# Workshop on Geomaterials

## Prague

## 25 - 27 September 2006

| | |
|---|---|
| Place: | Seminar room K1 (2nd floor), Faculty of Mathematics and Physics, Charles University, Sokolovská 83, Praha 8 – Karlín |
| Date: | 25 – 27 September 2006 |
| Internet: | http://www.karlin.mff.cuni.cz/~prusv/wog |

# Program

**Monday September 25, 2006**

| | |
|---|---|
| 09:00 - 09:10 | Josef Malek - Introductory remarks |
| 09:10 - 09:55 | K.R. Rajagopal (Lecture I: Overview of the theme of the workshop) |
| 10:10 - 11:05 | Ian F. Collins (Lecture I: Basic properties of soils) |
| 11:20 - 12:15 | J. Murali Krishnan (Lecture I: The physical and chemical structure of asphalt: with a brief history of their usage and availability) |
| 12:30 - 15:00 | break for lunch |
| 15:00 - 15:55 | Ian F. Collins (Lecture II: Extant models of clays and sands) |
| 16:10 - 17:05 | J. Murali Krishnan (Lecture II: The mechanical behavior of asphalt) |
| 17:20 - 18:15 | Barry Bernstein (Lecture I: A thermodynamic theory of finite viscoelastic strain) |

**Tuesday September 26, 2006**

| | |
|---|---|
| 09:00 - 09:55 | J. Murali Krishnan (Lecture III: Some of the open issues in modeling asphalt) |
| 10:10 - 11:05 | Barry Bernstein (Lecture II: A thermodynamic theory of plasticity and of hypoelasticity) |
| 11:20 - 12:15 | Eyad Masad (Lecture I: Modeling and Experimental Measurements of Water Transport in Asphalt Mixes Using X-ray Computed Tomography Images - part one) |
| 12:30 - 15:00 | break for lunch |
| 15:00 - 15:55 | Ian F. Collins (Lecture III: Thermomechanical models) |
| 16:10 - 17:05 | Eyad Masad (Lecture I: Modeling and Experimental Measurements of Water Transport in Asphalt Mixes Using X-ray Computed Tomography Images - part two) |
| 17:20 - 18:15 | K.R. Rajagopal (Lecture II: A general thermodynamic framework for the study of materials undergoing entropy producing processes) |

**Wednesday September 27, 2006**

| | |
|---|---|
| 09:00 - 09:55 | Eyad Masad (Lecture III: Damage and Anisotropic Viscoelastic--Viscoplastic Model for Hot Mix Asphalt) |
| 10:10 - 11:05 | Barry Bernstein and Ecevit Bilgili (Lecture III: Heat generation and pulverizing rubber) |
| 11:20 - 12:15 | R.G. Robinson (Lecture I: Interfacial friction between soils and solid surfaces) |
| 12:30 - 15:00 | break for lunch |
| 15:00 - 15:55 | R.G. Robinson (Lecture II: Consolidation of lumpy fill--an experimental investigation) |
| 16:10 - 17:05 | K.R. Rajagopal (Lecture III: Mechanics of Liquefaction) |
| 17:20 - 18:15 | Discussions |

# Lectures

## Barry Bernstein

*Illinois Institute of Technology, Chicago, USA*

### Lecture I: A thermodynamic theory of finite viscoelastic strain

A large strain visco-elastic theory, commonly now known as BKZ (Bernstein, Kearsley an Zapas) is presented. It is a non-equilibrium thermodynamic theory and gives a proper balance of energy and positive entropy production. It is a fluid theory in the sense that, although it can support transient shear stresses when out of thermodynamic equilibrium, it cannot do so in thermodynamic equilibrium. Its internal energy density depends only on current instantaneous temperature and specific volume so that during an isothermal isochoric stress relaxation, no heat is flowing: it is merely losing its ability to return as work the energy put into the deformation in the first place. Some experimental results on the mechanical predictions are presented.

### Lecture II: A thermodynamic theory of plasticity and of hypoelasticity

One possible generalization of infinitesmal elastic strain to large strain behavior is a rate theory known as hypoelasticity, the small strain version of which figures in the theory of plasticity. A unified set of elastic-plastic equations is presented in which plasticity occurs as a singular situation, which happens when the von-Mises yield condition is reached, in which case the equations automatically turn into those of Prandtl-Reuss. As long as loading is maintained, the stable solution is one in which the von-Mises condition continues to hold and it is readily shown that the entropy production is positive. Upon unloading, there is a return to elastic behavior. One thing that is interesting is that the stresses, and generally not the strains, serve as state variables. With this in mind, the thermodynamics is readily carried over to the theory of hypoelasticity when dealing with finite strain.

### (Barry Bernstein and Ecevit Bilgili) Lecture III: Heat generation and pulverizing rubber

The pulverization of materials, such as rubber, can be part of a process of recycling them. One method of doing so, is to pass them through an extruder designed for the purpose. Such a process has been named SSSE for Solid State Shear Extrusion. In studying this method, it was found that the heat generated can be severe enough to burn the material being extruded, and so a study was made of the heat generation and conduction. This study let to a redesign of the extruder so to remove heat by circulating water both outside the extruder's barrel and inside its screw. It also led to the study of functionally graded materials, which are non-uniform in thermo-mechanically properties.

---

## Ian F. Collins

*Department of Engineering Science, Auckland, New Zealand*

The object of this series of lectures is to describe the current state of the art of modeling geomaterials, particularly sands and clays. Emphasis will be put on recent developments based on the ideas of thermomechanics, and on highlighting unresolved issues.

### Lecture I: Basic properties of soils

Following an introductory, historical review, the basic concepts needed to formulate models of soils will be discussed. These include “cohesion”, “internal friction angles”, “effective stress”, “strength” and “failure”, “dilation”, “critical voids ratios and critical states”, “loose” and “dense” sands, “normally- and over-consolidated” clays. One of the problems in formulating models of geomaterials is the limited number of possible experiments that can be performed. These will be summarized and their intrinsic difficulties discussed. Specifically in tri-axial and shear tests, the initial preparation procedure is a key issue, as is the occurrence of diffuse or localized bifurcations. In this situation, the availability of simulated experiments, using discrete element methods (DEM), is highly valuable.A review of problems, such as slope failure and liquefaction, which are important to the geotechnical practitioner will also the outlined

## Lecture II: Extant models of clays and sands

This lecture will provide a critical overview of currently available models. The main issue is that very few of these have any conceptual mechanical or physical basis. They are in the nature of “recipes” which give formulae which can reproduce particular sets of experimental results, but which throw no light on the underlying physical mechanisms, and hence can not be used, with confidence” in “real world” situations. These models are based upon the classical theory of elastic/plastic solids, which has been so successful in modeling metals. However some new ideas have to be introduced to describe soil behavior, notably non-associated flow rules, volumetric hardening and in some cases bounding surfaces. Attention will be concentrated upon the “Critical State Models”, which are the most successful family of such models. Their strengths and weaknesses will be reviewed.

## Lecture III: Thermomechanical models

This lecture is concerned with the development of thermomechanically based models, using the procedures originally proposed by Ziegler. In this approach the details of the elastic/plastic models are derived from two postulated thermodynamic potentials – the free energy and the dissipation rate potential. This approach enables the modeler to include aspects of the micro and meso-level behavior, by appropriate choice of these potentials. This approach has introduced a number of concepts and results, new to soil mechanics. These include (a) an explanation of why the flow rules are non-associated and provides an explicit procedure for their formulation, which does not include the classical “plastic potential”(b) the concept of “frozen elastic energy”(c) the granular nature of the material can be modeled by introducing internal constraints that “do no work”(d) the nature of the micro-level in homogeneities are related to the shape of the continuum level yield surfaces (e) many of the issues of existence and uniqueness of critical and related states can be answered (f) some widely used models have been shown to violate the second law of thermodynamics. The lecture will conclude with some “open issues”.

---


# J. Murali Krishnan

*Department of Civil Engineering, Indian Institute of Technology, Chennai, India*


## Lecture I: The physical and chemical structure of asphalt: with a brief history of their usage and availability

Other than mud, stones and wood, no material can match asphalt when it comes to continuous and diverse uses that it has been put to from the beginning of recorded history to date. More importantly, each new day seems to bring newer applications for this material that was found in abundance naturally and which is produced today as a by-product during the refining process of crude oil. The Shell handbook lists over two hundred and fifty applications for asphalt. This talk will focus on the wide spread usage of asphalt from pre-historic time to its current and most wide-spread usage as the material of choice for constructing highways and runways. This talk will also detail the chemical and physical characteristics of asphalt and how even today the most elementary constitution of asphalt is still unresolved.

## Lecture II: The mechanical behavior of asphalt

Most of the studies carried out on constitutive modeling of asphalt model pure asphalt either as a Newtonian fluid or as a linear viscoelastic fluid over a wide range of temperatures. Also, the complexity related to the study of the constitutive behavior of asphalt is compounded by the fact that asphalt is a mixture of different chemical species some of which are amorphous and some of which are crystalline in nature. The relaxation mechanisms of asphalt are diverse with different relaxation mechanisms at different temperatures. In this lecture, we illustrate the use of a thermodynamic framework for the constitutive modeling of asphalt and we model asphalt as a material with multiple relaxation mechanisms. This framework recognizes the fact that materials like asphalt can exist in more than one natural configuration (for instance, stress free configuration). We use the experimental data available in the literature for asphalt from different sources and demonstrate the efficacy of the model.

## Lecture III: Some of the open issues in modeling asphalt

The issues related to understanding the precise mechanical and thermodynamic response of asphalt are quite complex. In this lecture, three open problems related to asphalt are presented.

The first one is concerned with the aging of asphalt. During the aging of asphalt, degradation of the viscoelastic property of the material takes place. This degradation can be due to chemical reactions taking place in the presence of environment (loss of volatiles, interconversion of the various chemical constituents etc.). On the other hand, it is possible for the material to age due to repeated application of traffic loading. This mechanical aging is essentially due to changes in the internal structure of the material taking place during every load application. Typically, the mechanical and chemical aging takes place simultaneously and this results in quite complex responses. Till today, no significant attempt in modeling the aging of asphalt has been made.

The second issue is concerned with modeling the response of polymer modified asphalt. Asphalts are added with admixtures such as polymer to improve the age resistance properties. Fluorescence microscopy have revealed that addition of 3 % of polymer exhibits a microstructure of polymer dispersed in asphalt matrix whereas addition of 9% of polymer shows a microstructure with asphalt dispersed in polymer matrix. Apparently at some critical percentage of polymers in asphalt, swelling of polymer takes place due to intake of one of the chemical constituents of asphalt resulting in this sudden transition. Also, it is not known how exactly the crystallization kinetics of waxes in asphalt change as polymer is added since polymers also crystallize during the same temperature range. Modeling the response of polymer modified asphalt especially for a complete temperature spectrum involves understanding the issues that take place at the microstructural level and this portion of this talk will highlight some of them.

Standard asphalt emulsions are normally considered to be of the oil in water type and contain from 40% to 75% asphalt, 0.1% to 2.5% emulsifier and 25% to 60% water. Some asphalt droplets may contain smaller water droplets within them; a better description of asphalt emulsion would be water-in-oil-in-water multiple emulsion. In asphalt applications, the emulsions are required to have precise storage stability for a specific period of time and they are required to breakdown due to mechanical rolling. Considering the fact that asphalt emulsions exhibit phenomenon such as viscous sintering, it will be a challenge to model the response of this material. It will also be interesting to look at the mechanical response of emulsified asphalt mixtures.

---


## Eyad Masad

*Texas Transportation Institute, Texas A&M University, College Station, USA*


### Lectures I and II: Modeling and Experimental Measurements of Water Transport in Asphalt Mixes Using X-ray Computed Tomography Images

Moisture damage in asphalt mixtures is caused by the loss of strength and durability due to the presence of moisture at the binder-aggregate interface (adhesive failure) or within the binder (cohesive failure). The presentation will discuss recent efforts for characterizing and modeling moisture damage in asphalt mixtures. It will discuss the development of a numerical model for the simulation of fluid flow in HMA three-dimensional (3-D) microstructure, and the calculation of permeability from the flow field. The HMA microstructure was captured using the nondestructive X-ray computed tomography (CT) technique. X-ray CT images were processed in order to identify and retain interconnected air voids and eliminate isolated voids. The X-ray CT images were analyzed and the results were used to determine the relationship between air void distribution and permeability directional distribution or anisotropy. The computed permeability values were found to correlate well with experimental measurements. The major and minor principal directions of the permeability tensor were found to correspond to the horizontal and vertical directions, respectively.

The presentation will also discuss experiments for measuring moisture transport in asphalt mixtures. Thermocouple psychrometers were used for measuring the total suction in HMA mixes. Suction measurements were related to physical and chemical properties of HMA that influence moisture damage. The suction measurements were used to calculate the moisture diffusion coefficient. The results revealed that mixes with higher diffusion coefficient are those that had poor resistance to moisture damage.

### Lecture III: Damage and Anisotropic Viscoelastic--Viscoplastic Model for Hot Mix Asphalt

This presentation will discuss the development of a damage viscoelastic-viscoplastic model for Hot Mix Asphalt (HMA). The model accounts for the influence of aggregate friction, dilation, anisotropy, damage, confining pressure, and strain rate on HMA response. The influence of the anisotropic aggregate distribution is accounted for in both the viscoelastic and viscoplastic responses. The presentation will also discuss a comprehensive experimental program that is designed such that quantification and decomposition of the response into viscoelastic and viscoplastic components is possible. This experimental program is adopted within a theoretical framework that is capable of modeling HMA response at different temperatures and loading rates. The developed experimental program and theoretical framework were used to analyze repeated creep and recovery tests conducted on three mixes that included aggregates with different characteristics.

X-ray Computed Tomography (CT) and image analysis techniques were used to analyze the microstructure in HMA specimens before and after being subjected to triaxial repeated creep and recovery tests. The microstructure characterization results revealed information about the microstructure evolution during loading that helped in validating the macroscopic measurements, and relating the model's parameters to measured material properties.

---

## K.R. Rajagopal

*Department of Mechanical Engineering, Texas A&M University, College Station, USA*

### Lecture I: Overview of the theme of the workshop

The rationale for the theme of the workshop and the importance of the subject matter with regard to both technological applications and interesting open issues in mathematical modeling will be presented. This will be followed by a brief description of the various talks that are being presented at the workshop and how they are connected to one another will be discussed.

### Lecture II: A general thermodynamic framework for the study of materials undergoing entropy producing processes

A general thermodynamic framework that takes into account the fact that the underlying "natural state" of a body evolves as it undergoes the process, with the g configuration's material symmetry also changing as the process progresses, will be presented. An application of the framework to the development of a mathematical model to describe the response of a complex material such as asphalt that undergoes a variety of chemical reactions and aging, while also exhibiting non-linear mechanical response characteristics.

### Lecture III: Mechanics of Liquefaction

"Liquefaction" of granular solids infused with fluids, not to be confused with liquefying a solid, is a phenomenon wherein at a critical "pore pressure" of the fluid, the mixture of the granular solid and fluid changes its response characteristics from being solid-like to being fluid-like. A mathematical model will be presented for the same, within the context of theory that melds the ideas of the thermodynamic framework presented in the previous talk and mixture theory.

---

## R.G. Robinson

*Department of Civil Engineering, Indian Institute of Technology, Chennai, India*

### Lecture I: Interfacial friction between soils and solid surfaces

The load transfer between soil and structural elements takes place at their interface. The behaviour at the interface plays an important role in the load-deformation response of soil-structure systems such as shallow and deep foundations, retaining walls and reinforced earth. Though the interface studies dates back several decades, there exists some apparent inconsistencies in the reported results. A critical evaluation of past studies indicates that two distinctly different test techniques were adopted in the literature, which influences the test results significantly. The influence of various factors affecting the interface friction is presented and the effect of mode of shear is highlighted.

### Lecture II: Consolidation of lumpy fill--an experimental investigation

Land is often created through reclamation by filling sea or lakes. The ideal fill material is sand or cohesionless materials. However, the cost of such materials is very high and is often not available locally. Therefore, clay is some times used as a fill, in spite of its poor engineering properties. The clay is conventionally, transported and placed at the site as a hydraulic fill in the form of clay slurry and then consolidated by sand surcharge. This requires double handling and therefore, in the present investigation the fill is placed in the form of lumps. The large voids formed between the lumps are closed by applying surcharge load. Some issues like swelling of lumps, consolidation of lumpy fill, permeability and shear strength of the fill are presented.