ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Laboratory of Soil Mechanics
Chair "Gaz Naturel" Petrosvibri

Professor Lyesse Laloui

BI-ANNUAL REPORT 15-16

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Preamble

Professor Lyesse Laloui

In 2015, we celebrated the 80th year anniversary of the Laboratory of Soil Mechanics – Chair «Gaz Naturel» Petrosvibri (LMS) which was established in 1935. Being the director of the LMS since 2008, I have seen the laboratory develop an internationally recognized expertise in various fields related to geo-energy and geo-environment, besides the conventional research activities on geo-mechanics.

Over the past two years, LMS has once again shown a substantial growth, contributing to fundamental and applied research activities on near-surface geothermal energy systems, nuclear waste storage, bio-improved soils, landslide analysis, shale gas behaviour and claiming an important key role in the field of geoengineering of CO_2 storage.

In 2016, LMS has been given the honour to organize one of the most prestigious and large international conference series on greenhouse gas control technologies, 13th Conference on Greenhouse Gas Control Technologies (GHGT-13) in Lausanne, Switzerland. Moreover, LMS has been involved in the organization of the First International Conference on Geo-Energy and Geo-Environment (GeGe-2015) in Hong Kong and leading the Second EAGE Workshop on Geomechanics and Energy in Celle, Germany.

Besides the various research projects, LMS has contributed to the outstanding educational activities of the Swiss Federal Institute of Technology Lausanne (EPFL) by publishing a new book on soil and rock mechanics, Mécanique des Sols et des Roches, introducing a new course in Slope Stability, and mentoring master students through their thesis goals. Our research group has also grown with new PhD students and postdoctoral researchers joining us.

Therefore, we had the urge of collecting these numerous LMS activities that have contributed to our success and growth over the past two years, not only to highlight and preserve the great memories but also to share it with our partners and colleagues, whom I would like to warmly thank for their support.

I hope you will enjoy discovering it.

Prof. Lyesse Laloui

Mission statement

The Laboratory of Soil Mechanics (LMS) is a part of the School of Architecture, Civil and Environmental Engineering (ENAC) at the Swiss Federal Institute of Technology, Lausanne (EPFL). Since its establishment - as the successor of the Geotechnical Laboratory founded in 1935 - the LMS has been contributing to fundamental and applied research activities, education, as well as consulting for civil engineering construction works.

The LMS focuses its activities in three major fields:

1. Education

Lectures given by our group at BSc and MSc levels include Soil Mechanics, Groundwater Flows, Slope Stability, Safety and Reliability Analysis, Construction and Environmental Geology, Geomechanics and others. Specific courses concerning, among others, Experimental Geomechanics is also offered within the doctoral program in Mechanics.

2. Research & Development

Research activities within the LMS deal, on one hand, with theoretical and applied aspects in geomechanics and, on the other hand, with the development of tools and computational methods for the analysis and the design of geostructures and the investigation of natural phenomena, aiming for the practical application of the obtained results.

3. Consulting Services

Consulting services offered by the LMS deal with the preparation and update of national and international standards and codes, laboratory and in-situ geomechanical tests, the monitoring of structures and construction sites, numerical modelling and expert evaluations.

80th Anniversary of LMS

Celebrating 80 years
of research and innovation
LABORATORY FOR
SOIL MECHANICS
CHAIR «GAZ NATUREL»
lms.epfl.ch

The geotechnical group of EPFL has celebrated its 80th anniversary. A special event to focus on the past, present, and future research in geotechnical engineering was organized on the 15th and 16th of January, 2016 by the Laboratory of Soil Mechanics (LMS) with the participation of the Laboratory of Experimental Rock Mechanics (LEMR) and the Laboratory of Geo-Energy (GEL).

The celebration of this anniversary has been an opportunity to put together all the pieces of the history of the laboratory, to learn from our past and celebrate those values that accompanied the laboratory throughout its fascinating journey.

On the occasion of this anniversary, the focus was put on the current research status of geotechnical engineering at EPFL and on the possible future challenges that the group and the entire community will face. Five distinguished professors have participated in the event to share their visions: Prof. Tomasz Hueckel (Duke University), Prof. Joseph Labuz (University of Minnesota), Prof. Patrick Selvadurai (McGill University), Prof. Ronaldo Borja (Stanford University), and Prof. Antonio Gens (Universitat Politècnica de Catalunya).

Everybody gathered on Friday the 15th of January in the beautiful location of Les Bois-Chamblard, in Buchillon. The presentations started at 9 am with Professor Laloui who took the audience on a journey back in the history of the laboratory. After this introduction, each of the invited Professors made a presentation on their research interests and their latest findings. Members of the LMS, LEMR and GEL laboratories took the floor after lunch. PhD candidates concluded the Friday talks with a presentation of their thesis in 180 seconds !

After this academic part, the geotechnical group and its guests went to the Hôtel Mirabeau where a delightful dinner had been served.

On the second day of the organization, everybody took the GoldenPass Panoramic train in Montreux to get to Gstaad where a more recreational program was foreseen. The entire group took the lift in Gstaad in order to sledge down back to the charming village covered by a blanket of fresh snow that had fallen during the night. After exercising in the breathtaking (but cold !) Swiss Prealps, the tobogganers headed straight to a restaurant to eat a warm fondue! Before going back to Lausanne, the group took a curling class. This introduction to curling will stay in the academic history: you will never see that many professors sweeping the floor !

New Releases

Mécanique des sols et des roches : A new book !

The book *Mécanique des Sols et des Roches, TGC 18,* has been published in Summer 2016 by the *Presses Polytechniques et Universitaires Romandes*. Students and practitioners have been waiting for almost twenty years to finally get this reference book. We have asked Professor Laurent Vulliet who was involved during all the steps of the project to comment on its publication. We also interviewed a former LMS student on his opinions about the book with regards to his professional life and education.

Professor Vulliet's interview

Professor, in what aspects the TGC 18 is different from the other books on soil or rock mechanics?

This book is the first one that includes the soil and rock mechanics in the same framework; whereas, usually soil and rock mechanics are treated in separate books. In an engineering office, there is no soil mechanics team and rock mechanics team, only a geotechnical team who should be able to deal with rocks or soils. It seems therefore logical to gather soil and rock mechanics in the same book. Also, groundwater seepage and heat transfer through geomaterials are detailed, which is again a particularity of this work.

For whom the book is it meant?

Mécanique des Sols et des Roches is an introductionary book that is aimed at geotechnical engineers, geologists, soil/rock mechanics testing laboratory supervisors, but also at students in civil engineering, geology, mechanical engineering, earth science, mining engineering, environmental engineering and pedology.

Can you tell us a little bit about the story of the book?

This is actually a long story! Writing it has taken a lot of time. The idea is born at the beginning of 2000s. The founders of the TGC 18 were Professors Edouard Recordon, François Descoeudres and Laurent Vulliet. If I remember well, the first contract with the PPUR was signed in 2000. Unfortunately, after the passing away of Prof. Recordon and the retirement of Prof. Descoeudres in 2002, the project fell through.

In 2008 however, the book was reborn with Prof. Vulliet and two other professors, namely Prof. Lyesse Laloui and Prof. Jian Zhao who joined in to complete the team. During the year 2008, Prof. Vulliet was on sabbatical. At the end of that year, almost 80% of the book was written. Then Prof. Vulliet went to work with the group BG Consulting Engineers. As the CEO of this company, he didn't have the time to finish the work and it was put on hold.

In 2015, after having left BG group, Laurent Vulliet picked up the book again. The most important work at this stage was to update the text with the latest norms like SIA 267 because all the norms had changed since the beginning of the story. Finally, at the end of June 2016, the book was published.

How did you feel when you handed out the last version to the publisher, PPUR?

I had mixed feelings. I felt really proud on one hand. After all these hours we have spent on writing, correcting, looking for references, etc. publishing the book was, on the other hand, a relief, a delivery. Let me use this metaphor (even if I am not a woman!) but it is like giving birth to a baby. However, once the baby was born, I had like the baby blues feelings.

Since you started writing the book about twenty years ago, are there some chapters you would write now in a different way?

As said before, the TGC 18 is an introductory book with basic concepts on soil, rock mechanics and on groundwater seepage and heat transfer. These basics are well accepted by the scientific community and will hold true. I think that it is important to have these fundamentals as a hard copy. References concerning more advanced and actual research topics are given in the book for readers who want to go beyond. These people can then go on the internet and read the information they are looking for. Each of these topics could actually be covered by an entire book and the TGC 18 already has more than 600 pages !

Of course soil and rock mechanics have made great progress during the last two decades. I think however that all the concepts and tools necessary for solving geotechnical problems are presented in this book that is thought of as a reference. One can really easily find the information s/he is looking for thanks to its clear structure.

The advantage of writing it during a long period of time is that the book has become mature because some parts of it have been used as teaching supports. Therefore, it is written in a very educational manner. The first full-scale test for TGC 18 will be next Spring (2017) when I will give the Soil Mechanics and Groundwater Seepage class to 2nd year bachelor students. Finally, with a hard copy of the TGC 18 !

Terence Reverdin[1] , former LMS student

Have you already bought the TGC 18? If yes, why?

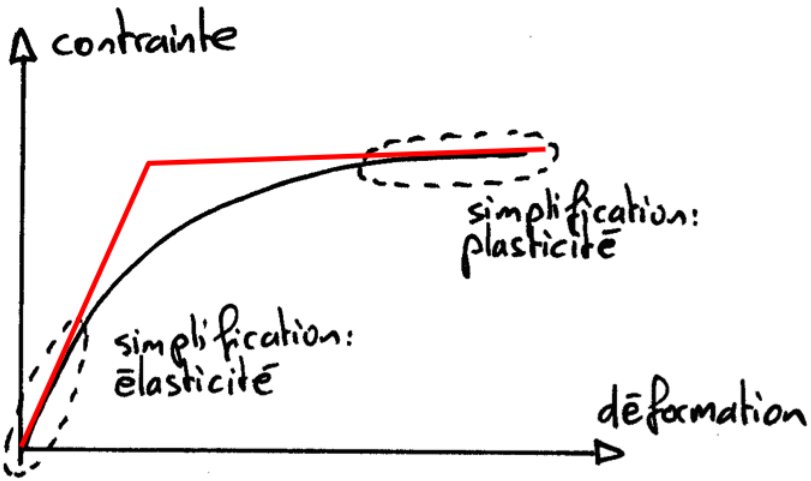
I bought it yes! I was actually waiting for its publication since I was a student in the soil mechanics class at EPFL. After looking inside the book, I understood why it has taken so much time for the authors and all the involved persons. I thought that the year 2011 would be the year of its publication because the PPUR had written on their website "à paraître" ("To be published"). Sadly, that was not the case (I was taking the soil mechanics and groundwater seepage classes that year!).

Do you think you are going to use the book in your professional life?

I think the TGC 18 is a book containing the basics (not only!) allowing the engineer to rapidly find the information she/he is looking for. I am actually working on railway infrastructure and the projects I am involved in are not directly linked with geotechnical engineering. However, just in case, I have a reference book in which I know I can find easily what I am looking for!

As far as education is concerned, what will the book bring?

I think it is necessary to have a complete, good and clear textbook besides the ex-cathedra courses. The notebook that was used before for the class was a good start but it contained only a part of the information and the format and the appearance did not make me want to dive into it… On the other hand, in my opinion, a book like this offers a better educational approach. About the publication of the TGC 18, only one regret: I could not have it earlier!

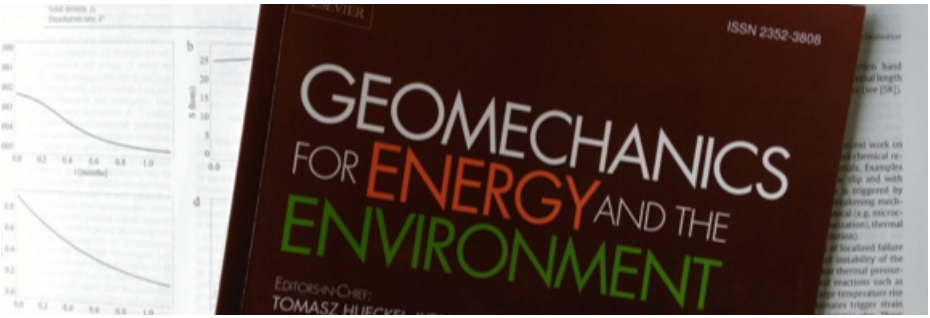


1 Currently working at DSP Ingenieure & Planer AG, Greifensee

New Journal: Geomechanics for Energy and the Environment

Professor Tomasz Hueckel, from Duke University (USA), together with Professor Lyesse Laloui are the editors-in-Chief of the journal Geomechanics for the Energy and the Environment.

The aim of the Journal is to publish research results of the highest quality and of lasting importance on the subject of geomechanics, with the focus on applications to geological energy production and storage, and the interaction of soils and rocks with the natural and engineered environment. Special attention is given to concepts and developments of new energy geotechnologies that comprise intrinsic mechanisms protecting the environment against potential engineering induced damage, hence warranting sustainable usage of energy resources.



The scope of the journal is broad, including fundamental concepts in geomechanics and mechanics of porous media, the experiments and analysis of novel phenomena and applications. Of special interest are issues resulting from the coupling of particular physics, chemistry and biology of external forcings, as well as of pore fluid/gas and minerals to the solid mechanics of the medium skeleton and pore fluid mechanics. The multi-scale and inter-scale interactions between the phenomena and the behaviour representations are also of particular interest. Contributions to general theoretical approaches to these issues, but of potential reference to geomechanics in its context of energy and the environment are also most welcome.

The purpose of the Journal is to foster scientific understanding of various processes in geomaterials, both induced by technology and natural, and their relationship to the underlying mechanisms. The intrinsic nature of the coupling of chemical, biological, thermal and mechanical properties, variables and fields distinguishes the related problems from those in classical geomechanics. Thus, emphasis is placed on the development and fusion of fundamental concepts in mechanics, physics, geochemistry and geo-biology and applications of such concepts to novel technologies related to geological energy production and storage as well as to the prevention of damage to the environment, in which the solid and fluid mechanics of geomaterials is of relevance.

The targeted audience (writers and readers): Geo-scientists, civil -, petroleum-, geotechnical - geological - mining- and rock- engineers, hydrologists, soil physicists, and geophysicists.

能源地下结构 **is Energy Geostructure in Chinese !**

The book Energy Geostructures: Innovation in Underground Engineering has been translated into Chinese in 2016. Its Chinese title is 能源地下结构. The book was originally written by Prof. Lyesse Laloui (吕塞 • 拉卢伊) and by Dr. Alice Di Donna (何莉塞 • 迪 • 唐纳), a former PhD student at LMS. The book has been translated by Prof. Kong Gangqiang (孔纲强) and his team, from Hohai University, China.

Education

Teaching

Members of LMS are involved in education at Bachelor, Master and Doctoral level. The courses are briefly described with a special emphasis on the course "Slope stability" which has been given since 2015. Many student projects are achieved at LMS, they are listed in this section and concisely summarized in the "Research Areas" section.

New course: Slope stability - CIVIL 530

Slope stability issues and landslide problems are among the major threats encountered by geotechnical engineers in their professional life. Switzerland in particular is a hazard-prone country exposed to debris, slides and rock falls. In order to provide future EPFL engineers with specific knowledge and tools to cope with those issues, the Slope Stability course was initiated in Spring Semester 2015. The course is held by Alessio Ferrari and Lyesse Laloui and is given to the Master students of Civil Engineering. It is also open to the students of the doctoral program in Mechanics (EDME) of the EPFL. It addresses landslide types and mass movement classification; slope failure mechanisms and methods for slope stability analysis are discussed; remedial measures and risk analysis are presented. Particular emphasis is given to the role of pore water pressure on landslide initiation and reactivation. Practical sessions on slope stability analysis and the design of remedial measures constitute an important part of the course, along with field visits to instrumented slope instabilities.

Mesa County mudslide, Colorado (source: www.kdvr.com)

Other courses

Soil mechanics and groundwater seepage

This course presents the basis of soil mechanics and groundwater seepage to 2nd year Bachelor students. The content of the course tackles the characterization of soils, the most important constitutive relationships describing the behaviour of geomaterials and fluid seepage. Basic geotechnical problems are also studied.

Geomechanics

This course is given during the Master cycle of civil engineering. Geomechanics deals with understanding, analysing and modelling the mechanical behaviour of geomaterials. The topics go beyond classical geotechnical engineering and provide students with a fundamental understanding of the behaviour of soils. The course focuses on the role of geomechanics in engineering practice, constitutive modelling (from linear elasticity to elasto-plasticity with hardening), in-situ tests for parameters determination.

Risk analysis and management

This course aims at giving the civil engineering Master students the tools for scientifically dealing with the management of natural and technological risks with a special focus on civil engineering works. The following aspects are seen during the class: estimation of risk and analysis methods, risk assessment, risk mitigation. Some case studies are also analyzed during the class.

Geology for construction and environment

During this course, the students are asked to distinguish different types of rocks and their physical properties. They learn about the physics of groundwater seepage and the transport of solutes and heat. At the end of the course, the Master students are able to analyze the different aquifer systems, evaluate the hazards linked with water, differentiate the principal rocks types, evaluate the propagation of heat in the ground, evaluate geological hazards.

Experimental geomechanics

This course is taught within the Mechanics Doctoral program. The aim is to provide the students with a detailed description of the modern experimental techniques for testing geomaterials. Techniques and apparatuses are presented to test materials under a variety of situations, including non-isothermal and partially-saturated conditions.

Student projects

Several semester projects and master thesis have been done under the supervision of the laboratory's staff. During the period 2015 – 2016, eight master thesis and twenty semester projects have been achieved at LMS!

Master thesis

Geotechnical analysis of a metro station with energy geostructures, master thesis by Thibaut Duparc.

Geotechnical, structural and energy design of energy piles, master thesis by Etienne Dominguez.

Thermo-mechanical behaviour of heat-exchanger piles, master thesis by Hani Taha.

Modelling the effects of the atmosphere on the stability of slopes, master thesis by Michela Ronda.

Glissement de La Frasse – Quantification de l'efficacité de la galerie de drainage de 2008, master thesis by Cyrille Sautier.

Glissement-coulée de Pont Bourquin, master thesis by Samuel Grangier.

Tunnel de Pinchat – Conception et dimensionnement, master thesis by Terence Reverdin.

Etude géotechnique des ouvrages d'amenée d'un aménagement hydro-électrique (aménagement de Fah-Serra), master thesis by Giorgia Questi.

Semester projects

Biologically induced change in permeability of sands, semester project by Hani Taha.

Effect of bio-polymer formation on the shear resistance of sands, semester project by Thibaut Duparc.

Effect of treatment on the mechanical behaviour of soils enforced with gellan-gum, semester project by Pia Hartmann.

Thermo-hydro-mechanical modelling of nuclear waste storage, semester project by Hani Taha.

Thermohydromechanical modelling of nuclear waste storage, semester project by René Carpaij.

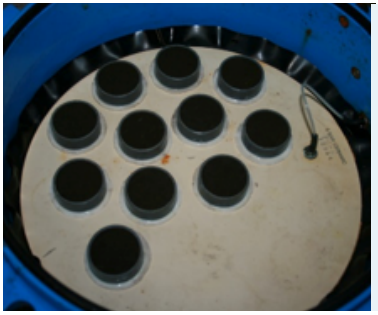
Modelling transport phenomenon in MX80 bentonite with homogenisation tools and application to nuclear waste storage, semester project by Geoffroy Melot.

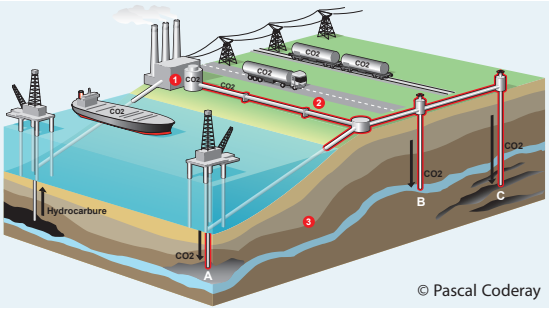
Assessment of suction measurement techniques, semester project by Guillaume Wymann.

Modelling of fault reactivation due to v storage in deep saline formations, semester project by Valentin Martyniak.

Modelling of storage in saline aquifers bounded by low permeability faults, semester project by Gil Bustarret.

Geomechanical implications of CO_2 leakage around wells, semester project by Geoffroy Melot.





The BIM technology applied to underground constructions, semester project by Mélissa Bidegain.

Glissement de terrain, revue de cas pratiques : glissement du Day, semester project by Aymen Achich.

Landslide case study: Steinernase Landslide, semester project by Lea Kaufmann.

Glissement de terrain, revue de cas pratiques : glissement de Cergnat – La Frasse, semester project by Etienne Moser.

L'effondrement en géotechnique, semester project by Claudia Ylla Arbos.

Analyse de la prise en compte des pressions des terres en géotechnique, semester project by Lionel Krayenbühl.

Performance of energy geostructures, semester project by Thibaut Duparc.

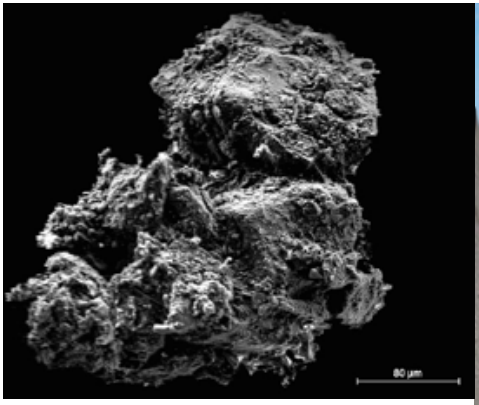
The equivalent pier method for energy pile groups, semester project by Benoit Cousin and pia Hartmann.

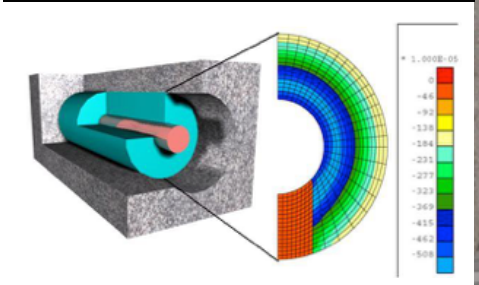
The interaction factor method for energy pile groups, semester project by Lea Kaufmann and Hani Taha.

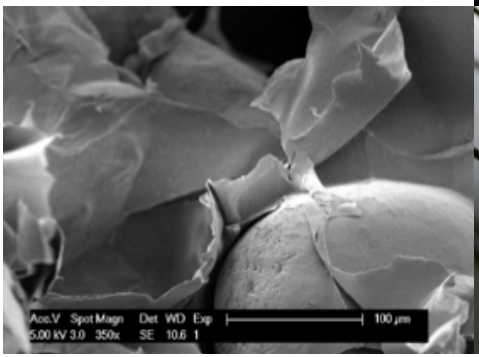
Thermo-mechanical performance of energy parking, semester project by Hani Taha.

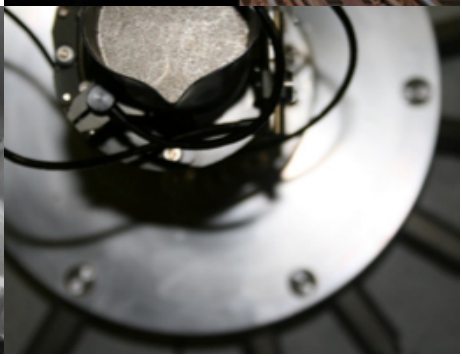
Research

Besides the conventional geomechanical research activities, the LMS research group gives priority to the protection of the environment, landforms and structures from geo-hazards and industrial damage. The LMS experimental and modelling resources are mobilised to understand, investigate and predict the environmental impact of the new technologies, such as nuclear waste disposal, and to provide tools for the up-to-date design of the geostructures. In addition, in the context of the Chair "Gaz Naturel", the laboratory focuses its activities on geo-engineering and CO_2 storage. The scientific and technological developments are permanently transferred to education and industry.





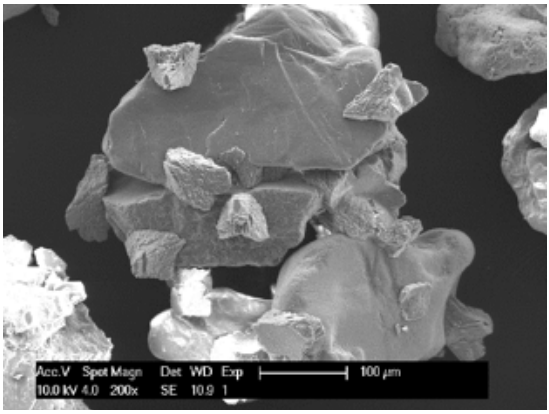




Geo-mechanical investigations of Bio-improved soils

Rocks and soils are the oldest materials on our planet and hold a crucial role by providing the necessary substrate for human engineering works. When it comes to the conception of foundation solutions for engineering works, though, engineers are often faced with weak and unstable soils. Soils with low capacity of supporting structures pose limitations to the implementation of construction works and threaten the overall integrity of structures. The solution engineers came up with is to interfere with the substrate in order to improve and strengthen it. In our laboratory we investigate such a novel soil improvement strategy, inspired by the natural process of biologically driven crystal mineralization. This bio-inspired technique imparts the subsurface soil with greater rigidity and resistance through the formation and growth of "microbe cement" crystals. Our goal is to shed light on this natural mechanism, adapt and control it to provide solutions to specific engineering problems. And, this is a mechanism that nature had billions of years of evolution to perfect!

Construction materials such as concrete, steel and wood can be designed and tailored according to the needs of the foreseen structure. Soils are rather unpredictable and. Thus, the ability to interfere with soils in order to alter their properties seems like sole solution in the strive towards securing the integrity of structures. Our work aims to fully understand the bio-cemented material's formation and deformation in order to propose a complete treatment strategy targeting the nature and specific needs of the foreseen engineering problems.



Calcium carbonate particles bridging soil grains as a result of soil bio-cementation (surface analysis via Electron Microscopy)

Among the foreseen applications of bio-cemented soils are: strengthening and stabilization of weak soils and slopes, mitigation of underground pollution, increasing soil-structure thermal exchanges for an efficient energy performance of buildings, sealing fractures in rocks, controlling and mitigating fugitive dust which is responsible for air pollution, as well as the production of bio-bricks.

Background and goals

The project focuses on a novel material: the bio-improved geomaterial. The goal of the project is to fully address the material's performance and investigate its potential in providing solutions for a series of engineering and environmental applications.

During the reporting period the following objectives are adopted:

(i) Apply the bio-cementation mechanism to different soil types to investigate what is the

yielded structure and level of improved properties.

(ii) Incorporate parameters inferred from the microstructure to account for the fabric of the material in the expression of the improved mechanical response.

(iii) Make a step towards a larger experimental scale, where the main goal is to investigate the performance of the technique in a series of pilot applications.

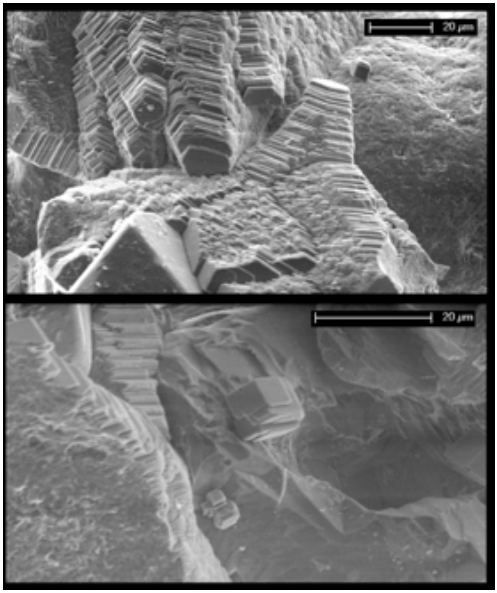
The study evolves at different scales: An extensive characterization of the material's fabric takes place at the microscale using advanced electron microscopy and computed scan tomography techniques. The samples are tested at the conventional laboratory scale where the material is tested to determine its strength and resistance. Finally, the tests are performed at the larger experimental scale.

Large scale implementation of soil bio-improvement on fine sand

Research activities

Employing materials of different grain sizes and mineralogical compositions allows for the investigation of: (i) the formation of the calcite lattice inside porous media to determine whether or not predominant patterns regarding the geometrical and spatial characteristics of the precipitated nuclei exist and (ii) potential variations in the overall mechanical response of each type of material. In order to evaluate the aforementioned hypotheses, three different types of sands are subjected to exactly the same treatment conditions: fine sand (average grain diameter of 0.19mm), medium sand (average grain diameter of 0.39mm) and a sand-gravel mixture (average grain diameter of 0.60mm).

The microstructural investigation of the obtained bio-cemented material through Energy Dispressive X-Ray (EDX) elementary analyses reveals that the lattice of calcite particles exhibits certain repetitive trends for each of the tested materials. Analyses are carried out for several cross sections of cemented materials of varying calcite bond content.



Growth of calcium carbonate crystals (Cubis shaped, plane expansion) on the surface of grains

Two application strategies are implemented for the upscaling of the technique by altering the injection source for the bacteria and the hydraulic conditions applied: (i) surface application of the MICP and (ii) a grid of injection points.

The obtained bio-cemented samples are subjected to triaxial drained shear tests under different confining pressures to determine the improved strength and stiffness. Results show that for the same mass of precipitated calcite the fine sand increases its cohesion to 250 kPa while the cohesion of the improved medium coarse sand reaches over 450 kPa.

After obtaining the microstructural images through electron microscopy, the geometrical and spatial characteristics are analysed through an image processing technique. Particles are therefore distinguished into two sorts based on their manner of precipitation habits:

(i) Active bonds which contribute with their stiffness to the overall stiffness of the improved material.

(ii) Inactive bonds that grow on grains' surface and do not connect soil particles.

A crucial question to be answered here is whether the same total mass of calcite particles fragmented into a larger number of small particles yields the same mechanical response as a smaller number of big particles that form the same total volume. Once the image processing is complete and the statistical analysis is carried out, the fraction of active bonds can be calculated, as well as the level of fragmentation of the total volume of calcite particles. The obtained results of the 2D analyses are compared to the ones from 3D X-Ray computed tomography analyses.

Ongoing PhD thesis

Geo-mechanical constitutive model for bio-improved soils by Dimitrios Terzis, funded by Swiss National Science Fondation, Lombardi SA and State Secretariat for Education Research and Innovation SERI.

Student projects

Biologically induced change in permeability of sands, semester project by Hani Taha. The project investigates the change in permeability of sands after applying a biopolymer treatment process. This latter induces the formation of a jelly substrate between spoil grains.

Effect of bio-polymer formation on the shear resistance of sands, semester project by Thibaut Duparc. The project investigates the variation of the shear strength of biopolymer treated sands for various degrees of bonding.

Effect of treatment on the mechanical behaviour of soils enforced with gellan-gum, semester project by Pia Hartmann. The project puts the focus on the deformation of polymer treated sand under oedometric conditions. Both saturated and unsaturated conditions are tested for investigating the material's response.

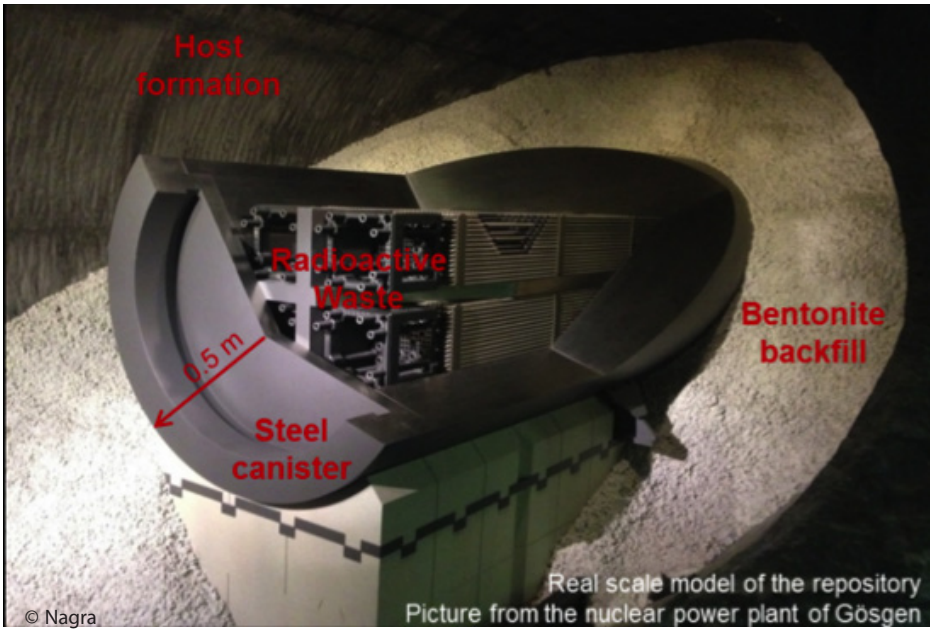
Relevant publications

D. Terzis, R. Bernier-Latmani and L. Laloui. *Fabric characteristics and mechanical response of bio-improved sand to various treatment conditions*, in Géotechnique Letters, vol. 6, num. 1, 2016.

S. Venuleo, L. Laloui, D. Terzis, T. Hueckel and M. Hassan. *Effect of Microbially Induced Calcite Precipitation on soil thermal conductivity*, in Geotechnique Letters, vol. 6, num. 1, 2016.

Nuclear waste storage

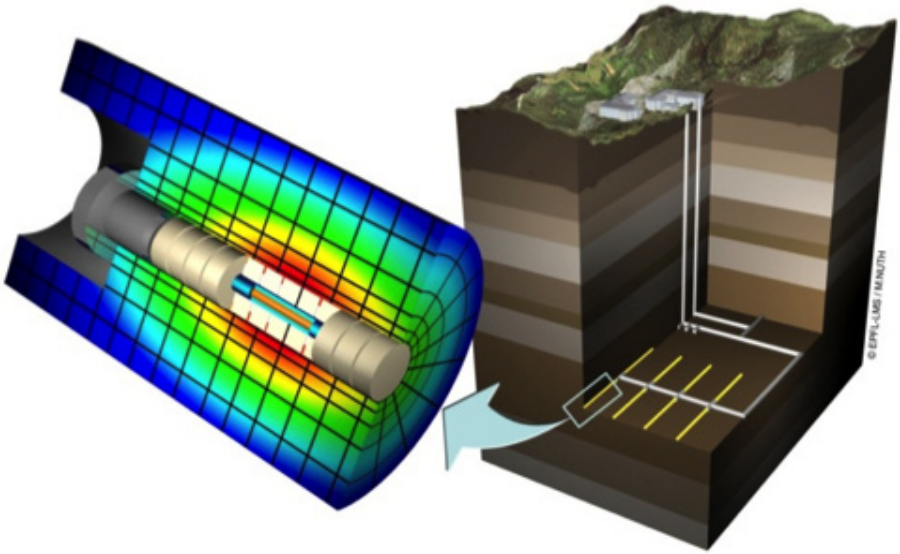
The long-term management of radioactive waste is one of the biggest challenges that our society has to face. The waste produced by the nuclear industry is indeed harmful to human health and the environment and will remain toxic for thousands of years. According to the National Cooperative for disposal of Nuclear Waste in Switzerland (NAGRA), the volume of low and intermediate-level waste that is predicted for a 50-year period can reach 93'000 m3. Among this volume, 60'000 m3 comes from the operation and dismantling of the five Swiss nuclear power plants and 33'000 m3 from research, industry and medicine.



Model of the nuclear waste repository

The most promising solution for the long-term management of the radioactive waste is their isolation in deep geological formations (typically several hundreds of meters below the surface). The idea is to dispose the waste in stable geological formations with good confining conditions. The safe isolation relies on a multi-barrier concept in which isolation from the biosphere is provided by a combination of natural barriers (the surrounding rock, i.e. shales in Switzerland) and engineered barriers (a metallic canister and a bentonite -a type of clay- buffer).

Under disposal conditions, these materials will experience complex physical processes resulting from heat production by the radioactive waste, bentonite buffer hydration and eventually gas production (as a result of the progressive degradation of the canister). For example, bentonite saturation will induce swelling of the material, such that a tight contact between the materials of the disposal will be created.



Finite Element modelling of the repository

The Laboratory of Soil Mechanics of the EPFL has developed a strong expertise in the comprehension and prediction of the behaviour of the geological disposal. By designing innovative experimental equipment, realizing advanced laboratory tests, developing new models and performing computer simulations, the Laboratory of Soil Mechanics contributes to the design of future geological disposals.

Research activities

Constitutive and numerical modelling

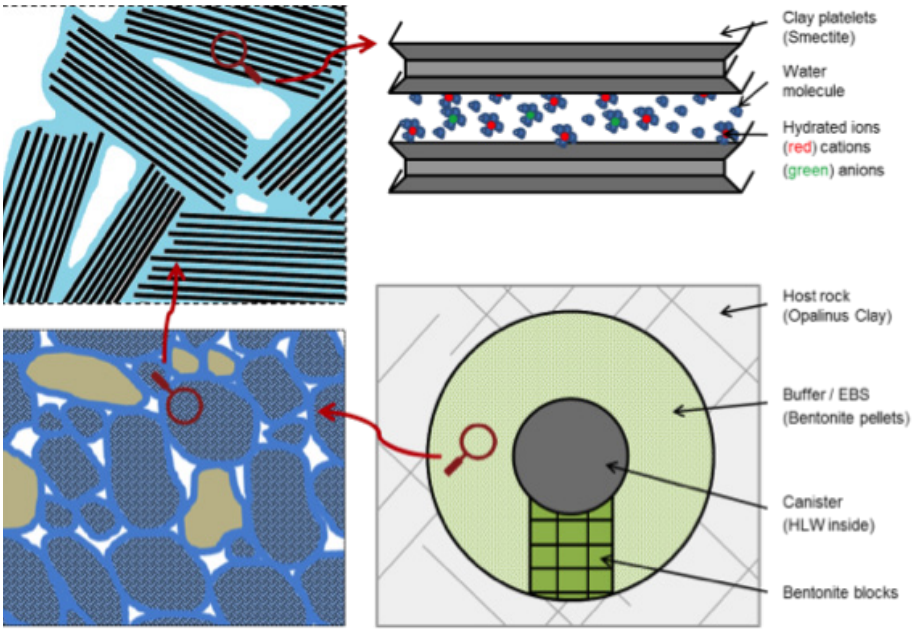
Modelling activities at LMS encompass multiscale and multiphase approaches.

Nanoscopic scale modelling focuses on the size of smectite (clay mineral): Smectite-based clays have low water and ions permeabilities as well as high thermal conductivities and swelling potentials. Because of these particular properties, these materials are to be used as a barrier in nuclear waste disposals. The understanding of the mechanical behaviour of swelling clays is a key feature for the safety of such disposals and it represents a major scientific challenge! The aim of the work is to derive a macroscopic constitutive law able to model the coupled thermo-hydro-chemo-mechanical behaviour of a sand/bentonite (S/B) mixture.

In Switzerland, the prime candidate for hosting the deep geological repository site is the Opalinus Clay. The research aims to improve the current predicting and modelling capabilities of the thermo-hydro-mechanical behaviour of shale by: (1) developing proper constitutive models tailor fitted to the purpose;

(2) validating the developed models against experimental findings at the small (laboratory) and medium (rock mass) scale.

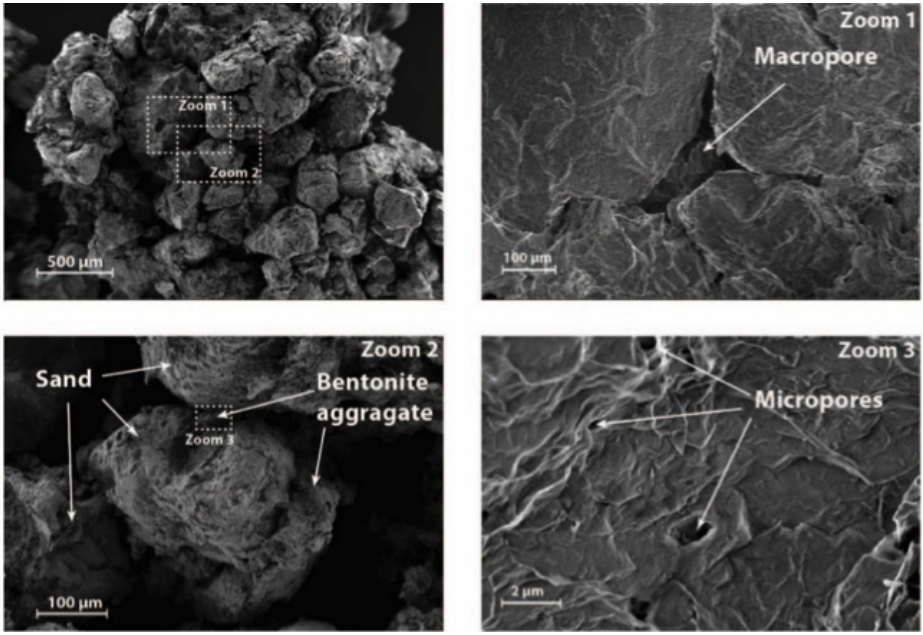
Numerical modelling at the large scale allows for the improvement of our understanding of the whole system behaviour by accessing information that cannot be obtained experimentally. In addition, it allows for the evaluation of various scenarios and for the study of very large structures over long time periods.



Looking at nuclear waste storage at different scales. The buffer of the deposit is made of a porous clay matrix with some impurities. The clay matrix itself can be seen, at a smaller scale, as an arrangement of stacks of mainly smectite platelets

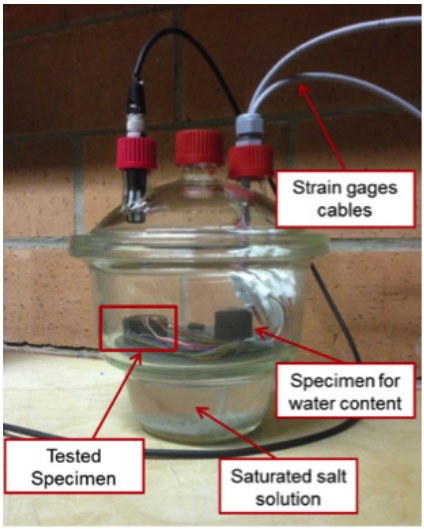
Experimental research

For the characterization of the buffer material at the macroscopic and microscopic level, a systematic approach is adopted. At the macroscopic level, free and confined swelling tests are performed on specimens compacted to different dry densities and wetted with different pore fluids. Water retention curves and permeability are determined for a wide range of densities. Gas injection tests on the mixture are performed in both saturated and unsaturated conditions. A highly advanced triaxial apparatus allows for the analysis of the volumetric response. An extensive microstructural characterization is performed using the mercury intrusion porosimetry (MIP) and a high-resolution scanning electron microscope.



Scanning electron microscopy images of sand/bentonite mixture

Concerning the shale behaviour, complex thermo-hydro-chemo-mechanical stress paths are designed for investigating the material behaviour. The mechanical response is investigated through the use of drained triaxial tests. Compaction and consolidation behaviour is investigated by means of high-pressure (up to 100 MPa), high-temperature (up to 100°C) oedometric tests.



Setup for anisotropic volumetric response of shales upon saturation/desaturation cycles

Opalinus Clay volumetric behaviour is known to be sensitive to water content and water chemical composition. A high-precision setup, using strain gauges and a vapour transfer technique, is established for detecting the volumetric anisotropic behaviour of Opalinus Clay samples under saturation/desaturation cycles.

Ongoing PhD thesis

Coupled Thermo-Hydro-Chemo-Mechanical modelling of bentonite in the context of nuclear waste storage by Etienne Cassini, funded by Swissnuclear.

Advanced constitutive law for Opalinus Clay by Eleonora Crisci, funded by NAGRA.

Recently concluded PhD thesis

D. Manca, L. Laloui and A. Ferrari (Dirs.). Hydro-chemo-mechanical characterization of sand/bentonite mixtures: with a focus on the water and gas transport properties. Thèse EPFL, n° 6790 (2015), funded by Nagra.

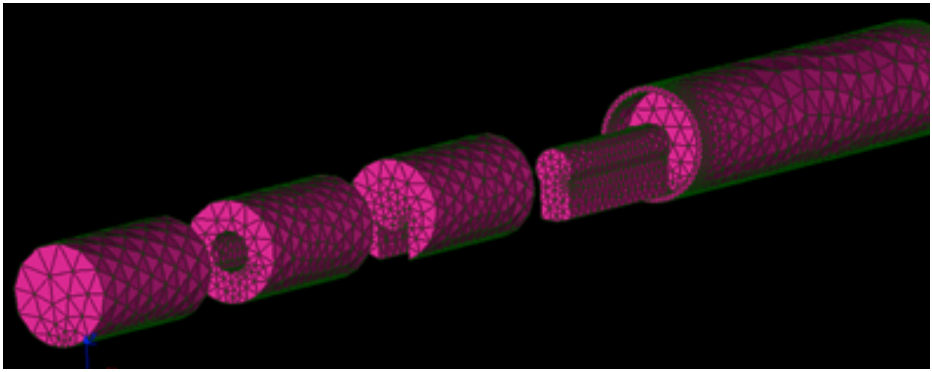
F. Parisio, L. Laloui (Dir.). *Constitutive and numerical modelling of anisotropic quasi-brittle shales*. EPFL PhD thesis, n° 7053 (2016), funded by SwissTopo and SwissNuclear.

Student projects

Thermo-hydro-mechanical modelling of nuclear waste storage, semester project by Hani Taha. A 2D finite element model is developed in the project to simulate the tunnel excavation, the emplacement of the shotcrete, bentonite blocks that support the canister that emits heat and the bentonite filling and heating caused by the canister.

Thermo-hydro-mechanical modelling of nuclear waste storage, semester project by René Carpaij. The 2D model is extended in this project to a 3D configuration in order to simulate the whole sequence of the in-situ experiment, which allows for the reproduction of the heating sequence of the three canisters and the analysis of the THM spatio-temporal response of the repository.

Modelling transport phenomenon in MX80 bentonite with homogenisation tools and application to nuclear waste storage, semester project by Geoffroy Melot. A review of ions transport model is done, focusing on the models developed and applied to smectite clays used as buffer material in the High Level Waste. Then a multi-scale approach is proposed to develop a physical model for MX-80 bentonite.



Finite Element model: containers, bentonite blocks and hydraulic seals (from René Carpaij's project)

Relevant publications

F. Parisio, S. Samat and L. Laloui Constitutive analysis of shale: a coupled damage plasticity approach, in International Journal of Solids and Structures, vol. 75-76, p. 88-98, 2015.

D. Manca, A. Ferrari and L. Laloui, Fabric evolution and the related swelling behaviour of a sand/bentonite mixture upon hydro-chemo-mechanical loadings, in Geotechnique -London-, vol. 66, num. 1, p. 41-57, 2016.

V. Vilarrasa, F. Parisio and L. Laloui. Strength evolution of geomaterials in the octahedral plane under non-isothermal and unsaturated conditions, accepted in International Journal of Geomechanics, 2016.

Geomechanics of shales

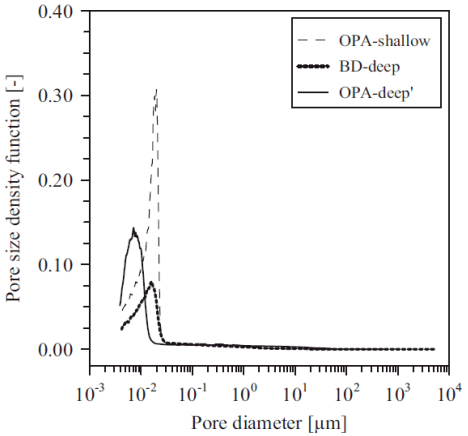
Shales are involved in several complex geo-engineering applications such as radioactive waste storage, CO_2 sequestration, oil and gas extraction, and deep geothermal energy. In these applications shales are subjected to several different physical phenomena involving mechanics, temperature, hydraulics, and chemistry. For this reason, the prediction of their behaviour under in-situ conditions, from hundreds to thousands meters underground, is quite difficult and poses several challenges.

The aforementioned physical processes need to be properly understood in order to facilitate successful storage of CO_2, safe disposal of radioactive waste, and an efficient extraction of gas and energy from the subsurface. Geomechanical characterization of shales through advanced laboratory testing plays a fundamental role in improving our knowledge and properly predicting their behaviour with advanced numerical simulations. Therefore, a reliable determination of the parameters and properties governing the geomechanical response of shales under multiphysical conditions is a key requirement for the success of the engineering operations.

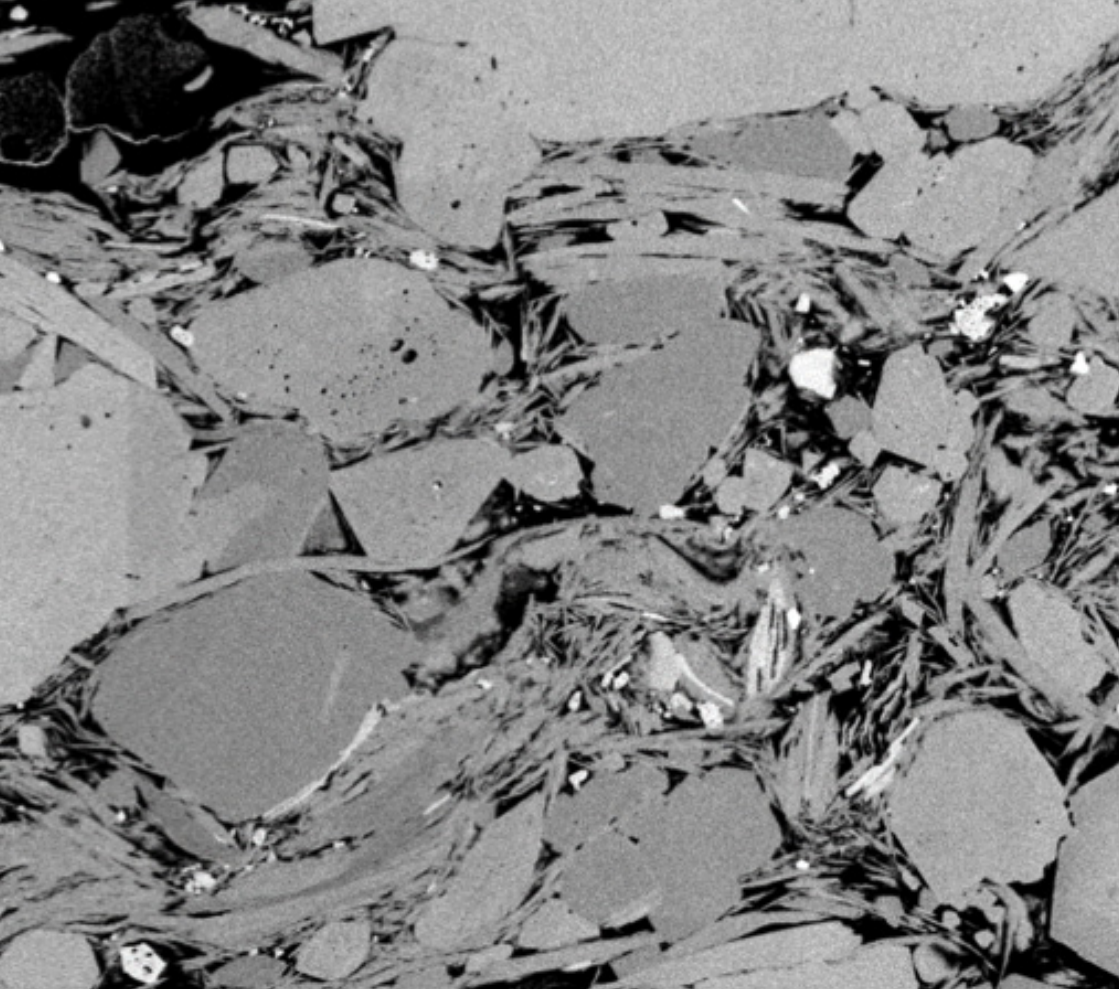
Part of the research activities of the LMS are carried out in this context where the laboratory testing and numerical modelling aim to provide solutions to the main challenges related to the previously discussed engineering applications.

Background and goals

Shales are very complex sedimentary geo-materials composed of clay minerals and tiny fragments (silt-sized particles) of other minerals, especially quartz and calcite. Common features of this natural material are, among others, very low conductivity, heterogeneous composition, anisotropic behaviour and high clay content. The complexities of this geo-material and of the specific engineering applications in which it is involved imply the need of experimental investigations and modelling approaches with special attention being paid to the coupled thermo-hydro-chemo-mechanical processes.



Pore size density function of some tested shales by LMS



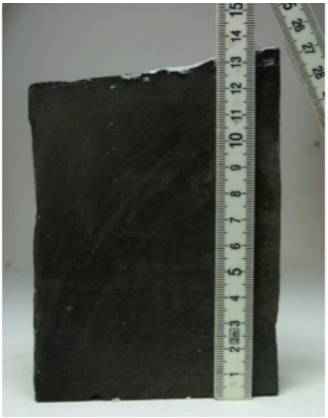
SEM image of a gas shale polished specimen. The figure highlights the complex and heterogeneous structure composed of carbonate grains, clay particles and organic matter

Research activities

The research team of the LMS has been involved in a large number of research activities in the experimental and modelling context of the geomechanics of shales.

A specific experimental campaign consisting of high temperature and high-pressure oedometric tests has been carried out at LMS in order to analyse the thermo-mechanical volume change of Opalinus Clay at different stress conditions and different over-consolidation ratios. The influence of temperature on some hydro-mechanical characteristics with reference to the same shale has also been investigated.

Due to the peculiar features of these geomaterials, this study has required a significant improvement

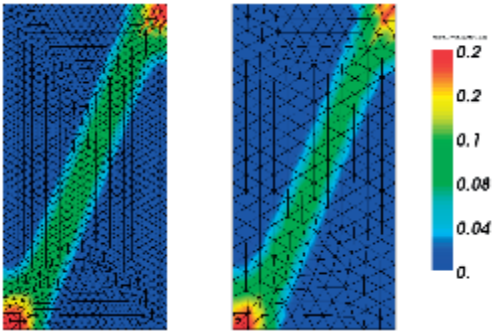


Example of gas shale core sample retrieved at thousands of meters depth

of the testing capabilities; indeed, an advanced testing set-up has been developed along with the establishment of experimental methodologies. The investigation focused on two main aspects: the water retention properties and the hydro-mechanical behaviour. To have a good understanding of these aspects, the key role of suction has to be taken into account and deeply analysed. An interesting analytical procedure to analyse the consolidation of the shales and an application to the Opalinus Clay has been further developed.

In order to improve the modelling and predicting capabilities of the behaviour of shales, attention has also been given to the formulation of new constitutive laws. A non-isothermal plastic constitutive model for unsaturated materials that accounts for the Lode's angle on the strength of geo-materials has been developed. The quasi-brittle behaviour of shales has been captured with a damage-plastic model.

After checking the capability of the model to reproduce some crucial characteristics of the behaviour of shales, the extension to take into account anisotropy and true triaxial strength has been developed. The mesh-dependency of the solution and the localization of deformation have been avoided by applying a proper regularization technique and verifying its efficiency. A practical application of the developed anisotropic plastic-damage model has been performed in a finite element analysis of a tunnel excavation in coupled hydro-mechanical conditions. The above mentioned points are only some of the main goals of the research activity of the LMS's group reached in the 2015-2016 academic years.



Damage-plastic model : damage distribution for a finer mesh (left) and for a coarser mesh (right)

Ongoing PhD thesis

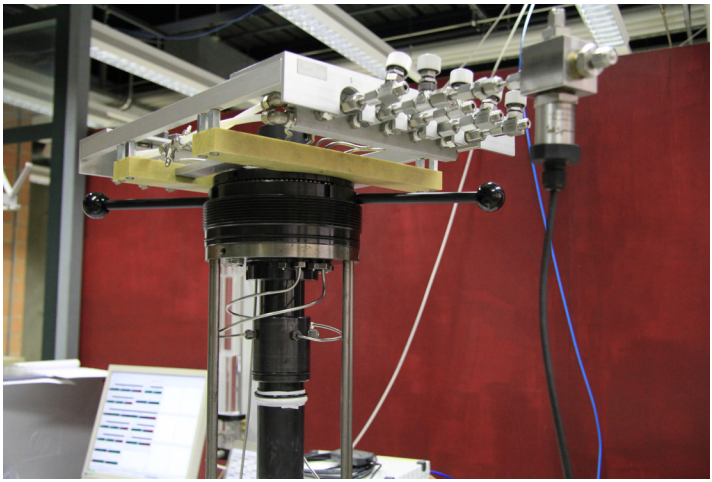
Thermo-Hydro-Mechanical characterization of shales by Valentina Favero, funded by Nagra.

Coupled chemo-hydro-mechanical behaviour of shales by Angelica Tuttolomondo.

Hydro-mechanical behaviour and transport properties of shales and gas shales by Alberto Minardi, funded by Nagra.

Student projects

Assessment of suction measurement techniques, semester project by Guillaume Wymann (student from Ecole des Ponts Paris Tech). The main goal of this project was to assess the accuracy of different experimental techniques to measure suction of gas shales.



Relevant publications

V. Favero, A. Ferrari and L. Laloui. *Thermo-mechanical volume change behaviour of Opalinus Clay,* in International Journal of Rock Mechanics and Mining Sciences, vol. 90, p. 15-25, 2016.

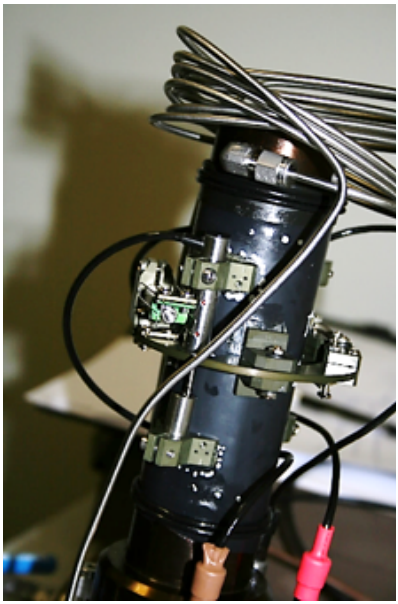
A.Ferrari, V. Favero and L. Laloui. *One-dimensional Compression and Consolidation of Shales,* in International Journal of Rock Mechanics and Mining Sciences, vol. 88, p. 286–300, 2016.

V. Favero, A. Ferrari and L. Laloui. *On the Hydro-Mechanical Behaviour of Remoulded and Natural Opalinus Clay Shale*, accepted in Engineering Geology, vol. 208, p. 128–135, 2016.

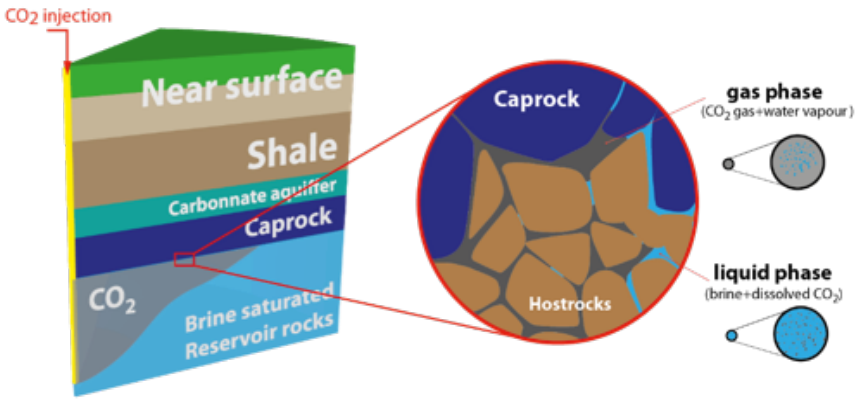
A. Minardi, E. Crisci, A. Ferrari, L. Laloui, (2016) Anisotropic volumetric behaviour of Opalinus Clay shale upon suction variation, in Geotechnique Letters, vol. 6, p. 1-5, 2016.

CO_2 capture and storage

CO_2 is considered to be the most important greenhouse gas released into the atmosphere, and their emission has increased drastically over the past decade. Each year, emissions of carbon dioxide are increasing contributing significantly to climate change. One of the most important decisions during COP21 was to reduce global warming by 2°C. Renewable energies are not yet sufficient to achieve this objective, and it is not economically feasible to stop fossil fuel based energy consumption. Carbon Capture and Storage (CCS) is a very promising solution to reduce CO_2 emissions. It consists of capturing CO_2 near a source, transporting it to a suitable geological site and storing it underground. CO_2 can be stored in a reservoir rock roofed by a caprock. The caprock acts as a barrier to prevent CO_2 from migrating upward.



Our team in the chair "Gaz Naturel" Petrosvibri (LMS) is working on developing an understanding of the complex interactions between CO_2 and both reservoir and caprocks.



Idealized configuration of an embedded caprock layer

Background and goals

To mitigate greenhouse gas emissions and counter the drastic climate changes, Carbon Capture and Storage (CCS) technologies are one of the most promising solutions. There is an important potential in storage sites: depleted oil and gas reservoirs and deep saline acquifers, which makes this solution very attractive.

The chair is willing to perform experimental analysis dedicated to engineering projects using specific experimental protocols and following high standards through the development of equipment that allows laboratory testing of geomaterials in contact with CO_2. Our equipment, which includes an advanced triaxial and oedometric cell, is designed to reproduce in situ reservoir conditions: high temperatures up to 50 °C which allows high pressure up to 500 MPa.

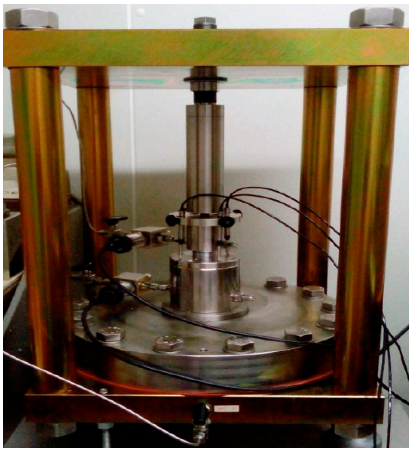
Those experiments would allow the characterization of brine-saturated host and caprock response and the characterization of the effect of CO_2 injection on permeability and mechanical properties.

The experimental data obtained from our laboratory testing will be used to validate a constitutive model of carbon dioxide effect on geomechanical response of rock-like materials. The interplay between multiphase transport, multi-components reaction and mechanics will be numerically tackled through innovative interdisciplinary research.

Research activities

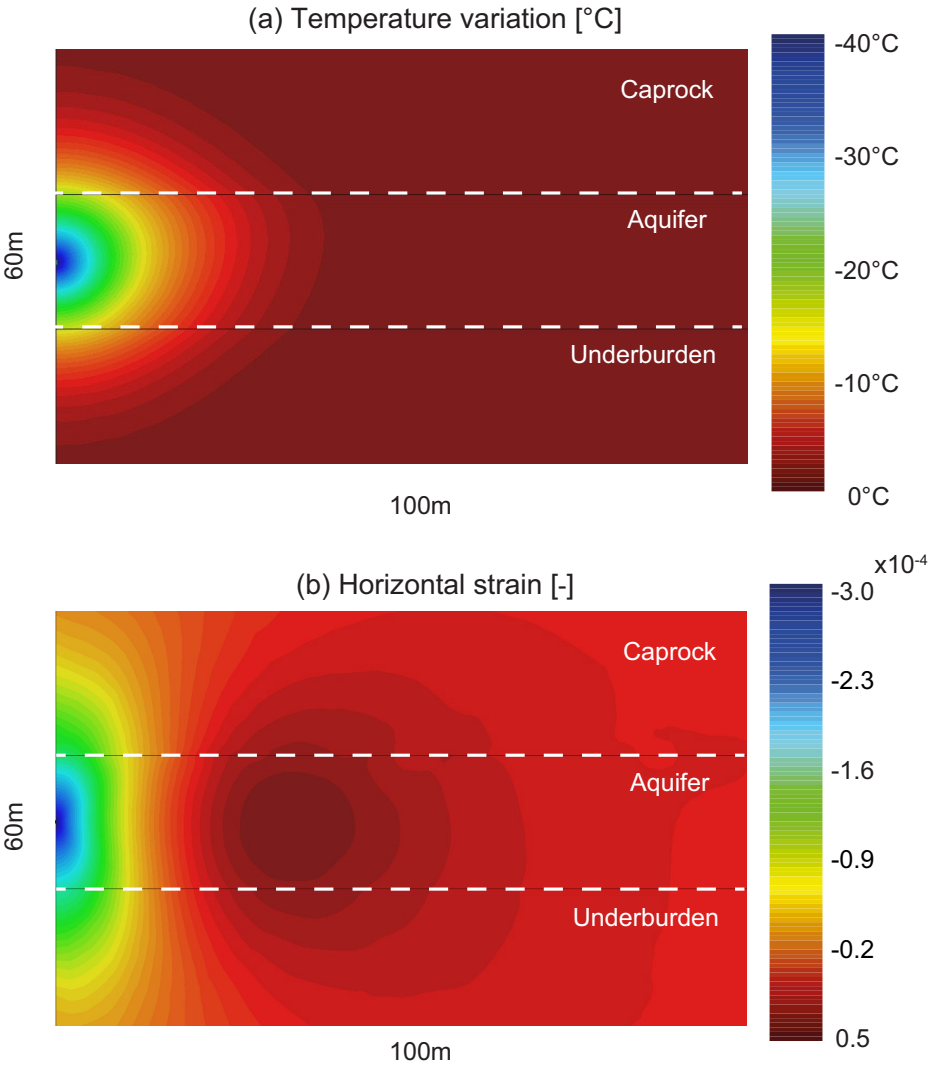
Security of CO_2 sequestration relies on the integrity of the caprock. Thermal and chemical interactions that occur at the interface between the caprock and the reservoir rock might change the properties of the caprock. For this reason, our research group focuses on the mechanical properties of rocks, that possess properties of caprock (i.e. shales, sandstones), in contact with CO_2.

The aim is to enhance our understanding of the mechanical properties of rocks interacting with supercritical and liquid CO_2 under in situ conditions (Temperature and pressure). We have developed advanced experimental equipment to allow for the laboratory testing of geomaterials in contact with CO_2. We are working on the experimental aspect of CO_2 storage, investigating the mechanical response of geomaterials in contact with supercritical and liquid CO_2 under in situ conditions. Advanced oedometric and triaxial cells were designed in order to perform CO_2 injection in the tested geomaterials under in situ conditions.



Advanced oedometric cell

Numerical simulations of CO_2 injections in depleted oil and gas reservoir or saline aquifer are a good tool to assess their behaviour under injection conditions. An important aspect, which must be taken into account during the analysis, is the coupling of different mechanisms that occur when CO_2 is injected in the storage site.



Spatial distribution of (a) the temperature variation and (b) horizontal strain after four years of injection

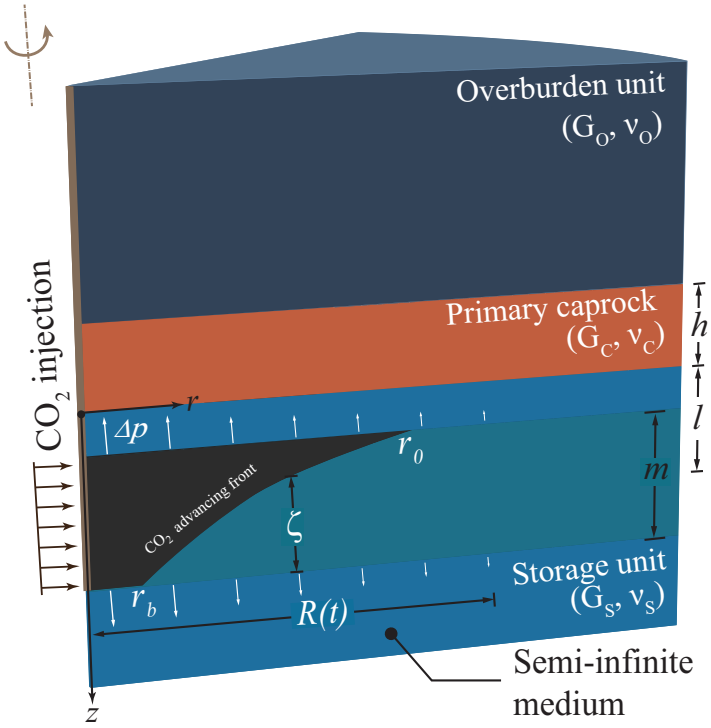
In fact we have to consider that, during the injection, the temperature in the reservoir changes because the CO_2 is generally injected in a supercritical state, so at a temperature of 31 °C, while in the reservoir the temperature is at about 50 – 80 °C; once the CO_2 comes in contact with the host rocks some chemical reactions may occur causing dissolution and precipitation phenomena; the injection changes the in situ stress conditions and the injection pressure may trigger fracture propagation in the reservoir and in the cap rock. In addition, we have to consider the mechanical aspect; we are injecting a fluid into a porous media so also the hydraulic part of the problem is important.

In the simulations when we take into account all this aspects (Temperature, Hydraulics, Chemistry and Mechanics) it means that we are dealing with a THCM coupled problem, and this is what we are developing now at the LMS.

Ongoing PhD thesis

Experimental characterization of mechanical properties and sealing capacity of shales for CO_2 storage by Houda Tadloui.

Thermo-hydro-chemo-mechanical modelling of CO_2 injection in deep saline aquifers by Matteo Bocco.



Student projects

Modelling of fault reactivation due to CO_2 storage in deep saline formations, semester project by Valentin Martyniak. This project investigated the effect of injecting CO_2 on the reactivation of a fault. This reactivation could in turn induce seismicity.

Monitoring of near-surface hydraulic fracturing, semester project by Valentin Martyniak and Geoffroy Melot. The goal of this project was to explain how to monitor the propagation of hydraulic fractures in a low permeable rock.

Modelling of CO_2 storage in saline aquifers bounded by low permeability faults, semester project by Gil Bustarret. This project aimed at quantifying the effect of permeable faults during the injection of CO_2.

Geomechanical implications of CO_2 leakage around wells, semester project by Geoffroy Melot. This project investigated the effect of a leaky well on the geomechanical response of the surrounding rock.

Relevant publications

V. Vilarrasa, F. Parisio and L. Laloui. *Strength evolution of geomaterials in the octahedral plane under non-isothermal and unsaturated conditions*, accepted in International Journal of Geomechanics, 2016.

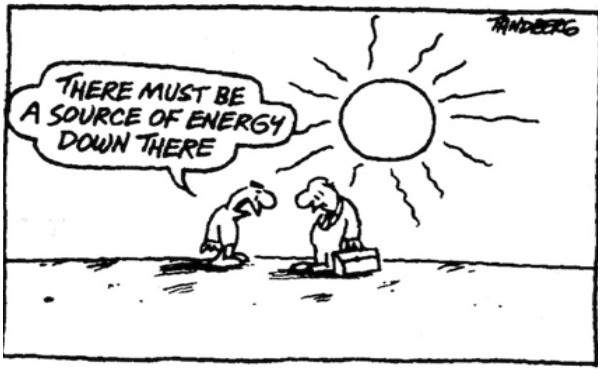
C. Li and L. Laloui. *Coupled multiphase thermo-hydro-mechanical analysis of supercritical CO_2 injection: benchmark for the In Salah surface uplift problem*, in International Journal of Greenhouse Gas Control, vol. 51, p. 394-408, 2016.

C. Li, L. Laloui (Dir.). *Geomechanical modelling of CO_2 injection in deep aquifers.* Thèse EPFL, Lausanne, n°6979 (2016).

V. Vilarrasa and L. Laloui. *Impact of thermally induced stresses on fracture stability during geological storage of CO_2*, in Energy Procedia, vol. 86, p. 411-419, Energy Procedia, 2016.

Energy geostructures

Worldwide population growth and the improvement of living standards lead to the depletion of fossil energy sources, environmental pollution, and climate change. In this framework, a major challenge is the conceptual development, demonstration and dissemination of innovative environmental friendly technologies that exploit renewable energy sources to satisfy an increasing proportion of worldwide energy needs. Energy geostructures are an example of these innovative technologies.



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Energy geostructures are ground structures that couple the role of the structural support with that of the geothermal heat exchanger in order to satisfy the energy needs of the built environment. Embedded in these foundations and/or ground structures, which are necessary for structural purposes, are pipes with a circulating heat carrier fluid, which allows to exploit the ground as a heat exchanger and storage medium to heat and cool buildings and infrastructures.

The twofold role of energy geostructures involves coupled multiphysical phenomena and loading actions. These characteristics, which govern the thermo-mechanical performance and the structural, geotechnical and energy behaviour of energy geostructures, represent innovative challenges for civil engineers. The reason is because they require multidisciplinary competences in structural, geotechnical and energy engineering related to the mechanics of solids and structures, heat and mass transfer, and materials science, to perform the analysis and design of energy geostructures.

In our group, we are addressing the aforementioned challenges through a multidisciplinary approach based on full-scale field testing, numerical modelling, analytical modelling and laboratory testing. The ultimate goal of these activities is to develop a sound knowledge on the behaviour and performance of energy geostructures, looking at a worldwide diffusion of this innovative technology through optimal designs.

Research activities

Over the last two years, we have focused our attention on three main aspects related to energy geostructure applications:

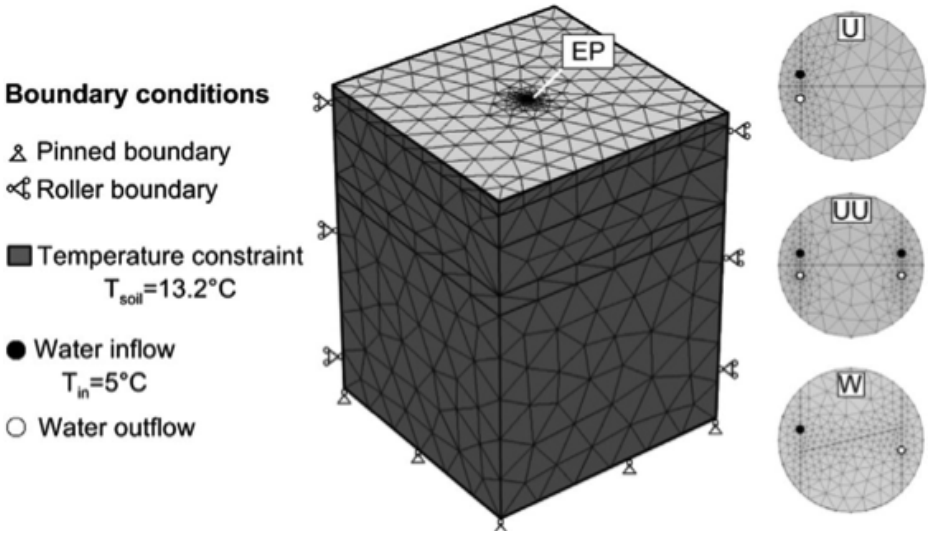
1. Thermo-mechanical behaviour of single and groups of energy piles

The research about single energy piles has been devoted, from one side, to investigating the fundamental mechanisms and phenomena governing the thermo-mechanical behaviour of these foundations under significant thermo-mechanical loads, and, from the other side, to analysing the energy, geotechnical and structural performance of these foundations considering different design solutions applicable to such foundations.

A number of finite element analyses and centrifuge tests have been performed to investigate the aforementioned aspects of the thermo-mechanical behaviour of energy piles. An example of the finite element models that have been built is reported in the figure below.

The research about energy pile groups has been primarily focused on the thermally induced group effects and interactions among closely spaced energy piles.

Full-scale in situ tests have been performed on an energy pile group located under the recently built Swiss Tech Convention Centre at EPFL.



Example of three dimensional finite element model used to investigate the energy, geotechnical and structural performance of energy piles for different design solutions (Batini et al., 2015).

2. Thermo-mechanical behaviour of soil-concrete interfaces

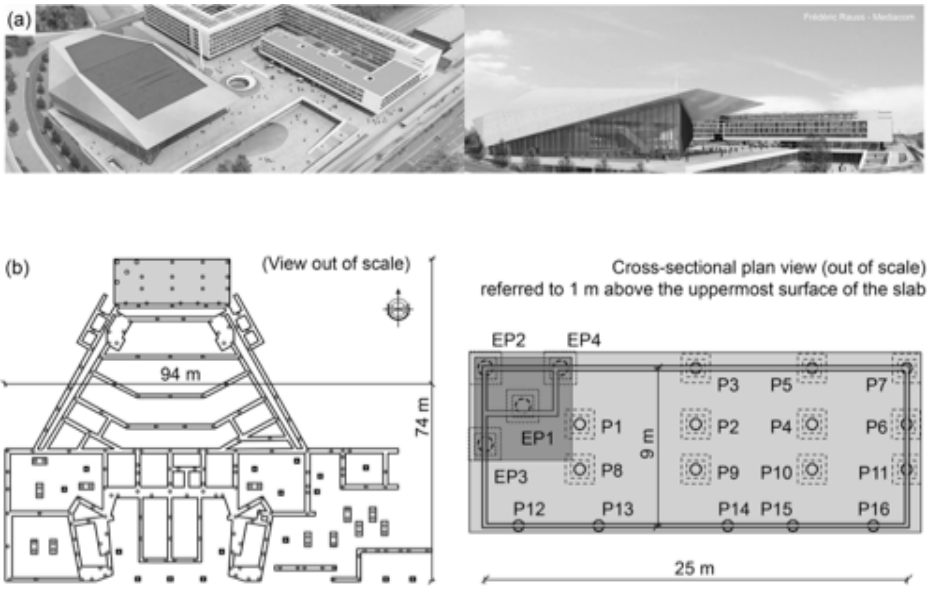
The research about the thermo-mechanical behaviour of soil-concrete interfaces has focused on the response of these settings to thermal cyclic loading.

An extensive number of soil-concrete interface shear tests have been performed under non-isothermal conditions through the use of an apparatus developed for the considered purpose, which is shown. Finite element analyses have also been performed to deepen the understanding of the considered aspects.

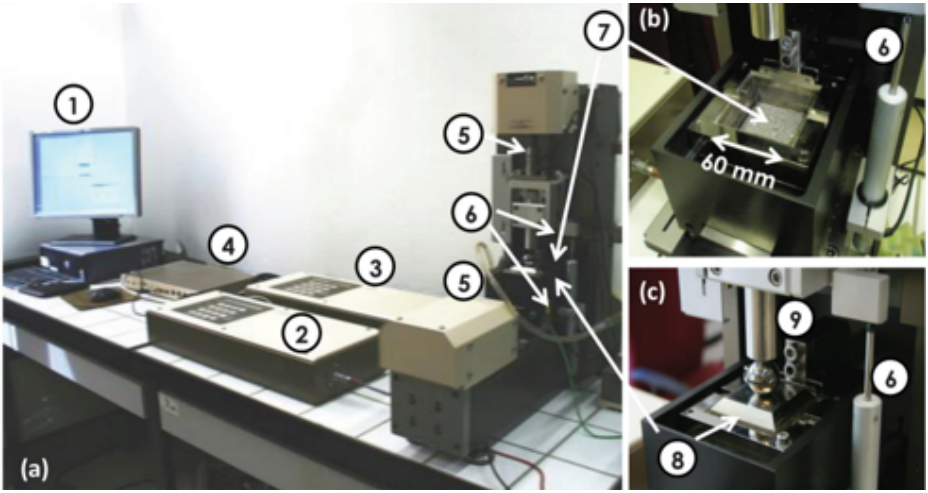
3. Thermo-hydro-mechanical behaviour of soils

The research about the thermo-hydro-mechanical behaviour of soils has focused on the response of these materials to thermal cyclic loading.

An extensive number of experimental laboratory tests and an advanced constitutive model have been utilized for this purpose. The experimental programme has included oedometric tests at various constant temperatures aimed at studying the sensitivity of the material to temperature and thermal cyclic tests under constant vertical effective stress in oedometric conditions, with temperature ranging between 5 and 60 °C. Both normally consolidated and overconsolidated soil samples have been tested.



(a) The EPFL Swiss Tech Convention Center (modified after original image, courtesy of Richter et Dahl Rocha Bureau d'architectes SA Architects); (b) plan view of the foundation including the four energy piles.



Original version of the GDS direct shear device: (a) global view, (b) detail of the open shear box, and (c) detail of the closed shear box. 1, GDSLAB software control; 2, normal actuator; 3, horizontal actuator; 4, LVDTs acquisition pad; 5, load cells; 6, LVDTs; 7, specimen placement; 8, top cap; 9, axial piston (Di Donna, Ferrari and Laloui, 2015).

Ongoing PhD thesis

On the geo-structural behaviour of thermo-active pile groups under mechanical and thermal cyclic actions by Alessandro Rotta Loria, funded by Swiss National Science Fondation.

Soil-structure interaction – theory and applications by Cristiano Garbellini, funded by State Secretariat for Education, Research and Innovation SERI.

Student projects

Geotechnical analysis of a metro station with energy geostructures, master thesis by Thibaut Duparc. The project is devoted to analysing the feasibility of including energy geostructures in a metro station and analysing the resulting thermo-mechanical behaviour of the structure.

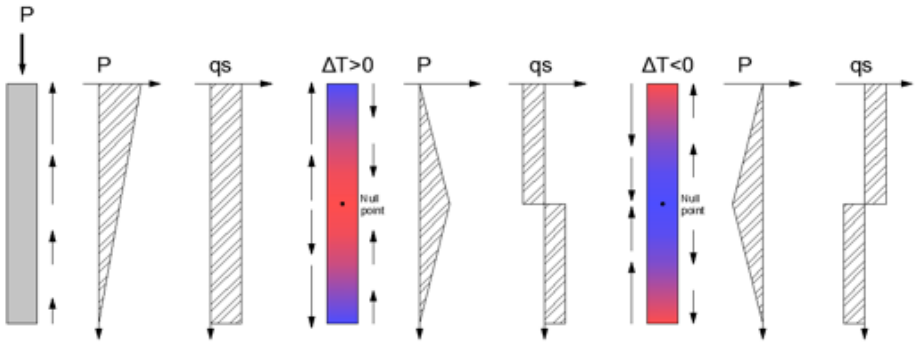
Geotechnical, structural and energy design of energy piles, master thesis by Etienne Dominguez. The project has been devoted to performing a literature study of the best design practices to design pile foundations in the framework of Eurocodes, and to propose extensions of these practices to tackle the design of energy piles.

Thermo-mechanical behaviour of heat-exchanger piles, master thesis by Hani Taha. The project has pro-

posed an investigation and a summary on the current knowledge of the thermo-mechanical behaviour of energy piles based on full-scale field data related to energy pile applications.

Performance of energy geostructures, semester project by Thibaut Duparc. The project has been devoted to performing a survey about the features that characterize current and past applications of energy piles in the world.

The equivalent pier method for energy pile groups, semester project by Benoit Cousin and Pia Hartmann. The project has been devoted to propose insights for an analytical model able to capture the vertical average displacement behaviour of energy pile groups by the analysis of a unique, single equivalent pier that behaves representatively for no matter which kind of energy pile group.



Behaviour of a pile subjected to mechanical and thermal loads. Source: Rapport Etienne Gonzalez Dominguez.

The interaction factor method for energy pile groups, semester project by Lea Kaufmann and Hani Taha. The project has been devoted to proposing insights for the development of an analytical model able to capture the thermally induced group effects and interactions among energy piles by the analysis of a pair of piles only.

Thermo-mechanical performance of energy parking, semester project by Hani Taha. The project has been devoted to analysing the thermo-mechanical mechanisms that characterize energy walls in the framework of underground parking.

Relevant publications

A. Di Donna, A. F. Rotta Loria, L. Laloui, *Numerical study of the response of a group of energy piles under different combinations of thermo-mechanical loads,* in Computers and Geotechnics, vol. 72, p. 126–142, 2016.

A. F. Rotta Loria, L. Laloui, *The interaction factor method for energy pile groups*, in Computers and Geotechnics, vol. 80, p. 121-137, 2016.

A. F. Rotta Loria, L. Laloui, *Thermally induced group effects among energy piles*, Géotechnique -London-, http://dx.doi.org/10.1680/jgeot.16.P.039, 2016.

A. Di Donna, A. Ferrari, L. Laloui, *Experimental investigations of the soilconcrete interface: physical mechanisms, cyclic mobilisation and behaviour at different temperatures,* in Canadian Geotechnical Journal, vol. 53, p. 659-572, 2015.

A. Di Donna, L. Laloui, *Numerical analysis of the geotechnical behaviour of energy piles,* in International Journal For Numerical And Analytical Methods In Geomechanics, vol. 39, num. 8, p.861888, 2015.

A. Di Donna, L. Laloui, *Response of soil subjected to thermal cyclic loading: experimental and constitutive study*, in Engineering Geology Amsterdam, vol. 190, p.6576, 2015.

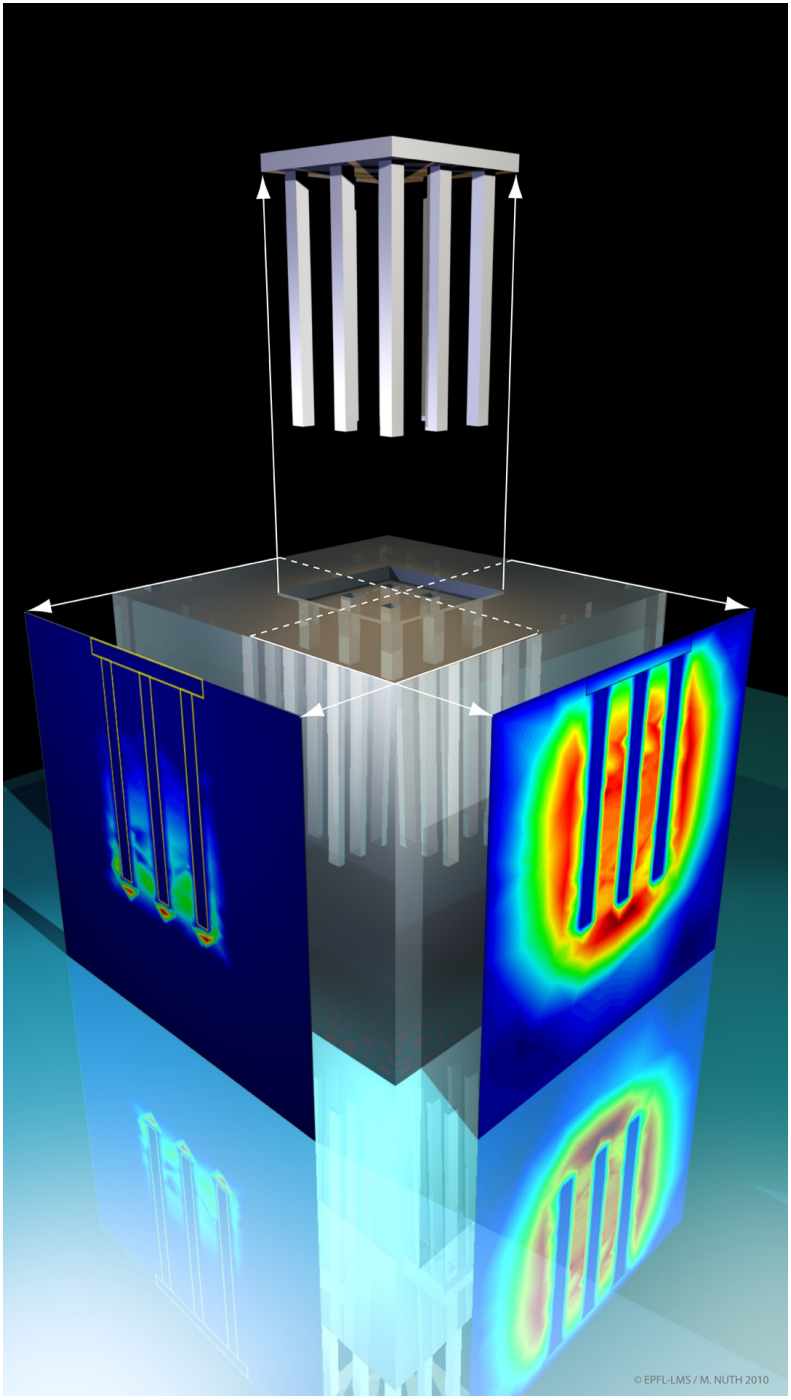
T. Mimouni, L. Laloui, *Behaviour of a group of energy piles,* in Canadian Geotechnical Journal, vol. 52, num. 12, p.19131929, 2015.

T. Mimouni, L. lei, L. Laloui, *Estimating soil thermal diffusivity with interference analyses*, in Acta Geotechnica Springer Verlag, vol. 10, p.197–208, 2015.

A. F. Rotta Loria, A. Gunawan, C. Shi, L. Laloui, C. W. W. Ng, *Numerical modelling of energy piles in saturated sand subjected to thermomechanical loads,* in Geomechanics for energy and the environment, vol. 1, p.115, 2015.

A. F. Rotta Loria, L. F. Orellana Espinoza, Minardi A., J.-M. Fuerbringer, L. Laloui, *Predicting the axial capacity of piles in sand,* in Computers and Geotechnics, vol. 69, p.485–495, 2015.

A. F. Rotta Loria., A. Di Donna, L. Laloui, *Numerical study on the suitability of centrifuge testing for capturing the thermalinduced mechanical behaviour of energy piles*, in Journal of Geotechnical and Geoenvironmental Engineering, 04015042, 2015.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Landslide analysis

Background and goals

Landslides cause a lot of economic losses and fatalities all over the world and this trend is increasing due to two main reasons which are bad land planning and climate change. The cost related to landslides reaches up to 4.7 billion Euros for all of Europe and up to 40 million Euros per year for Switzerland. Understanding landslide mechanisms is a key for risk mitigation and better land use in the future. In the context of climate change, natural hazard prediction has become a global concern for people who are in charge of the management of risk. Many questions arise on the reliability of old statistics used for "forecasting" landslides. However, the change in weather patterns might trigger slopes that have remained still for centuries, others might, on the other hand, slow down or even stop their movements. Landslide models have to account for the incoming changes in the weather patterns for a better evaluation of the risk related to slopes.

Research activities

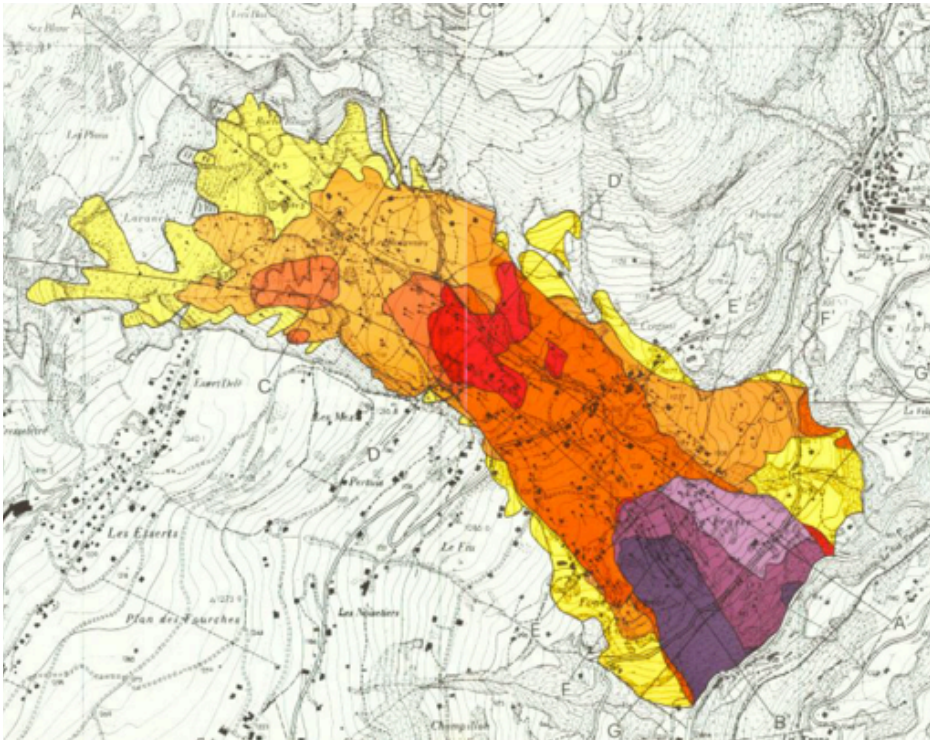
The Soil Mechanics Laboratory (LMS) research activities in landslide analysis cover several aspects for a proper understanding of landslide behaviour. The materials involved in the instabilities are thoroughly characterized under saturated and unsaturated conditions by means of advanced laboratory analyses for model parameter determination. Numerical modelling of slope behaviour has been performed using coupled hydro-mechanical finite element analyses and advanced unsaturated soil mechanics constitutive

laws. The effect of the climate on the stability of the slopes is also investigated. This is especially relevant in the context of the current ongoing climate change.

Over the last two years, the research activities have focused on the application of the Material Point Method (MPM) to the analysis of landslides initiation and runout. This modelling method is quite young, compared to the Finite Element method for instance, but has the advantage of being able to model large displacements.

The impacts of the climate change on the stability of slopes are also investigated. Change in rainfall patterns and increases in temperature are modelled and the differences between the model and the current situation are compared. In this framework, understanding the physical phenomena of soil behaviour is of the utmost importance. Indeed, by capturing the key physical mechanisms, future scenarios can be analysed thoroughly.

Since Spring 2015, a master level course, entitled Slope stability, is entirely dedicated to landslide analysis.



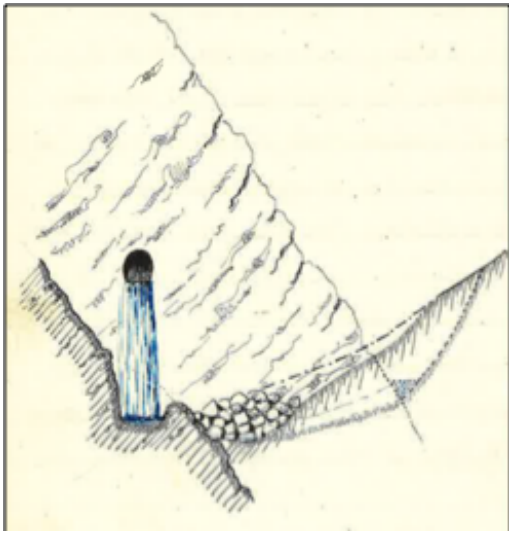
Map showing the different velocities of the La Frasse Landslide (projet Duti 1985)

Student projects

Glissement de terrain, revue de cas pratiques: glissement du Day, semester project by Aymen Achich. During this project, the displacements of the Day Landslide, measured in the 80s, have been analysed. A probabilistic slope stability analysis method has been used.

Landslide case study: Steinernase Landslide, semester project by Lea Kaufmann. This project first summarized the work done for the analysis of the Steinernase landslide (geotechnical and in-situ tests, numerical modelling, monitoring, ...). In a second part, the project presented the possible remediation work that could be undertaken.

Glissement de terrain, revue de cas pratiques : glissement de Cergnat – La Frasse, semester project by Etienne Moser. During this project, the student made a historical review of the different studies done to better understand the La Frasse Landslide, starting from 1863 with an engineer named Chavannes until the final study in the year 2000 that leads to the stabilization of the Landslide.

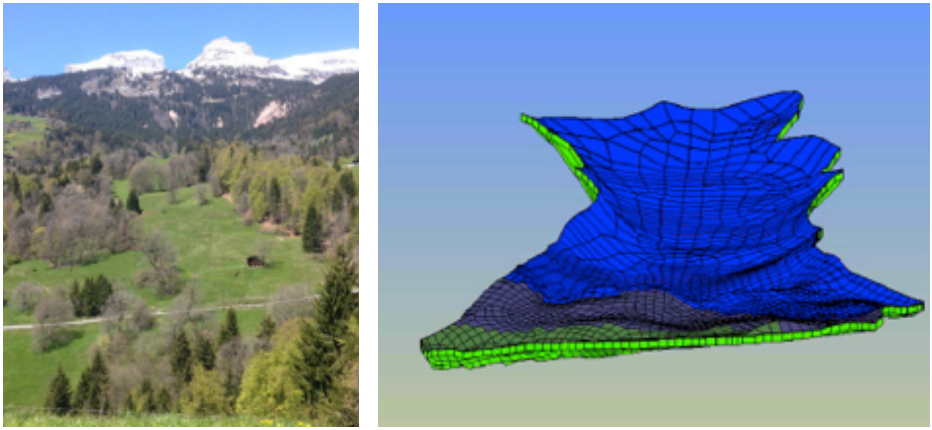


One of the first remediation work suggested for stabilizing La Frasse Landslide, Cuénod 1866

L'effondrement en géotechnique, semester project by Claudia Ylla Arbos. The aim of this project was to gain an understanding of the collapse phenomenon observed in compacted soils and study its importance on the stability of embankments. To achieve this goal, coupled hydro-mechanical numerical simulations were performed using an advanced numerical model.

Modelling the effects of the atmosphere on the stability of slopes, master thesis by Michela Ronda. During this project, the student was asked to represent the exchange of water between the soil and the atmosphere through rainfall, seepage and evaporation.

Glissement de La Frasse – Quantification de l'efficacité de la galerie de drainage de 2008, master thesis by Cyrille Sautier. The objective of this project was to analyse the current behaviour of La Frasse Landslide accounting for the drainage tunnel constructed in 2009 to stabilize the sliding mass.



Picture of La Frasse landslide and 3D mesh (source : master thesis Cyrille Sautier)

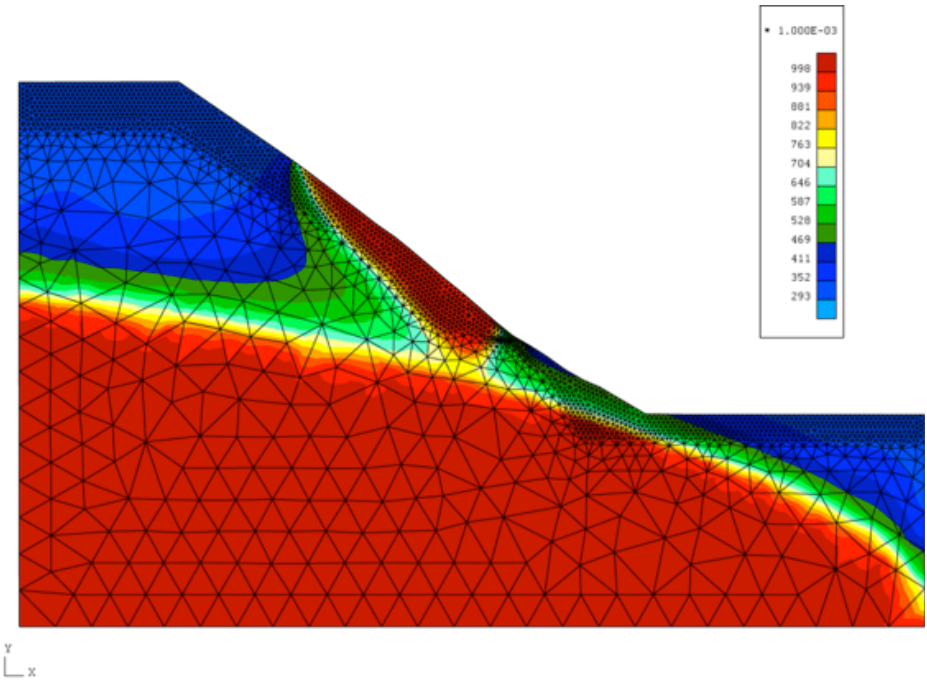
Glissement-coulée de Pont Bourquin, master thesis by Samuel Grangier. The aim of this project was to capture the behaviour of a landslide that is threatening an important Swiss mountain road with the help of numerical simulations. A risk analysis and remediation work have also been suggested.

Comparison of areal pictures of the Pont Bourquin landslide (source : master thesis Samuel Grangier)

Relevant publications

S. Bandara, A. Ferrari and L. Laloui, *Modelling landslides in unsaturated slopes subjected to rainfall infiltration using material point method,* International Journal for Numerical and Analytical Methods in Geomechanics, vol. 40, p. 1358-1380, 2016.

L. Laloui, A. Ferrari, C. Li and J. Eichenberg, *Hydro-mechanical analysis of volcanic ash slopes during rainfall,* Geotechnique, vol. 66, num 3, p.220-231, 2016.



Other topics

The Laboratory for Soil Mechanics is active in all kinds of geotechnical problems. The highly qualified professionals of LMS rely on an advanced testing laboratory and on state-of-the-art numerical modelling tools to deliver consulting services in the various domains such as numerical modelling (finite elements, THM coupling), computation of geotechnical structures, judicial or private expert evaluations.

Therefore, besides the main research topics, the LMS can be commissioned in the framework of civil engineering projects such as dams, roads or tunnels.

Student projects

Analyse de la prise en compte des pressions des terres en géotechnique, semester project by Lionel Krayenbühl. A good assessment of the earth pressure acting on retaining walls is a crucial issue for the design of these structures. The project aimed at developing a numerical model of the Hochstetten field experiment, comparing the results with the observations and studying the effect of the chosen constitutive model.

The BIM technology applied to underground constructions, semester project by Mélissa Bidegain. Building Information Modelling (BIM) technology is a process which consists of building and using an interactive 3D model of a project in order to manage and optimize decision making. The aim of this project was to investigate the possible application of BIM in underground structures.

Tunnel de Pinchat – Conception et dimensionnement, master thesis by Terence Reverdin. Project concerning the design of one of the two main tunnels of the railway line of Cornavin-Eaux-Vives-Annemasse (CEVA). The tube passes through silty-clay soil and old alluvium. The excavation phases are subdivided by side galleries and by crown-stross-base in order to reduce the surface settlements. The excavation is made by conventional methods.

Etude géotechnique des ouvrages d'amenée d'un aménagement hydro-électrique (aménagement de Fah-Serra), master thesis by Giorgia Questi. The purpose of this master project was the design of the structures needed to exploit the power plant of Fah-Serra (VS).

Awards and Keynotes

Awards

Houda Tadlaoui, PhD student at LMS, has been among the winning team of the Exposure Hackathon 2016. Their short movie "Cut it Out" explains to a non-scientific public the importance of Carbon Capture and Storage to mitigate climate change. The movie is available on the LMS website.

Dimitrios Terzis, PhD student at LMS, is the winner of the Swiss-Indian branch of the Academia Industry Training 2016 with his start-up project «MeduSoil». This project is based on his PhD research on soils bio-consolidation.

Dimitrios Terzis, winner of the Swiss-Indian branch of the Academia Industry Training 2016 (photo from VentureLab)

Samuel Grangier, former Master student at LMS, has been awarded the Stucky Award for his Master Thesis done at LMS and entitled "Glissement-coulée de Pont-Bourquin (CH): analyse du comportement hydro-mécanique de l'instabilité et risques associés".

The paper "Behaviour of a group of energy piles" written by Dr. Thomas Mimouni and Prof. Lyesse Laloui has received the 2016 RM Quigley Award Winner for the best paper published in the Canadian Geotechnical Journal in 2015.

Dr. Victor Vilarrasa received on November 26th, 2015, in Girona (Spain) the Alfons Bayó Award to Young Researchers from the International Association of Hydrogeologists.

Samuel Grangier receiving the Stucky Award

Dr. Thomas Mimouni and Prof. Lyesse Laloui during the ceremony

Keynotes

Professor Lyesse Laloui was invited to give a keynote lecture during the Prague Geotechnical Days 2015 (11th and 12th of May). The talk was entitled "Analysis of a volcanic ash slope subjected to wetting and drying cycles".

Picture of Prague, hosting the Geotechnical Days 2015

The 2nd International Workshop on Geomechanics was organized from the 13th to the 15th of October 2015 in Celle, Germany. At this occasion, Professor Lyesse Laloui gave a keynote lecture entitled "Geomechanical Solutions to Geo-energy Issues".

Professor Lyesse Laloui gave a keynote lecture entitled "Testing of the hydro-mechanical behaviour of shales" during the 6th Asia-Pacific Conference on unsaturated Soils held in Guilin, china, November 23rd-26th 2015.

During the 6th International Symposium on Deformation Characteristics of Geomaterials held in Buenos Aires, Brasil, from the 15th to the 18th of November 2015, Professor Lyesse Laloui delivered a conference on "Multiphysical Behaviour of Shales".

During the 1st International Conference on Geo-Energy and Geo-Environment, held in Hong Kong the 4th and 5th of December 2015, Professor Lyesse Laloui gave a keynote lecture entitled "Analysis of the thermo-mechanical behaviour of geothermal heat exchanger foundations".

Professor Lyesse Laloui gave a one-hour "webinar" entitled "Multiphysical process and design of thermo-active foundations", on Monday 29th of February, for the International Society for Soil Mechanics and Geotechnical Engineering webinar. The talk can be found on the ISSMGE website.

Professor Lyesse Laloui gave a keynote lecture at the International Mini Symposium Chubu, Nagoya, Japan, on May 26th, 2016. The lecture was entitled "Analysis of canister movements in an engineered barrier system".

View of Nagoya, city hosting the International Mini Symposium Chubu

A keynote entitled "Geotechnical analysis of energy piles" was given by Professor Lyesse Laloui at the 4th International Conference on the New Developments in Soil Mechanics and Geotechnical Engineering, held from June 2nd to 4th in Nicosie, Greece.

Professor Lyesse Laloui was invited to Łódź, Poland, to give a lecture, entitled "Geomechanical solutions for Geo-Energy issues", as part of the XVII French-Polish Colloquium of Soil and Rock Mechanics that took place from the 28th to the 30th of November 2016.

Gilbert's retirement

In February 2016, Gilbert Gruaz retired after almost 49 years of work at EPFL. This long relationship with EPFL started in 1967, when Gilbert began his apprenticeship as physics laboratory assistant. At this time, the school was still called EPUL (École Polytechnique de l'Université de Lausanne). After his apprenticeship, he started at the engineering school of Lausanne while at the same time he was working at the LMS. Gilbert graduated in 1975. Since then, he worked for the Laboratory for Soil Mechanics until February 2016.

Gilbert during his apprenticeship in 1967 at EPFL and at his retirement party on the 1st of February 2016

Triaxial apparatus used in the 70's

During his stay at EPFL, Gilbert was responsible for the geotechnical conventional tests. He also taught the practical coursework for civil engineering bachelor students. He was even called “Mister TP” (TP for travaux pratiques in French).

The laboratory’s football team

On the 1st of February 2016, Gilbert invited his friends, the old and current staff of LMS for a retirement party. During the event, he made a very nice presentation of his journey at EPFL, reminding everybody the story of the laboratory (particularly the move from Lausanne to Ecublens), the friendships with colleagues, the special work experiences (for instance the expedition to Vientiane in Laos), the evolution of the laboratory and of the informatics ! …

The Laboratory for Soil Mechanics thanks you Gilbert for your work and your good mood! All the best for your retirement!

Events

A keynote lecture during the plenary session

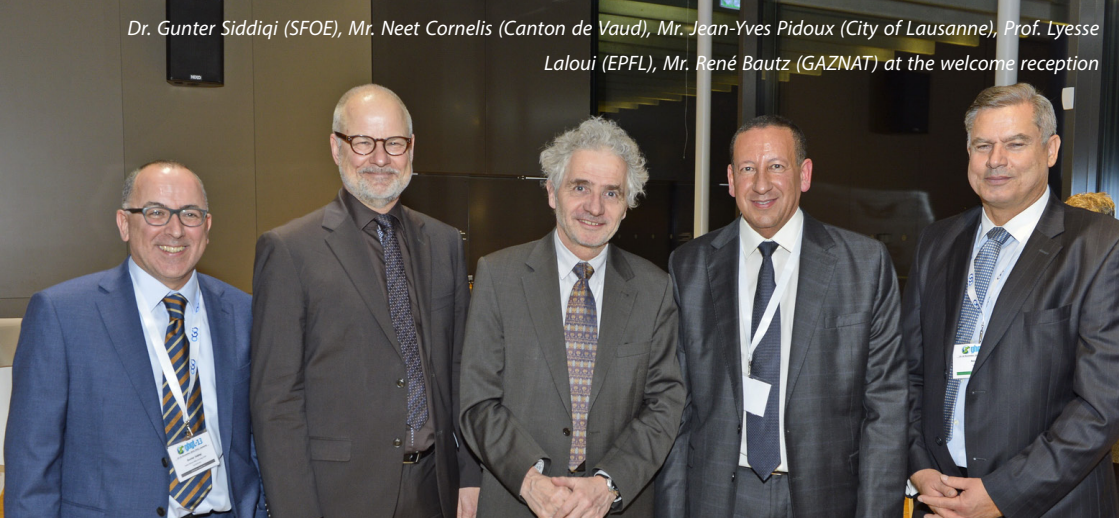
GHGT-13

GHGT-13 is an international conference on Greenhouse Gas Control Technologies which is held every 2 years. This year the Laboratory for Soil Mechanics – EPFL was pleased to co-organize the 13th edition of GHGT. The conference took place at the Swiss Tech Convention Center from the14th November to the18th November. 2016.

Description of the week

A huge number of scientists, researchers, professionals coming from universities, institutions and companies from all over the world, made presentations focusing on the technologies and the developments in the field of CO_2 capture and storage (CCS).

The conference started with a welcome reception at the Olympic Museum of Lausanne where the participants visited the Museum and got to know each other in a convivial atmosphere.

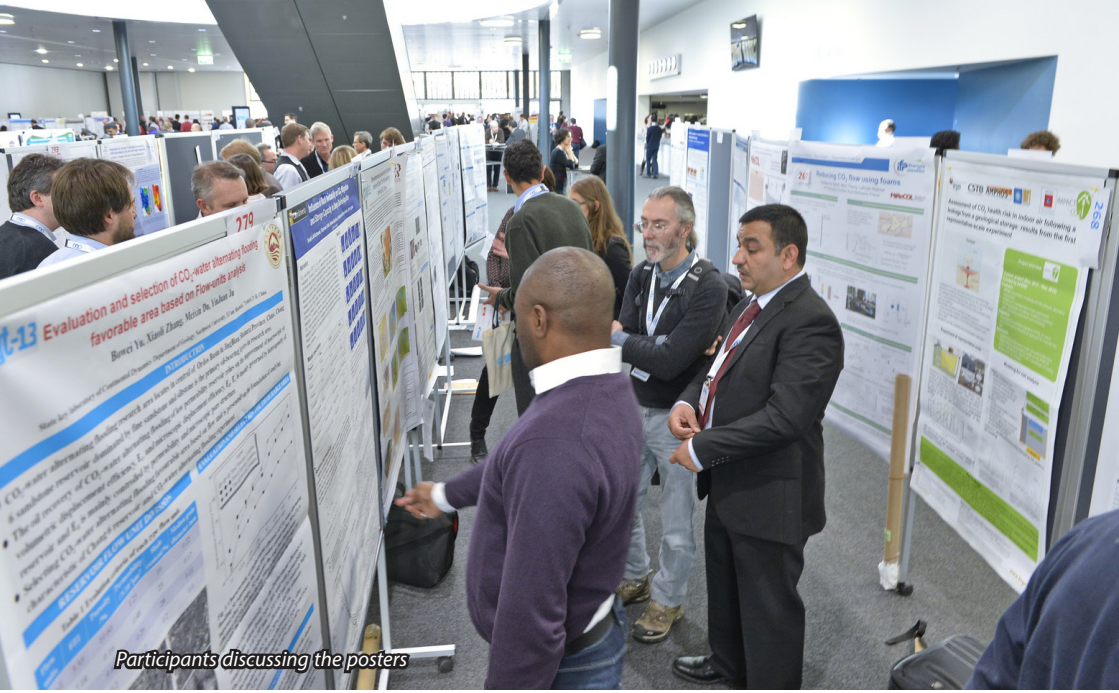


Dr. Gunter Siddiqi (SFOE), Mr. Neet Cornelis (Canton de Vaud), Mr. Jean-Yves Pidoux (City of Lausanne), Prof. Lyesse Laloui (EPFL), Mr. René Bautz (GAZNAT) at the welcome reception

During the conference, an exhibitor space had been reserved for the Chair Gaz Naturel – Petrosvibri (EPFL), in which the research activities done at the Chair, focusing on the advanced multiphysical testing and modelling of CO_2 storage, were presented.

The conference started each day with a plenary session where a keynote speaker gave a lecture. Afterwards, seven parallel sessions were held. During these sessions all the topics related to CCS were covered: capture of CO_2, storage, transport, demonstration projects, geomechanics, legal issues, policies, public perception of CCS. One of the parallel sessions was a panel discussion where 4 to 5 speakers gave a short presentation followed by a discussion.

Part of the LMS team at the Stand



Participants discussing the posters

Poster sessions were scheduled on the 16th and the 17th of November. More than 450 posters were presented.

A Gala dinner was organized on the fourth day of the conference. Participants discovered the Swiss culture through an alphorn concert while testing some Swiss cheese, chocolate and wine.

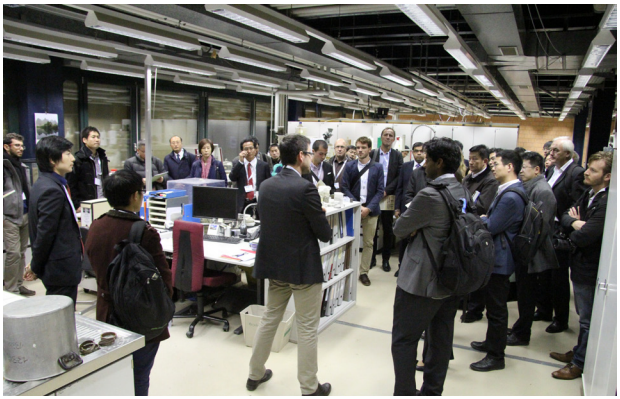
Participants to the gala dinner enjoying the alphorn concert

The lab visit

LMS organized a Laboratory visit to the participants of GHGT-13. For this, more than 90 participants visited our laboratory.

Dr. Ferrari Alessio, Dr. Makhnenko Roman, Ms. Favero Valentina and Mr. Minardi Alberto were very pleased to share our experimental facilities with the attendants.

People from different backgrounds: international universities, companies and industries showed a great interest in our activities and interacted with our team.



Dr. Alessio Ferrari giving an overview of the experimental activities of LMS

Some Statistics

The number of scientists, researchers, professionals present was very impressive: almost 1560, including the authors and co-authors of the presented papers. The participants came from universities, institutions and companies (333 in total) from all over the world (33 countries including 5 continents). The number and the quality of the presentations was very high: 337 papers were presented, pointing out important and interesting results and challenges concerning the CO_2 capture and storage.

The LMS contributed with one presentation (Dr. Roman Makhnenko presented a paper entitled "Hydro-mechanical aspects of CO_2 breakthrough into clay-rich caprock") and one poster (Dr. Chao Li presented a poster entitled "Caprock and surface deformation induced by carbon dioxide injection").

1st Int. Conf. on Geo-Energy and Geo-Environment - GeGe2015

Professor Lyesse Laloui was the vice-chair of the First International Conference on Geo-Energy and Geo-Environment. The conference took place on December 4 - 5, 2015 at the Hong Kong University of Science Technology (HKUST) Jockey Club Institute for Advanced Study (IAS).

On the first day of the conference, the topics related to geo-energy were covered including energy geo-structures (piles, tunnels, walls), geo-storage (CO_2 sequestration and radioactive waste disposal), energy extraction applications (conventional and unconventional energy, geothermal energy), energy policy and management related to geotechnical aspects.

Participants of GeGe2015

Professor Lyesse Laloui addressed a keynote lecture on "Analysis of Groups of Energy Piles" along with chairing a technical session on the first day of the conference. LMS student and PhD candidate Alessandro Rotta Loria gave a presentation on the "The Role of Null Point Movements on the Thermo-Mechanical Analysis of Energy Piles" as a part of the geo-energy research area.

For the second day of the conference, the topics associated with the geo-environment were addressed such as; reused and recycled materials for geotechnical works, bio-geotechnology such as the use of vegetation and bacteria, landfills and geo environmental policy and management.

2nd EAGE Workshop on Geomechanics and Energy

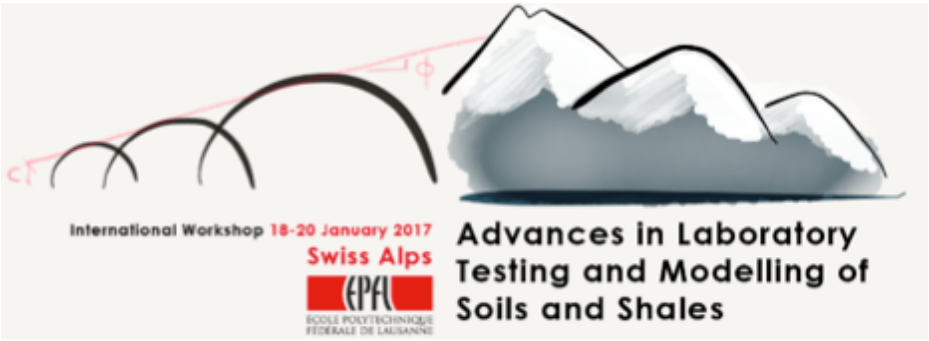
Second EAGE Workshop on Geomechanics and Energy has been held in Celle, Germany between 13-15 October, 2015. Professor Lyesse Laloui was the organizer of the workshop with Professor Bertrand François from Free University of Brussels, Belgium.

The workshop focused on areas related to geomechanical application in the subsurface extraction of energy and the storage of waste. It gathered various research fields on nuclear waste disposal, geomechanics for CO_2 storage, geomechanics for geothermal energy, hydrocarbon exploration and production, and put emphasis on the cross-disciplinary point of view linking different topics.

Professor Laloui addressing his keynote lecture on "Analysis of Groups of Energy Piles" during GeGe2015

LMS faculty and students have been highly involved in the workshop from organization to giving presentations on various topics. Dr. Alessio Ferrari, research associate at LMS, not only served as a member of the steering committee of the workshop but also gave a presentation on "Cyclic Water Retention Behaviour of Compacted Granular Bentonite" during the technical session on Nuclear Waste Disposal. LMS student and PhD candidate Valentina Favero, delivered her presentation on "Hydro-Mechanical Behaviour of Reconstituted and Intact Shales". Dr. Victor Vilarrasa, former postdoctoral researcher at LMS, presented "Influence of Poromechanical and Thermal Properties of the Caprock on the Safety of CO_2 Storage" during the technical session on Geomechanics for CO_2 Storage.

International Workshop on Advances in Laboratory Testing and Modelling of Soils and Shales (ATMSS 2017)



After the great success of the First Workshop on "Advances in Multiphysical Testing of Soils and Shales" in 2012, Laboratory of Soil Mechanics (LMS) will host the second edition of the workshop, ATMMS 2017, organized by Prof. Lyesse Laloui and Prof. Alessio Ferrari. Villars-Sur-Ollon has been chosen for the location of the workshop not only because of the wonderful view of Swiss Alps but particularly to ensure an isolated and pleasant environment for the exchange of ideas. During the first edition in 2012, there were 75 participants from 22 countries. For the second edition, the workshop will host over 100 attendees from 25 countries.

The three-day workshop will feature plenary lectures and technical sessions with over 50 oral presentations from the 100 abstracts received. In fact, the workshop was originally planned for a duration of 2 days but was extended to 3 days due to the large number of contributions received.

On the first day of the workshop, Prof. Herve Di Benedetto will give the Third Bishop Lecture, the title of which is "Advanced Testing and modelling of granular materials with and without viscous glue: Research and practical implication". Prof. Di Benedetto originally gave the Third Bishop Lecture during the 6th International Symposium on Deformation Characteristics of Geomaterials, in 2015, in Buenos Aires, Argentina.

There will be 6 keynote lectures from Prof. Mario Manassero, Prof. Charles Ng, Prof. Russell Ewy, Prof. Antonio Gens, Prof. Bernardo Caicedo and Prof. Richard Wan. Moreover, 6 feature lectures will be given by Prof. Charles Shackelford, Prof. Cristina Jommi, Prof. Feng Zhang, Prof. Mahdia Hattab, Prof. Frank Wuttke and Dr. Matthieu Vandamme.

Apart from the plenary lectures, the three-day programme will feature a series of presentations covering a broad spectrum of the mechanics of soils and shales, during 11 technical sessions. The topics will range from unsaturated behaviour of soils and shales, multiphysical testing of geomaterials, hydro–mechanical

behaviour of shales and stiff clays, a dedicated section to the Opalinus Clay shale, advanced laboratory testing for site characterization and in–situ applications, soil – structure interactions.

These special topics are not gathered in ATMSS 2017 by coincidence. The scientific and technological challenges that are faced nowadays require deep knowledge on the mechanics of soils and shales. Applications such as geo-energy exploitation and energy storage in the ground, CO_2 sequestration, nuclear waste disposals, enhanced geothermal system, can only be carried out if a sound understanding of the involved geomaterials is achieved through advanced theoretical and experimental research. Thus, in ATMSS 2017, the emphasis is placed on the discussion and fusion of fundamental concepts in mechanics, physics and geochemistry to address the multiphysical behaviour of soils and shales.

Attendees from the first edition of the workshop in 2012, Lausanne, Switzerland

The proceedings of the workshop are already published by Springer and indexed in Scopus and SpringerLink. Moreover, the outstanding contributions will be published in the Journal of Geomechanics for Energy and the Environment.

The social events during the workshop are not left out either. The participants will enjoy the wine and cheese tasting from the surrounding regions. Moreover, to finalize the workshop in a memorable way, a gala dinner at an altitude of more than 1800 meters has already been organized which will be followed by a surprise for the participants in the end.

LMS in the Media

RECHERCHE VERTE

Stocker la chaleur de l'été en sous-sol

Les géostructures énergétiques permettent de conserver la chaleur de l'été pour la redistribuer durant l'hiver. Cette méthode développée à Lausanne essaime dans le monde entier.

Directeur de la section de génie civil de l'EPFL, Lyesse Laloui a développé une technique permettant d'utiliser les fondations des bâtiments pour stocker de la chaleur.

Utiliser les fondations comme un système de chauffage, il fallait y penser. Directeur de la section de génie civil de l'Ecole polytechnique fédérale de Lausanne (EPFL), Lyesse Laloui a consacré une bonne partie de sa carrière à mettre au point ce que l'on appelle des géostructures énergétiques. «Toutes les constructions reposent sur des fondations, explique-t-il. Ces piliers qui servent à supporter le poids du bâtiment sont tout désignés pour jouer un rôle de réserve de chaleur.» Cela fait vingt ans que Lyesse Laloui et son équipe de chercheurs étudient la possibilité d'utiliser le sol comme lieu de stockage.

Le système qu'ils ont développé repose sur une pompe à chaleur située dans le bâtiment. Elle fait circuler de l'eau dans un réseau de serpentins, comme pour un chauffage conventionnel. Mais après avoir pris la température de l'air ambiant, elle est envoyée dans les fondations. C'est là, à quelques dizaines de mètres sous la surface du sol, que l'eau passera plusieurs mois, tout en conservant une température élevée. «Imaginons qu'il fasse 20 degrés en surface, résume Lyesse Laloui. Même si l'eau perd un peu de chaleur, sa température sera toujours de 15 ou 16 degrés sous terre. Elle chauffe alors le béton du pilier, ainsi que la terre environnante.» Puis, lorsque le besoin se fait sentir, la pompe remonte l'eau. Un processus de compression lui fait gagner quelques degrés et elle est réinjectée dans le circuit de chauffage.

Les avantages de cette méthode, dont l'installation ne provoque qu'un faible surcoût, lui valent de se multiplier, en Suisse, mais surtout à l'étranger. «Dans notre pays, les ingénieurs hésitent à utiliser des techniques qu'ils ne connaissent pas, regrette le professeur. Pourtant, les propriétaires ont beaucoup à y gagner. Prenez le nouveau terminal de l'aéroport de Zurich: les piliers énergétiques comblent 75% de ses besoins en chauffage. Et le tout gratuitement!» D'ailleurs, les enjeux ne sont pas uniquement financiers, puisque le chauffage des bâtiments est responsable de la moitié des émissions de gaz carbonique en Suisse.

Souffler le chaud et le froid

Soucieux de combattre la frilosité helvétique, Lyesse Laloui encourage les collectivités à franchir le pas. «A Londres, chaque projet de construction publique doit prendre en compte cette alternative», cite-t-il en exemple.

Des géostructures énergétiques pourraient soutenir tous types de bâtiments, de l'usine à la maison individuelle. «Ce qui compte, c'est le volume de stockage de chaleur, soit le nombre et la longueur des pieux. Du coup, cette installation est forcément moins rentable pour une construction de petite dimension.» Justement, à deux pas de son bureau, Lyesse Laloui éprouve désormais ses théories en grandeur nature: le Swiss Tech Convention Center, inauguré en 2014, repose sur 150 pieux dont une partie peut stocker de la chaleur. Bardés de capteurs, ils enrôlent une multitude de données aux scientifiques.

Lyesse Laloui ne compte pas s'arrêter en si bon chemin. En fin de semaine, il s'envolera pour Abu Dhabi, où il présentera une nouvelle application de son concept: «Si les pieux peuvent conserver de la chaleur, cela fonctionne aussi dans l'autre sens. On peut utiliser ce système pour refroidir les bâtiments lors des périodes de forte chaleur.» Mais tout n'est pas si facile: un sol sablonneux ne conserve pas aussi bien la chaleur que la terre. En laboratoire, l'équipe de scientifiques a donc utilisé une bactérie qui agglomère le sable, le changeant en une roche bien plus utilisable.

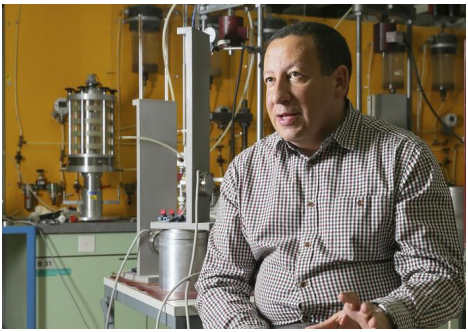
Au chapitre des projets, Lyesse Laloui aimerait aussi exploiter la chaleur présente dans les tunnels routiers et ferroviaires, ou encore éviter que le tablier des ponts ne gèle en hiver. A la croisée des intérêts financiers et écologiques, les pieux énergétiques ont un bel avenir.

CLÉMENT GRANDJEAN ■

+ D'INFOS Laboratoire de mécanique des sols de l'EPFL: lms.epfl.ch

RSI RETE UNO Radiotelevisione svizzera

On the 30th of January 2015 Dr. Alessio Ferrari was interviewed by the RSI Radiogiornale about the storage of nuclear wastes in Switzerland.



On December 17th 2015, an interview of Prof. Laloui, about the research at LMS on the CO_2 sequestration, was on the first page of the EPFL website.

TRACÉS

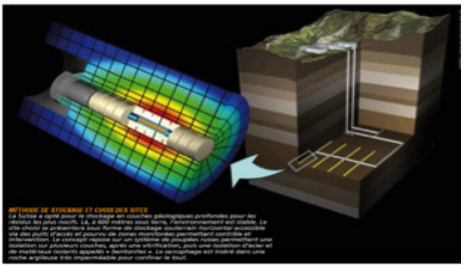
Sols biorenforcés: vers un changement de paradigme

Des chercheurs du Laboratoire de mécanique des sols de l'Ecole polytechnique fédérale de Lausanne (EPFL) développent une méthode permettant de renforcer et imperméabiliser le sol à l'aide de bactéries. Ils démontrent ainsi qu'un changement de paradigme est possible dans un domaine où l'utilisation d'un ciment industriel est actuellement prédominante. A plus petite échelle, la méthode pourrait s'appliquer également au renforcement de briques en terre.

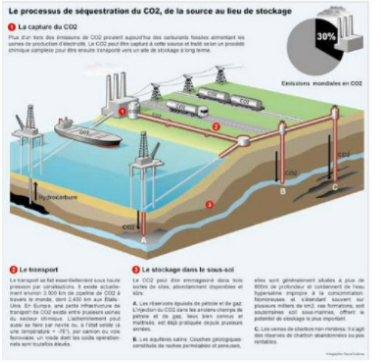
Lyesse Laloui, Dimitrios Terzis

The issue of Tracés of September 2016, illustrating current questions and debates around the role of earth materials in construction, features an extended article on the activities of the LMS around the bio-cemented soils.

SORTI DU NUCLÉAIRE : QUID DES DÉCHETS ?



In December 2016, the journal L'Extension asked Prof Laloui about the main issues concerning the storage of nuclear wastes.



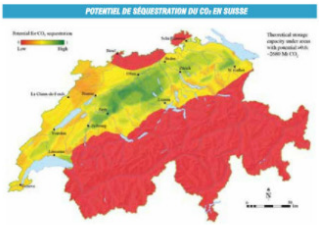
LE STOCKAGE DU CO_2 : UNE SOLUTION IMMEDIATE POUR LE CLIMAT

Les grands rendez-vous pour la planète s'enchainent et ne se ressemblent pas. A peine la COP21 terminée, voici poindre en novembre prochain la GHGT 13, la 13ème Conférence internationale sur les technologies de contrôle des gaz à effet de serre (GreenHouse Gas control Technologies) un événement scientifique phare organisé par l'Agence Internationale de l'Energie (IEA). Elle a choisi la Suisse et notamment le tout nouvel EPFL Swiss Tech Convention Center pour l'accueillir. L'occasion de revenir sur les grands enjeux environnementaux liés à la production électrique et l'industrie lourde en Europe avec le Prof. Lyesse Laloui directeur de la Chaire « Gaz Naturel » - Petrosvibri à l'EPFL. Grand ordonnateur de la manifestation, il prône la séquestration souterraine des gaz à effet de serre comme réponse majeure au réchauffement climatique.

PAR SOPHIE BARENNE

1 En quoi consiste cette technologie et quelle quantité de CO_2 permet-elle de stocker ?

Lorsqu'il est injecté à grande profondeur, avec des températures et pressions suffisamment élevées, le CO_2 passe à un état dit « supercritique ». Dans cet état, il occupe 500 fois moins de volume que dans son état gazeux à la surface de la terre. Le procédé de stockage du CO_2 tire profit de cette caractéristique en récupérant le dioxyde de carbone à la source, dans les fumées des centrales thermiques et des usines, et en l'enfouissant dans des formations géologiques profondes onshore ou inshore, permettant ainsi d'éviter son rejet dans l'atmosphère. En 1996, la Norvège, pionnière, l'a expérimenté puis le procédé s'est disséminé à travers le monde comptabilisant aujourd'hui pas moins de 80 projets permettant de séquestrer en moyenne un million de tonnes par an et par site.



Source : Diamond, L.W., Lou, N., Chevalier, G., 2010. Potentiel for geological sequestration of CO_2 in Switzerland (Studie zur Abschätzung des Potentials für CO_2-Gesperichtung in der Schweiz), Report for the Swiss Federal Office of Energy p. 21.)

de répondre aux exigences des nouvelles stratégies énergétiques. En Suisse, pour remplacer progressivement d'ici 2050 la production fossile qui produise le moins de CO_2 ces émissions restant problématiques. Pour pallier cette difficulté, on ou n'ait acheter des « droits à

3 Si la séquestration du CO_2 est une solution viable, quels sont les principaux écueils à une mise en œuvre élargie du procédé?

En Suisse, nous possédons l'essentiel: d'une part la technologie, et d'autre part, les couches géologiques nécessaires au stockage à plus de 800 m sous terre, notamment au niveau du plateau situé entre Fribourg et Baden (voir carte). Les principaux blocages sont d'ordre réglementaires, chaque canton possédant un cadre juridique propre qui, pour le moment, ne prend pas en compte la possibilité de stockage soutenuin du CO_2; d'ordre psychologique, notre pays n'ayant pas une culture développée en matière d'hydrocarbure, la population et les politiques se montrent toujours très méfiants à l'égard des solutions énergétiques qui en découlent; et d'ordre financier enfin, ce frein ayant tendance à diminuer considérablement avec le temps.

4 Et quels risques présente-elle ?

stockage et aux probabilités de fuites pouvant altérer la biodiversité en surface. C'est pourquoi nous développons des possibilités de monitoring en temps réel et des outils de prédiction permettant de rendre de plus en plus négligeables ces considérations.

5 Quelles sont vos attentes à l'égard de ce grand rendez-vous de la science qu'est le GHGT 13 ?

Au-delà des contributions scientifiques, il s'agira de transmettre aux

« En Suisse, pour remplacer progressivement d'ici 2050 la production des 40% de nos besoins en électricité fournis par l'énergie nucléaire, il n'existe pas d'autre option réelle que de produire l'électricité à partir des centrales à gaz, (...) et de stocker durablement [le CO_2] dans le sous-sol. »

Prof. Lyesse Laloui was interviewed about CO_2 sequestration on the 23rd of March 2016 by the journal L'Extension.

Comment changer le CO2 en roche, une recette pour refroidir l'atmosphère

4 minutes de lecture

Environnement

Julie Schüpbach
Publié vendredi 10 juin 2016 à 16:58.

En transformant du dioxyde de carbone en une roche calcaire, des chercheurs ont fait un pas de plus dans la lutte contre le réchauffement climatique

In June 2016, more than 15 journals and internet websites explained the research about the geological sequestration of CO_2. Among these jounals were Le Temps, Le Nouvelliste, La Côte, 24Heures...

On November 16th 2016, Prof. Lyesse Laloui gave an interview to the television channel "La Télé" within the framework of the conference GHGT-13 which took place from the 14th to the 18th November at the Swiss Convention Center, at the EPFL.

Visitors

LMS receives many guests each year! They come from all over the world. The visitors either come to make a presentation and/or to stay at LMS during a given period which allows them to share research, results, and discoveries. During the period 2015 – 2016 LMS has received about 20 visitors. Among them, there are world-renowned Professors such as Prof. Marcelo Sanchez (Texas A&M University, USA) who came in August 2015 and spoke about the challenges that geomechanics is facing, Prof. Carlos Santamarina (King Abdullah University of Science & Technology, Saudi Arabia) came in September 2015, Prof. Bernardo Caicedo (Universidad de Los Andes, Colombia) gave a seminar on the interaction between the soil and the atmosphere in December 2015. Prof. Emilios Comodromos (University of Thessaly, Greece) came in March 2016 and in November 2016. Prof. Alexander Puzrin (ETHZ, Zürich) gave a presentation in May 2016. He demonstrated how well the shear band propagation approach could better predict historical submarine landslides than traditional approaches.

Prof. Marcello Sanchez (Texas A&M University, USA)

Prof. Alexander Puzrin (ETHZ, Zürich)

Prof Carlos Santamarina (King Abdullah University of Science & Technology, Saudi Arabia)

Prof. Bernardo Caicedo (Universidad de Los Andes, Colombia)

Prof. Emilios Comodromos (University of Thessaly, Greece) with Pof. Lyesse Laloui

Outside Lab Activities

The LMS group is very serious at work but they can also have fun outside of the lab! An official group outing is organized every year as well as one or two small events. In January 2015, the LMS' staff went to the Jura to visit the Mont Terri underground rock laboratory and for outdoor activities for which snow was expected (husky sledging). However, at the beginning of 2015 there was no snow. Hence, LMS people exchanged their sledge for a bike! It was a lot of fun! The outing of 2016 was in Gstaad during the 80th anniversary. PhD students, technicians and Professors sledged down from the top of the mountain to the village where they played curling. Other outside lab activities consisted of snowshoeing, skiing, hiking, … As far as nutrition is concerned, in general the outing is finished with a very light fondue !

Jura trip 2015: Arrival in beautiful Jura region and visit of the Mont Terri underground rock laboratory

PhD students' ski day at Les Portes du Soleil

Husky «sledging» and meal after the sportive activity during the Jura trip in 2015

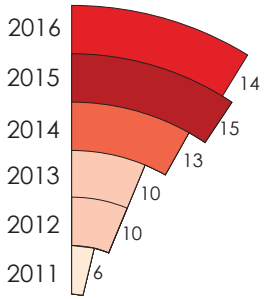
Snowshoeing in Les Paccots

Sledging in Gstaad surrounded by amazing landscapes

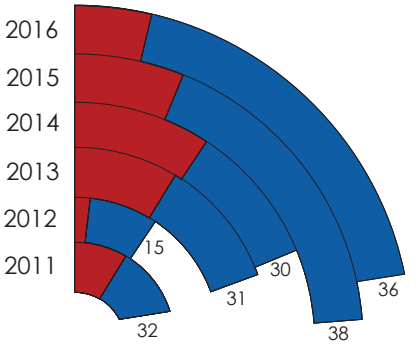
During its outings, the international team of the LMS makes sure to take some time for discovering aspects of the Swiss culture !

LMS in numbers

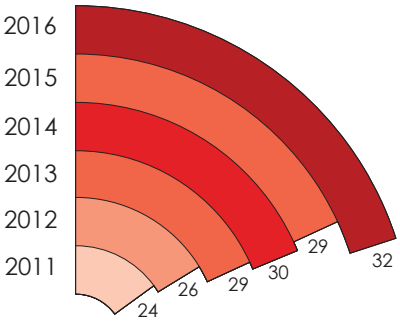
PhD candidates



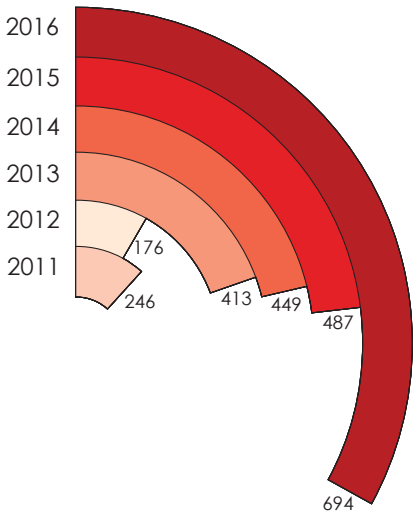
Journal papers
Conference papers



Staff



Citations



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The Team

LMS team during the GHGT-13 gala dinner

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Laurent Vulliet

Alessio Ferrari

Laurent Tacher

Chao Li

Anne-Catherine Dieudonné

Aldo Madaschi

Roman Makhnenko

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Hiram Arroya Chavez

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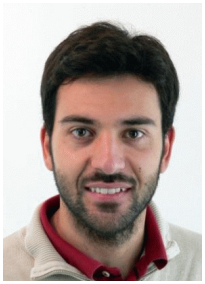

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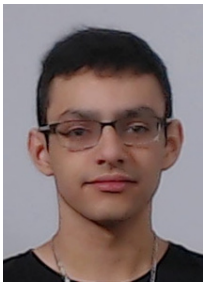

Erwan Romann

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