Comité Français de Mécanique des Roches

CFMR

Séance technique : retour sur l'ISRM 2024

Organisée par Muriel Gasc, Philippe Cosenza et Philippe Vaskou
Jeudi 19 octobre 2023 de 14h00 à 17h15

NB : Bien que les titres soient en anglais, la majorité des présentations seront en français

14 : 00 **Introduction à la séance : 15ème ISRM, Salzbourg 2023 - quelques chiffres**
Muriel Gasc, Philippe Cosenza et Philippe Vaskou

14 : 10 **Multi-scale analysis of a porous carbonate rock under triaxial conditions**
Catherine Doré-Ossipyan (Navier – LMS)

14 : 25 **Assessment of the creep behavior of siltstone for the Snowy 2.0 hydropower station using multistage uniaxial and triaxial creep tests**
*S. Abou Kheir (*Tractebel Engineering S.A*)*

14 : 40 **Development of a Post-mining multi-hazard assessment methodology**
H. Djizanne (Inéris)

14 : 55 **Mechanical origin of seismic repeaters and multiplets in the Garpenberg mine (Sweden)**
E. Lhoumaud (Géoressources)

15 : 10 **Self-sealing experiments with gas and water injection on Callovo-Oxfordian claystone under X-ray tomography**
M. Agboli (Géoressources)

15 : 25 ***10 min de questions aux orateurs puis pause 10 min***

15 : 45 **18 years of monitoring pore pressure evolution during and after excavation in the Callovo-Oxfordian claystone: the main insights**
G. Armand (Andra)

16 : 00 **Fluid injection influence on fracture propagation near an underground drift**
M. *Fallah Soltanabad. (ENPC)*

16 : 15 **Numerical modeling of cracking process in partially saturated porous media and application to rainfall-induced slope instability analysis**
M. Wang (Université de Lille)

16 : 30 **Numerical modelling of the swelling of clayey geomaterials by a multiscale approach**
H. Mhamdi Alaoui (HydrASA)

16 : 45 **Applicability of Artificial Neural Networks (ANN) for equilibrium state prediction in tunnel excavation**
A. Tristani (ENPC)

17 : 00 *15 min de questions aux orateurs puis discussion finale*

17 : 15 **Fin de la séance**

Multi-scale analysis of a porous carbonate rock under triaxial conditions

Doré-Ossipyan, Catherine[1,2]; *Sulem, Jean*[1]; *Bornert, Michel*[1]; *Dimanov, Alexandre*[2]; *Aimedieu, Patrick*[1]; *De Greef, Vincent*[2]
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One of the solutions being considered for reducing greenhouse gases is their capture and geological storage. Deep saline aquifers or depleted former gas reservoirs have large storage capacities, since sedimentary rocks account for more than 70% of the earth's surface. Carbonate rocks are thus considered excellent candidates due to their high porosity and permeability. For these applications, it is necessary to be able to understand their long-term evolution, as well as the effect of multiphysical solicitations on the mechanical and transport properties. However, the very large variability of heterogeneities induced by the diversity of sedimentation environments, as well as the complexity of geological processes, means that we do not fully understand their behavior and in particular the evolution of properties such as permeability, which is an essential parameter for the applications envisaged.
Experimental and field studies carried out in the last two decades on porous carbonates have shown that, under multiaxial loading conditions, they accommodate deformation by localizing it in planar zones a few grains thick. When they are associated with an intense porosity reduction, they form an obstacle to fluid flow, since the permeability can be reduced by up to several orders. Due to the complexity of the microstructure, the micromechanisms involved at different scales in band formation are not yet fully identified. These phenomena are studied experimentally on a carbonate rock with high porosity (38% on average), the Saint-Maximin limestone. An earlier study on 40mm diameter samples showed that their nucleation and propagation is controlled by the heterogeneity of porosity at that mesoscale. A triaxial device compatible with in situ X-ray tomography imaging allows us to observe the localization phenomenon more continuously and at a smaller scale (15 mm diameter samples). We describe the experimental method to understand the behavior of a rock with complex microstructure.

Assessment of the creep behavior of siltstone for the Snowy 2.0 hydropower station using multistage uniaxial and triaxial creep tests

Abou Kheir, Samer[1]; *Brogiato, Andrea*[1]; *Lambrughi, Angelo*[2]; *De Carli, Gabriele*[2]; *Frontini, Damiano*[2]; *Diederichs, Mark*[3]; *Ching, Ivan*[4]
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Multistage uniaxial and triaxial creep tests with durations up to four months were performed to investigate the time-dependent behavior of the siltstone rock formations into which the Snowy 2.0 hydropower station will be excavated. Short term experimental tests and stress numerical models were used to determine the stress levels applied during the creep tests and to assess the effect of creep on the short-term parameters of the siltstone. The samples were collected from boreholes at a depth of about 650-850 meters beneath the surface where the power station complex will be constructed.
The samples were extracted from the Ravine Beds Unit formation and the main lithology is composed of siltstones with interlaminated to interbedded sandstones. The relative percentage of siltstone/sandstone within the rock mass ranges from 80/20% to 50/50% and on average is 70/30%. The siltstone intact rock features a medium strength, a very stiff matrix, and a very low porosity.
The results of the triaxial creep tests were compared to the results of the uniaxial creep tests. Both show consistently negligible secondary creep deformations after full development of the primary stage and the impact of the confining pressure into the creep behavior and deformation amplitude was examined.

Development of a Post-mining multi-hazard assessment methodology

Djizanne, Hippolyte ; Al heib, Marwan; Gouzy, Aurélien ; Franck, Christian
Ineris

In France, the risk management is based on the development of tools for each category of hazard, the Risk Prevention Plans. Particularly, for poste-mine territories Mining Risk Prevention Plans (PPRM) is used. However, in the context of post-mining management, mining hazards may interact with other mining hazards, natural hazards, or/and technological hazards. Multi-hazard is a new concept allowing risk assessment in complex situations such mining legacy.
This paper aims to develop a methodology and a tool for a sustainable management of abandoned mining areas through the evaluation of the interactions between the main hazards identified around abandoned mines.
The methodology is based on two steps. For a given territory, the first step of the developed methodology is to identify the residual mining hazards, natural hazards and technological hazards. The second step consists in analyzing and discussing the different interactions between hazards: between mining hazards, mining hazards versus natural hazards and mining hazards versus technological hazards. In total, the interaction in-between 19 mining hazards, 21 natural hazards and 17 technological hazards were analyzed by experts. A scale of potential interaction has been suggested: no or low interaction, medium and high hazards interactions.
The paper outlines the approaches taken to assess multi-hazards. Interaction matrices and interaction loops are used to help analyse and visualize potential interactions between hazards.
The methodology was applied to one case study concerning abandoned coal mine (France) exposed to ground movement, fire (mine) and flooding (natural). Findings from this study will help assessing multi-hazards for managing the abandoned mines.

Mechanical origin of seismic repeaters and multiplets in the Garpenberg mine (Sweden)

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Seismic multiplets and repeaters (i.e. repeating seismic signals with highly similar waveforms) have been shown to represent the main part of the seismic events recorded in the deep mine of Garpenberg, in Sweden (Kinscher & al., 2020). Repeaters are commonly interpreted as evidences for the repeating rupture of the same rough asperities on a fault plane, loaded by aseismic creep in the surrounding areas (Chen & Lapusta 2009). Their presence implies that aseismic slip plays a role in the redistribution of stresses and in the triggering of seismicity.
We aim at identifying the mechanical origin of repeaters in the Garpenberg mine, and the role played by aseismic slip in the triggering of mine-induced seismicity. More precisely, we are testing the applicability of an asperity-based repeater model (Bourouis & Bernard 2007), by combining geophysical, geological and geotechnical in-situ data, and geomechanical numerical modeling.
Spatial comparison between the seismic events and the rock types in the mine show a correlation between the location of seismicity and the presence of talc-hosted dolomite volumes. Moreover, stresses changes induced by mine excavations, as deduced from an elasto-plastic numerical modelling, seem insufficient to trigger the measured seismicity, which supports the hypothesis of the presence of aseismic deformation.
A recent measurement campaign targeted one specific family of repeaters, that has been active over several years despite the huge stress changes induced by mining in their source area. Source mechanism inversion suggests the presence, in this zone, of one sub vertical fracture. Drillings were undertaken, and strain cells and one fiber optic were installed in this volume. We now aim at confronting the previous hypothesis to the field and identify the structure and/or lithology responsible of this local and persistent seismicity.

Self-sealing experiments with gas and water injection on Callovo-Oxfordian claystone under X-ray tomography

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Claystone is a clayey rock that has properties favorable for the storage of radioactive waste. The fractures generated during the excavation can self-seal due to the water circulation and restore the initial permeability of the claystone in the excavation damaged zone. In addition, the degradation of waste containers can produce gas which can have an imp act on the self-sealing process. In order to understand and characterize these phenomena, a series of self-sealing tests were performed on artificially fractured cylindrical samples of Callovo-Oxfordian claystone of Bure (Meuse/Haute-Marne, France) in a triaxial compression cell. During the test, water and gas (nitrogen) were injected successively in the fractured samples and both water and gas permeability were measured. The tests were carried out on cylindrical samples oriented in two directions, parallel and perpendicular to the bedding plane. The opening of the initial fracture is 0.4 mm. The cells body made of PEEK (i.e., a X-rays transparent polycarbonate), allows X-rays 3D scans during the tests at selected times (up to one month).
First self-sealing tests without gas injection showed that the water permeability decreases rapidly at the beginning and then stabilizes to 10-17-10-18 m2. Even after a one-month test run, the permeability is still far from the permeability of the undisturbed claystone (10-20-10-21 m2). The 3D scans allowed us to confirm the reduction of the crack volume. These first results are very promising and give confidence to the positive impact of the self-sealing process due to water circulation. When gas is injected during the self-sealing test, the water is removed from the fracture. The gas permeability also decreases and stabilizes to 10-16 to 10-17m2. Because of the desaturation of the fractured sample due to the gas circulation, the self-sealing process is slowed down and water permeability decreases more slowly.

18 years of monitoring pore pressure evolution during and after excavation in the Callovo-Oxfordian claystone: the main insights

ARMAND, Gilles; Plua, Carlos; Vu, Minh-Ngoc
Andra

Clay formations in their natural state exhibit very favorable confining conditions for the construction of a radioactive waste repository because they generally have a very low hydraulic conductivity, small molecular diffusion, and significant retention capacity for radionuclides. Nevertheless, one concern regarding the hydromechanical behavior around drifts in such claystone is the associated pore pressure field disturbance during and after excavation works. At the short-term, the very low permeability leads to a “quasi-undrained” condition, meaning that the stress change due to front advancement will create volumetric strains leading to an increase or decrease of pore pressure. If the effective stresses reach the failure criterion, the induced damage around these excavations might change the favorable properties of such formations.
Since 2004, Andra has been developing the Meuse/Haute-Marne underground research laboratory's network of galleries in the Callovo-Oxfordian claystone and testing different excavation methods. An important piezometric measurement network has been set up to monitor the evolution of pore pressures during and after excavations. It allows obtaining data at different scales, from the size of a borehole to galleries with a diameter of 9 m excavated in different directions with respect to the major horizontal stress, as well as with different excavation methods. The article presents the data acquired over a large number of structures and a long period. These observations highlight the large distances of influence where pore pressure change are observed, the impact of the in situ stress state and velocity rate of excavation on the pore pressure. The measurements give an important insight into the anisotropy of the hydro mechanical behavior of the Callovo-Oxfordian claystone and the relationship between pore pressure and excavation induced fractures zone

Fluid injection influence on fracture propagation near an underground drift

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The aim of this work is to investigate the propagation of fractures around a gallery under fluid injection. First, some concepts about the modeling of fracture propagation in a porous medium are recalled. Then, 2D simulations of a fractured medium problem are performed using the finite element code Disroc. These simulations take into account the in-situ stress and material anisotropy for a variety of fracture geometries around a gallery, which represents typical cases of interest with respect to the excavation damage zone. The impact of hydro-mechanical couplings under the effect of fluid pressurization is assessed by considering three different scenarios. For the first one, the pressure is assumed to act only in the fractures and in the gallery and there is no pressure in the rock mass (short time scale). For the second scenario, the pressure field is assumed stationary within the simulated domain (long time scale). Finally, the last scenario considers the more realistic case of a transient diffusion of the fluid within the fracture and rock mass, coupled with the mechanical calculation of fracture propagation. An example of application is illustrated that considers the heterogeneity of the different geological layers around the gallery. And some semi-analytical estimates of fracture propagations are proposed. Finally, conclusions are drawn and perspectives are mentioned for future studies.

Applicability of Artificial Neural Networks (ANN) for equilibrium state prediction in tunnel excavation.

Tristani, Alec; Guayacán-Carrillo, Lina-María; Sulem, Jean
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Preliminary stage of tunnels design is in general simplified by means of a plane-strain approach. However, when the ground exhibits large deformation and/or when the support is very stiff and installed close to the tunnel face, 3D numerical simulations are required. Such simulations can represent a rather high computational effort and cost. As an alternative, emergent artificial intelligence techniques begin to be the more and more used.
In this paper, we explore the applicability and the accuracy of ANN models for analyzing the ground-support interaction and evaluate the ground displacement and support stress at equilibrium state. Using a synthetic data set obtained by previous 3D numerical simulations (De La Fuente M. et al. 2019. Rock Mech. Rock Eng. 52(7):2361-2376), different ANN models are trained and a hyper-parameter analysis is performed. In this first approach, Mohr–Coulomb elastoplastic model to describe the constitutive behavior of the ground is used and a linear elastic model is assumed for the support. This analysis takes into account a large range of ground conditions, support characteristics, distances of support/lining installation from the tunnel face and variations on tunnel radius. Moreover, the calculations are performed for some representative values of the stability number N. This notion is related to the development of a plastic zone near the tunnel face (Panet M. and Sulem J. 2022. Springer).
The results show that ANN models perform well with the small dataset used in this study and can be considered a useful alternative. Last one can be used as quick and reliable estimation tools, which is of prime interest for an application in the engineering field. This analysis could be then extended by taking into account the time-dependent behavior of the ground.

Numerical modeling of cracking process in partially saturated porous media and application to rainfall-induced slope instability analysis

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Rainfall-induced landslides are one of the major natural catastrophes causing heavy economic and human loses. Among others, time-dependent deformation and cracking are two important mechanisms controlling the onset and evolution of landslides. These two processes are enhanced by rainfall inducing weakening effects of rock mechanical strength. In this study, a new numerical model is proposed by considering creep deformation, crack initiation and propagation and hydromechanical coupling. The basic mechanical behavior is rock is described by an elastic-viscoplastic model. And the key mechanical parameters are affected by water saturation degree in unsaturated zone and fluid pressure in saturated zone. For the description of cracking process, a new phase-field model is developed for porous media with hydromechanical coupling process. In particular, a new evolution law is proposed by considering both tensile and shear cracks as well as mixed-mode. Based on relevant results issued from micro-mechanical analysis, the effects of pore pressure and capillary pressure on cracking evolution are properly taken into account. The crack growth is also influenced by the viscoplastic deformation of rock. Inversely, the creep strain evolution is enhanced by the growth of cracks while the elastic properties are weakened. Moreover, the intrinsic permeability of rock is also modified by the induced cracks. The proposed model is implemented in the framework of finite element method. It is applied to the analysis of rainfall-induced landslides. Typical cases are considered with different rainfall scenarios. Different deformation and cracking patterns are identified and analyzed. Furthermore, based on a sensitivity study, the roles of key parameters affecting the instability are discussed. Finally, a real high slope is considered. Numerical results are compared with field measurements in terms of displacement monitoring, with a good agreement found.

Numerical modelling of the swelling of clayey geomaterials by a multiscale approach.

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Swelling of clayey rocks finds it origin at the nanoscale of the clay layer. However, deformations are noticeable at the macroscopic scale. Swelling of clay minerals is governed by two different phenomena: crystalline swelling and osmotic swelling. The first type of swelling occurs when the water molecules access the interlayer space between two 2:1 clay sheets following an order of one water layers i.e. 1W to three water layers 3W; whereas 4W hydration state stands for the interlayer osmotic swelling regime. Osmotic swelling depends mainly on ionic parameters (valence, concentration…) of the inter-particle solution or of the exchangeable cations in the interlayer space. In this work, we propose a multiscale numerical model that considers both the crystalline and osmotic swelling. To this end, we itemized the different interactions that occurs in both the interlayer space with respect to the disjoining pressure and the interparticular pores considering the osmotic pressure through modified Poisson-Boltzmann equation. The overall model is based on the upscaling of the constitutive law from the nanoscopic scale to the macroscopic scale by adding all the different interactions that appears while upscaling. In addition, the general model developed in this paper can be considered as a new definition of the effective stress governing the chemo-hydro-mechanical behavior of clayey rocks. The numerical model is then implemented in a FEM software for hydro-mechanical coupling models. The validation of our model is conducted by reproducing different swelling tests existing in the literature e.g. the constant-volume swelling test which its modeling can be easily conducted. The initial capillary pressure is calculated considering the initial saturation degree and a new sorption isotherm based on the pore distribution. The first simulation results showed good accuracy between the experimental results and the numerical modeling with comparison to classical models (general elasticity with Van Genuchten sorption isotherm).