Laboratory for Soil Mechanics

Chair "Gaz Naturel" Petrosvibri

Professor Lyesse Laloui

Annual Report 2017

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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Preamble

Prof. Lyesse Laloui

Over the years, the Laboratory of Soil Mechanics – Chair «Gaz Naturel» Petrosvibri (LMS) has developed an internationally recognized expertise in various fields related to geo-energy and geo-environment, alongside the conventional research activities on geo-mechanics and geotechnical engineering.

Last year, LMS once again showed 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 a key role in the field of geoengineering of CO_2 storage.

In 2017, it was our pleasure to host the second edition of the "Advances in Laboratory Testing and Modelling of Soils and Shales" (ATMSS) workshop, which included participants from all over the world. Further, we also hosted an International School on Unsaturated Soil Mechanics, inviting leading experts from all over Europe to share their knowledge with many budding young researchers.

Besides various research projects, LMS has contributed to the outstanding educational activities of the Swiss Federal Institute of Technology Lausanne (EPFL) by introducing the first course in the world on Energy Geostructures. We've had a large number of succesesful PhD defenses this year as well as post-docs who have been appointed professorships abroad. Our research group has also grown with new PhD students and postdoctoral researchers joining us.

I hope you all enjoy discovering as we not only look back on another successful year at LMS but also forward, to another year of exciting research and challenges.

Prof. Lyesse Laloui

Director of LMS

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 other things, Experimental Geomechanics and Energy Geostructures are also offered within the doctoral program in Mechanics.

2. Research & Development

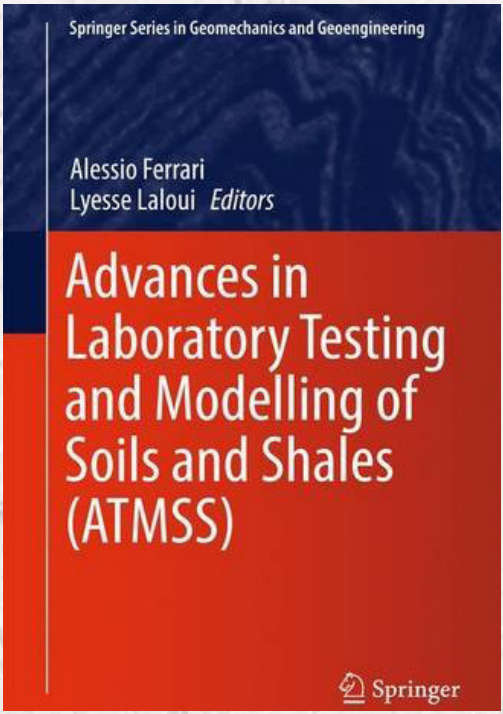
Research activities within the LMS deal, on one hand, with theoretical and applied aspects in geomechanics, geo-energy, and geo-engineering, as well as, on the other hand, with the development of tools and computational methods for the analysis and the design of geostructures and the investigation of 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.

New Releases

New book published by LMS



The presentations and keynote lectures of the workshop organized by LMS in 2017, "Advances in Laboratory Testing and Modelling of Soils and Shales (ATMSS)" have been published in a book of the same title (ISBN 978-3-319-52773-4). The book covers a wide variety of topics from theoretical to experimental in nature. The book has been edited by Dr. Alessio Ferrari and Prof. Lyesse Laloui.

The book contains over 60 papers and covers a wide range of theoretical and experimental research topics, including unsaturated behaviour of soils and shales, multiphysical testing of geomaterials, hydro–mechanical behaviour of shales and stiff clays, the geomechanical behaviour of the Opalinus Clay shale, advanced laboratory testing for site characterization and in–situ applications, and soil – structure interactions.

The proceedings have over 18 thousand chapter downloads and have already begun to accumulate their first citations.

Technical Committee website launch

A new website for the technical committee TC 101, the technical committee focused on laboratory testing of geomaterials, in the context of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) was launched by LMS. The committee aims to promote co-operation and exchange of information concerning research and developments in advanced laboratory geotechnical testing, including apparatus, techniques, data acquisition and interpretation. It also encourages the application of advanced laboratory testing in research; in integrated site characterization studies; and in ground modelling.

To advance these aims the committee encourages collaboration with specialists working in laboratory and field testing, sampling, theoretical and numerical analysis, and in project engineering and full scale observation. This also involves close liaison with other ISSMGE Technical Committees.

The goal of the new website is to keep people current with the latest updates and developments in this domain of research and to further promote the collaboration of researchers and experts.

Prof. Laloui served as vice-chair of TC101 from 2013-2017.

TECHNICAL COMMITTEE 101 OF THE INTERNATIONAL SOCIETY OF SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

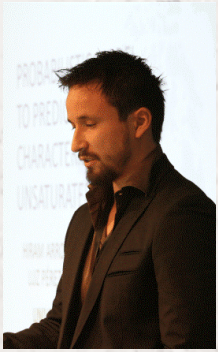
News

Dr. Anne-Catherine Dieudonné appointed as assistant professor

Dr. Anne-Catherine Dieudonné has been nominated as an assistant professor at TU Delft in the Netherlands. Her new position is in the area of Engineering Geology. Anne-Catherine had been working at LMS since December 2015 as a post-doc and was primarily focused on the numerical modelling associated with nuclear waste storage. We wish Dr. Dieudonné a very successful career.

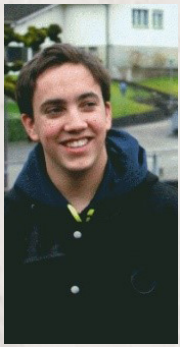
Dr. Hiram Arroyo Chavez appointed as assistant professor

Dr. Hiram Arroyo Chavez has been nominated as an assistant professor at the Universidad de Guanajuato in Mexico. Since September 2017, Hiram has been a part of the university's Civil Engineering Section. Hiram joined LMS in October 2016 as a post-doc and his work was primarily dedicated to constitutive models for unsaturated soils with the goal of predicting the onset of fracturing. We also wish Dr. Arroyo Chavez a successful career.



Ms. Lotrecchiano and Mr. Brede obtain their federal degrees

Our apprentices, Ms. Michela Lotrecchiano and Mr. Swann Brede, have succeeded in obtaining their federal degrees. Ms. Lotrecchiano earned her CFC (a Swiss diploma conveying that a candidate has completed their 3 or 4-year apprenticeship) in commerce and Mr. Brede earned his CFC in laboratory technics. We wish them the best in all their future endeavors.



A new SNSF research grant on energy piles

FNSNF
FONDS NATIONAL SUISSE
SCHWEIZERISCHER NATIONALFONDS
FONDO NAZIONALE SVIZZERO
SWISS NATIONAL SCIENCE FOUNDATION

The Swiss National Science Foundation (SNSF) has funded the Laboratory for Soil Mechanics with over 450 thousand Swiss Francs for a new research project focusing on the cyclic thermo-mechanical behaviour of energy piles. The ultimate goal of this project is to acquire a thorough understanding of the response of energy piles to daily and seasonal cyclic thermal actions, through an exhaustive experimental and numerical campaign. A post-doc (Dr. Melis Sütman) and a PhD candidate (Ms. Elena Ravera) will be involved in this project.

Prof. Laloui joins scientific council

Prof. Laloui joined the scientific council of the International Centre for Mechanical Sciences (CISM), a non-profit organization located in Italy whose primary function is the organization of seminars, workshops, symposiums, and conferences which aim to spread knowledge associated with mechanical sciences.

motus CISM est vita

Prof. Laloui member of the Executive Committee of SCCER-SoE

Prof. Laloui is now a member of the executive committee of the Swiss Competence Center for Energy Research - Supply of Electricity (SCCER-SoE). SCCER-SoE is intended to enable Switzerland to achieve the goals of Energy Strategy 2050. Prof. Laloui is responsible for leading the "Geo-Energies" work package. This work package intends to especially employ Enhanced Geothermal Systems and CO_2 storage to achieve these lofty goals.

Dr. Ferrari nominated as representative member of Swiss Geotechnical Association

Dr. Alessio Ferrari has been nominated as representative member of the Swiss Geotechnical Association for the Technical Committees 101 and 308 of the ISSMGE, which concern themselves with laboratory testing and energy geotechnics respectively.

Cristiano Garbellini nominated to represent Switzerland

Cristiano Garbellini, doctoral assistant at the LMS, has been nominated as one of the two young engineers that will represent the Switzerland at the 26th European Young Geotechnical Engineers Conference 2018 in Vienna. On behalf of the ISSMGE, the Austrian Society for Soil Mechanics and Geotechnical Engineering will host the conference.

Most Cited Article in the International Journal for Numerical and Analytical Methods in Geomechanics

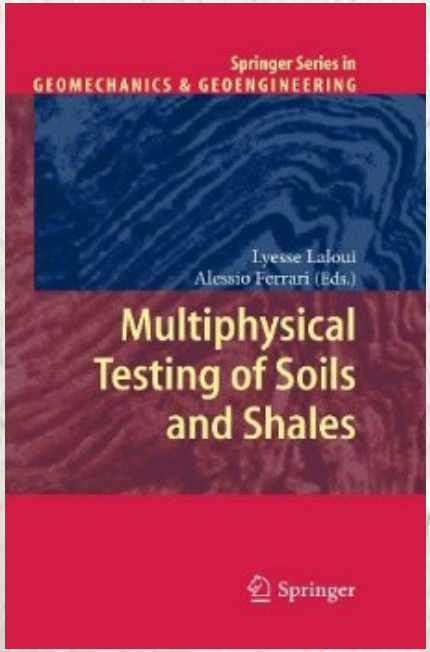
The article entitled «Numerical analysis of the geotechnical behaviour of energy piles» by Dr. Alice Di Donna and Prof. Lyesse Laloui is within the Top 5 Most Cited Articles over the past 2 years in the International Journal for Numerical and Analysis Methods in Geomechanics! Moreover, with its large number of citations it is in the 3rd position of the papers making the highest impact in the journal!

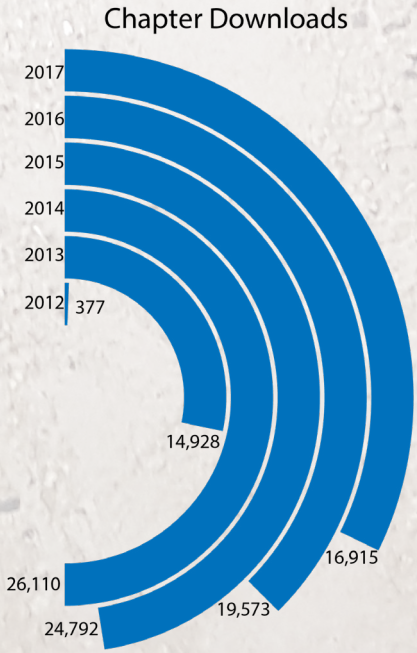
Most Cited Article in the journal Geomechanics for Energy and the Environment

The collaborative research paper between the Swiss Federal Institute of Technology in Lausanne (LMS-EPFL) and the Hong Kong University of Science and Technology (HKUST), entitled "Numerical modelling of energy piles in saturated sand subjected to thermo-mechanical loads" by Alessandro F. Rotta Loria, Anthony Gunawan, Chao Shi, Prof. Lyesse Laloui, and Prof. Charles W. W. Ng, is the most cited article since 2014 in the journal Geomechanics for Energy and the Environment.

Book Success

The book "Multiphysical Testing of Soils and Shales", edited by Prof. Laloui and Dr. Ferrari (ISBN 978-3-642-32492-5), has been enjoying great success. The book is part of the Springer Series, "Geomechanics and Geoengineering", and, as of January 2018, there have been a total of 102,000 chapter downloads for the eBook on SpringerLink since its online publication in 2012. In fact, the book was one of the top 25% most downloaded eBooks in the relevant SpringerLink eBook Collection in 2016. Not only that, just last year the book had over double the average number of citations of the discipline average, bringing its total to 33 citations overall.





Intellectual Property

New Patent

Soil bio-improvement has been studied in our laboratory since 2008. Two doctoral theses have been completed, under the supervision of Prof. Laloui, on the topic by Dr. Suzanne Fauriel in 2012, and by Dr. Dimitrios Terzis in 2017. The former introduced a novel approach towards addressing coupled bio-chemo-hydro-mechanical phenomena through the development of a reactive-transport constitutive model. The latter provided state-of-the-art characterization of the micro-architecture of the material as well as an extensive experimental series to characterize its mechanical response.

Biochemically active geosynthetic carrier © LMS/EPFL

Further, a new application method based on soil bio-improvement has been developed by Dr. Terzis and Prof. Laloui which aims to provide mainstream engineering solutions based on soil bio-cementation. This technique is disclosed in a patent application, "A Geosynthetic Element for Bio-improvement", filed in collaboration with the technology transfer office of EPFL under application number PCT/EP2017/062995.

Core sample resulting from application of the technique

Involvement in EU Projects

EU Project TERRE

The LMS is participating in the EU project called "Training Engineers and Researchers to Rethink geotechnical Engineering for a low carbon future", or TERRE. The goal of TERRE is to improve the competitiveness of the European construction industry in a low carbon manner. TERRE is a Marie Skłodowska-Curie Innovative Training Networks (ITN-ETN) project funded from the H2020 Programme (H2020-MSCA-ITN-2015) of the EC under grant agreement ETN-GA-2015-675762. TERRE aims to promote a vision that not only has a mechanistic view of the geotechnical behavior of the ground but also has a nature-centric scientific approach. LMS's involvement is lead by Dr. Ferrari and sees the contribution of two PhD students, Jacopo Zannin and Gianluca Speranza.

EU Project BEACON

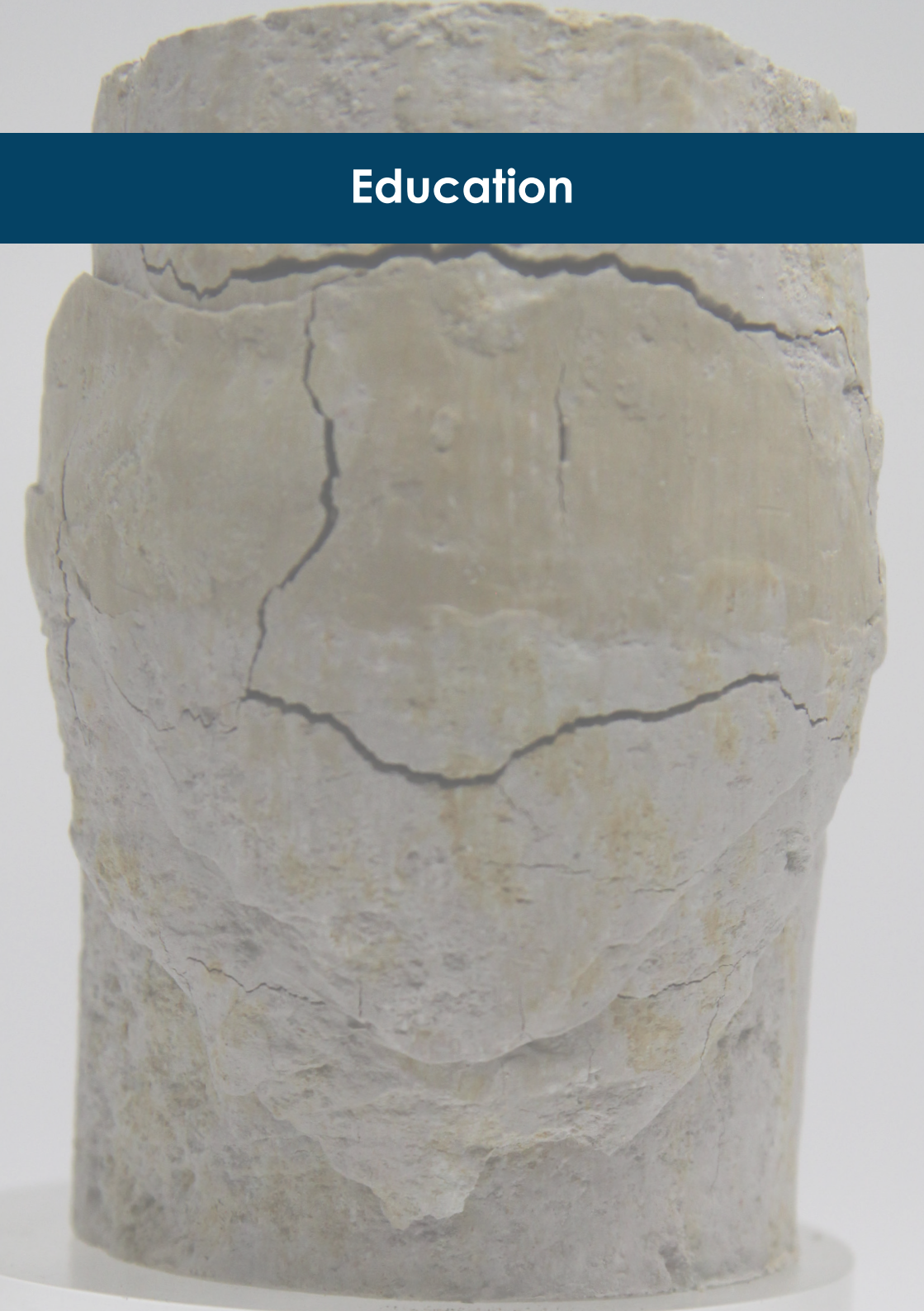
BEACON is a European project whose goal is to develop a fundamental understanding of bentonite behaviour in order to allow for the assessment of the long-term safety of a geological repository. To make this kind of assesement, a robust model of the spatial and temporal distribution of the relevant properties of bentonite is required. To this end, BEACON undertakes research that will be able to build confidence amongst regulators and stakeholders regarding the perfomance of safety barriers in such a repository. The LMS contribution is lead by Dr. Ferrari and one of our PhD students, Jose Antonio Bosch Llufriu, who began his PhD this year, is involved in the project.

EU Project GREAT

LMS has succeeded in being selected to participate in the EU project called "Geotechnical and Geological Responses to Climate Change Exchanging Approaches and Technologies on a Worldwide Scale", also known as GREAT. The project is primarily focused on sharing mitigation strategies regarding climate change and hopes to facilitate the access of Europeans to research and innovation which has been carried out in emerging economies. Additionally, the project strives to promote Europe as an attractive location to perform research and innovation on a global scale. GREAT will address four major research areas: climate resilient geo-infrastructure, carbon-efficient geo-infrastructure, carbon capture and energy extraction using conventional geo-infrastructure, and geological carbon storage and deep geothermal extraction.

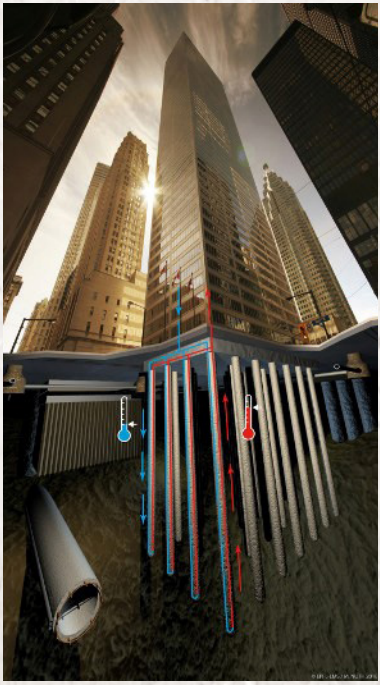
GREAT stimulates this collaboration through the support of 50 PhD/Post-doc researchers and 50 senior members of staff. The PhD/Post-doc researchers will develop projects which are jointly supervised by both senior staff members at their home and host institutions in order to ensure an effective scientific exchange. These projects will be integrated into the researchers' standard activities and are anticipated to lead to a substantial number of joint publications. Stimulation will also be encouraged through networking opportunities such as six monthly virtual workshops, a Facebook portal to facilitate day-to-day interaction, and a dedicated Youtube channel to make lectures delivered by senior staff readily available the world over.

Education



Teaching

A New Course - Energy Geostructures (CIVIL-444)



As of this last year, a new course is offered at the EPFL entitled, "Energy Geostructures". The master course is given by Prof. Laloui and aims to introduce students to the technology of energy geostructures. The course covers both theoretical and practical aspects of paramount importance for the analysis and design of energy geostructures.

Buildings are one of the major sources of CO_2 release into the atmosphere. Decreasing the environmental impact of buildings and developing renewable energy solutions is therefore a crucial challenge in terms of sustainable development. The LMS researches environmental methods of cooling and heating buildings: energy geostructures. These structures adsorb and transport ground thermal energy to the buildings via fluid pipes cast in the foundations. This avoids the energy-intensive and CO_2-emitting aspects of classical heating systems and air-conditioning. The LMS is therefore very well placed to offer students the chance to learn more about these structures which are of ever-increasing importance. By following the course, students gain insight into the key points listed below:

- Energy geostructures: concepts, developments and challenges
- Thermal laboratory testing and in-situ thermal response testing of energy piles
- Thermo-mechanical testing of soils and soil-structure interactions
- Design of a single and groups of energy piles
- Extension of Eurocodes to such structures
- Alternative energy geostructures: energy tunnels and walls

Other courses

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 teach students how to address these issues, the Slope Stability course was initiated in the spring semester of 2015. This course deals with 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.

Soil mechanics and groundwater seepage (CIVIL-203)

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 behavior of geomaterials and fluid seepage. Basic geotechnical problems are also studied.

Geomechanics (CIVIL-402)

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-plastic with hardening), and in-situ tests for parameter determination.

Risk analysis and management (CIVIL-438)

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 (CIVIL-403)

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, and evaluate geological hazards.

Experimental geomechanics (ME-705)

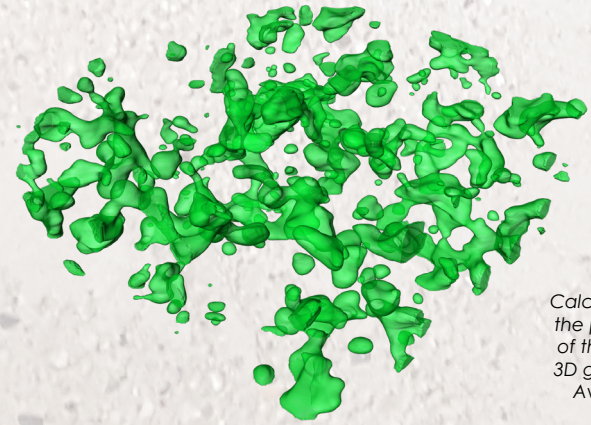
This course is taught within the Mechanics Doctoral program. The aim is to provide the students with a detailed description of the modern experimental techniques for testing geomaterials. Techniques and apparatuses are presented to test materials under a variety of situations, including non-isothermal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

Ongoing Master Theses

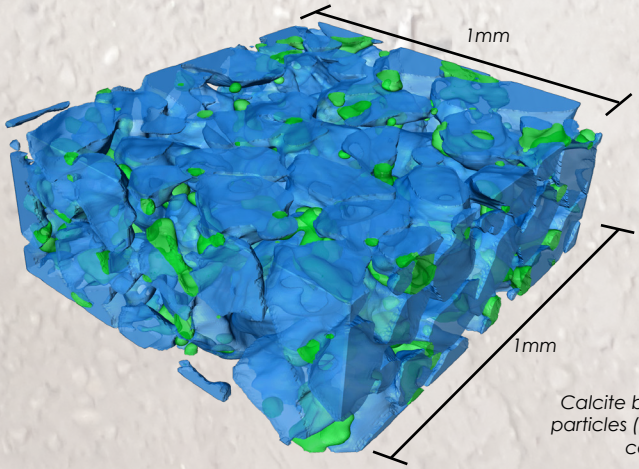
- **Achich, Aymen** – "Numerical simulation of deck de-icing using energy piles", in collaboration with the University of Hohai, Nanjing, China
- **Aguettant, Grégoire** – "Etude des interactions roue-sol", in collaboration with the University of Los Andes, Colombia
- **Cingari, Stefano** – "Study of the weaknesses of energy geostructures in stations", in collaboration with BG Ingénieurs Conseils
- **Cousin, Benoît** – "Study of the weaknesses of energy geostructures in tunnels", in collaboration with CSD Ingénieurs
- **de Saussure, Arabelle** - "A comparison of induced seismic events caused by hydraulic fracturing in Engineered Geothermal Systems (EGS) and shale reservoirs exploitation", in collaboration with MIT, USA
- **Delessert, Nicolas** – "Tranchée couverte d'une ligne de chemin de fer à Monthey et dans l'agglomeration", in collaboration with BG Ingénieurs Conseils
- **Harran, Ray** – "Tunneling in shales", in collaboration with MIT, USA
- **Peltier, Margaux** – "GSHP application for heating and cooling at 'City Scale'", in collaboration with BG Ingénieurs Conseils
- **Schmid, Nicola** – "Geotechnical study of the extension of the Lavey hydroelectric development", in collaboration with BG Ingénieurs Conseils

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 geo-structures. 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.



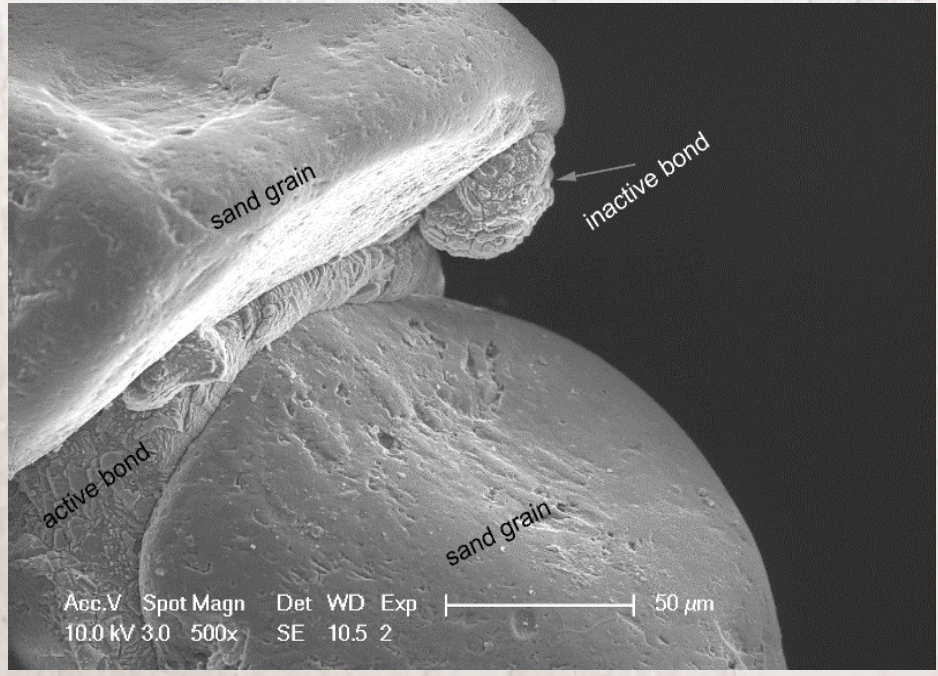
Calcite bridges (green) formed under the presence and metabolic activity of the soil bacterium S. Pasteurii. The 3D geometries are reproduced using Avizo following micro-computed tomography analyses.



Calcite bridges (green) among soil particles (blue) forming the new, bio-cemented structure.

Geo-mechanical investigations of Bio-improved 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 ! Dr. Dimitrios Terzis has recently completed his PhD on this topic. A more in-depth overview of his work is given on the following page.



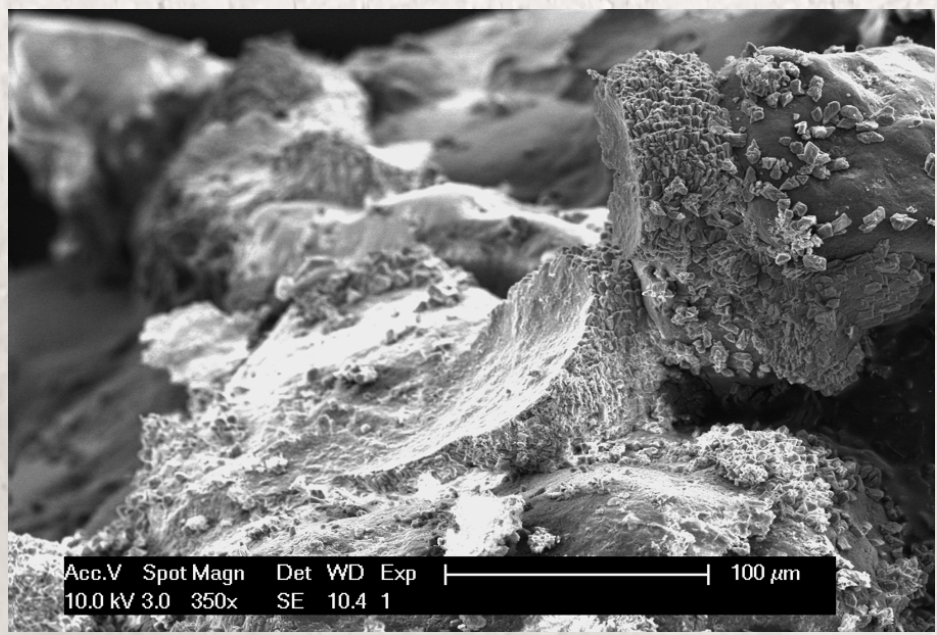
PhD thesis: "Kinetics, Mechanics and Micro-structure of Bio-cemented Soils" by Dimitrios Terzis, Thesis n° 8147

Supervisor: Prof. L. Laloui

Funding agencies: The Swiss National Science Foundation (SNSF), The Swiss Federal Comission for Scholarships for Foreign Students, and The Lombardi Foundation

The quest for novel, performant materials and methods in the engineering practice is driven nowadays by the need to offer solutions to complex problems by coupling technical innovation with environmental responsibility. Such problems emerge in the geo-technical engineering field related to soil stabilization and rehabilitation applications. Especially in urban areas, soils are already taken and the remaining land often requires extensive soil strengthening works for securing the integrity of structures and mitigating risks related to failures and environmental threats.

This thesis puts the focus on bio-mediated soil cementation, a technology which substantially alters the structure of geo-materials and endows them with improved overall mechanical behaviour. The technique integrates bacterial metabolic activity in soil-permeation solutions to induce the formation of calcite bonds in granular



Terzis et al. 2016

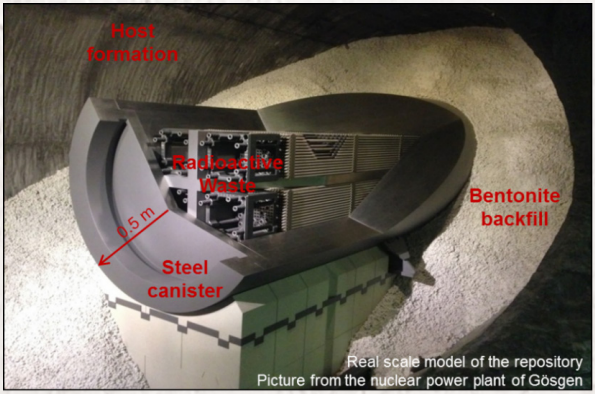
soils. In recent years, studies have found that altering biochemical treatment conditions affects the material's mechanical response. However, the role of the intrinsic properties of the base material on the formation of the crystalline bond lattice remains underexplored. Moreover, the peculiar structure of bio-cemented soils has been previously addressed solely based on qualitative methods, via surface and textural observations, which provide only limited insight into crucial fabric parameters that cannot be considered representative of the material at the macroscale.

This research work introduces a new approach to experimentally characterize the behaviour of bio-cemented materials in light of quantitative evidence related to its micro-architecture. The goal is to go beyond established experimental approaches, by adopting a single treatment strategy for three different base materials and provide state-of-the-art determination of microscale parameters.

The main finding is that the average mass of bond content is not sufficient, as a parameter, for expressing the strength and stiffness of bio-treated geo-materials. The three different bio-cemented geo-materials are found to exhibit distinctive trends in their mechanical behaviour under unconfined and drained triaxial compression, for similar final bond contents. The obtained unconfined strength of medium-grained bio-cemented sand falls between 3 and 11.3 MPa for bond contents in the range of 5% to 10%. Contrarily, fine-grained bio-cemented sand reaches approximately 2.6 MPa for similar bond contents. Another finding relates to an alternative method for microbial-induced calcite precipitation (MICP) via the ureolytic bacterium S. Pasteurii in freeze-dried form. The study of kinetics reveals that urea hydrolysis continues upon the complete breakdown of cell clusters. This confirms that the execution of MICP persists as a cell-free mechanism. This new application method can be seen as a preliminary step towards enhancing overall MICP reproducibility for mainstream geo-engineering applications. Therefore, the thesis provides a new understanding of: (i) factors affecting MICP efficiency, (ii) the peculiar micro-architecture of the bio-cemented material and (iii) its mechanical response.

Nuclear Waste Storage

The long-term management of radioactive waste is one of the biggest challenges that our society has to face. The most promising solution for the long-term management of the radioactive waste is their isolation in deep geological formations. 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 buffer).



Real scale model of the repository
Picture from the nuclear power plant of Gösgen

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.

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.

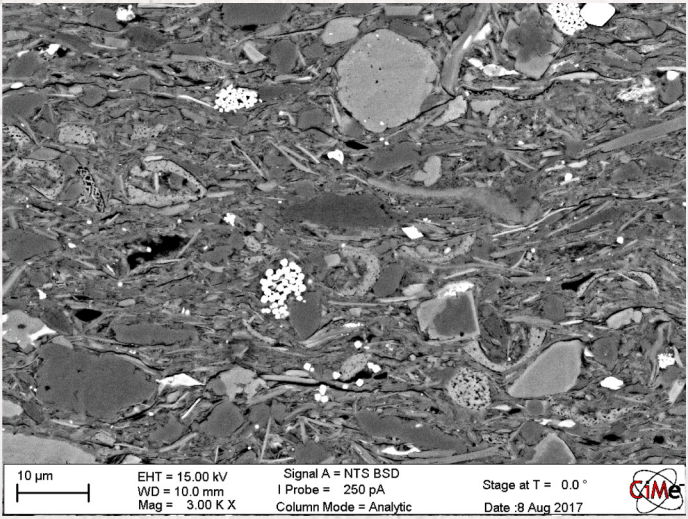
Ongoing PhD theses:

- "Chemo-mechanical modelling of MX-80 bentonite from the atomistic Clay-Ions-Water interactions" by Etienne Cassini, funded by swiss*nuclear*.
- "Advanced constitutive law for Opalinus Clay" by Eleonora Crisci, funded by The National Cooperative for the Disposal of Radioactive Waste (NAGRA).
- "Constitutive modelling of active soils under environmental actions" by Jose Bosch, funded by European Project BEACON.

PhD thesis: "Advanced constitutive law for Opalinus Clay" by Eleonora Crisci

Supervisors: Prof. L. Laloui, Dr. A. Ferrari

Funding agency: The National Cooperative for the Disposal of Radioactive Waste (NAGRA)



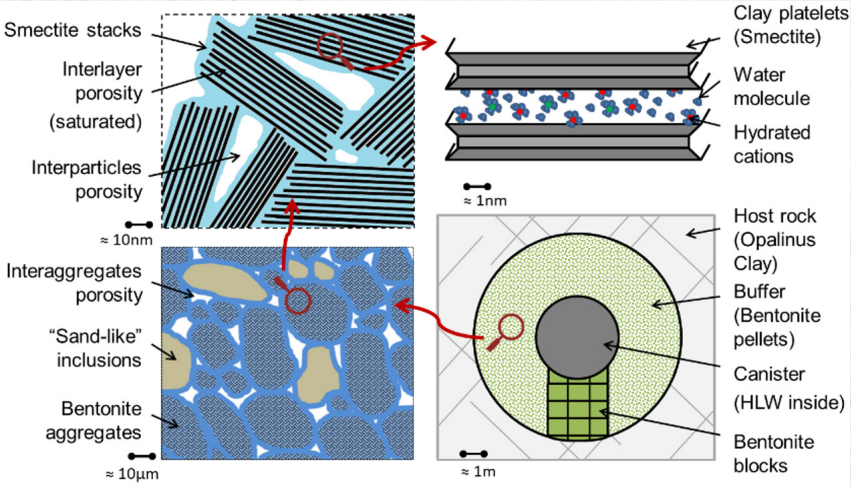
Scanning electron microscope image of a polished surface of Opalinus Clay shale sample (sourced at the Mont Terri Underground Rock Laboratory). Imaging performed at CIME-EPFL.

Opalinus Clay shale is the selected host formation for the construction of a repository for radioactive waste in Switzerland. For its typical features (e.g., low porosity, low permeability, high stiffness and capacity of self-sealing cracks upon saturation) it can guarantee the insulation of the waste from the biosphere. The formation is found over a wide area in the subsurface of the country. Because of the complex geological history of the area, the formation can be found at depths ranging from a few to hundreds of meters, with variable mineralogical composition; these two aspects affect the hydro-mechanical behaviour of the formation. The goal of the thesis is to investigate the impact of these factors on the Opalinus Clay behaviour. To this aim, careful characterization and testing of samples sourced from different sites and depths are carried out, and the material intrinsic properties are correlated with the mechanical findings. The results of the PhD thesis contribute to improve the understanding of the material behaviour at the final construction site.

PhD thesis: **"Chemo-mechanical modelling of MX-80 bentonite from the atomistic Clay-Ions-Water interactions"** by Etienne Cassini

Supervisor: Prof. L. Laloui

Funding agency: swiss*nuclear*



Multi-scale fabric of the bentonite buffer in the Swiss concept for High Level Waste storage. Scales from low right to top right corner (clockwise): repository; aggregates; clay stacks; smectite platelets.

Deep geological storage is actually seen as the only way to dispose safely nuclear waste and, because of its swelling potential, MX-80 bentonite is expected to be used as buffer in the Swiss concept for the storage of High Level Waste. The MX-80 swelling is foreseen to close the different existing technological gaps, therefore ensuring the closing of preferential flow paths and the overall low permeability of the buffer. However, bentonite swelling is sensitive to the water chemical composition, which will evolve during the lifetime of the repository with a risk of buffer shrinkage. The goal of the PhD work is to derive, on a physical base, an appropriate chemomechanical model for compacted MX-80 bentonite. In particular, the interaction between smectite clay, ions and water, which is the main origin of swelling, is modelled with Statistical Mechanics tools, improving the classically used description from Poisson-Boltzmann double layer theory. Taking into account the material fabric, these results at the atomic level are then upscaled to the macroscopic repository scale.

Geomechanics of Shale

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 extremely difficult and poses several challenges.

Shale sample (34mm in diameter)

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.

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. Recent research on this topic has been performed by Dr. Valentina Favero and Dr. Alberto Minardi in their recently completed PhDs. Their work is discussed on the following two pages.

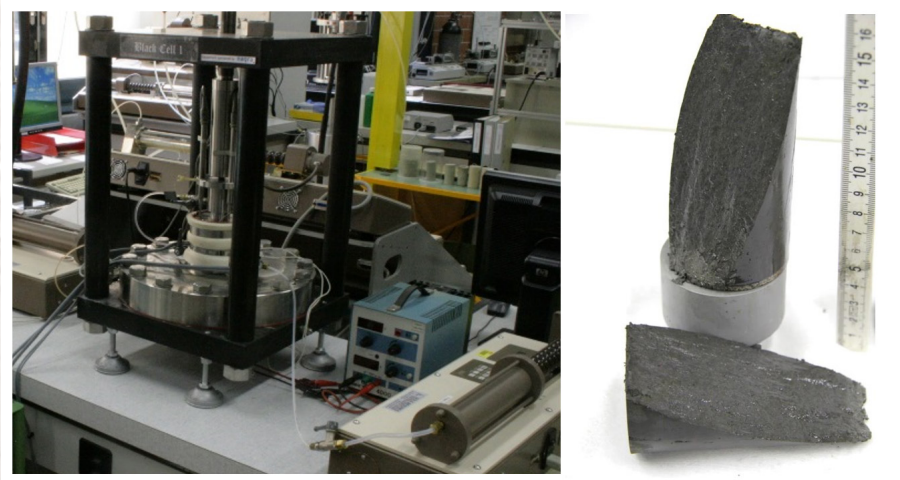
Ongoing PhD thesis:

- "Coupled chemo-hydro-mechanical behavior of shales" by Angelica Tuttolomondo, funded by The National Cooperative for the Disposal of Radioactive Waste (NAGRA).

PhD thesis: "Multiphysical behaviour of shales from Northern Switzerland" by Valentina Favero, Thesis n° 7539

Supervisors: Prof. L. Laloui, Dr. A. Ferrari

Funding agency: The National Cooperative for the Disposal of Radioactive Waste (NAGRA)



Advanced experimental device to investigate the multiphysical behaviour of shales

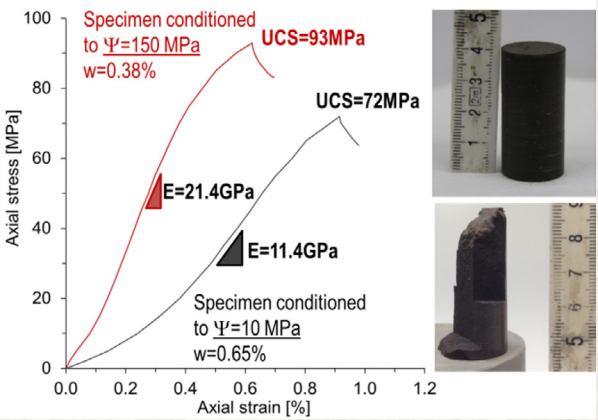
Shales are nowadays involved in energy-related applications, such as CO_2 storage, deep geothermal energy exploitation and nuclear waste storage. In these contexts, fundamental issues come along with the complex multiphysical environment in which shales are found, where mechanics, temperature, chemistry and unsaturated conditions play a significant role. The thesis has the objective of investigating the coupled thermo-hydro-chemo-mechanical behaviour of shales from Northern Switzerland both from experimental and constitutive points of view, with the aim of predicting shale response when subjected to multiphysical actions. To reach this goal, new experimental devices and methodologies are established in order to successfully investigate the multiphysical behavioral features of shales. An elasto-plastic constitutive framework is subsequently formulated in order to further predict their response.

The results of the PhD thesis are currently contributing to the site selection process carried out by the National Cooperative for the Disposal of Radioactive Waste (NAGRA), for the construction of a nuclear waste repository in Switzerland.

PhD thesis: "Hydro-mechanical characterization of gas shales and Opalinus Clay shale in partially saturated conditions" by Alberto Minardi, Thesis n° 8315

Supervisors: Prof. L. Laloui, Dr. A. Ferrari

Funding agencies: The National Cooperative for the Disposal of Radioactive Waste (NAGRA) and Chevron Energy Technology Company

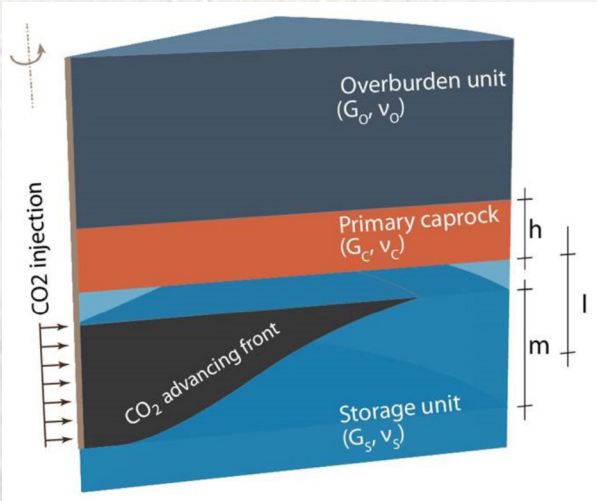


Stress-strain response of gas shale specimens tested at different total suction in uniaxial compressive tests.

The goal of this research has been to improve the assessment and the quantification of the impact of partially saturated conditions on the hydro-mechanical behaviour of shales involved in the extraction of shale gas and the disposal of radioactive waste. The Opalinus Clay shale and gas shales from different unconventional reservoirs have been studied. Although the analysis of the geomaterials' behaviour considering partial saturation is a well-established practice in Soil Mechanics, several additional challenges arise in the case of shales. These challenges are mainly related to their features, which make most of the experimental and theoretical frameworks adopted for soils not suitable for shales. A key part of this work has been dedicated to the establishment of advanced experimental methodologies and testing protocols. The obtained experimental results demonstrate that the consideration of partial saturation is fundamental for a reliable and comprehensive hydro-mechanical characterization of the tested shales. Changes in partially saturated conditions have been found to induce significant anisotropic volumetric deformations, which are dependent on the applied mechanical stress, and to affect both elastic and strength properties of the tested shales. These outcomes are expected to be of great importance not only for the aforementioned engineering applications, but also for the performance of laboratory tests on shales.

CO_2 Capture and Storage

CO_2 is considered to be the most important greenhouse gas released into the atmosphere, and its emission has increased drastically over the past decade. Each year, emissions of carbon dioxide are increasing, contributing significantly to climate change. 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.



The 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.

Our equipment, which includes an advanced triaxial and oedometric cell, is designed to reproduce in situ reservoir conditions: high temperatures up to 50 °C and high pressure up to 500 MPa which 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 the laboratory testing is used to validate the constitutive model of carbon dioxide effect on geomechanical response of rock-like materials. The interplay between multi-phase transport, multi-component reactions and mechanics are numerically tackled through innovative interdisciplinary research.

Ongoing PhD thesis:

- "Hazard and Risk Assessment of Large Seismic Events Owing to Fluid Injection" by Barnaby Fryer, funding by the Swiss Federal Office of Energy (SFOE).

PhD thesis: "Hazard and Risk Assessment of Large Seismic Events Owing to Fluid Injection" by Barnaby Fryer

Supervisors: Prof. L. Laloui, Dr. G. Siddiqi

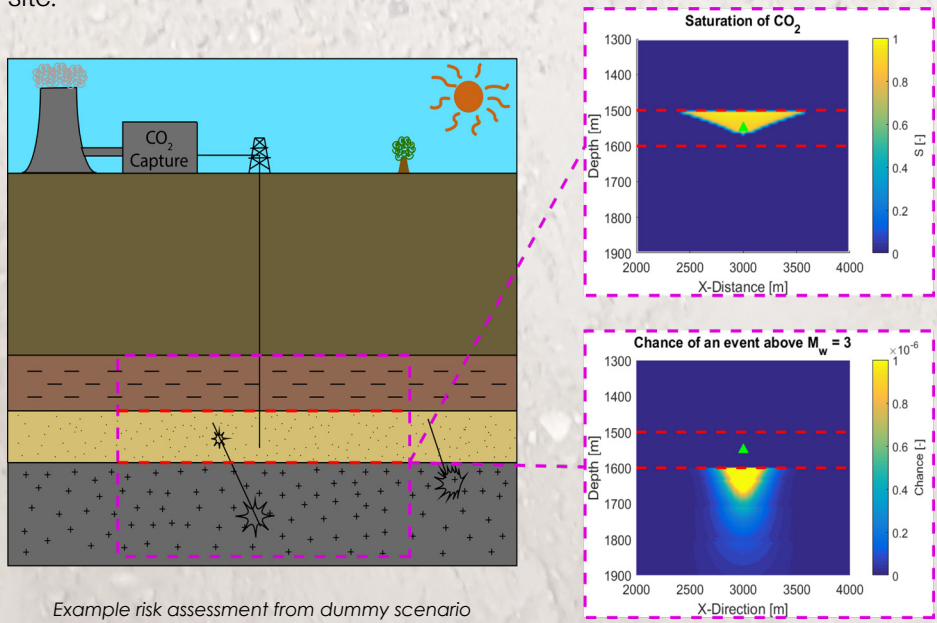
Funding agency: Swiss Federal Office of Energy (SFOE)

The capture and storage of CO_2 in, for example, deep saline aquifers, Carbon Capture and Storage (CCS), is a promising tool that can be used in the fight against climate change. The nature of the climate change problem necessitates the storage of large volumes of CO_2 if CCS is to have a meaningful impact. An analogous technology that has been much more widely implemented is waste or co-produced water disposal. Waste water disposal involves high injection rates over long periods of time into deep aquifers which are similar to those which would be targeted for CO_2 storage. Regrettably, waste water disposal has been known to be capable of causing seismicity of a not insignificant magnitude, suggesting that this risk also exists for CCS operations. Given the similarities waste water disposal has to CO_2 storage, the fledgling nature of CCS, and CCS's frequently delicate public acceptance, care has to be taken to ensure that the induced seismicity risk associated with CCS is mitigated as much as possible.

One key component to the mitigation of induced seismicity risk in CCS is, among other things, the careful selection of a proper target injection interval. The criteria for selecting such an interval already involve many key points: distance to a source of CO_2, the ability of hold large volumes of CO_2, and cap rock stability; however, the potential for induced seismicity should also be a key factor. By gleaning lessons from waste water disposal, it can be clearly seen that inducing pore pressure or stress changes specifically in underlying basement rock or underlying geologic formations can induce negative consequences with regard to induced seismicity. However, realistically, given the injection rates that CCS will require to be successful, the time scales involved, and the separation required between potential injection intervals and shallower drinking water aquifers, there is a strong likelihood that pressure and stress perturbations associated with CO_2 storage will come into contact with deep lying basement faults. This, however, does not mean that the safe storage of CO_2 is unattainable.

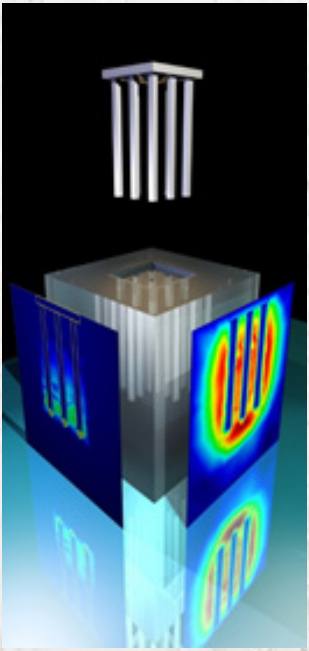
Despite the numerous cases of induced seismicity due to waste water injection, the overwhelmingly vast majority of waste water disposal wells have not induced any felt seismicity. This is especially encouraging when one considers the loose regulations, lack of geotechnical data, and little, if any, concern for the geological basement that was associated with waste water disposal over many decades.

This work is based on the idea that the selection of injection horizons for CO_2 storage needs to honor the inherent differences of the lithologies that will be affected by this storage whilst respecting the reality that there is great uncertainty surrounding our knowledge of any specific subsurface site. Namely, the consideration of the different frictional properties of faults likely to be present in the different types of layers in the subsurface, the creation of a worst-case, yet realistic, stress profile, and the assumption that a well-oriented fault may exist at any location in the subsurface are all incorporated into a modelling approach to quantitatively asses the risk associated with a given injection site. This approach is able to predict the aseismic or low magnitude seismic slip that occurs in the sedimentary intervals (i.e. the caprock and injection horizon). It also predicts a relatively large risk of a large seismic event associated with the underlying basement rock. The methodology therefore has utility in site selection where it can be used to assess the risk of a large induced seismic event at a proposed site.



Example risk assessment from dummy scenario

Sustainable 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 technologies that exploit renewable energy sources. Energy geostructures, ground structures that couple the role of the structural support with that of the geothermal heat exchanger, are an example of these innovative technologies.

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. 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. Dr. Rotta Loria has recently completed his PhD on this topic. His thesis is dicussed on the following page.

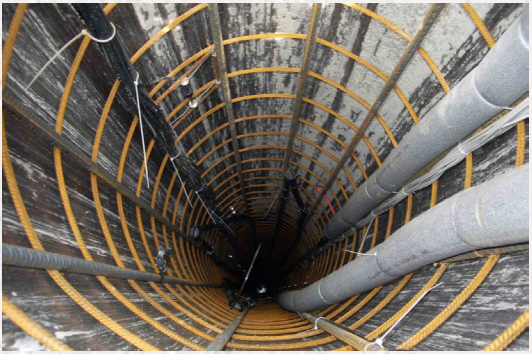
Ongoing PhD theses:

- "Soil-structure interaction – theory and applications" by Cristiano Garbellini, funded by the State Secretariat for Education, Research, and Innovation (SERI).
- "Modelling and design of energy geostructures from a holistic perspective with special emphasis on energy walls" by Jacopo Zannin, funded by European Project TERRE.
- "Experimental and numerical analyses for the sustainability of retaining structures in unsaturated soils" by Gianluca Speranza, funded by European Project TERRE.
- "Cyclic thermo-mechanical behaviour of energy piles" by Elena Ravera, funded by Swiss National Science Foundation (SNSF).

PhD thesis: "Thermo-mechanical performance of energy pile groups" by Alessandro Rotta Loria, Thesis n° 8138

Supervisor: Prof. L. Laloui

Funding agency: Swiss National Science Foundation (SNSF)



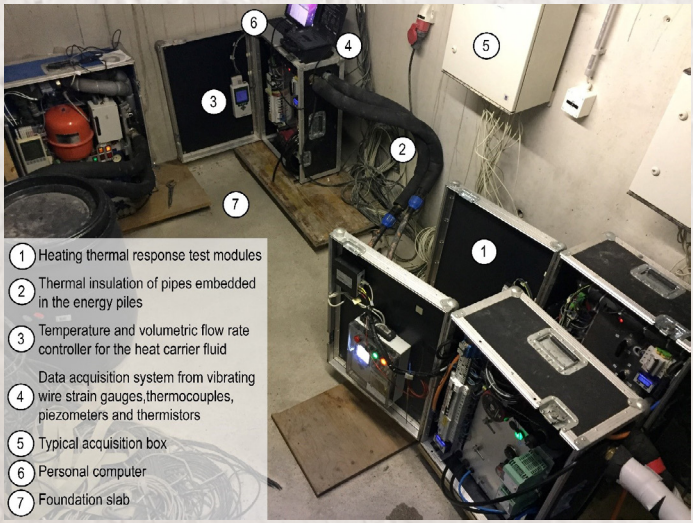
Example of a bored energy pile made of reinforced concrete constructed at the Swiss Federal Institute of Technology in Lausanne (EPFL).

Employing geostructures as structural supports and geomaterials as heat exchangers, storage or extraction media has represented an effective means to meet human activity needs since ancient times. This doctoral thesis focuses on the thermo-mechanical behaviour and performance of an innovative, multifunctional technology that couples the aforementioned roles for the structural support and energy supply of any type of built environment, i.e., energy piles. The multifunctional role of energy piles involves mechanical and thermal loads applied to such geostructures. These loads pose unprecedented challenges to engineers because they cause variations in the temperature, stress, deformation and displacement in the subsurface that need to be considered during analysis and design.

Prior to this work, a substantial amount of research had been made available to address the thermo-mechanical performance of single energy piles. Seminal guidance has also been proposed to advise in the geotechnical and structural design of such geostructures. However, energy pile foundations do not consist of a single energy pile but of a group of energy piles.

In this framework, (i) limited knowledge, if available, was present to address the thermo-mechanical behaviour and performance of energy pile groups subjected to thermal and mechanical loads; (ii) no simplified models and methods were accessible to perform the analysis and design of energy pile groups against the action of such loads; and (iii) no comprehensive

framework for the effect of thermal (and mechanical) loads on the performance and the related design of both single and groups of energy piles was available. To address such challenges, this doctoral research was performed to (i) investigate the thermo-mechanical behaviour and performance of energy pile groups over typical time-scales of practical applications via the first available in situ tests and coupled numerical analyses of such geostructures; (ii) provide the only simplified analytical models and methods for predicting the vertical deformation of energy pile groups subjected to thermal and mechanical loads; and (iii) propose a comprehensive framework for the effect of thermal and mechanical loads on the performance and related performance-based design (e.g., geotechnical and structural) of single and groups of energy piles. The results presented in this thesis suggest the conclusion that (a) the thermo-mechanical behaviour and performance of energy pile groups are critically different from those of single energy piles; (b) thermal loads, applied alone or in conjunction with mechanical loads, represent a serviceability and not an ultimate limit state problem; and (c) no energy pile analysis and design can be considered complete without addressing the behaviour of piles as both isolated elements and in a group. The results presented in this thesis contribute to the development of buildings and infrastructure resorting in a technology that harvests renewable energy, the improvement of human progress goals in an environmentally friendly way and, from a broader perspective, the establishment of a better world.



Experimental equipment used for the full-scale in situ tests of a group of energy piles performed at the Swiss Federal Institute of Technology in Lausanne (EPFL).

Awarded PhD and MSc Degrees

LMS is very proud to report the successful graduation of five of our PhD students this year. Dr. Valentina Favero, Dr. Alberto Minardi, Dr. Dimitrios Terzis, Dr. Alessandro Rotta Loria, and Dr. Yafei Qiao all successfully defended their theses this year. We are excited to see what the future holds for each of them and their careers.

Dr. Valentina Favero
Supervisors: Prof. Lyesse Laloui, Dr. Alessio Ferrari
Multiphysical Behaviour of Shales from Northern Switzerland

Valentina began her PhD at LMS in 2012 and successfully defended her thesis, entitled, "Multiphysical Behaviour of Shales from Northern Switzerland", on March 3rd 2017. The research was aimed at investigating the behavior of the host-geomaterial that has been selected for the construction of a deep geological repository for radioactive waste disposal in Switzerland. The research was sponsored by The National Cooperative for the Disposal of Radioactive Waste (NAGRA), with the aim of advancing the process of site selection for repository construction.

Along with her successful research, Valentina also managed to catch the public eye (or rather ear) as she gave a radio interview for Radio Télévision Suisse, demonstrating the importance of her research for the society. Valentina was also very involved in many of the extra activities that take place at LMS. For example, she took the lead in managing the organization of the ATMSS Workshop (Advances in Laboratory Testing and Modelling of Soils and Shales) which took place in Villars-sur-Ollon in January 2017 and hosted about 100 participants from all over the world. Thanks to the knowledge acquired in our field in these years, she became reviewer for scientific journals, and she actively participates in the scientific initiatives of the European Association of Geoscientists and Engineers (EAGE).

Since her graduation, Valentina continued to work at LMS as a post-doctoral researcher, she was primarily focused on the geomechanical behavior of caprocks during CO_2 injection and storage. She has since moved on to work for the Swiss Federal Office of Energy (SFOE).

Dr. Alberto Minardi
Supervisors: Prof. Lyesse Laloui, Dr. Alessio Ferrari
Hydromechanical Characterization of Gas Shales and Opalinus Clay Shale in Partially Saturated Conditions

Alberto joined the Laboratory for Soil Mechanics at the EPFL in November 2013. The research carried out during his PhD was focused on the hydro-mechanical behavior of shales in the context of nuclear waste disposal and shale gas extraction. The work was sponsored by The National Cooperative for the Disposal of Radioactive Waste (NAGRA) and Chevron Energy Technology Company.

During the four years spent at the LMS, Alberto gave a strong contribution to the improvement of the experimental facilities and expertise of the laboratory. The performed research was mainly devoted to investigate the mechanical behavior of shales in unsaturated conditions at the experimental level. New laboratory methodologies and testing apparatuses were developed to perform the experimental study. In particular, Alberto took advantage of the advanced facilities at the EPFL to design a completely new testing device to study the mechanical response of shales during gas injection. More than two years were required for the design and the manufacturing of the apparatus at the mechanical workshop of the EPFL. Moreover, the possibility to interact and exchange ideas with international experts in the research fields provided a significant contribution to the performed research.

The main outcomes of the research were presented by Alberto in several conferences and workshops, such as the "5th EAGE shale workshop" in 2016, the ATMSS 2017 workshop, and the Swiss Geoscience meeting in 2017. Moreover, three articles have been published in international peer-reviewed journals; two others have been submitted and they are currently under review.

After the conclusion of his PhD with the public defense, Alberto is now working as a post-doctoral researcher at the LMS; his research activities focus on the assessment of the sealing capacity of shale caprocks for the underground storage of CO_2.

Dr. Dimitrios Terzis
Supervisor: Prof. Lyesse Laloui
Kinetics, Mechanics and Micro-structure of Boi-cemented Soils

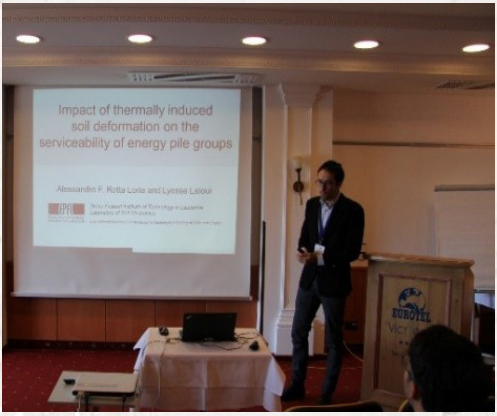
Dr. Terzis successfully defended his PhD, entitled "Kinetics, Mechanics and Micro-structure of Bio-cemented Soils", on October 30th 2017. Dimitrios was particularly focused on providing state-of-the-art fabric characterization of the peculiar, bio-cemented material and improving the understanding around the mechanical response of bio-improved sand. This involved significant amounts of laboratory testing and analysis. This work has been published in Geotechnique Letters and has been presented at numerous conferences around the world including the 19th International conference on Soil Mechanics and Geotechnical Engineering in Seoul, South Korea.

Dimitrios managed to not only perform research during his time at LMS but also set the basis for transferring the technology developed at LMS to the industry. To this end, a new start-up project, MeduSoil, has been developed with Prof. Laloui. MeduSoil aims to provide solutions for the emerging challenges in the construction field related to weak soils, as well as for implementing foundation repair works. MeduSoil introduces a flexible and adaptable strategy to target and access specific areas in the subsurface in order to increase their resistance, in a fast and cost-effective way.

MeduSoil has been met with resounding success up to this point. In 2016, Dimitrios won the Swiss-Indian branch of the Academia Industry Training (AIT) 2016 for his start-up project. Then, in 2017, he and Dr. Melis Sütman won the Swiss national award of ClimateKIC Launchpad for their work with MeduSoil. They finished first place out of eleven teams at the national level. This qualified them for the international competition in Cyprus in September 2017. Out of the roughly 1,000 green business ideas that entered the competition from 35 countries across the globe, MeduSoil finished in second place.

Since his graduation, Dimitrios has been continuing his work on bio-cemented soils as a post-doctoral researcher at LMS.

Dr. Alessandro Rotta Loria
Supervisors: Prof. Lyesse Laloui
Thermo-mechanical performance of energy pile groups



Dr. Alessandro F. Rotta Loria obtained his MSc and BSc degrees from the Politecnico di Torino (in 2011 and 2013, respectively) in Building Engineering. Due to his profound passion for the mechanics of geomaterials and structures and multiphysical phenomena, in 2013 Alessandro decided to undertake a PhD at LMS under the supervision of Prof. Laloui. During the course of his research, Alessandro spent a period as a visiting PhD student at the Hong Kong University of Science and Technology. In February 2017, Alessandro earned the qualification as a Professional Civil and Environmental Engineer from the Italian Order of Engineers. In December 2017, he earned his PhD from EPFL. Alessandro's PhD was funded by the Swiss National Science Foundation (SNSF).

Throughout his PhD, Alessandro investigated the thermo-mechanical behaviour and performance of energy pile groups through (I) full-scale field tests on the only fully instrumented group of energy piles in the world; (II) laboratory experimental campaigns of undisturbed soil samples; (III) centrifuge tests of energy piles; (IV) multidimensional and multiphysical numerical analyses; and (V) the first analytical methods to characterize the vertical deformation of energy pile groups.

The major achievements earned by Alessandro throughout his PhD at EPFL are: the acquisition of research prizes and awards by international journals and institutions; the co-authorship of seventeen refereed journal papers and fourteen refereed conference articles; and the development with Prof. Laloui of a short-course for practitioners and scientists. Currently, Alessandro has received 106 citations of his publications and he has an H-index of 5. Since January 2018, Alessandro has been further developing his research activities at the Laboratory of Soil Mechanics as a post-doctoral researcher.

Dr. Yafei Qiao
Supervisors: Prof. Lyesse Laloui, Prof. Wenqi Ding
Thermoviscoplastic Constitutive Model and Double-structure Swelling Model: Application to Nuclear Waste Geological Disposal

Yafei Qiao has successfully defended his PhD dissertation entitled, "Thermoviscoplastic Constitutive Model and Double-structure Swelling Model: Application to Nuclear Waste Geological Disposal" at Tongji Uninversity. Dr. Qiao's work was co-supervised by Prof. Laloui. During his time at LMS Yafei was able to build strong relationships with many of his fellow colleagues such as Dr. Alessio Ferrari, Dr. Chao Li, and Dr. Anne-Catherine Dieudonné. His work was key in redefining nonstationary flow surface theory which promises to be an important framework for describing viscoelastic behavior. Yafei's thesis was selected as Best Thesis by the Chinese Society of Rock Mechanics and Engineering. His work was sponsored by The National Cooperative for the Disposal of Radioactive Waste (NAGRA) and the Chinese government.

Yafei has many fond memories of his time at LMS (indeed, Yafei has said himself that his time as a PhD student absolutely flew by). This included many conferences such as the 80th anniversary workshop of LMS, the 6th Asia-Pacific unsaturated soil conference, the international workshop on the Advances in Laboratory Testing & Modelling of Soils and Shales (ATMSS17), and the series of EBS meetings. Beyond his research, Yafei also enjoyed numerous social events with LMS such as our summer party and numerous dinners and outings with friends and colleagues.

Yafei entered into the field of nuclear waste storage through the FEBEX and EBS projects under the support of The National Cooperative for the Disposal of Radioactive Waste (NAGRA). Since then, he has earned the position of assistant professor at Tongji University.

Eight Completed Master Theses

Victoire Denis du Péage

Mirko Rezzonico

Etienne Moser

Paolo Pagani

Pia Hartmann

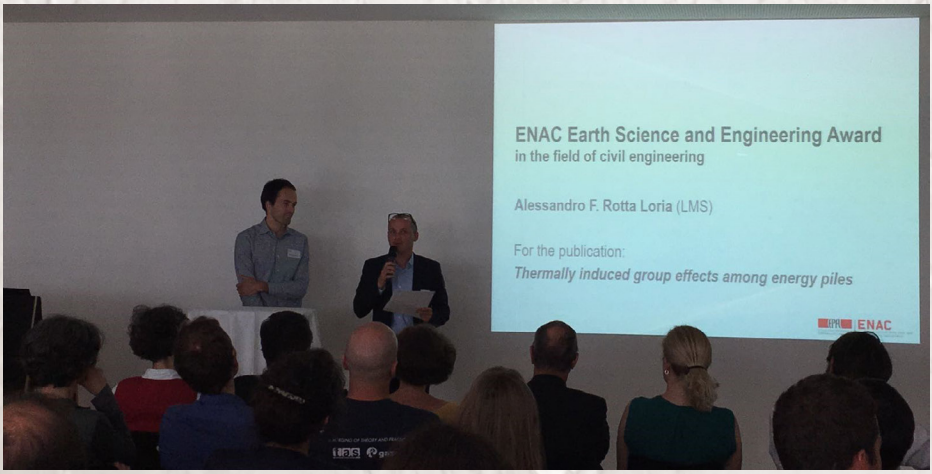
Thibaut Duparc

- "Exploring mechanisms leading to large induced seismic events during hydraulic stimulations in Engineered Geothermal Systems (EGS) and Hydrocarbon Extraction" by **Victoire Denis du Péage**. In collaboration with MIT
- "Geotechnical study of a shallow pedestrian tunnel in an urban area" by **Mirko Rezzonico**. In collaboration with BG Ingénieurs Conseils
- "Stability of excavations and slopes of the Loveresse tunnel gates" by **Etienne Moser**. In collaboration with BG Ingénieurs Conseils
- "Study of the stability of excavation chambers" by **Lea Tabea Kaufmann**. In collaboration with BG Ingénieurs Conseils
- "Geotechnical study of underground structures of a hydroelectric development" by **Paolo Pagani**. In collaboration with BG Ingénieurs Conseils
- "Geotechnical study of the special works of a real estate complex" by **Pia Hartmann**. In collaboration with BG Ingénieurs Conseils
- "Geotechnical study of the extension of an existing metro station with geothermal structures" by **Thibaut Duparc**. In collaboration with BG Conseils Ingénieurs
- "Geotechnical study of a road tunnel" by **Lionel Benoît Joël Krayenbühl**. In collaboration with BG Ingénieurs Conseils

Awards and Keynotes

Awards

In July of this year Prof. Laloui was awarded the honorary position of Advisory Professor at the Department of Civil Engineering and Transportation at Hohai University, China.



Dr. Alessandro Rotta Loria has won the "Earth Sciences and Engineering" Civil Engineering Institute, EPFL Award 2017 for his publication "Thermally Induced Group Effects Among Energy Piles".

MeduSoil wins a prestigious prize

Born in LMS at EPFL, the start-up project MeduSoil came second at the Climate Launchpad Grand Final in Cyprus, the world's largest green business idea competition, against roughly 1,000 competitors.

Dr. Dimitrios Terzis and Dr. Melis Sütman at the Swiss National ClimateKIC, September 2017, Basel, Switzerland

In September, the start-up project MeduSoil, won the Swiss national ClimateKIC 2017 finishing first place out of eleven projects at the national level. This also qualified it to continue on and compete at the Climate Launchpad Grand Final.

During the Climate Launchpad Grand Final in Cyprus, roughly 1,000 green business ideas were submitted from 35 countries across the globe. Each participant had to pitch his or her idea in front of a renowned jury. Dr. Dimitrios Terzis and Dr. Melis Sütman, scientists at LMS, presented MeduSoil, which finished in second place worldwide!

At the Climate Launchpad Grand Final, November 2017, Limassol, Cyprus

The start-up project MeduSoil was born and raised in the Laboratory for Soil Mechanics (LMS) of EPFL to provide sustainable solutions for the emerging challenges in the construction field related to weak soils, as well as for implementing foundation repair works. With this new technology, a natural form of performant cement is produced which ultimately increases the resistance and cohesion of soils, by using natural soil bacteria.

Prof. Lyesse Laloui, Dr. Melis Sutman and Dr. Dimitrios Terzis at LMS with bio-cemented soil samples

MeduSoil is supported by the ENABLE program of the Technology Transfer Office at EPFL and Innoseed ENAC, a program which helps ENAC researchers to broaden their horizons when considering the outreach of their academic work and its value for society.

Keynote Lectures

Prof. Laloui gave a keynote lecture during the International Conference on Geo-Energy and Geo-Environment (GeGe) 2017 on the advances in energy pile design in July 2017 in China.

Prof. Laloui gave a keynote lecture during the 7th Geotechnical Symposium with International Participation in Istanbul in November 2017. Prof. Laloui's lecture covered the design of thermo-active foundations.

Events

LMS hosted a fruitful conference on the Advances in Laboratory Testing & Modelling of Soils and Shales in the rather scenic environment of Villars-sur-Ollon, which is a quaint village situated in the Swiss Alps.

Participants from the world over came to share ideas and learn from industry leading experts in the fields of laboratory testing and the modelling of soils and shales. The conference also had the honor of hosting a Bishop Lecture by Prof. Hervé Di Benedetto, who spoke about "Advanced testing and modelling of granular material with and without viscous glue: research and practical implication". Prof. Di Benedetto originally gave the lecture during the 6th International Symposium on Deformation Characteristics of Geomaterials, in 2015, in Buenos Aires, Argentina.

With over 100 attendees from 25 countries, the three-day workshop featured 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.

The three-day programme featured a series of presentations covering a broad spectrum of the mechanics of soils and shales, including 6 keynote lectures and 6 feature lectures during 11 technical sessions. The topics ranged 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, and soil – structure interactions.

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

As most of our guests were not from Switzerland, we thought it a good idea to give them not only a taste of Swiss culture, but also of their wine and cheese with our wine and cheese tasting session. While Switzerland is a fairly famous cheese producer, it also produces a quite a bit of wine, some of which comes from the vineyards along the shores of Lake Geneva about ten minutes by train from the EPFL. There was also a conference dinner organized for the guests atop one of the adjacent mountains. This was followed by an outdoor disco in the snow. Here it became clear that our participants are not only enthusiastic while discussing their field of research, but also while dancing.

International Doctoral School on Unsaturated Soil Mechanics
April 4-7, 2017
EPFL, Lausanne, Switzerland

Students from all around the world participated in the International Doctoral School on Unsaturated Soil Mechanics. Experts from all over Europe came to give lectures on a variety of topics surrounding unsaturated soil mechanics. Unsaturated soils have some very real applications, especially in the realm of slopes and embankments. Students were able to learn from experts about a wide range of topics within the field, ranging from theoretical developments, experimental work, modelling approaches, and real world instances where unsaturated soils were of the utmost importance. In fact, it was seen that a proper understanding of these soils can be as important as life and death when a slope failure near the Vajont Dam caused the death of 1,910 people.

The school also served as an opportunity for the members of project TERRE, "Training Engineers and Researchers to Rethink geotechnical Engineering for a low carbon future" to meet and discuss their work. TERRE is a project focused on low-carbon technologies. The idea being that, through Marie Skłodowska-Curie Innovative Training Networks funding this intra-European coordinated PhD program, new geo-technologies will be developed for the geo-infrastructure industry. There are currently fifteen TERRE researchers in doctoral schools throughout Europe, two of which are located here at LMS.

The school also included a visit to the Mont-Terri underground testing laboratory where students had an opportunity to hear from researchers about the background of the Mont-Terri facility and learn about some of the experiments being conducted there. The students were also able to participate on a guided tour through tunnels where they were able to see many of the experiments themselves, including some active drilling!

Of course, we couldn't let our guests leave without a celebration, so we organized a barbeque to treat them to our unique mixed Texan-Italian style cooking. While such an event is primarily social, it also offers a great opportunity for participants to cement some of the new connections and friendships they had been making throughout the week. We hope that some of these new connections will lead to more collaborations and idea exchange throughout Europe (and indeed the world), such as that already occurring in the European Project TERRE.

Upcoming Events

SEG 2018

In **September 2018** LMS will be hosting the International Symposium on Energy Geotechnics (SEG 2018), recognizing the strong need for shared knowledge in innovative and challenging applications on energy geotechnics. SEG 2018 aims to serve as a forum for promoting the exchange of ideas, practices and state-of-the-art on a broad range of topics in the area.

SEG 2018 will be hosting a variety of topics related to the energy geotechnics field including carbon sequestration, energy geostructures, hydraulic fractured sediments, nuclear waste deposits, and many more. There will also be an emphasis on discussing innovative ideas, and the presentation of start-ups and patents which fall within the broad spectrum of energy geotechnics will be strongly encouraged.

With LMS serving as the hosting organization, the symposium will be held at EPFL's very own SwissTech Convention Center. Further, the symposium will be preceded by an optional course on energy geostructures and followed by a visit to the Mont-Terri Underground Rock Laboratory, located 300m underground. Numerous experiments are carried out here on the Opalinus Clay, which is, among other things, a potential host rock for future nuclear waste storage activities in Switzerland.

More information regarding the conference can be found on its website at https://seg2018.epfl.ch/

Annual Conference of Swiss Geotechnical Association

LMS will host the Annual Conference of Swiss Geotechnical Association titled "Innovation and Research" on **24-25 September 2018**. The conference will start with a half-day short course focusing on numerical modeling in geotechnical engineering which will be followed by the gala dinner and awards ceremony. On the second day of the conference, presentations from experts from both national and international bases will take place, which will cover the "research" aspect of the conference. Moreover, start-up and patent presentations will take place, along with exhibitions, to fulfill the "innovation" feature.

European Cooperation in Science and Technology Action (GABI) Meeting

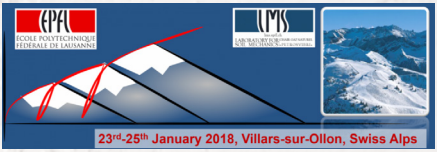
COST (European Cooperation in Science and Technology) Action TU1405, European Network for Shallow Geothermal Energy Applications in Buildings and Infrastructures (GABI) meeting will be held by LMS at the EPFL on **September 25th 2018**. The COST Action TU1405 meeting is scheduled to coincide with the Annual Meeting of Swiss Geotechnical Association and the International Conference on Energy Geotechnics (SEG 2018), both organized by LMS, in order to enhance the interactions between these organizations at an international level, under the stewardship of Switzerland.

COST Action 1405 GABI meetings are organized twice a year, during which ideas and expertise of the various member countries are shared and design guidelines for energy geostructures are developed, which is of paramount importance in terms of collaborative progress in a relatively new subject, energy geostructures.

On **September 24th 2018**, a one-day short course is organized with the involvement of LMS and COST Action 1405 GABI, to synthesize research and practice-based knowledge from across national and disciplinary boundaries in order develop better understanding and more widespread use of energy geostructures. The second day of the meeting, 25 September 2018 will be reserved for the Working Group Meetings of COST Action 1405 GABI.

Winter Doctoral School

The Laboratory of Soil Mechanics is organizing a winter school dedicated to Geomechanics for Energy and the Environment. These themes have become increasingly relevant and merit extra attention as they are fundamental in many applications. The school itself will take place from **January 23rd to January 25th 2018** in Villars-sur-Ollon, Switzerland. Lectures from industry leaders from all over the world have been organized to provide participants with an opportunity to pick the brains of some of the field's top experts. The key topics of the course program are computational poromechanics, advanced thermos-hydro-mechanical laboratory testing, the mechanics of hydraulic fractures, the chemical effects in mechanical behavior of geo-structures, and the multiphysical constitutive framework for soils and shales. Find out more at https://gete-school.epfl.ch/



Energy Geostructures Analysis and Design

On **March 20th to 22nd 2018**, the Laboratory of Soil Mechanics will be hosting a course on the analysis and design of energy geostructures through Formation Continue. The target audience of the course are professionals and scientists who want to acquire knowledge on the energy, geotechnical and structural performance of energy geostructures. Participants will undergo a three-day course which explores such topics as the typical operations and applications of ground source heat pump systems, heat transfer in the context of energy geostructures, the thermo-mechanical behavior of single and grouped energy piles, the estimation of thermal potential of sites and design parameters, and a variety of other related topics. There will also be a modelling component to the course and participants will be given a three-month license of the academic version of the Thermo-Pile software. The instructors of the course will be two of our labs leading experts on the topic, Prof. Laloui and Dr. Rotta Loria, along with three other industry experts. At the end of the course, participants should understand the thermal and mechanical behavior of energy geostructures, be able to perform the analyses necessary to design energy geostructures and be able to perform all steps of the design process, and have a firm knowledge of the current design standards at the European level. More information can be found at http://www.formation-continue-unil-epfl.ch/en/formation/energy-geostructures-analysis-design/

LMS in the Media

Prof. Laloui starts his year with four interviews

In January and February of this year, Prof. Laloui gave three interviews about nuclear waste storage and one about the geosequestration of CO_2. Specifically, Prof. Laloui discussed the problems associated with burial depths which are too close to the surface, the construction of storage sites for nuclear waste, and the problems associated with nuclear waste storage (especially with regard to a possible early departure from nuclear energy in Switzerland). The interviews appeared in such places as Journal Moustique (a Belgian magazine), 24 Heures (24 Hours – a Swiss newspaper), La Tribune de Genève (Geneva Tribune – also a Swiss newspaper), and L'Extension (a Swiss magazine). His interview regarding CO_2 storage appeared in Earth and Nature. All of our news, including the full interviews, can be found at https://lms.epfl.ch/news.

9 FÉVRIER 2017 Nature Tere@Nature 11

ENVIRONNEMENT

L'EPFL envisage le stockage du CO_2 comme une planche de salut

Enfouir le CO_2 plutôt que le laisser s'échapper dans l'atmosphère: l'idée séduit les chercheurs. Le fait que cette technique encore en développement soit sujette à débat n'empêche pas l'École polytechnique fédérale de Lausanne (EPFL) de plancher sur la question.

Que l'aquatique CO_2, dioxyde de carbone ou anhydride carbonique, incomodie de manque ce qui gêt bien gênes tiers de la presse et donne des ailes à quelques chercheurs qui, eux, ont en cœur des discours sur le climat. C'est le plus célèbre des gaz à effet de serre: s'il est inévitable, son impact ne l'est pas. La lutte contre le réchauffement pourrait prendre un tournant avec la séquestration du CO_2, une méthode qui consiste à enfouir le dioxyde de carbone plusieurs centaines de mètres sous terre.

Depuis la COP21 et son traité universel sur le climat, la réduction des émissions de CO_2 figure en tête des résolutions des pays signataires. Ainsi la Suisse s'est-elle engagée à diviser par deux ses rejets de dioxyde de carbone d'ici à 2030 et à les ramener à zéro au cours des décennies qui le suivent. C'est le plus célèbre des gaz à effet de serre: s'il est inévitable, son impact ne l'est pas. La lutte contre le réchauffement pourrait prendre un tournant avec la séquestration du CO_2, une méthode qui consiste à enfouir le dioxyde de carbone plusieurs centaines de mètres sous terre.

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La Suisse est en retard

Le chercheur Laurent Laloui de l'ensee Lausanne. La stratégie fédérale repose sur un changement de nos habitudes ne suffira pas. On ne pourra pas se passer aussi vite des hydrocarbures. La séquestration des gaz à effet de serre est une alternative intéressante.» Lyesse Laloui dirige le laboratoire de mécanique des sols de l'EPFL. Il travaille sur les projets menés depuis vingt ans pour non-voisine «Pluéhers pour exploitant déjà cette technologie. Ils permettent de stocker des millions de tonnes de CO_2 «Plutôt que des initiatives gouvernementales, ces expériences sont souvent le fait de groupes pétroliers qui y voient un moyen de s'affranchir des taxes sur le CO_2 émis.

Le processus est simple (voir ouvre infographie): on capte le CO_2 à la sortie d'une cheminée à la source, soit à la fin du cycle de production d'une usine, puis le transporte jusqu'au lieu de stockage. «Le CO_2 peut être manipulé sous forme liquide ou gazeuse, explique Lyesse Laloui. On choisit le moyen le plus adapté à chaque situation. Aux Etats-Unis, on le transporte sous forme liquide par naturel. La séquestration proprement dite consiste à injecter le gaz carbonique dans le sol. «On doit trouver une couche de roche poreuse. On creuse un puits à bon mètres à cette profondeur, remplissant et pression leur atteindre au CO_2 en état qui est supercritique. Il prend de la densité et de la viscosité. Il se comporte comme un liquide. Pour empêcher le dioxyde de carbone de remonter à la surface, il faut vérifier à ce que la roche poreuse soit recouverte d'une couche de roche imperméable. Argument de poids, en revanche des zones poreuses sous sous les pays du monde. D'après une estimation, la Suisse dispose d'un potentiel lui permettant de stocker 2 fois 2 mètres ans de sa production actuelle de CO_2.

Enfouir un gaz, c'est mal?

Si Lyesse Laloui prêche le pragmatisme, c'est parce qu'il sait que l'idée d'injecter un gaz sous sous rien plaît à quelque chose d'inquiétant. «Il faut que les populations soient sûres que les gaz ne sauront le possible. «Mais on ne fait que reproduire un processus naturel, étonnant» il. Ce CO_2 provient des hydrocarbures que l'on a extraits du sol. On le remine d'où il vient.» Selon le scientifique, les réticences du grand public sont avant tout liées à une dimension culturelle: «Les professeurs de cette technique sont des pays pétrolifères. Mais ce n'est pas le cas du Canada. Pour eux, l'exploitation du sous-sol fait partie du quotidien. Ce n'est pas le cas chez nous. On a l'impression que il l'on cache quelque chose, c'est mal. Mais ses ce voulaient moins bien d'injecter un produit dans le sol que de l'extraire, comme le font les pays pétrolifères. Ce n'est pas mieux». Notons qu'une fois enfoui, le CO_2 se reste pas longtemps sous forme gazeuse: en cinquante à centaine, on transfert chimique le change en roche.

En Suisse, le sous-sol est propriété des cantons, mais la législation actuelle ne permet pas d'envisager de tels projets. Les recherches menées par le laboratoire de Lyesse Laloui restent donc théoriques. «Nous tirons pas de site pour faire des tests en conditions réelles. Nous nous contentons de simulations, ce qui ne nous empêche pas de travailler avec des ingénieurs, des équipes de l'injection et de la minéralisation du CO_2. C'est une question de maîtrise technologique et personne n'est forcé le pour où la Suisse se réveillera à cette solution, nous devons essayer des spécialistes à l'étranger. L'expertise a de la valeur».

Le chercheur ne se prononce pas sur le fait que les entreprises ne dépensent pas de chèque coûte entre 80 et 100 francs par tonne de CO_2. Une fortune faut ses à Berne par tonne dont s'acquitte la Suisse pour acheter des certificats destinés à soutenir des projets à l'étranger, outil sur lequel elle s'appuie lajoutant pour s'approcher de son objectif. Lyesse Laloui en est convaincu, le CO_2 ne peut pas être stocké dans des conditions, comme en Norvège, le gouvernement a décidé de prendre en charge les coûts liés à l'endommagement du CO_2. La captation, elle, est financée par les entreprises qui le produisent. «Il faut agir sans tarder, on peut non seulement limiter le réchauffement climatique, mais aussi le ramener à 1, 5°C. Pour cela, il faut qu'on ait recours à des technologies» ?

LAURENT GRANGEAN

• COP 21/22 www.unfccc.epfl.ch

À la tête du laboratoire de mécanique des sols de l'EPFL, Lyesse Laloui est très sûr de la nécessité de respecter les engagements pris par la Suisse.

BIEN À SAVOIR

La Confédération suit la question de près

«Le stockage du CO_2 concerne d'abord les industries, souligne Angela Simonet, porte-parole de l'Office fédéral de l'énergie. Or c'est pour cela qu'il ne relève pas de la stratégie énergétique 2050 du Conseil fédéral. L'Office fédéral de l'environnement suivant attentivement les recherches dans ce domaine. Une étude a été effectuée dans le laboratoire souterrain de Mont Terri LAB.

CLIN D'ŒIL

Sommités scientifiques réunies à Lausanne

Du mercredi dernier au vendredi 17 mars, à Lausanne-Ouchy et à l'Ecole polytechnique fédérale de Lausanne (EPFL), 12e conférence «Greenhouse gas control technologies». Une manière de «Lancer le débat sur le rôle de la séquestration du CO_2 dans la lutte contre le réchauffement climatique et la préservation des ressources naturelles», les conférences a été le cadre d'un exercice de l'Agence internationale de l'énergie placée sous l'égide des Nations unies. Représentation absolue le stockage du CO_2 ne serait pas que la technique doit être prise en compte.

• AT EXTENSION www.ieagreen.org

LA SÉQUESTRATION DU CO_2

Énergie/

SORTI DU NUCLÉAIRE : QUID DES DÉCHETS ?

4 Suisse

24 heures | Samedi-dimanche

Nucléaire

Plus de déchets nucléaires à gérer, plus tôt que prévu

La construction du site d'entreposage des déchets radioactifs est faite de compromis, tant scientifiques que politiques.

Lucie Monnat

Winterthour s'ap prévenir la radio

Déchets nucléaires

L'ÉTERNELLE QUESTION

Stockage des déchets nucléaires à Bure (France)

L'État compte enfouir des matières radioactives à 200 mètres de profondeur. Puis les sceller à tout jamais. Une hérésie pour les écologistes.

NOTRE EXPERT

LYESSE LALOUI EST LE DIRECTEUR DU LABORATOIRE DE MÉCANIQUE DES SOLS DE

Que faut-il faire de nos déchets nucléaires? C'est la question à plusieurs milliards d'euros que se posent opposants comme partisans de cette énergie. C'est surtout une question à plusieurs centaines de milliers d'ans... originales. Certains pays comptaient les envoyer sur la Lune, d'autres - Russie et Angleterre en tête - ont commencé par les jeter au fond des océans à 10 kilomètres de profondeur. Tandis que les moins scrupuleux d'entre eux les déchargeaient sur des plages africaines... Heureusement, ce temps est (quasi) révolu et un consensus se dégage aujourd'hui sur l'enfouissement En Belgique, pays le plus densément nucléarisé au monde, l'Organisme national des déchets radioactifs et des matières fissiles enrichies (ONDRAF) a bien évidemment son idée sur la question. Précisons qu'on parle ici des matières de moyenne à très haute radioactivité, soit environ 15.000 m³ de déchets à très longue vie. L'Ondraf compte donc les enfouir à 200 mètres de profondeur dans

Prof. Laloui interview with L'Extension

Les Alpes oppressées

par le temps ?

Bien qu'il soit hasardeux d'attribuer formellement au changement climatique un événement isolé tel le glissement de terrain ayant emporté huit personnes à Bondo dans les Grisons, ces dernières années ont révélé une forte concentration de phénomènes intenses en lien avec des événements météorologiques extrêmes, particulièrement prononcés dans les régions alpines.
Ces événements sont-ils si exceptionnels ou relèvent-ils plutôt du fonctionnement "normal" de la montagne ? Faut-il apprendre à vivre avec ces catastrophes ou peut-on s'en prémunir ? Nous avons demandé l'avis d'un expert, le Professeur Lyesse Laloui, directeur du Laboratoire de mécanique des sols de l'Ecole polytechnique fédérale de Lausanne.

In September Prof. Laloui gave an interview with L'Extension, a magazine which covers stories relevant to the area of Geneva. Prof. Laloui was invited to discuss how climate change could potentially influence extreme weather and how these conditions could influence the Alps. Of course, as attested by Prof. Laloui himself, it is impossible to attribute an event such as a landslide purely to climate change; however, we can develop technologies and tools to help us mitigate the effects of such disasters.

Prof. Laloui interview with Radio Télévision Suisse

In August Prof. Laloui was interviewed by Radio Télévision Suisse regarding climate change and how this would affect natural hazards in Switzerland. Prof. Laloui explained that the probable natural hazard increase would most likely bring about a change in not only the way new infrastructure is constructed but also necessitate change in existing infrastructure.

Prof. Laloui interview Swiss National Radio

In May Prof. Laloui gave an interview about nuclear waste storage in Switzerland describing some of the fundamental principles and challenges associated with this large and very important project.

Prof. Laloui was the principal invitee of a radio emission by Radio Télévision Suisse

In March Prof. Laloui gave an interview covering the basic concepts of the mechanics of soils as well as some of the primary applications of these concepts and why the type of research performed by LMS is so critical in tackling some of the most difficult challenges faced in Switzerland today.

The 4th edition of the Technologies and Innovation Expo of Lausanne

A startup stemming from LMS and founded by Prof. Laloui and PhD candidate, Dimitrios Terzis, was presented at the 4th edition of the Technologies and Innovation Expo of Lausanne. The startup, named MeduSoil, is primarily focused on the use of microbes to reinforce soils. MeduSoil has already experienced success through winning the Swiss-Indian branch of the Academia Industry Training Program in 2016.

Article about a publication on a nuclear waste storage by LMS

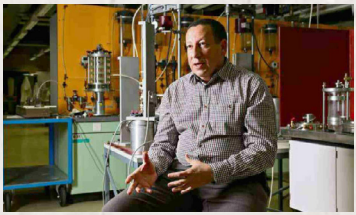
A study on the identification of sites that may potentially be suitable for the storage of radioactive waste which was performed by LMS was published by Homeland Security News Wire.

Dr. Valentina Favero gives an interview for Radio Télévision Suisse

Research performed by LMS has allowed for a better understanding of the potential sites put forward for nuclear waste storage. Dr. Valentina Favero gave an interview on the subject on Radio Télévision Suisse. Key research presented in the thesis of Dr. Valentina Favero has led to an improved understanding of sites which may one day serve as storage sites for nuclear waste.

Prof. Laloui has an interview with Le Temps

In July, Prof. Laloui discussed China's potential to implement energy geostructures in an interview with Le Temps. China is well-suited to the technology as it is constructing many large towers and has access to significant sources of geothermal energy.



MeduSoil Success makes the headlines

MeduSoils recent success at international competitions was recently featured in an article by L'Extension. The article provided an overview of the startup's goals as well as their experience at Climate KIC.

LMS Youtube Channel

LMS has recently launched a new Youtube channel. The Youtube channel contains interviews given by LMS personnel, lectures, and other events. The Youtube channel can be found by searching EPFL LMS on Youtube. A brief description of some of the uploads is given below. Note that some of the videos are in French.

Interview du Prof. Lyesse Laloui à la RTS (Prof. Lyesse Laloui's interview with Radio Télévision Suisse)

On May 12th 2017 Prof. Lyesse Laloui was invited by RTS (a Swiss public broadcasting company) to discuss nuclear waste storage and how it relates to Switzerland. Informing the public on these kinds of matters has an added importance in Switzerland as it is a direct democracy where citizens vote on many important issues. One such vote was on May 21st 2017, where the Swiss people voted on their energy plan. This plan included a move away from nuclear energy (therefore making the storage of nuclear waste of added importance).

Interview Prof. Lyesse Laloui Grand Invité de l'émission CQFD sur la RTS (Prof. Lyesse Laloui interviewed as the principal invitee of Radio Télévision Suisse's science-based emission CQFD)

On March 27th Prof. Laloui gave an interview covering the basic concepts of the mechanics of soils as well as some of the primary applications of these concepts and why the type of research performed by LMS is so critical in tackling some of the most difficult challenges faced in Switzerland today.

GHGT-13 Gala

A short video overview of the GHGT-13 Gala in December last year. The gala included a variety of exciting performences, and the highlights of some of them along with some of the guests can be seen in this video.

Et si on maîtrisait l'enfouissement de nos déchets nucléaires ? (And if we master underground nuclear waste storage?)

Prof. Lyesse Laloui gave a lecture on nuclear waste storage, with a special focus on how it relates to Switzerland. The lecture included discussions of the history of nuclear energy, nuclear waste, the storage of nuclear waste, and the possible risks associated with nuclear waste storage.

Outside Lab Activities

In July, LMS hosted a summer barbeque with the Laboratory of Experimental Rock Mechanics and the Geo-Energy Laboratory. The barbeque had a tropical/Mexican style theme with many people sporting a lei. The theme was chosen in part because of the nice summer weather at the time but also because our post-doc, Dr. Hiram Arroyo-Chavez, was leaving us to begin as a professor back in his home country of Mexico (at the Universidad de Guanajuato). While Hiram leaving is a bit bitter-sweet, we did manage to have a very enjoyable time during the barbeque (which isn't hard when there's tasty Mexican food on offer!). Despite the tropical theme, we all brought food from our own home countries, which, given our international backgrounds, resulted in a plethora of great food from all over the world. It's just as well there was no prize for tastiest dish, as it would have been very difficult to declare a winner!

Speaking of competitions, we also had a limbo battle at the end of the evening (these kinds of things can't be at the beginning of course – you need at least one glass of wine to get the bravery levels up!). Although there were some outstanding performers, I think it is safe to say that most of us will not be quitting our day jobs at the LMS to move into the professional limbo dancer industry. That said, we have to congratulate Mateo Acosta at being the most limber researcher of the three laboratories.

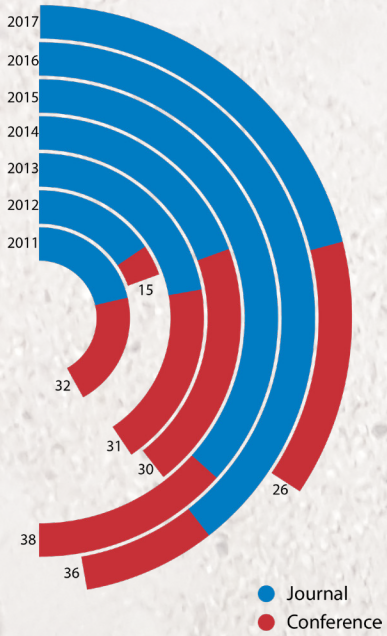
Just before digging in, Prof. Laloui spoke to us about our year so far and also made a tribute to some of the people who would be leaving soon. While we never like to see friendly faces depart, it does make way for new ones. Also, many of our former colleagues now work all across the world, and, as more people come and go, our network slowly grows into a very international one. In this way, you are never sure which old friends you will bump into at the next conference.

All in all, the barbeque was a success. The weather was good, the food was good, and watching your coworkers attempt the limbo was great. It was also a great opportunity to mingle with people from the other laboratories. Of course we see them often at the university, but somehow it is very enjoyable to have everyone together at the same time in a relaxing social atmosphere. Now that our (for the moment still unofficial) Barbeque Committee has chalked up their second successful barbeque of the year, we hope that we've gotten the art of hosting barbeques down to a tee and can continue to host many more barbeques in the near future.

In December, LMS held an end of year party at Prof. Laloui's house. This jovial occasion was a great opportunity to reflect back on our year through all the ups and downs – mostly ups of course! However, at the end of the day although we had to say goodbye to some members of our family who have moved on to new challenges this year, we were also able to welcome new faces here at LMS. Our new recruits will quickly become integral parts to our team and experience their own exciting challenges as we all grow and learn together. The end of year party gave us all a chance to digest everything that had happened over the course of the year; of course it was also a great opportunity to eat some great food! This included some lovely hot wine, appetizers and tasty dinner. Afterwards, Dr. Alessio Ferrari and Jacopo Zannin teamed up with their guitars and got the whole group singing. Overall, the end of year party was a lovely way to finish of the year. Certainly, after a short break for the holidays, we all came back raring to go!

Statistics

Papers



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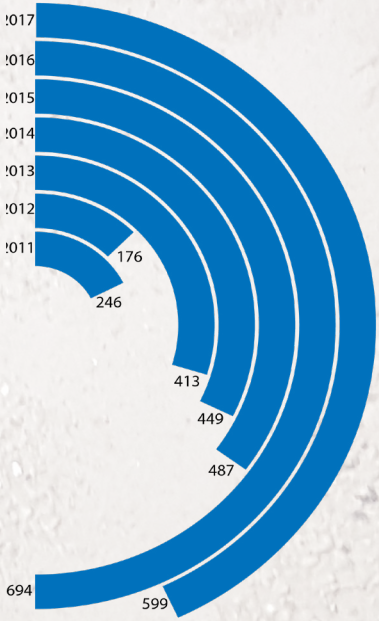
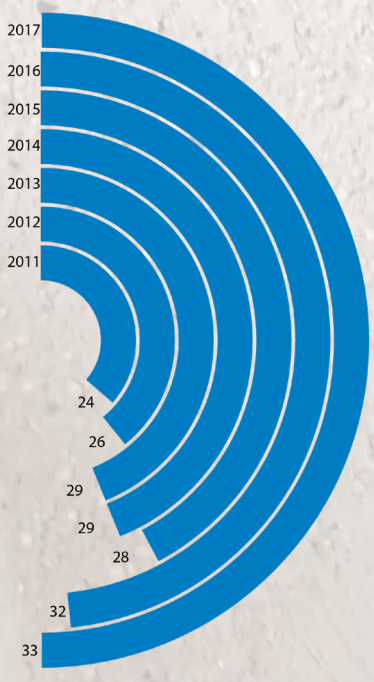
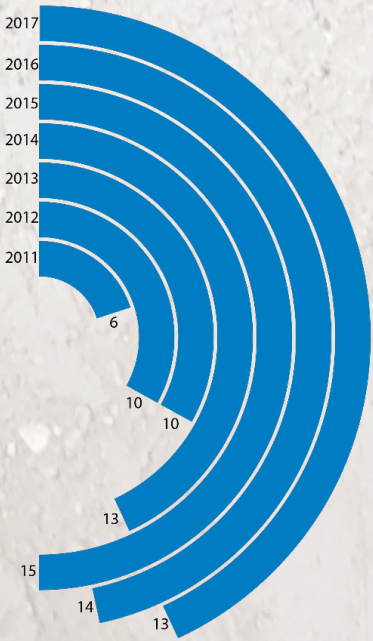


Staff



PhD Students



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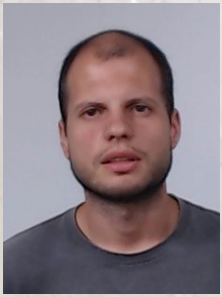

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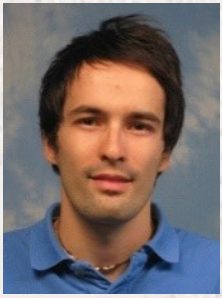

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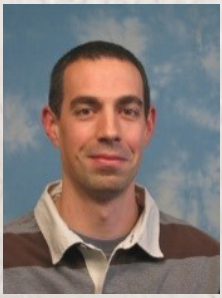

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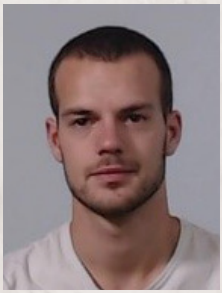

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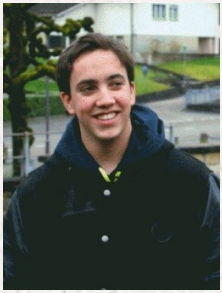

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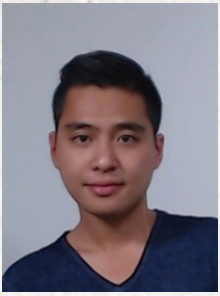

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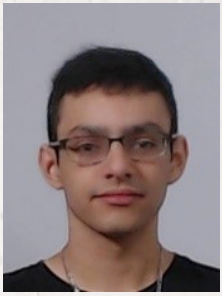

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Printing :

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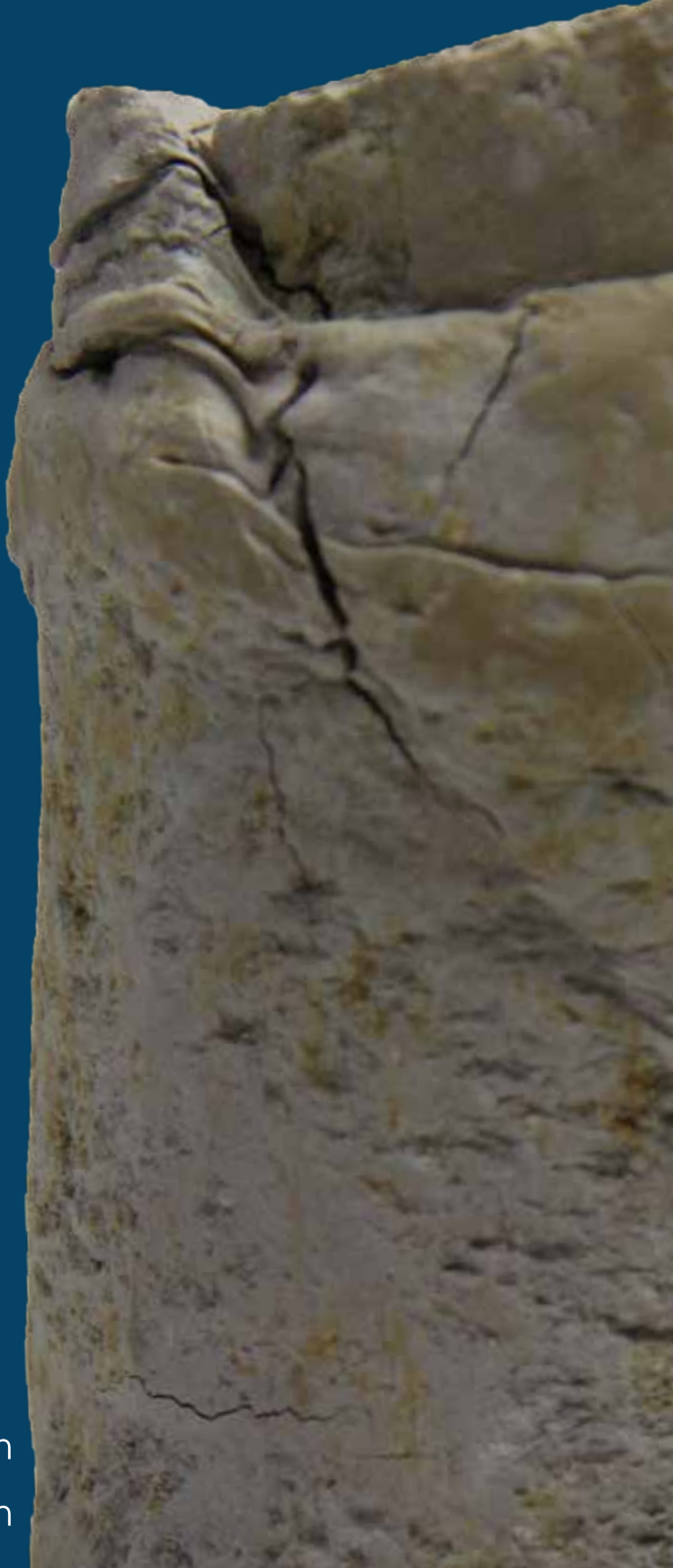

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