Coordinated Research Project

On

Uncertainty Analysis of Engineering and Environmental Systems

At

Indian Institute of Science, Bangalore

in collaboration with

Board of Research in Nuclear Sciences, Mumbai

&

Bhabha Atomic Research Centre, Mumbai
(Department of Atomic Energy)

IISc **BRNS** **BARC**

BACKGROUND

Quantitative modeling of uncertainties in safety-critical engineering systems such as nuclear power plants is of fundamental importance. Over the past several years, the Department of Civil Engineering at the Indian Institute of Science has been actively involved in R&D and education activities in the areas of stochastic analysis of engineering system. This has led to a host of publications in leading international journals, development of several graduate courses (covering probabilistic modeling, random vibration analysis, structural reliability analysis, seismic risk analysis of engineering systems, stochastic finite element methods, stochastic calculus, probabilistic system identification, and Monte Carlo simulation methods), research training of masters and doctoral students, successful execution of several sponsored research projects, interactions with industries on problems of safety analysis, and contributions to continuing education programmes. Through the present suite of proposed collaborative research programmes, a group of faculty members from the Department aims to focus their energies on addressing wide ranging problems that are of relevance to nuclear power plant engineering programmes of the Country. Various themes of research that have been developed in collaboration with scientists from BARC/BRNS include the following:

- Safety and global sensitivity analyses of structures with alternative uncertainty models (Investigators: C S Manohar and M Sekhar)
- Stochastic Modeling of Hydration Process in Concrete: Investigation into Creep and Shrinkage (Investigators: Ananth Ramaswamy, K Sajeev, and C S Manohar)
- Petrographical, Chemical and Computational Studies on Concrete at High Temperature (Investigators: K Sajeev, Ananth Ramaswamy, and C S Manohar)
- Studies on Fatigue Crack Growth in Graphite (Investigators: J M Chandra Kishen and C S Manohar)
- Uncertainty quantification in multiscale analysis of nanocomposite materials (Investigators: Debraj Ghosh and J M Chandra Kishen)
- Stochastic modeling of groundwater flow and contaminant transport modeling at the proposed uranium tailings pond (Investigators: M Sekhar and C S Manohar)
- Development of probabilistic design and analysis procedures in radioactive waste disposal in NSDF and design of NSDF closure (Investigators: G L Sivakumar Babu and M Sekhar)

BRIEF DESCRIPTION OF THE PROJECTS

- **Safety and global sensitivity analyses of structures with alternative uncertainty models**

  It is proposed to develop mathematical models (based on theories of probability, interval analysis, convex modeling and fuzzy sets) for uncertainties in the specification of loads and system parameters for externally loaded engineering structures and subsequently evaluate measures of structural safety and global sensitivity using finite element modeling, Monte Carlo simulations, and optimization tools. Furthermore, the tools thus developed are proposed to be integrated with professional finite element analysis packages such as NISA and Abaqus.

- **Stochastic Modeling of Hydration Process in Concrete: Investigation into Creep and Shrinkage**

  The proposed study aims to develop a hydration based hygro-thermo-chemo-mechanical model for predicting mechanical properties of concrete. The short and long term predictions of time dependent deformations are sensitive to both material parameters of the mix, the ambient environmental conditions and the uncertainties in hydration and related gradient driven processes. The influence of parameter uncertainties will be accounted for in the model development. Time dependent deformations in concrete, both creep and shrinkage, play a critical role in prestressed concrete structures, such as bridge girders, nuclear containment vessels, etc. These strains result in losses, through release of prestress, and thereby influence the safety of these structures. Data on the effects of ambient humidity and temperature on time dependent deformations in normal and heavy density concrete obtained experimentally in an earlier study together with other reported information in the literature will be employed in the present study for model validation. Predictions of creep and shrinkage in structural elements, such as beams and slabs using this model will also be undertaken as a validation of the modeling features.

- **Petrographical, Chemical and Computational Studies on Concrete at High Temperature**

  The proposed study aims to work on the effect of high temperature (e.g., fire) on concrete and its strength degradation which in turn influence the safety of these structures. Many such previous studies internationally concentrate on the dehydration and degradation of cement but less emphasis has been given to the aggregate and its behaviour under different temperature conditions. Here we propose a study with more emphasis on the type of course and fine aggregate (e.g., granite or other rocks formed at very high temperature pressure conditions) and its behaviour when exposed to different temperature conditions. Experimental studies to assess effects of high temperature will be undertaken as part of the proposed study and used to validate the model development. The coarse and fine aggregates for the concrete samples will be selected after calculating the formation (crystallization) temperature and pressure of the rock through mineral composition and iso-chemical phase diagrams. Petro-graphical studies on aggregate samples after being exposed to different temperature will be conducted and information obtained on melts and other thermodynamic aspects derived from these studies would serve as inputs to the hydration based model to account for aggregate effects on the development of concrete. The chemical diffusion during the high temperature may also have a roll in controlling the strength of concrete. This will be assessed in a micro scale from samples exposed at different temperature. The integrated hydration based model accounting for aggregate effects will be used to predict the degradation of concrete under high temperature conditions. Uncertainties inherent in the various physical process parameters will be accounted for in the simulation. Experimental studies on structural member responses to fire / high temperature will be used to assess the capabilities of the model.

- **Studies on Fatigue Crack Growth in Graphite**

  Components of nuclear power plants make use of graphite as one of their primary materials. These components are subjected to varying amplitude of loads. Hence, it is proposed to carry out experimental and analytical studies on graphite under static and fatigue loading. A fatigue crack growth curve would be developed using the experimental data for graphite. A crack propagation law would be proposed from first principles using the theory of fracture mechanics and concepts of dimensional analysis. A probabilistic study would be conducted in order to determine the most sensitive parameters involved in fatigue failure of graphite.

- **Uncertainty quantification in multiscale analysis of nanocomposite materials**

  This project is aimed at developing an uncertainty quantification tool for multiscale analysis in a nanocomposite material made up with carbon nanotubes (CNT) in an Alumina matrix, with a potential application being a quoting material. In the multiscale analysis, the nanotube will be analysed using molecular dynamics (MD), and the metal matrix will be modeled and analysed using the finite element (FE) method. Broadly the work will have two parts (1) studying the effect of uncertainties in the behavior (such as elastic response, buckling) of the CNTs, (2) studying the effects of these uncertainties in the nanocomposite through a multiscale analysis. A probabilistic framework will be used to model and analyse uncertainty. A homogenisation method will be used for multiscale analysis. For the molecular dynamics simulation, the freely available computer code LAMMPS will be used, whereas the FE codes will be written in-house, at least in the first phase. Later on an attempt will be made to couple ABAQUS with the atomistic code for multiscale analysis. Among the sources of uncertainty, defects, chirality, random orientation, distribution of CNTs, heterogeneity in the properties of the alumina matrix will be considered.

- **Stochastic modeling of groundwater flow and contaminant transport modeling at the proposed uranium tailings pond**

  Analysis of groundwater flow and contaminant transport near the proposed uranium tailing ponds needs to consider the uncertainties in the spatial variability of subsurface flow and transport parameters (hydraulic conductivity, porosity, dispersivity, reaction parameters of the contaminant etc.), conceptual model uncertainty and scenario uncertainty, which results in the uncertainty in the prediction of concentration fronts. The aim of this project is to analyze the probabilistic behavior of contaminant concentrations in three dimensions in the vicinity of the tailing ponds. Methods to tackle uncertainties due to parameters, conceptual model and scenario will be investigated that are applicable to this problem. Stochastic modeling will be performed using numerical models of flow and contaminant transport to simulate the prediction uncertainty in the contaminant concentrations due to the combined effects of all the three uncertainties. The field investigations carried out at the tailing pond site would be utilized for performing model calibration and parameter estimation.

- **Development of probabilistic design and analysis procedures in radioactive waste disposal in NSDF and design of NSDF closure**

  Low and intermediate level radioactive waste generated at various stages of nuclear fuel cycle and from other applications (e.g. medical, agriculture and various research labs) are treated, conditioned and disposed off in engineered disposal modules of Near Surface Disposal Facility (NSDF). In India this practice is being adopted successfully since over five decades. The multi barrier approach adopted in disposal programme minimizes the risk to humans and the environment from the harmful effects of radioactive waste. A number of geotechnical and geo-environmental parameters are used in the design of multi barrier disposal modules, liners as well as cover system, and in the assessment of stability and settlement response of cover material as well as migration of contaminants. These parameters have significant variability and are correlated and hence considerably influence decisions pertaining to design, analysis as well as performance. The implications also have significant influence on the risk assessment. In the proposed research, waste disposal modules currently being used for disposal of radioactive wastes in NSDF will be examined. Field and laboratory test results provided by BARC will be used to obtain relevant properties for modeling and their variations. Reliability analysis of covers, lining systems, slope stability, settlement predictions and contaminant migration will be performed. Probabilistic analysis using simple first order methods, using Monte Carlo simulations and numerical analysis using FLAC will be performed. The results of the study will be used to examine the current guidelines of disposal modules design and construction.