International Society for Rock Mechanics and Rock Engineering

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Probabilistic Analysis of a Rock Salt Cavern with Application to Energy Storage Systems

Dr. Elham Mahmoudi (Deltares, The Netherlands)

Size effects on strength and deformability of intact and artificially-jointed hard rock samples

Dr. Manuel A. González Fernández (University of Vigo, Spain)

Using Synthetic Rock Mass and Discrete Fracture Network approaches to study rock mass strength properties

Dr. Etienne Lavoine (Itasca Consultants S.A.S., France)

A hybrid approach for adequate rock support design in hard rock tunnelling

Dr. Jorge Terron-Almenara (Norwegian University of Science and Technology, NTNU, Norway)

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Probabilistic Analysis of a Rock Salt Cavern with Application to Energy Storage Systems

Abstract

Solution-mined caverns in rock salt formations offer an ideal solution for underground renewable energy storage, such as compressed air and hydrogen. These caverns face varying loading conditions during construction and operation, making it essential to understand the mechanical response of rock salt over time to ensure stability and serviceability. Robust constitutive laws are required to accurately describe rock salt behavior across different time scales. An elastic-viscoplastic-creep model is used to predict the stress-strain relationship around the cavern during construction and cyclic operations. Numerical simulations of a typical salt cavern's excavation and cyclic loading are performed. The mechanical response's sensitivity to different variables is analyzed using the elementary effect global sensitivity method. To evaluate the failure probability efficiently, a subset simulation methodology is implemented, validated against a Monte Carlo-based probabilistic analysis. To further reduce computational costs, the original finite element model is replaced with a surrogate model. Lastly, a reliability-based analysis identifies the minimum internal pressure needed to maintain cavern safety, ensuring a reliable and efficient underground energy storage solution.

Speaker

Dr. **Elham Mahmoudi** is a researcher and consultant at Deltares, The Netherlands, specializing in numerical simulation of geotechnical problems, reliability-based analysis, and machine learning. She earned her master's degree in 2012 from IKIU, Iran, focusing on numerical modeling of underground pipelines across active faults. She then pursued a doctoral program in Germany under Prof. Tom Schanz, where she completed her thesis on the probabilistic analysis of underground energy repositories with distinction. In 2016, she joined the Chair of Computing in Engineering as a senior researcher, working on system adaptation and parameter identification in mechanized tunneling and subsurface modeling. In 2023, she became a risk and reliability expert in geotechnics at Deltares, focusing on reliability-based design for flood defense structures and railway embankments.

Size effects on strength and deformability of intact and artificially-jointed hard rock samples

Abstract

The present work encompasses three research lines, each exploring different aspects of rock mechanics and size effects in triaxial testing. The first line investigates the anisotropic mechanical behavior of slates, focusing on the influence of cleavage plane orientations on deformability and strength. Experimental results clearly demonstrate anisotropy in both properties, with failure predominantly occurring along the cleavage planes. The second line examines the size effects on the triaxial compressive strength of granite samples. Triaxial tests on granitic specimens reveal trends in peak and residual strength as a function of sample size with ascending descending trends. Also these tests indicate that the influence of size becomes less pronounced at higher confining pressures. The third line presents an extensive experimental study on artificially jointed hard rock, highlighting the dependency of peak strength on joint sets and the moderate size effects observed. Elastic parameters, including Poisson's ratio, show minimal dependence on sample size and confinement, providing new insights into the mechanical behavior of jointed rocks.

Speaker

Dr. **Manuel A. González Fernández** graduated as a mining engineer in 2012 from the School of Mining Engineering at the University of Vigo (Spain). Over the years, he has gained experience in various industries. He worked in the metallurgical sector as the head of the R&D department, in the food industry as a production manager, and in construction as a project manager during the development of a photovoltaic farm. In 2019, he joined the University of Vigo as a researcher at the Department of Natural Resources and Environmental Engineering. In 2024 he obtained a PhD in rock mechanics, with a PhD thesis focusing on the scale effects on hard rocks and the study of transversely isotropic rocks.

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Using Synthetic Rock Mass and Discrete Fracture Network approaches to study rock mass strength properties

Abstract

In most rock masses, the ubiquitous presence of natural fractures reduces the deformation modulus and strength compared to the properties of intact rock. The widely used rock classification systems, such as the Geological Strength Index (GSI), take this effect into account only qualitatively. Their predictive capacity is very limited especially when extrapolation to scale and anisotropy aspects are important. A description of the fracture network relevant to strength includes the fracture density, the preferential orientation sets but also the multiscale organization of fracture sizes, generally described by power-law models and scaling exponents. All these parameters are keys to quantify rock mass properties, as well as their scaling behaviour, in terms of connectivity, flow and transport capacity and mechanical modulus properties.

The presented research proposes the use of the Discrete Fracture Network (DFN) approach combined with the Synthetic Rock Mass (SRM) approach for modelling the fractured rock mass. Numerous DFN-SRM samples are generated in the software 3DEC® on which UCS and tensile mechanical tests are performed. In these numerical simulations, cracks appear in the rock surrounding the fractures as the deformation increases until peak stress is reached. Based on indicators quantifying the evolution of damage between the initial and the peak stress state, we try to relate the ratio between the strength of the intact rock and the strength of the effective rock to the geometric and mechanical variables characteristic of fracture networks.

Speaker

Etienne Lavoine is an engineer specialized in numerical modelling applied to geomechanics and hydrogeology, working for the company ITASCA. His research experience has led him to work on the modelling of fractured media and the characterization of their hydraulic and mechanical properties. His current work as a consultant focuses on various civil engineering projects, including the study of the long-term behavior of nuclear waste underground repositories.

A hybrid approach for adequate rock support design in hard rock tunnelling

Abstract

Rock mass classification systems and empirical methods have been used for several decades for rock mass description, classification, and tunnel support design. In Norway, the presence of hard rock conditions has also favored the use of these methodologies, to the extent that the local guidelines for tunnel support design are merely based on the plain use of classification methods. In general, such methodology has worked rather well, with tunnel projects completed successfully. However, there are also a number of sites in which deviations, tunnel failures, and/or construction over-costs have been experienced when encountering poor ground conditions. With the retrospective analysis of more than 100 case studies in poor ground conditions, the author has identified rock mass properties and ground conditions that do indeed affect to the ground behavior and indeed, to the design of tunnel support. The author has similarly derived a procedure called “hybrid approach” which consists of the combination of several design methodologies to overcome the traditional challenges of classification methods. With this in mind, the author will give a presentation today about the analyses, the main findings and conclusions, that helped to the conceptualization of such hybrid approach.

Speaker

Dr. **Jorge Terron** holds a MSc in Geology by the UGR (University of Granada) 2008, and has specialized in rock engineering, tunnelling, and underground works with a Master program organized by UNED (Universidad Nacional a Distancia, Spain) and AETOS (Spanish Tunnelling Society) in 2009. Since 2010, Jorge has worked in consultancy as engineering geologist and been mostly involved in tunnelling projects in difficult ground conditions. Since 2020, he is conducting a PhD with the topic “Tunnel rock support design in poor ground conditions”, in which the current, traditional design practice used in hard rock tunnelling (mostly empirical) is investigated. The aim is to find scientific background as to develop new design recommendations or procedures which help in deriving more optimal support designs in poor ground conditions.