physiological-based 3D models of IPs including both the fluid and structure domains. The commercial finite elements software ADINA (ADINA R&D Inc., MA) is used to incorporate the dynamics of the elastic tube, the contact between the pincher and the tube, the fluid dynamics, and the fluid-structure coupling at the interface. The study includes a comprehensive study of the waves' propagation along the elastic tube and reflected by the impedance mismatch. The relationship between pressure and flow in the IP are used to extract characteristics of energy and impedance in the pump. The effect of different pumping conditions, designs and boundary conditions are examined. The resonant nature of the pump is demonstrated, and the physical mechanisms driving the net flow are discussed for the different designs. In addition, specific biomedical applications are demonstrated under physiological conditions.

THE DEVELOPMENT OF EPIDERMAL WOUND HEALING: A COMPUTATIONAL APPROACH

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הדמיה חישובית של תהליך איחוי פצעי עור

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ABSTRACT

A multi-scale computational model of biological processes enables selected key aspects of the underlying biology to be investigated individually, and to be applied to a wide range of biophysical systems. Wound healing is essential for the survival of an organism. The mechanisms responsible for cell migration across the surface of an epidermal wound remain the subject of much biophysical debate. Previous mathematical modeling techniques for the wound healing process include using sets of coupled reaction-diffusion equations for the cell density and chemical concentration. This macro-scale approach makes inclusion of the stochastic behavior of individual cells difficult to treat. Owing to the multi-scale nature of wound healing in order to capture both continuum and the micro-mechanics events, the wound healing development is best modeled by a hybrid composition of the two.

In the present work, we describe a two-dimensional multi-scale computational model for wound healing development, which combines the extended cellular Potts model of cell aggregation with the finite element model describing the chemical reaction-diffusion. Our study reveals that for a certain range of the characteristic parameters, the moving front undergoes a fingering instability as encountered in recent experiments. We then use the computational model to perform "computational experiments" on the variation of the healing time with wound shapes. Having tested a model against existing experimental data, one can go on to make predictions which may suggest new ideas and directions for experimental studies.