BRNS sponsored
Coordinated research project on

Uncertainty analysis of engineering and environmental systems

(2012-2015)

Overall objectives

- Develop broad based modeling, experimental and computational tools to address a wide spectrum of problems encountered in the area of uncertainty analysis of engineering and environmental systems.
- To apply these tools for solving a range of engineering problems that are of importance to nuclear industry.
- To contribute to the capacity building in the country in an advanced and difficult area of engineering research by training young researchers

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Themes

- **Safety and global sensitivity analyses of structures with alternative uncertainty models**
- **Stochastic modeling of hydration process in concrete: investigation into creep and shrinkage**
- **Petrographical, chemical and computational studies on concrete at high temperature**
- **Studies on fatigue crack growth in graphite**
- **Uncertainty quantification in multiscale analysis of nanocomposite materials**
- **Stochastic modeling of groundwater flow and contaminant transport modeling at the proposed uranium tailings pond**
- **Development of probabilistic design and analysis procedures in radioactive waste disposal in NSDF and design of NSDF closure**

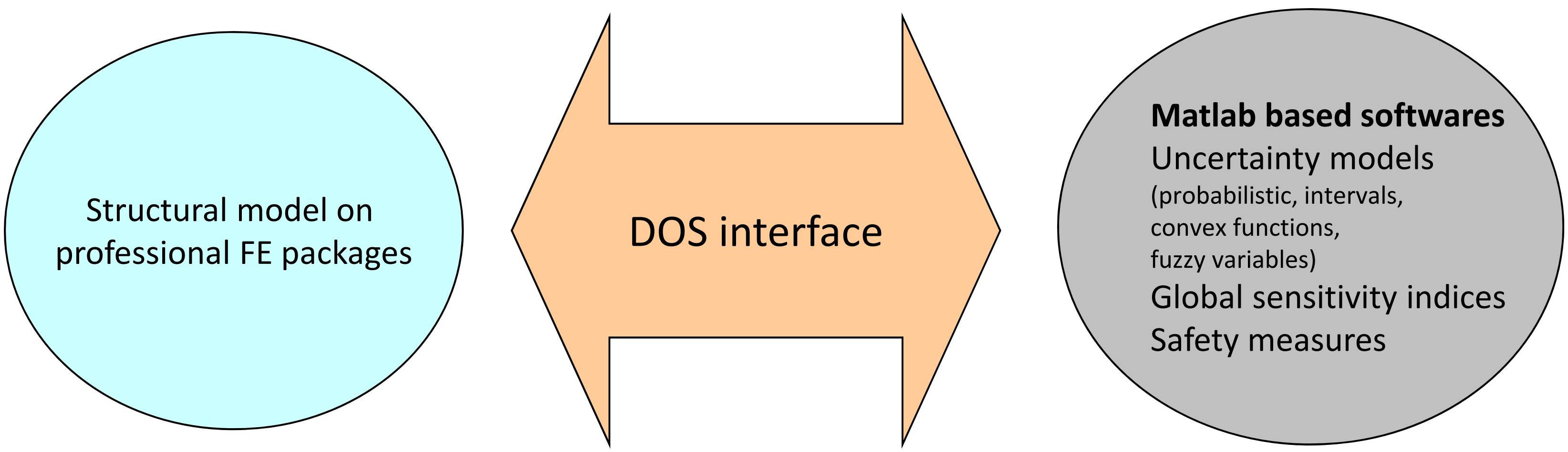
Project-1

Safety and global sensitivity analyses of structures with alternative uncertainty models
(C S Manohar and M Sekhar)

To develop a suite of unified computational methods for assessment of safety of structures when the underlying uncertainties are modeled using interval analysis, convex functions, fuzzy sets, and (or) probabilistic models. Examine the inter-relation between alternative models of safety. Tackle forward and inverse reliability problems and questions on system reliability.

To develop simulation based methods for evaluation of variance based global sensitivity factors for structural engineering applications taking into account the non-Gaussian distributions and mutual dependence of the basic random variables. Examine relations between these sensitivity factors and those obtained in reliability analysis. Explore the nature of global sensitivity measures when uncertainties are modeled using non-probabilistic tools.

Interface the algorithms developed in (a) and (b) above with FE based models for structures created on professional packages (such as NISA and Abaqus).
Illustrate the procedures developed on case studies involving broad ranging structural engineering problems encompassing structural nonlinearities, static/dynamic loads, and thermo-mechanical effects.



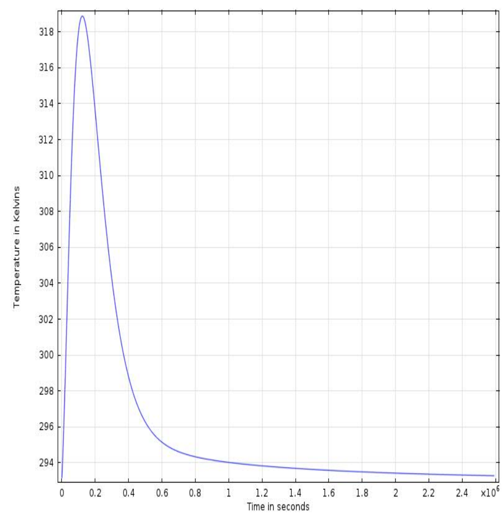
Project-2

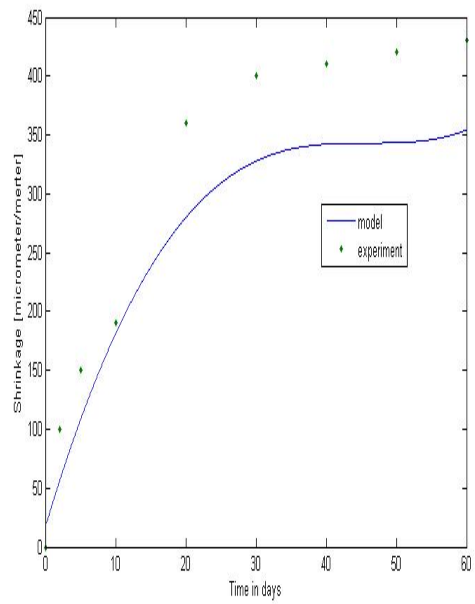
Stochastic Modeling of Hydration Process in Concrete: Investigation into Creep and Shrinkage (Ananth Ramaswamy, K Sajeev, and C S Manohar)

Develop a cement hydration based computational model for concrete that accounts for variations in material properties of the concrete mix constituents, relative humidity and temperature effects.

Include effects of uncertainties associated/ inherent in the model and its parameters on hydration and consequently on the mechanical properties of concrete.

Assess the influence of material properties of mix ingredients, humidity and temperature on mechanical properties of concrete. Model validation through simulation of structural concrete responses.



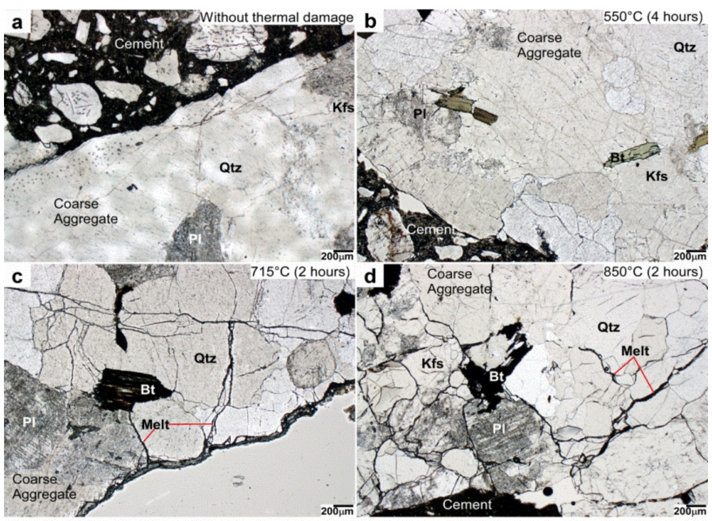


Development of heat of Hydration over time and Comparison of Shrinkage predictions of model with test data

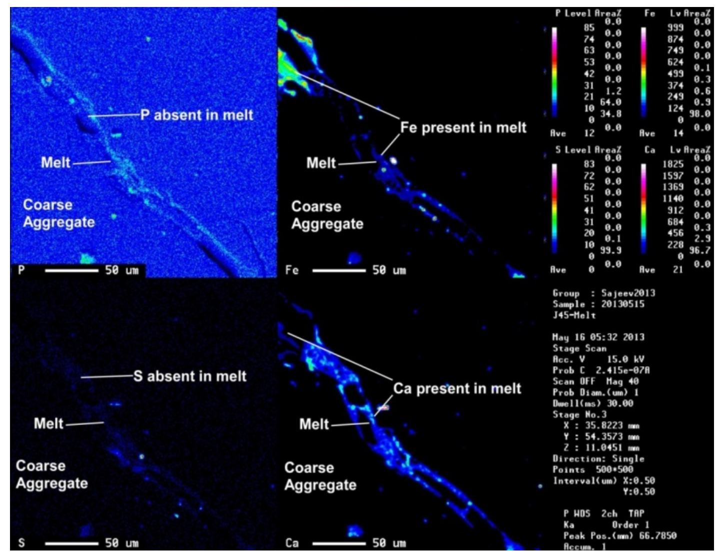
Project-3

Petrographical, Chemical and Computational Studies on Concrete at High Temperature (K Sajeev, Ananth Ramaswamy, and C S Manohar)

1. Behavior of coarse aggregate when exposed to different temperature.
2. Melting of coarse aggregate and melt migration effect.
3. Chemical diffusion and chemical reaction at high pressure temperature conditions.
4. Develop a data set on the behavior of concrete to fire (very High Temperature) with different coarse aggregate material (rocks).
5. Concrete degradation model under thermo-mechanical loading will be developed and validated with available test results from the present study and others reported in the literature.
6. Uncertainties that influence the material properties of mix ingredients, moisture and heat transfer processes and their effect on mechanical properties of concrete will be studied.
7. Results from tests on structural members exposed to high temperature and loading will then be used to validate the model.



Photomicrographs of concrete samples from undamaged sample (a), exposed to 550°C for 4 hours (b), 715°C for 2 hours and 850°C for 2 hours.



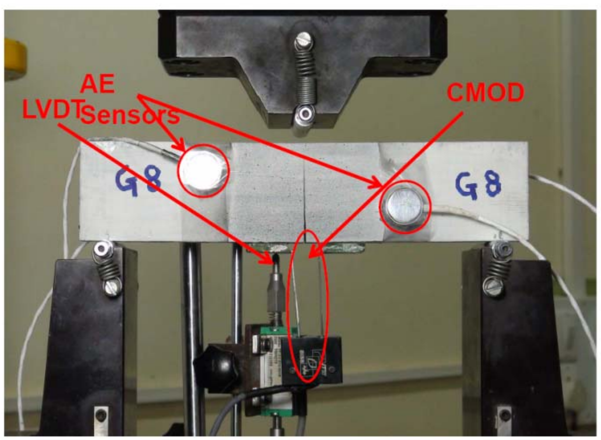
X-ray elemental mapping of granite aggregate after exposed to 850°C for 4 hours. Note the Ca-Fe bearing glass filled along the fractures. P and S is absent in the glass.

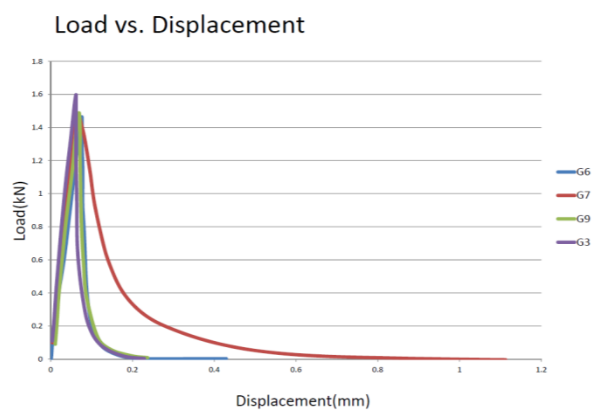
Project-4

Studies on Fatigue Crack Growth in Graphite (J M Chandra Kishen and C S Manohar)

The proposed study deals with the fatigue crack propagation in graphite. The fatigue crack growth curve for graphite would be developed using the principles of fracture mechanics. This would require extensive experimental data. The data from experiments would help in identifying the threshold stress intensity factor for graphite below which there would be no crack propagation and also to classify the different regimes of crack growth. Furthermore, an analytical crack propagation law would be proposed from first principles using the concepts of dimensional analysis. Various parameters related to loading (frequency, amplitude, load ratio), geometry (size, crack length) and material (tensile strength, fracture toughness) would be considered in the analytical model to describe the rate of crack propagation. Since, most of these parameters are random in nature, a probabilistic analysis would be carried out to determine the sensitivity of each parameter to crack growth. The steps involved in this study would include:

- determination of important elastic and fracture properties of graphite, namely Mode I and Mode II fracture toughness (K_{Ic} and K_{IIc}), specific fracture energy (G_F), length of fracture process zone, the brittleness number, stress-crack opening relationship, R-curve, tensile strength and width of fracture process zone.
- determination of fatigue crack growth curve through fatigue tests on small compact tension graphite specimens.
- development of an analytical crack propagation law from first principles to describe the rate of fatigue crack growth.
- determination of sensitivity of various parameters involved in the crack growth law through probabilistic studies.





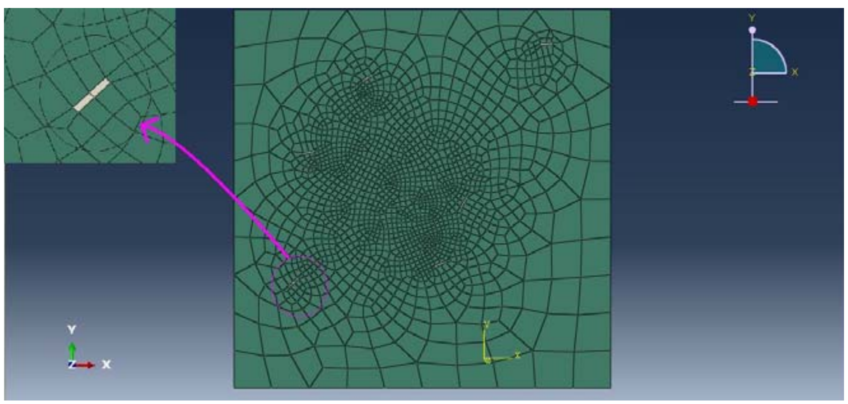
Experimental studies on fracture of graphite

Project-5

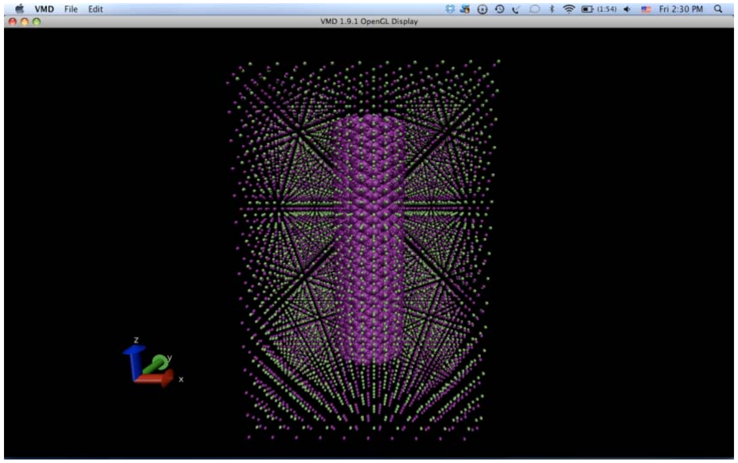
Uncertainty quantification in multiscale analysis of nanocomposite materials (Debraj Ghosh and J M Chandra Kishen)

Develop a multiscale model for a ceramic nanocomposite reinforced with nanotubes. The nanocomposite is already modeled and analyzed using molecular dynamics (MD), the multiscale part is about to start.

Damage analysis of a graphite block considering randomly distributed microcracks. This work also has seen some progress. An ABAQUS model is developed for a small graphite blocks with a few microcracks and analyzed.



FE model of a graphite block with microcracks modeled using cohesive elements



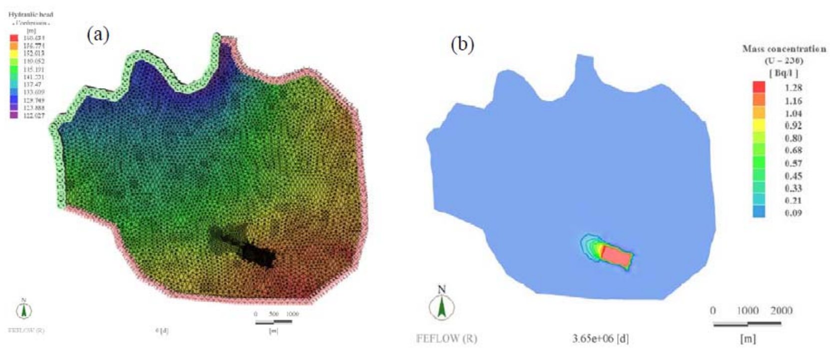
Molecular model of a nanocomposite

Project-6

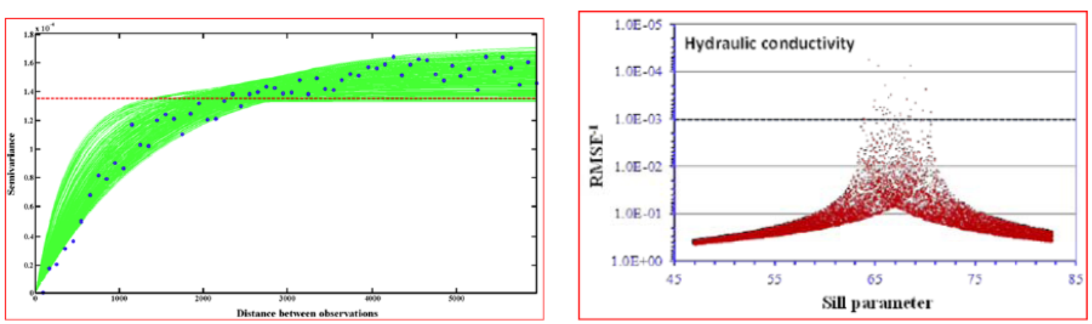
Stochastic modeling of groundwater flow and contaminant transport modeling at the proposed uranium tailings pond (M Sekhar and C S Manohar)

Develop and test methods for tackling the uncertainties in parameters, conceptual model and scenarios applicable to the problem of flow and contaminant transport.

Application of these methods near uranium mine tailing pond sites to simulate the prediction uncertainty in the contaminant concentrations due to the combined effects of these uncertainties using numerical models of flow and contaminant transport.



FEEFLOW model grid for the site (b) U-238 concentration plumes at the end of 10000 years from the simulations of the contaminant transport from the Uranium tailing pond at this site



(a) (b)

Uncertainty in hydrogeological parameters based on the semi-variogram model and GLUE for studies on the contaminant transport at the Uranium tailing pond site (a) uncertainty in the semi-variogram model, (b) behavioral parameters of the semi-variogram model of hydraulic conductivity

Project-7

Development of probabilistic design and analysis procedures in radioactive waste disposal in NSDF and design of NSDF closure (G L Sivakumar Babu and M Sekhar)

- Literature review in design of radioactive waste disposal modules
- Collection of data pertaining to waste characteristics, NSDF field condition and laboratory testing, also collect data from literature on properties and variations
- Analysis of data of laboratory/field test results.
- Analysis of typical designs using various computational software such as Pollute, Hydrous 2D, HELP and FLAC
- Analysis of role of variability and uncertainties and formulation of limit state functions for different designs in landfills and reliability analysis.
- Report preparation.