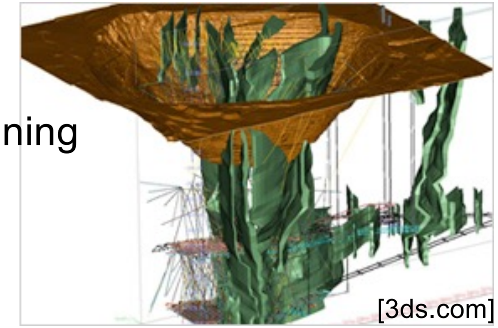
Civil-423
Computation geomechanics

Introduction

Natural hazards

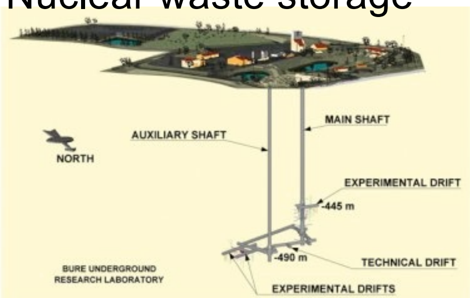
[blogs.agu.org/landslideblog/]

Mining



[3ds.com]

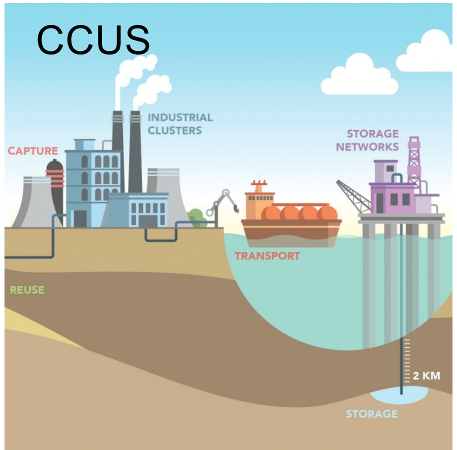
Nuclear waste storage



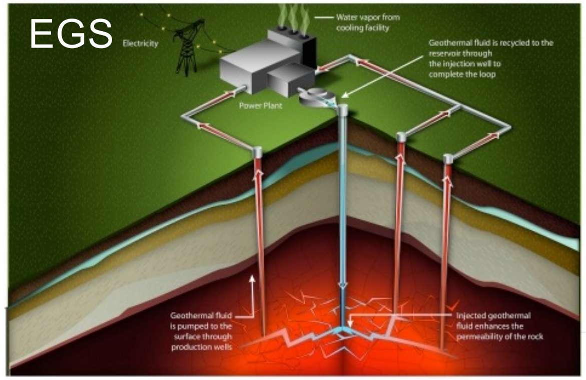
[ANDRA]

Oil & Gas

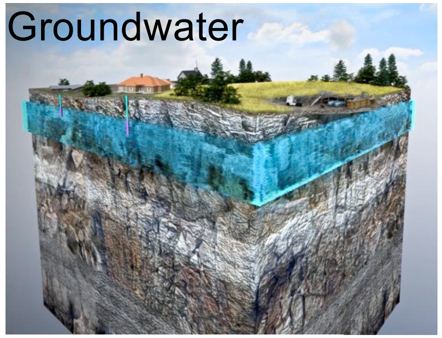
[pubs.spe.org/en/jpt]



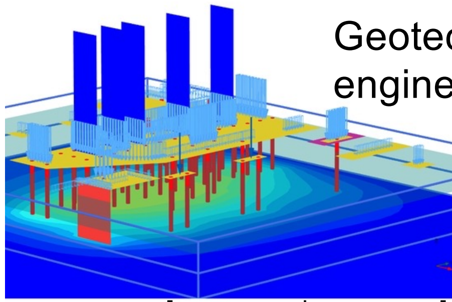
[alignccus.eu]



[DOE, Geothermal Technologies Program]



Geotechnical engineering



[cmwgeosciences.com]

Some assumptions throughout this course:

- Single phase flow in porous media
  (although we address unconfined problems – so we'll do an example of simplified multi-phase)
- Quasi-static deformation (no inertial effects / no waves)

Type of constitutive behavior

- Linear poroelasticity
- Rigid plasticity (Mohr-Coulomb)
- poro-Elastoplasticity (Mohr-Coulomb, Cam-Clay)

- Introduction to the coupling between soils & structural elements
- Introduction to Joint elements

Agenda / exercises

1. Mesh, estimating derivatives at nodes from value at nodes via FEM
2. Steady-state Confined groundwater flow (Laplacian) (e.g. sheet pile wall)
3. Steady-State Unconfined flow (e.g. flow through an Earth dam)
4. Transient groundwater flow (e.g. in-situ injection test)
5. Undrained poro-elasticity (e.g. building load / Boussinesq)
6. Poroelasticity 1 (undrained to drained response / Boussinesq)
7. Poroelasticity 2 (deformation around a deep wellbore/ tunnel)
8. Non-linear behavior 1 / non-linearity at the element level 1
9. Drained / undrained test (Cam-Clay soil) / non-linearity at the element level 2
10. Rigid Plasticity for limit analysis 1 (e.g. slope stability / excavation)
11. Rigid Plasticity for limit analysis 2 (e.g. slope stability / excavation)
12. Poro-elastoplasticity 1 (E.g. Boussinesq / shallow foundation revisited)
13. Poro-elastoplasticity 2 (E.g. Phased excavation)

Numerical methods we will **NOT** address

- Boundary elements / boundary integral equations techniques
- Finite volume methods (although we will address the concepts)
- Discontinuous Galerkin FE methods, Mixed-hybrid FE discretization, Spectral FE methods
- Material point method, Smooth particle hydrodynamics
- Distinct elements methods, Peridynamics, Molecular dynamics
- …

Using numerical codes require in-depth understanding

- Verifications (against known solutions) are mandatory
  - [note it is pre-requisite before validation (against experimental results)]

- One must check everything (Intuition is often not sufficient)
- One must always criticize his/her results obtained
- One must understand what controls the accuracy of a numerical method

Think before you compute !

What we will not cover

- Other multi-physics coupling, notably:
  - Thermo-poro-elasticity (THM)
    - Thermal pressurization (heat induced pp increase), heat conduction / convection (hydro-thermal problems) …
    - Note that mechanics do not influence thermal effects (TH->M, but no M->T)
  - Chemo-poro…
    - Most of the time chemical reactions→ change in mechanical respons: C-> M (not M-> C)
    - Notable exception: pressure solution
- Dynamics
  - Dynamic liquefaction, waves and poroelasticity (squirt flow) etc.
- Material rate dependent effects
  - Viscoplasticity etc.
- Fracture growth
  - Come & do semester projects with us

Course organization

- Partly ”Reverse” teaching ! Partly usual lecturing.
- You have all the courses notes… we will go over them week by week
  - I strongly encourage you (i.e ‘you must’) to rederive things yourself (reading is usually not enough to properly understand)
- On Thursdays
  - Quizzes to check that you understood
  - I can re-derive things that you do not understand
  - I will not re-derive everything
- Take ownership of your learning
  - Use additional resources (textbooks)
- Expectations
  - That you understand the theory (no need to learn things by heart – but understand how to eventually get it back with the help of textbooks, notes etc.)
  - That you understand your code
  - That you built know-how in *modeling* geomechanical problem
  - That you realize that complexity does not necessarily lead to better predictability

Assistant

- Antareep Sarma

Modeling in geomechanics – an art form

Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol. 25, No. 3, pp. 99–106, 1988
Printed in Great Britain

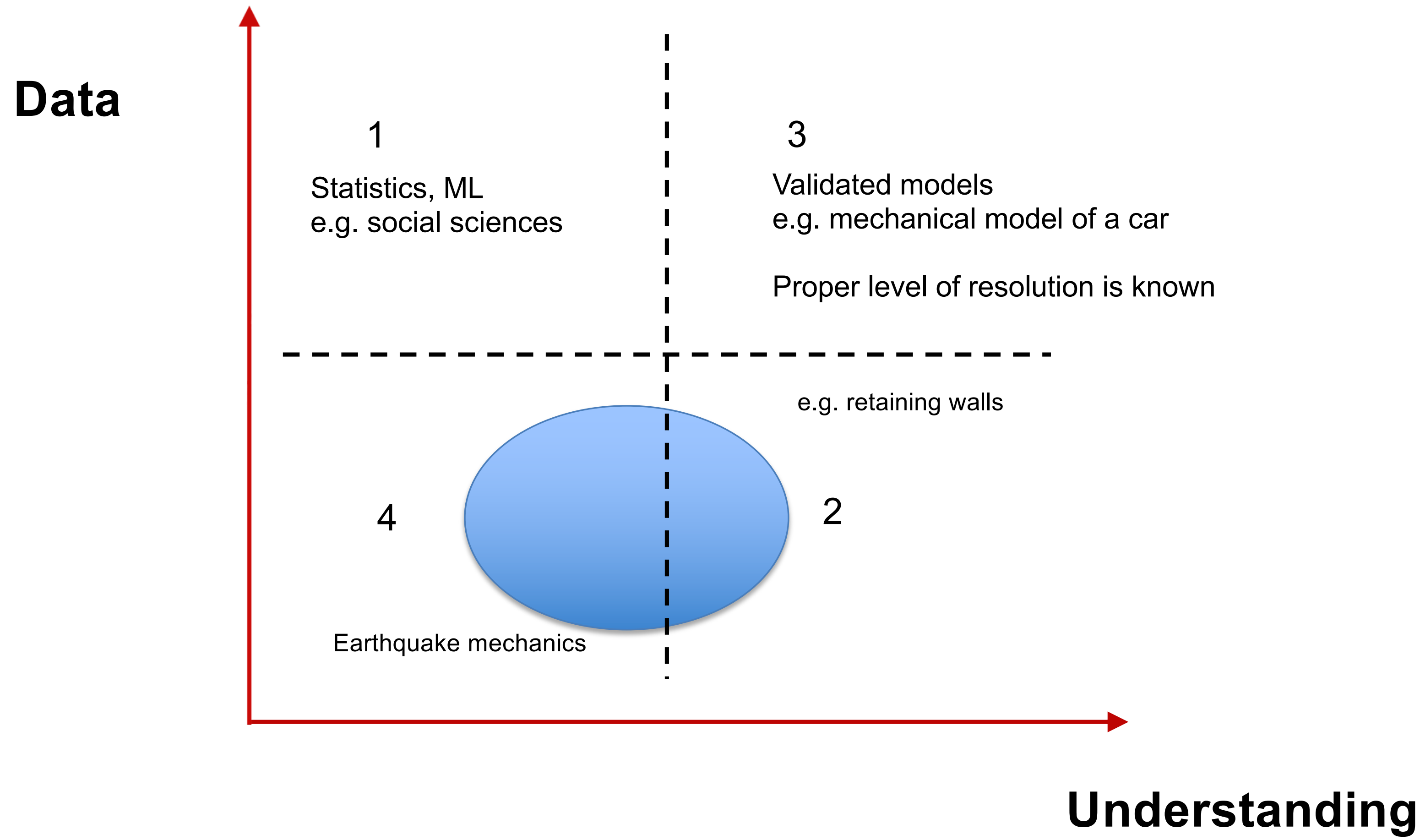
0148-9062/88 $3.00 + 0.00
Pergamon Press plc

Towards a Methodology for Rock Mechanics Modelling

A. M. STARFIELD*
P. A. CUNDALL*

Rock mechanics models fall into the class of "data-limited problems"; one seldom knows enough about a rock mass to model it unambiguously. Modellers are beginning to realize that data-limited problems require a very different modelling approach from that developed in, for example, electrical or aerospace engineering.

It follows that one cannot use models in rock mechanics in a conventional way, and that there is a need to adopt a distinctive and appropriate methodology for rock mechanics modelling. Some guidelines and heuristics, which may be considered as the first steps towards developing such a methodology, are presented. Three case studies are then used to illustrate the application, in practice, of these ideas.


Data
1
Statistics, ML
e.g. social sciences
3
Validated models
e.g. mechanical model of a car
Proper level of resolution is known
e.g. retaining walls
4
2
Earthquake mechanics
Understanding

Model verification vs validation

- Verification
  - Ensure that the numerical tool **correctly/accurately** solve the equations it is supposed to solve
    - E.g. check a FEM elastic model against Boussinesq analytical solution for a circularly loaded area
    - Same for more complex equations…
    - If no reference solutions exist -> benchmarking between different numerical codes.
- Validation
  - Ensure that the numerical model **correctly/accurately** reproduce the physical phenomena observed
    - e.g. comparison between the prediction of a model and a lab experiment WITHOUT FITTING the model parameters
    - e.g comparison between the prediction of a model and a field experiment, allowing a reasonable adjustment of the model parameters

- **Validation without verification is the road to disaster**

Modeling in geomechanics

- “ A model is a simplification of reality rather than an imitation of reality. It is an intellectual tool that has to be designed or chosen for a specific task.”
- “The design of a model should be driven by the questions that the model is supposed to answer rather than the details of the system that is being modelled”
  - Over-complexification of models do not lead to better predictability
- “… appropriate to build a few very simple models rather than one complex model; the simple models would either relate to different aspects of the problem, or else address the same questions from different perspectives”
- “Instead of trying to validate a model, one should aim at gaining confidence in it and modify it as data arrives. “
- “Purpose of modeling data limited problems is to gain confidence and explore potential trade-offs and alternative, rather than to make absolute predictions”

[Starfield & Cundall, 1998 – towards a methodology for rock mechanics modeling]

In practice

- Why modeling ? What is/are the question/s ?
- Use a model early – do not delay until receiving field data
- Look at the mechanics of the problem – perform dimensional analysis and scaling
- Think of an experiment to decipher between possible mechanisms – this can be numerical experiments
- Start simple, and complexify **only** when required (when the simple model is invalidated)
- If the model has weaknesses that can not be remedy, make a series of simulations to bracket the true case
- Once simple models have been mastered, complexify slowly to investigate the effects previously neglected

“There is a dialectic between geological detail and engineering understanding”

Step by step

- Always start with a “toy” model
  - Keep the most important features to investigate
    - This is where experience & knowledge make the difference
  - Solve it rigorously
- Slowly complexify
  - e.g. add some geometrical effects, heterogeneous properties
- Model the ”full monty” (if needed only !)
  - At this stage, we should already know the answers – this is mostly to dot the Is and cross the Ts (e.g. please the client, show off…)
  - E.g. model in 3D with all the geometrical / layering details, etc.

Some Commercial Tools

- Itasca C.G.
  - FLAC 2D / 3D (THM) – explicit FV code – shine for very non-linear problems (elastoplastic)
  - DEM codes: Udec, PFC …
  - Mining, nuclear waste, O&G

- Plaxis
  - 2D/3D – (T)(H)M – elasto-plastic
  - Geotech.
- RS2/RS3 (RocScience)
  - FE (H)M - elasto plastic

- Optum
  - G2/G3 – (H)M – elasto-plastic, limit analysis

- ParaGeo
- ELFEN (RockField)

- Abaqus (DS), ANSYS …..

Know your PDEs !

- On the black board.