PLENARY LECTURES

Reliability analysis of structures by adaptive support vector regression model

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The most direct, conceptually straightforward and accurate means of structural reliability analysis (SRA) is based on the Monte Carlo simulation (MCS) approach. However, the direct MCS technique requires a large number of MCS samples to estimate a small failure probability with acceptable accuracy, particularly for estimating a very low failure probability. Various metamodeling approaches, e.g., polynomial response surface method, artificial neural network, Kriging method, etc., have emerged as an effective alternative for solving computationally challenging complex SRA problems involving finite element response analysis. Apart from such empirical risk minimisation principle-based metamodels, the support vector machine for regression, i.e. the support vector regression (SVR), which is based on structural risk minimisation, has revealed improved abilities of response approximation using small sample learning. The presentation focuses on the applications of adaptive SVR-based metamodel for efficient SRA.

The accuracy of any metamodeling approach for SRA largely depends on the proper selection of training data. The sample size requirement is an important issue with regard to efficiency. A two-stage iterative algorithm is proposed to construct the SVR model adaptively by addressing the issue of accuracy and efficiency for SRA. The algorithm hinges on improving the prediction accuracy of a metamodel near the failure surface region. In the first stage, an initial design of experiment (DOE) is built by a space-filling design over the entire physical domain of the random variables. In the next stage, a subset of MCS samples is selected based on the predictions at MCS points using the previous SVR model. These are now used to enrich an existing DOE by adding more data points sequentially so that the new points are closer to the limit state surface and as far as possible from the existing points. The optimum choices of hyperparameters involved in the SVR model are obtained by minimising the generalised root mean square error (GRMSE).

Further, a three-stage adaptive SVR model is developed by modifying the previous two-stage adaptive metamodeling approach to deal with estimating very low failure probabilities. In detail, a subset of MCS points with an approximated LSF magnitude, as predicted by the initial SVR model, smaller than the noted GRMSE value, are selected as candidates for new training samples. It is important to note that the subset may lack sufficient candidate samples for SRA problems involving small failure probabilities. An important sampling technique is proposed to obtain more candidate points to address this issue. In doing so, obtaining the reduced space for sequential sampling is altered by automatically changing the reliability evaluation method between the brute-force MCS approach and the importance sampling method based on the coefficient of variance of the failure probability. This ensures the availability of sufficient simulation points near the approximated failure plane. The reliability estimates by the two-stage and three-stage adaptive SVR-based metamodeling approaches, including a small probability of failure estimate, are elucidated numerically to demonstrate the efficacy of the proposed approach.

Keywords: Structural reliability analysis, Support Vector regression, Adaptive Metamodel, Sequential Sampling

Interfacial instability in liquid chromatography separation columns

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Liquid chromatography columns separate the chemical components of a given mixture by passing it through a porous medium. In preparative or size exclusion chromatography, the mixture viscosity significantly differs from that of the displacing fluid (the eluent). Displacement of the sample by the eluent of different viscosity leads to a hydrodynamic instability of the front or rear interface of the mixture sample, leading to deformation of the initial planar interface. The less viscous fluid penetrates the more viscous zone, forming a finger pattern; hence, it is called "viscous fingering (VF)" instability. This VF is dramatic for the performance of the separation technique as it contributes to peak broadening. The solute in the mixture can adsorb onto the porous matrix of the column. Mathematical modelling of such adsorption effects through linear and nonlinear adsorption will be discussed. Based on a spectral method, the numerical simulations of the non-linear viscous fingering phenomena in a porous medium with the effects of linear and Langmuir-type adsorption of the solute onto the porous matrix will be discussed. Numerical results with shock and rarefaction waves will be compared with the experimental investigation obtained in a chromatographic separation.

Keywords: Viscous fingering, Porous media flow, Spectral Methods, Convection-diffusion equations, Hydrodynamic Instability

MEMORIAL LECTURES

Prof. G.I. Taylor Memorial Lecture

Unsteady Solute Dispersion in non-Newtonian Flows in a Circular Tube with Wall Absorption and Body Acceleration/Deceleration

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This lecture is intended to present the developments on the solute dispersion in circular tubes. The study on solute dispersion was initiated by G. I. Taylor for the Newtonian fluid flow. Current research shows the study is lead up to exploring unsteady solute dispersion in the pulsatile flow of non-Newtonian fluids under the periodic body acceleration/deceleration. Several variants of the non-Newtonian fluid models such as the Casson, H-B, K-L, Carreau and Carreau-Yesuda and Ellis models are considered in this lecture.

The time-dependent velocity profile is obtained analytically for smaller values of the Womersley frequency parameter for yield stress fluid such as the K-L fluid or the non-yield stress model such as the Ellis fluid while for larger values of this parameter, a numerical solution is computed using an explicit finite difference method. The generalized eigen function expansion method and the Aris' method of moments are widely used by researchers to examine the solute dispersion; both these methods are discussed here. Estimates for the exchange coefficient due to the irreversible first order boundary reaction, the convection and the dispersion coefficients, the skewness and the kurtosis are examined and their response to the system governing parameters is analysed. The discussion on the solute dispersion is made in the three flow and dispersion regimes: (i) viscous flow with diffusive dispersion regime, (ii) viscous flow with unsteady dispersion regime and (iii) the unsteady flow with unsteady dispersion regime. These regimes are characterized by the interplay between the values of the Péclet number, the Womersley frequency parameter, which is associated with the pressure pulsation, and the oscillatory Péclet number which has inherently the Schmidt number.

For a specific non-Newtonian fluid such as the Ellis fluid, the impact of the body acceleration parameter, the wall absorption parameter, the degree of shear thinning behaviour index, shear stress parameter, the Womersley frequency parameter, and the fluctuating pressure parameter, on the axial mean solute concentration is discussed here. It has been noticed that the value of the dispersion coefficient decreased monotonically in the viscous flow with the diffusive dispersion region, while the skewness and kurtosis both have shown significant variations in the unsteady dispersion regime, which lead to the significant variation in the axial mean concentration. Graphical analysis shows that a leftward shift and also a reduction in the peak of the mean concentration leading to the non-Gaussianity of the solute dispersion in the non-Newtonian fluid flow under the body acceleration/deceleration conditions. The contrast in the axial mean concentration results with and without the higher order moments is tabulated along with the presence and absence of the wall absorption parameter. This analysis can be used in understanding the solute dispersion in blood flow, with specific applications such as nutrient transport and directed drug delivery.

Keywords: Solute dispersion, non-Newtonian fluids, circular tube, higher order moments,non-Gaussianity.

Prof. A.S. Gupta Memorial Lecture

Forced Convection Heat Transfer from a Heated Horizontal Cylinder in Partially Groundwater-Saturated Soil

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The forced convection heat transfer from a heated cylinder embedded in porous media such as partially water-saturated soil, where the water table is located near the cylinder has been investigated numerically. Analytical formulas to estimate the heat transfer rates are also proposed. This study primarily focuses on a cylinder buried in the ground, with the water table located near the cylinder's depth.

The problem is categorized into three distinct cases:

1. Water table above the cylinder: In this case, the heat transfer rates are primarily determined by the fully saturated scenario. However, significant errors may occur if the groundwater velocity is low or if the gap between the top of the cylinder and the water table is small.

2. Water table below the cylinder: When the water table is slightly below the cylinder and the groundwater velocity is high, the water table behaves like a constant-temperature boundary, which can significantly influence the conduction heat transfer from the cylinder.

3. Water table at the cylinder level: For this scenario, a rigorous mathematical treatment would be complex. Therefore, a simple approximation formula is proposed based on two key observations. First, there is a measurable difference in heat conduction between the water-saturated layer and the unsaturated layer above it. Second, heat transfer on the cylinder surface wetted by groundwater is significant, where convective heat transfer is expected.

In all three cases, the proposed approximate methods show good agreement with numerical results.

Keywords: Forced convection, Heated Horizontal Cylinder, Partially Saturated Porous Media, Ground Water

Prof. P.L. Bhatnagar Memorial lecture

Linear and nonlinear stability of fluid flows: State of the art

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Various constitutive relationships for fluid description and their application situations shall be taken up for detailed discussion. To introduce different procedures of studying linear and nonlinear stability of fluid flows, the Rayleigh-Benard convection problem shall be considered as a representative problem. Innovations required for theoretical investigations involving non-classical boundary condition and non-rectangular geometry shall be elaborated upon. Both regular convective and chaotic regimes of convection will be presented in essential detail. Several aspects of modern day analysis of dynamical systems like AI intervention in such problems shall be discussed. The lecture shall end with a brief mention about ideas for making application for national and international patents concerning RBC problems and this shall be the pinnacle point of the lecture.

Keywords: Linear and nonlinear stability, Rayleigh-Benard convection, Regular convective motion, Chaos, Non-classical boundary condition

Prof. B.R. Seth Memorial Lecture

Free Vibration of Cross-Ply Laminated Plates Under Higher-Order Theory Using Splines

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This paper studies on free vibration of cross-ply laminated plates under higher order shear deformation theory. The arbitrary number of layers oriented in symmetric and anti-symmetric manner are considered to analyse the frequency characteristic of laminated plates. The plates kinematics is based on higher-order shear deformation theory (HSDT). The vibrational behavior of multi-layered plates is analyzed for simply supported end conditions. The coupled differential equations in terms of displacement and rotational functions are obtained. These displacement and rotational functions are invariantly approximated using cubic and quartic spline. A generalized eigenvalue problem is obtained and solved numerically for an eigenfrequency parameter and an associated eigenvector of spline coefficients. The material properties of Kevlar-49/epoxy, Graphite/Epoxy and E-glass epoxy are used to show the parametric effects of plate’s aspect ratio, side-to-thickness ratio, stacking sequence, number of lamina and ply orientations on the frequency of the plate. The numerical results obtained using spline approximation are validated through existing literature.

Keywords: Free vibration; Higher-order theory; Spline; Composite plate; Cross-ply

Prof. B KARUNES Memorial lecture

Earthquake Analysis of Concrete Gravity Dams considering Fluid-Structure-Soil Interaction in Finite Element Framework

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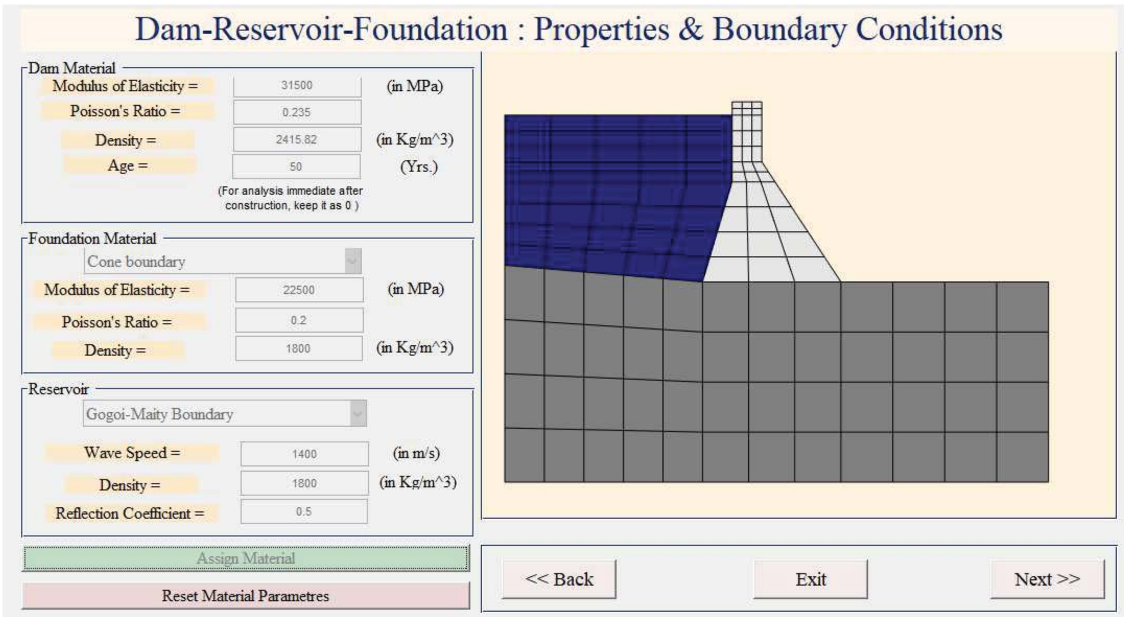
The Government of India prioritizes interlinking rivers to optimize water resource utilization through inter-basin water transfers. This initiative enhances the necessity of seismic-resistant design for concrete dams across the country, especially in the seismically active regions of Northeast India. Many existing dams were built prior to the development of modern computer analysis procedures. Earthquake forces were accounted for in designs by using methods that are now considered oversimplified.

Prediction of the performance of concrete dams during earthquakes is one of the most challenging and complex problems found in the field of structural dynamics because of several factors such as (i) complicated shapes of dam and retained reservoir, (ii) response of dam is influenced to a significant degree by the interaction of the motions of the dam with the impounded water and the foundation rock, (iii) difficulty in the finite element modelling of infinite reservoir and foundation rock, (iv) insufficient information on the spatial variation of ground motion and many more. With the advent of high-speed computers, significant progress has been made in understanding earthquake effects on dams.

This paper presents a robust and efficient algorithm, developed by the author, for the seismic analysis of concrete dams. The algorithm integrates critical parameters to enhance accuracy and practicality for design engineers. Key features include:

- Finite Element Modelling of Complex Geometries: The dam, reservoir, and foundation are accurately modelled to account for real-world complexities.
- Novel Truncation Boundary Conditions: Developed and implemented to effectively simulate infinite reservoir domains.
- Compressibility of Reservoir Water: Incorporated to reflect its significant influence on seismic responses.
- Sedimentation and Porosity Effects: Integrated to address reservoir bottom conditions.
- Boundary Conditions for Foundation Rock: Suitable boundary conditions of infinite soil rock.
- Coupled Analysis: Direct interaction between the dam, reservoir, and foundation is included for comprehensive modelling.
- Aging and Material Behavior: Orthotropic and isotropic damage models to assess the seismic safety of aging dams.

Extensive parametric studies were conducted to evaluate the effects of water compressibility, reservoir height, sedimentation, reservoir bed porosity, material properties, dam geometry, aging, and foundation flexibility under diverse seismic excitations. The developed algorithm allows practicing engineers to analyse dams efficiently and achieve optimal designs. A user-friendly graphical user interface (GUI) was developed to facilitate widespread adoption of the software, enabling engineers to perform detailed seismic analyses with ease. Results from this research have been published in high-impact journals. A snapshot of the GUI is presented to illustrate its application.



Keywords: Fluid-structure interaction; Soil-structure interaction, Concrete gravity dam, Infinite reservoir; Earthquake analysis; Finite element method

INVITED LECTURES

Stability of Rayleigh-Benard Convection in Hybrid Nanofluid Mixtures

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The research focuses on the linear analysis of a Rayleigh-Bénard convection problem that is exposed to general boundary condition. This general boundary condition is made up of approximate temperature and velocity boundaries. Through the utilization of non-dimensional characteristics, such as the Biot and slip-Darcy numbers, we have successfully combined sixteen Rayleigh-Bénard convection problems into one. Additionally, the study makes use of hybrid nanofluid, which is a binary base fluid mixture consisting of water and ethaline glycol and contains spherical-shaped nanoparticles (alumina/copper). Mixture theory is used to calculate the thermophysical characteristics of the binary base fluid mixture and the related nanofluids. The primary goals of the work are to shed light on the simplicity of using general boundary conditions and to provide a theoretical foundation for selecting the best nanofluid for convection issues. Limiting examples of the Rayleigh-Bénard problem for sixteen boundary conditions are obtained, hence offering a solid validation for the study. For a more concrete understanding of the problem, stream function plots for various boundary conditions are provided.

Keywords: Hybrid nanofluids, Rayleigh-Benard convection, general boundary conditions, convective heat transfer

Transformer Based Architecture – Fluid flow modelling

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In recent years data driven modelling and algorithms is accelerating research in many areas of Science and Technology. Deep Learning models are having many applications such as computer vision, Natural Language Processing etc. Similar algorithms are used in CFD in modelling turbulent flows. Many deep learning algorithms are optimizers used in many fluid flow modelling problems in place of numerical solvers. CNN, RNN, LSTM, CGAN, Encoders are few popular deep neural network models used in fluid flow modelling and analysis. Data visualization is also very helpful in understanding the fluid flow problems.

Attention based architecture and its applications in modelling fluid flow problems is presented in this.

Keywords: Fluid flow modelling, Deep Neural Networks, CNN, LSTM, Transformers

Numerical investigation of thermo-bioconvection of oxitactic micro-organism in a tilted square cavity heated sinusoidally

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This study examines the thermo-bioconvective flow in a square tilted porous cavity, which is heated sinusoidally and contains oxitactic microorganisms. The bio-convection flow in porous material is formulated using the Darcy model with the Boussinesq approximation. The governing equations are expressed in terms of dimensionless stream function, concentrations, and temperature. For a wide variety of relevant parameters, including Rayleigh number Ra = $10, 100$, bioconvection Rayleigh number Rb = $10, 100$, Lewis number Le = $1, 10$, Peclet number Pe = $0.1, 1$, and slanted angle $\epsilon = 0, \pi/6, \pi/3, \pi/2$, numerical results are produced using the finite difference approach. The average Nusselt number Nu, average Sherwood number Sh, and average density of motile microorganisms Nn are thoroughly analysed.

Keywords: Discontinuous Galerkin Method, Locally Conservative, Convergence, Stable.

Nonlinear Rotating Rayleigh-Bénard Convection in a Dielectric Fluid under a Vertical AC Electric Field

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The linear and nonlinear behaviour of rotating Rayleigh-Bénard convection in a dielectric fluid under a vertical AC electric field is analyzed with stress-free boundary conditions. The nonlinear governing equations are solved using a regular perturbation method. The effects of physical parameters, such as the Taylor number, electric Rayleigh number, and Prandtl number, on the threshold values for the onset of convection are investigated. It is observed that, at the onset of convection, the system exhibits either stationary or oscillatory convection depending on the choice of control parameters. Flow visualizations are analyzed using streamlines. The concept of a heat function is employed to illustrate convective heat transport within the channel, and the energy distribution is examined. The average heat transport rates are evaluated, and power-law relations between the average Nusselt number and Rayleigh numbers are determined. Additionally, regression coefficients for the average Nusselt number are computed using deep learning techniques.

Keywords: Rayleigh-Benard convection, dielectric fluid, electric field, non-linear analysis

Numerical Simulations and Modeling of Geodynamo

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Geoscientists describe the outer core of the Earth as "geodynamo." For a planet to have a geodynamo, it must rotate, it must have a fluid medium in its interior, the fluid must be able to conduct electricity, and it must have an internal energy supply that drives convection in the liquid. Variations in rotation, conductivity, and heat, impact the magnetic field of a geodynamo. Earth's magnetic field is crucial to life on our planet. It protects the planet from the charged particles of the solar wind. Without the shield of the magnetic field, the solar wind would strip Earth's atmosphere of the ozone layer that protects life from harmful ultraviolet radiation. Although Earth's magnetic field is generally stable, it fluctuates constantly. As the liquid outer core moves, for instance, it can change the location of the magnetic North and South Poles. Geoscientists cannot study the core directly. All information about the core has come from sophisticated reading of seismic data, analysis of meteorites, lab experiments with temperature and pressure, and computer modeling. Complex computer modeling has also allowed scientists to study the core. In the 1990s, for instance, modeling beautifully illustrated the geodynamo—complete with pole flips. Direct numerical simulations of geodynamo flows, where all continuum spatial and temporal scale are fully resolved for a large system undergoing unsteady motion, have advanced significantly over the last two decades or so. Such simulations have been used to examine a large number of multiphase systems and have resulted in a significantly improved understanding of their dynamics. The challenges now are twofold: How to use the results to increase our ability to predict geophysical flows and how to conduct direct numerical simulations of such complex systems. The interesting link between the dynamics of geophysical fluid flows and their vortical structures in physical space will be elucidated in this talk using the finite volume method and dynamical systems with the physical setup and material properties that are similar to those considered in the experimental work available in the literature. The transition of structures with respect to the control parameters arising in the system will also be discussed.

Keywords: Earth's outer core; plane layer dynamo; Direct numerical simulations; vortical structures.

A New Solution for the Flow of a Fluid with Heat Transfer: Variety of Boundary Conditions

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The boundary layer flow past stretching/shrinking sheet is widely discussed due to their significance in chemical and engineering applications. A class of laminar boundary layer flows driven by a permeable stretching/shrinking boundary with power-law velocities is under investigation as well as in the presence of mass transpiration and Darcy-Brinkman porous media.

The fluid flow is modelled into coupled highly non-linear partial differential equations and these are mapped into nonlinear ordinary differential equations via similarity transformations, which as a consequence are analytically solved.

The domain of solution so derived is a function of mass transpiration, stretching/shrinking boundary, Brinkman viscosity ratio and power-law index. The associated nonlinear equations exhibit lower- and upper-branch solutions that reveal very interesting axial and transverse profiles for various physical parameters under different cases of power-law indices. The boundary-layer effect of various power-law indices over the moving surface is thoroughly revisited in the present study to include the influence of mass transpiration and porous media. In the mass suction case, velocity is a monotonically decreasing function and highest velocity happens at the wall. In the mass injection case, the highest velocity does happen in the fluid region.. Interestingly, we can obtain an exact analytical solution for the velocity though the equation is non-linear.

Keywords: Similarity transformation, Mass transpiration; Brinkman ratio; Power-law index; Darcy-Brinkman model.