LMS Laboratoire de Mécanique des Sols

Acquis et perspectives pour la mécanique des sols

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Laboratory Snapshot - Focus

Our experimental and modeling resources are mobilized to understand, describe and predict the behaviour of natural and man-made systems.

NATURAL HAZARDS & CLIMATE CHANGES
- Debris flows, landslides and their triggering mechanisms
- Multidisciplinary analysis of risks related to soil slopes

CIVIL ENGINEERING
- Geotechnical and foundation engineering
- Soil-groundwater flows interaction
- In-situ and laboratory testing
- Soil-structure interactions
- Soil dynamics

GEOENVIRONMENTAL ENGINEERING
- Geological disposal of nuclear waste
- Effects of gas emissions

ENERGY
- Energetic geostructures and thermal piles
- Deep geothermal energy
- Enhanced oil production
  - Field subsidence
Advanced Constitutive Models for Environmental Geomechanics: a general framework for THM modelling

- Saturated Thermo-Plasticity
- Unsaturated soils
- Unsaturated Thermo-Plasticity
- Structured soils
- Dessiccation and cracks

Heat conduction
Fluid density
Fluid viscosity
Water and Gas flow

Porosity

3-phase THM field equations

Thermal strain
Desiccation cracks

Effective stress
Suction change
Dessication cracks
Present Research Themes

Experiment-based multi-physical modelling of Soils

Development of an Advanced Experimental Soil Mechanics Laboratory, with several research-class prototype equipment to its credit. The laboratory is recognized Internationally as one of the Leading Centers for experimental research in Soil Mechanics.
Examples of present research themes

- Natural Hazards and Climate Change
- Nuclear Waste Storage
- Heat Exchanger Geostructures
Natural Hazards and Climate Change
Main ongoing projects

**SafeLand**
*Living with landslide risk in Europe*
- Assessment
- Risk management
- Effects of global change

*25 institutions from 13 European countries*

**TRAMM**
*Triggering of Rapid Mass Movements in Steep Terrain*

**COGEAR**
*Coupled seismogenic Geohazards in Alpine Regions*

**Mountain Risks: from prediction to management and governance**
*20 international institutions*

- EU-WANDLAND (effects of wet-dry cycles on landslide activity): Marie Curie Reintegration Grant
Risk associated with landslides is in general growing due to an increase in exposure and climate change.
Natural Hazards and Climate Change

Deep seated landslides

Hydrogeological modelling
Geomechanical modelling

Main features
Active area: ~1 km²
Mean inclination: 20°
Mean depth: 10 - 15 m
Movement rates: 1-2 cm/yr

Comparison of model results and measurements

Hydro-mechanical modelling of a natural slope affected by a multiple slip surface failure mechanism.
[Ferrari, Laloui, and Bonnard 2009]
Natural Hazards and Climate Change
Shallow landslides in unsaturated soils

Degree of saturation during rainfall event

Hydraulic response
TRAMM in-situ experiment
[Springman et al. 2009]

Active mechanism
Inactive mechanism

Mechanical response
Development of plastic strains

Triggering of shallow landslides
[Eichenberger, Nuth and Laloui 2010]
Natural Hazards and Climate Change
Landslide behaviour under seismic inputs

- Governing Equations for Poro-elastoplastic Media

\[
\text{div } \sigma' - \text{grad } p + \rho g = \rho \ddot{u}_s + \rho_f \ddot{u}_{rf}
\]

\[
\ddot{u}_{rf} = K \left[ -\text{grad } p + \rho_f \left( g - \ddot{u}_s - \ddot{u}_{rf} / n \right) \right]
\]

\[
\text{div } \dot{\epsilon} + \text{div} \left\{ K \left[ -\text{grad } p + \rho_f \left( g - \ddot{u}_s - \ddot{u}_{rf} / n \right) \right] \right\} = -\frac{\partial P}{\partial Q}
\]

- Cyclic Constitutive Model with Kinematic Hardening

- Paraxial Elements simulated at the Interface
Recent progress in modelling seismic propagation allows the use of a site-specific ground motion, combined with the use of advanced HM cyclic constitutive model.

Earthquake triggered landslides
[Li, Dupray, Seiphoori and Laloui 2011]
Nuclear Waste Storage
Nuclear waste storage and multi-barrier systems

First barrier: metal

Second barrier: swelling clay

Third barrier: low permeability host rock

Argilaceous materials constitute one of the key elements of the multi-barrier system.
Nuclear Waste Storage
Main ongoing projects

FORGE
Fate of repository gases. Understanding of how corrosion gases or vapour move in the repository. 24 international institutions

Thermal impact on the damaged zone of around a radioactive waste disposal in day host rocks 20 international institutions

ABM
Alternative Buffer Material Long-term behaviour of several types of buffer materials.

FEBEX
Full-scale Engineered Barriers Experiment. Modeling of the in-situ test
Nuclear Waste Storage
Experimental facilities (NSF R, Equip)
Nuclear Waste Storage
Experimental facilities

- Inner cell system for specimen volume change assessment
  - At each base:
    - Air flushing
    - Water flushing
    - Pore air pressure control
    - Pore water pressure control
    - water volume change measurement

- Double PV controller for
  - outer cell pressure control
  - Inner cell pressure control
  - inner cell volume change measurement

- 2 PV controllers for the independent control of the pwp at the two bases

EPFL Advanced Triaxial System

[Ferrari, Seiphoori and Laloui 2011]
Nuclear Waste Storage
Numerical simulations

Hydraulic gradient ▲
• Granite-bentonite interface: resaturation of bentonite
• Canister-bentonite interface: drying of bentonite

Important thermal gradient/load
TCanister =100°; Tfar-field = 12°C ▲

THM modelling of the FEBEX experiment
[Dupray, François and Laloui 2011]
Heat Exchanger Geostructures
Use of foundations and underground infrastructures for heat production and energy storage

Today:
Current technology uses 0-20°C range (GSHP+Free cooling).

Future:
But the 30-60°C (Solar heat+direct heating) can be foreseen in buildings T°>60°C will require development for storage applications.

-> Geotechnical challenges <-
Heat Exchanger Geostructures
Main ongoing projects

GRETEL
Geotechnical REliability of Thermo-piles Energy storage in soils

Constructive recommendations for optimized and reliable heat exchanger pile systems
Sponsored by Swiss Federal Office of Energy

Heat exchanger anchors for thermo active tunnels
Sponsored by Swiss Federal Roads Office and Swiss Tunnelling Society

Heat storage system for road infrastructure
Study of energy geostructure for thermal regulation of road infrastructure
Heat Exchanger Geostructures
A software for geotechnical design of energy piles

[Knellwolf, Péron and Laloui 2011]
Heat Exchanger Geostructures
Geostructures modelling

The effect of temperature changes on global foundation behaviour can be studied, helping engineers to design each pile, but also a globally efficient energy foundation.

![Graph showing volumetric plastic strain over time for different depths.](Image)
Heat Exchanger Geostructures
EnerFound – Behaviour of group piles

- Group effect on stress state of a group of piles
- Cap rigidity effect on a group of piles
- Temperature influence on piles bearing capacities
- Sustainability of heat storage

Swiss Tech Convention Center

[Mimouni, Dupray and Laloui]
Our research activities open continuously important scientific, technological and educational horizons. In the coming years, priority will be given to:

- Conventional geomechanical research activities to provide tools for the up-to-date design of the geo-structures

- Protection of environment, landforms and structures from geo-hazards and industrial damage

- Understand, investigate and predict the environmental impact and behaviour of the new energy related technologies
Examples of initiated research topics

**Thermo-hydro-mechanical processes in nuclear waste disposal**
- Depth of storage: 1000 m
- Max. temperatures: 150°C
- Host rock/clay

**CO₂ sequestration**
- Injection into depleted oil and gas reservoirs, deep saline aquifers

**Geotechnical engineering**
- Soil reinforcement by biogrouting

**Shales**
- Unconventional gas

In all these problems, geomaterials endure extreme loading conditions:
- Mechanical stresses
- Suctions (drying wetting), Chemistry, Bacteria
- Temperatures
Soil reinforcement by biogrouting

Microbially Induced Calcite Precipitation

- Microbially catalyzed urea hydrolysis
- Carbonate production and pH increase
- Precipitation of calcite (in presence of calcium)

Biogrouting
- Effective strengthening (→ 300%)
- Cost effective
- Environmentally friendly
- Reversible
Shale gas exploitation

**FACTS**
- Increasingly important energy source
- Expected to rise
- 45% of USA energy in 2035

**CHALLENGING IN-SITU CONDITIONS**
- High temperatures: may reach 100°C
- High pressures: dozens of MPa’s

[Link to drilling contractor organization website](http://www.drillingcontractor.org/)
THM behaviour of gas shales

Water retention curve of a Swiss shale
[Ferrari, Manca, Witteveen, Laloui]

HIGH-PRESSURE OEDOMETER

SORBTION BENCH

Oedometric curve of a Swiss shale
[Ferrari, Manca, Witteveen, Laloui]
EPFL, Lausanne, Switzerland

Advances in Multiphysical Testing of Soils and Shales

3 – 5 September 2012

ISSMGE TC-101 WORKSHOP

organized by Prof. Lyesse Laloui and Dr. Alessio Ferrari
Conclusion

Our Foundations for the future

Construction, Energy and Environmental related Geomechanical Challenges