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Technical session 1e: Analysis

Séances techniques 1e: Analyse

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1 INTRODUCTION

Technical Session (TS) 1e entitled "Analysis" comprised a total of thirty papers addressing a wide range of applications under different topics. The session was held on 14th September, 2005 at 10:30-12:30 and had about a hundred participants. The session started with the opening remarks by the chairman Prof. R. Nova. Prof. A. Murakami then presented the general report for thirty minutes. The general report provided a review of all the papers involved in the session by classifying them into eight groups. The general report can be found in the conference proceedings. Second, five panelists presented the following topics which will be discussed at the session. Each panelist gave a ten minutes presentation.

The Technical Sessions were intended for discussions and debates on issues of importance and interest arising from the papers submitted to the proceedings. The following six main themes have been chosen from the contents of the thirty accepted papers in TS 1e to cover the subjects of the accepted papers.

1) Newly-proposed method: analytical solutions, formulations, constitutive models and numerical algorithms, performance and validation,
2) Deformation and failure of geomaterials: strain localization and instabilities, large strain vs small strain, drained vs undrained,
3) Soil-structure interaction problems: foundations, embankments, retaining walls and underground works, ground improvement and geosynthetics, modeling of soil-structure interface,
4) Dynamic, soil-water coupled and environmental problems,
5) Prediction of soil-structure behavior in fields: selection of proper constitutive model for the problem, parameter determination from laboratory and field testing,
6) Practical design with numerical analysis: making of design charts with numerical analysis, direct use of numerical analysis for practical design.

Five panelists proposed that the following topics were discussed at the session as they are related to one of the chosen topics.

Prof. M. Rouainia: "Constitutive modeling of anisotropy and destructuration of natural soils" related to Theme 1,
Prof. P. Delage: "THMC couplings in geoenvironmental engineering" related to Theme 4,
Prof. A. Gens: "Coupled analysis for materials with double structure" related to Theme 4,
Prof. J. Pestana: "Importance of objective parameter determination for constitutive soil models" related to Theme 1 or 5,
Prof. D.V. Griffiths: "Probabilistic methods applied to classical geotechnical analysis" related to Theme 6.

2 SUMMARIES OF PANELIST PRESENTATIONS

The presentations by the panelists are summarized as follows.

2.1 *Constitutive modeling of anisotropy and destructuration of natural soils by Prof. M. Rouainia*

The mechanical behavior of natural clays is significantly affected by their in situ or initial structure in the form of cementation or interparticle bonding. This behavior can differ substantially from the behavior of reconstituted clays. In addition, when natural clays are deformed they lose their in-situ structure and sensitivity and are transformed into a remoulded material. Another main characteristic of natural soils is anisotropy with respect to both strength and stiffness. This property may be inherent due to the past stress history of the soil, i.e. developed by nature of sedimentation, glacial transportation or in situ weathering, or induced as a result of subsequent plastic deformation. The mechanical characteristics of the soil change as anisotropy develops or gradually degrades must be incorporated into the constitutive modeling. A rate-independent constitutive model for natural clays within the framework of kinematic hardening has been developed by Rouainia & Muir Wood (1999) in which effects of damage to structure caused by irrecoverable plastic strains caused by sampling, laboratory testing, or geotechnical loading, has been included. Extensive triaxial test simulations using this model were carried out on low sensitivity clay from Norrköping, Sweden, and on natural and reconstituted Pisa clay Figure 1 shows the effective stress paths and stress strain relationships from the undrained triaxial test with Norrköping clay. The results obtained have shown the capability of the model to reproduce the appropriate stress-strain relations of natural clays subjected to a variety of stress paths.

The presentation in outline is as follows: first the constitutive model is presented, in which the anisotropy induced by loading histories is introduced through the additional rotational hardening; second the model is validated by comparing its predictions against available experimental data; third robust computational procedures for the numerical integration of the model are formulated.

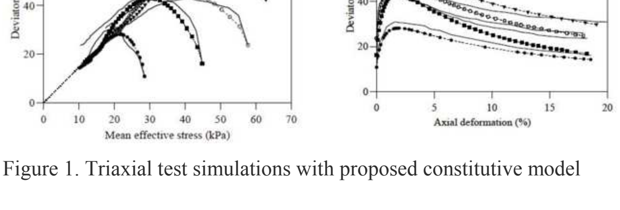


Figure 1. Triaxial test simulations with proposed constitutive model

2.2 *Thermo-Hydro-Chemo-Mechanical (THCM) couplings in Geoenvironmental Engineering by Prof. P. Delage*

Geoenvironmental issues concern a wide range of problems including Soil pollution, Waste disposal and Ground-atmosphere interactions. A lot of diverse, complex and coupled physico-chemical phenomena with temperature effects add to the complexity of standard geotechnical problems, as seen in Table 1. In the Table, the three topics are described in terms of pollutant and geomaterials concerned, together with the phenomena involved. Natural and compacted soils are involved, generally in surface except in the case of nuclear waste disposal.

Some couplings are already accounted for in numerical modeling so as to help predicting the long term behavior of surface or deep (nuclear) waste disposal facilities (see 2.3 by Gens below for example). Other couplings can be accounted for by using existing background in hydrological, chemical or biological engineering. Natural or man made variability however add to the complexity of analysis. Research is progressing in this area and it is thought that progresses in the analysis will help for a better protection of the environment.

Table 1. Coupled THMC phenomena involved in Geoenvironmental issues

a) Soil pollution

	Pollutant	Geomaterial	Phenomena
Accidental	NAPL, other	Vadose zone	Immiscible HC Infiltration, evaporation, venting
Below roads	Ions, heavy metals	Subgrade compacted layers	Water infiltration, pollutant transfer (advection-diffusion), precipitation – dissolution
Active and abandoned industrial facilities	Anything : HC (polar - non polar), chemical heavy metals…	Vadose zone	Water infiltration, pollutant transfer (advection-diffusion), precipitation – dissolution
Atmospheric	Heavy metals, chemical, ashes,…	Vegetal surface layer	Fixation, precipitation, infiltration, transfer

b) Waste disposal

	Pollutant	Geomaterial	Phenomena
Surface Waste disposal (urban, industrial, nuclear…)	Anything HC (polar - non polar), chemical heavy metals…	Compacted clay liner, attenuation layer, cover liner	Leaks, leachate infiltration, ion diffusion, heat effects (heat transfer, water evaporation, vapour transfer, water condensation, liquid transfer), evaporation (cover liner), cracking
Deep waste disposal (nuclear)	Radio-nucleides	Engineered clay barrier, geological barrier (ventilation)	Water infiltration, confined swelling, microstructure changes, heat effects (see above), radio-nucleides diffusion, cracking

c) Ground water interactions

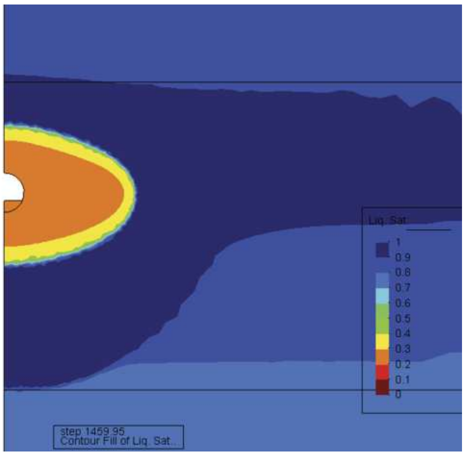
Geomaterial	Phenomena
Natural surface plastic soil (unsaturated or saturated) Damage to buildings (swelling-shrinkage)	Evaporation, water transfer, shrinkage, cracking, swelling, effect of vegetals (grass, trees)
Cover layer of surface waste disposal (urban, industrial, nuclear)	Evaporation, water transfer, shrinkage, cracking, effect of vegetals (grass)

2.3 *Coupled analysis for materials with double structure by Prof. A. Gens*

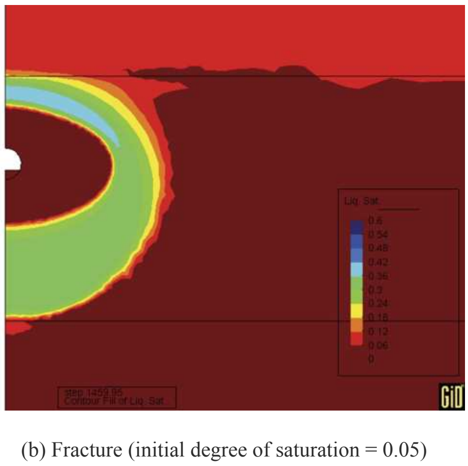
Materials with two (or more) levels of structure are relatively common in Geotechnical engineering. This feature must be accounted for in analysis, especially when performing coupled computations. The following two numerical examples based on thermal-hydro-mechanical coupled theory are presented.

The first one is the simulation of the drift scale test (DST) in a fractured tuff in Yucca Mountain. A double finite element model had to be used because of two different permeability and storage properties of the matrix and the fractures. The length and conductivity of the connection between the matrix and fracture are key parameters in the model. In the test, the evolution of the degree of saturation of the fractures was evaluated by measuring the gas permeability at various stages of the test. The simulated distributions of degree of saturation around the drift are shown in Figure 2. The computed gas permeability variation and the temperature fields around the drift agreed with the measured ones. More details are given in Olivella and Gens (2005).

The second one is the simulation of a large scale mock up heating test in compacted swelling clay. The test involves the observation of a compacted clay barrier subjected simultaneously to heating and hydration. A constitutive model for a double structure material was used in this analysis. The constitutive model (Sanchez et al. 2005) is built on a conceptual approach for unsaturated expansive soils in which the fundamental characteristic is the explicit consideration of two pore levels. The generalized stress-strain rate equations are derived within a framework of multi-dissipative materials, which provides a con-



(a) Matrix (initial degree of saturation = 0.92)



(b) Fracture (initial degree of saturation = 0.05)

Figure 2. Degree of saturation around the drift after 4 years

sistent and formal approach when there are several sources of energy dissipation. The model is formulated in the space of stresses, suction and temperature; and has been implemented in a finite element code. The proposed model is able to reproduce satisfactorily the measured water inflow into the test as well as the evolution of relative humidity at different locations of the swelling clay barrier.

The way of incorporating double structure features in analysis depends on the problem under consideration. It may involve the numerical formulation itself (double mesh in the case of a fractured tuff) or the constitutive model adopted (double structure model for compacted swelling clay).

2.4 *Importance of parameter selection in coupled deformation-flow problems by Prof. J.M. Pestana*

There exist many well known models which describe the deformation behavior of geotechnical materials. However, these models often are overly simplified for their specific interest, and it becomes very difficult to extend the use of the same model beyond their range of applicability. Furthermore, many model parameters have to be evaluated piecewise linearly over the range of interest (i.e., parameters are not constant), since they change as the deformation, time, temperature or other significant process progresses. The use of model that does not consider these effects will result in misleading predictions, or will not capture the full range of mechanisms involved.

A good example addressing the importance of parameter determination in coupled problems is that of sand reservoir compaction and subsidence problem. Conventionally people consider sand as relatively incompressible, and the rate effect is often ignored. Seldom is the effect of temperature on the deformation response of sand or the change in hydraulic conductivity during deformation taken into account. However, in an extreme environment like in an oil reservoir, all of these are significant, and they are closely related to each other. Particularly, flow properties, such as the hydraulic conductivity, are subject to change as the material is compacted and the sand particles crush due to the change in stress. Stress changes due to oil production results in a reduction in porosity, a change in gradation due to particle crushing, and thus an overall decrease in hydraulic conductivity. To completely describe such a complex coupled deformation-flow behavior, the need of a better framework and constitutive model, which describes the changes in compressibility and hydraulic conductivity over a wide range of stresses, is self evident.

Pestana and Whittle (1995) proposed a simple, yet comprehensive four-parameter compression model, which describes the non-linear volumetric behavior of cohesionless soils in hydrostatic and one-dimensional compression. This compression model is a good backbone to describe a change in porosity, and when it is coupled with Kozeny-Carman equation, it allows us to predict permeability variation. Kim and Pestana (2005) extended the original model to include the variation of specific surface area in the Limiting Compression regime where particle crushing is a significant mechanism. Tests showed that the stress-permeability relationship is highly non-linear and the decrease in permeability can be orders of magnitude, if high enough stress is applied (David et al., 1994). Kim and Pestana (2005) successfully modeled this stress-permeability coupling (Figure 3). Only one set of parameters captures the entire compression behavior and hydraulic conductivity variation as a function of stress as opposed to other models which require stress-level dependent parameters. The stress dependency of permeability cannot be modeled properly, if simple linear elastic deformation model or model with highly variable model parameters for different stress level is used.

In conclusion, we should aim at a better framework of soil behavior which is likely to involve a more sophisticated soil model. An overly simplified model or extrapolating model beyond their applicability will result in poor prediction. A better model ensures that the model parameters could be objectively selected, and the model parameters would be valid over a wide range of conditions. As a result, the model would have a significantly increased predictive power.

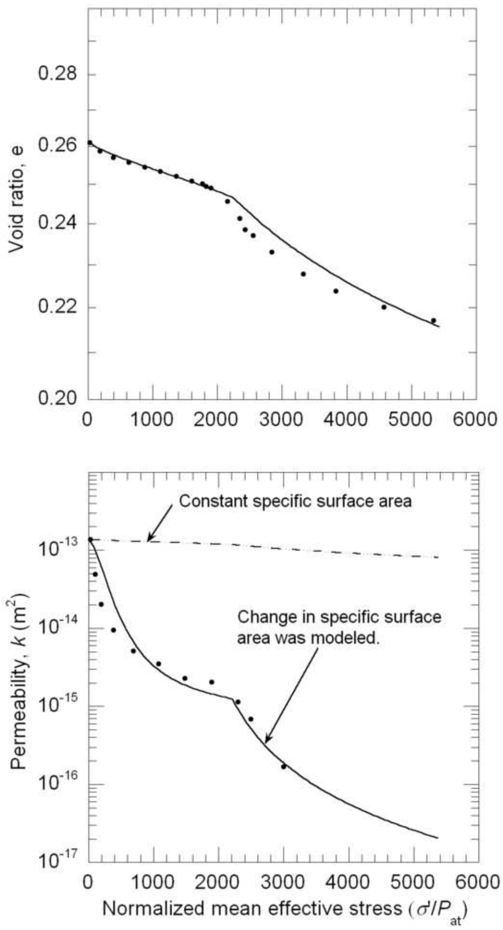


Figure 3. Modeled compression behavior of Adamswiller sandstone and stress-permeability coupling with modeling change in specific surface area due to particle crushing during compression. (data from David et al., 1994)

2.5 *Probabilistic methods applied to classical geotechnical analysis by Prof. D.V. Griffiths*

The presentation described a powerful method for probabilistic geotechnical analysis called the Random Finite Element Method (RFEM). The method involves a combination of the finite element method and random field theory in a Monte-Carlo framework. The RFEM takes full account of spatial correlation and local averaging. The method has been applied to numerous areas of classical geotechnical analysis (Griffiths and Fenton 2005), however the Panel presentation concentrated on slope stability analysis. Attention was drawn to the sensitivity of the Factor of Safety in some slope problems, to the assumed shape of the failure surface even using traditional methods (e.g. Bishop vs. Spencer). Examples were given of slope stability analysis using the elasto-plastic FE, which makes no a priori assumption about the shape or location of the failure surface. The method naturally finds the critical failure mechanism, and hence the "minimum" factor of safety by allowing a slope to "fail where it want to fail" (Figure 4). Examples were given where an incorrect (and unconservative) Factor of Safety could be predicted by classical methods if the wrong search strategy was adopted.

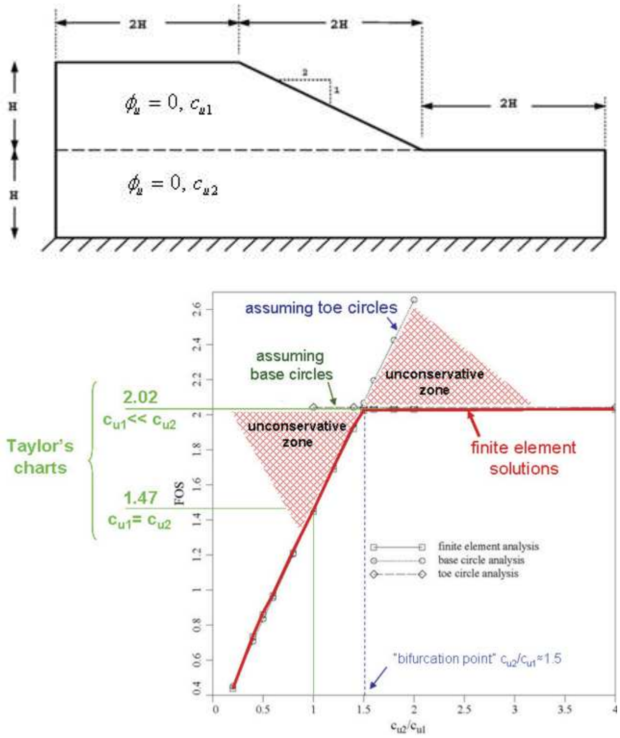


Figure 4. Relationships between undrained strength ratio (c_{u2}/c_{u1}) and factor of safety from slope stability analysis using the elasto-plastic FE

The benefits of the RFEM approach to slope stability analysis and its ability to "seek out" the critical mechanism are even more important in probabilistic analysis of highly variable soils. In this case, the presence of strong and weak soils occurring in the same slope implies that the shape and location of the failure surface is quite unpredictable. In some cases, the failure mechanisms given by the RFEM approach in such soils are so complex, that meaningful analysis using classical slope stability would be impossible. It is argued that even with proper local averaging, probabilistic slope stability analyses based on traditional methods are flawed in that they are based on failure mechanisms that are unlikely to be critical. The RFEM represents one of the very few methods able to perform qualitative probabilistic geotechnical analysis in an objective and fundamental way.

3 DISCUSSION AND SUMMARY

Prof. Nova led the floor discussion between the panelists and participants in this session. The discussion was too animated to be enough in the two allotted hours. In particular, the probabilistic slope stability analysis with finite element method interested participants. The following topics were discussed between panelists and participants: independent mechanism in structured soil, major effect in multi-phase behavior, evidence of double structure, interface modeling between different soil layers, mesh size dependency of FEM, three-dimensional effect in slope stability analysis. We sincerely would like to appreciate the participants in facilitating the fruitful discussion during the session.

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