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ROCK MECHANICS AND ITS APPLICATIONS IN CIVIL, MINING, AND PETROLEUM ENGINEERING

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Preface

This special publication contains 24 technical papers which cover recent advances in rock mechanics and its applications. The extended abstract of an invited keynote presentation which served as the 2014 Jun Sun Lecture is also included in this publication.

Each paper published in this ASCE Geotechnical Special Publication (GSP) was evaluated by at least two reviewers including the editors. The authors of the accepted papers have addressed all the reviewers' comments to the satisfaction of the editors. All published papers are eligible for discussion in the Journal of Geotechnical and Geoevironmental Engineering and are also eligible for ASCE awards.

The papers included in this publication were presented during the GeoShanghai 2014 International Conference held in Shanghai, China, May 26-28, 2014. This conference was hosted by Tongji University, the Chinese Institution of Soil Mechanics and Geotechnical Engineering, the Chinese Society for Rock Mechanics and Engineering and the Shanghai Society of Civil Engineering in cooperation with ASCE Geo-Institute, the International Society for Soil Mechanics and Geotechnical Engineering, the International Association of Chinese Infrastructure Professionals, the Deep Foundations Institute in the USA, the Alaska University Transportation Center (USA), University of Edinburgh (UK), Ruhr University Bochum (Germany), University of Cambridge (UK), Ecole des Ponts Paristech (France), Virginia Polytechnic Institute and State University (USA), the Shanghai Society of Theoretical and Applied Mechanics, Nagoya Institute of Technology (Japan), University of Arizona (USA), the Transportation Research Board (TRB) (USA), University of Kansas (USA), Georgia Institute of Technology (USA), Vienna University of Natural Resources and Applied Life Sciences (Austria), and University of Tennessee (USA).

The GeoShangai 2014 International Conference was chaired by Professor Wenqi Ding and co-chaired by Professor Lianyang Zhang.

Finally, we would like to acknowledge the assistance of Donna Dickert of ASCE and Robert Schweinfurth of ASCE Geo-Institute (G-I). We also give special thanks to the following individuals who provided the technical review for the papers submitted to the conference:

Antonio Bobet
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Zhen Liu
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Louis Wong
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Zhiduo Zhu

For any reviewers whose names were inadvertently missed, we offer our sincere apologies.

Editors:

Lianyang Zhang, University of Arizona

Louis N. Y. Wong, Nanyang Technological University

January 18, 2014

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Keynote Presentation—Jun Sun Lecture

Theoretical and Experimental Study of Rock Behavior

Applications of Rock Mechanics and Case Studies

Research in Energy Related Rock Mechanics

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EXTENDED ABSTRACT

Initial Comment

Rather than submitting the complete paper at this time, an extended abstract is provided. The reason for doing so is that some relevant research is going on, which should be included in the final paper. This paper will be made available to Congress participants both in form of a preprint and electronically.

Context

Rock mechanics and energy production have always been strongly related. One can make the argument that rock mechanics as a separate domain of geotechnical engineering was established with the failure of Malpasset Dam in 1959. Implicitly rock mechanics played an "energy role" much before that in the context of constructing pressure tunnels for hydroelectric plants and in coal mining. Energy resource extraction is now dominant in rock mechanics or geomechanics, in general, particularly related to hydrocarbon resources but including also direct heat extraction through Engineered Geothermal Systems (EGS, formerly called Hot Dry Rock). Also related to rock mechanics and energy is nuclear based energy production. Because of the very high safety requirements, this has been a driver of rock mechanics research and application for powerplant foundations and, particularly, with regard to nuclear waste storage.

Research

The problem areas involving energy and rock mechanics have been addressed in research conducted by the author and his students and collaborators. Highlights of this work will be presented in the sequence: Shale as intact material, fracture geometry and fracture flow, fracture mechanics, and EGS well construction. All this is representative of the author's interests, namely, conducting experimental work and based on this, develop predictive models and also looking into practical applications ranging from engineering design and to construction.

It has to be emphasized that what will be described in the paper and in this abstract is what was done by the author and his co-workers. Given the extent of energy related rock mechanics, it cannot be a general review of the state of the art.

Shale as Intact Material

Tunnels in many shales are affected by swelling and creep of the material. Experiments have shown that shearing and swelling are interrelated. It is particularly appropriate to discuss such experiments in the context of this keynote lecture since Professor Sun (Sun, 1984) was the first to recognize this interrelationship. Based on these experiments, material models were developed and incorporated in numerical analyses for deep lying nuclear waste storage tunnels. – Transitioning from a purely intact material to one that considers some structural effects related to bedding planes is the development of the combined anisotropic Matsuoka-Nakai-Coulomb model for transversely isotropic material. Comparisons of model results with those of true and standard triaxial tests are very satisfactory.

Fractured Rock

Fracture geometry and fracture mechanics, although discussed separately below, have been looked at as an entity by this author. The so-called persistence problem, i.e. the fact that fractures or joints are usually interrupted by intact rock bridges requires that the geometry of fracture systems is considered together with the mechanical fracturing of the intact rock bridges.

Fracture Geometry and Flow Through Fractured Systems

Fracture systems are characterized by fracture orientation, - spacing, - size and - shape. Extensive work has been done to obtain information on the geometry from boreholes and outcrops on the one hand, and incorporating this information in stochastic fracture pattern models on the other hand. Given the uncertainties involved statistical and probabilistic approaches have been developed to obtain the information on intensity, - size and – shapes, and to create the resulting stochastic models. Both efforts will be discussed in detail. The stochastic fracture pattern model, GEOFRAC has been recently extended to a three-dimensional fracture flow model that can be used for any application involving fluid flow through fracture networks and that can also model heat extraction for use with EGS.

Fracture Mechanics

As mentioned above, this work started from the necessity to better represent the fracturing of intact rock bridges. Others, most importantly Lajtai (1969), established that rock bridge fracturing is not only through shearing but through tensile fracturing, combined tensile and shear fracturing or shear fracturing depending on the stress level. Initial analytical modeling at MIT showed that a much better understanding of the mechanics was necessary. Hence, the process of fracture initiation, - propagation and - coalescence was systematically investigated in experiments on the model material gypsum, on marble and on granite. Sophisticated experimentation including high-speed camera observations made it possible to identify the details of the fracture process. Very interestingly, this work made it also possible to see process zone development and to investigate this aspect in detail, i.e. the underlying microcracking. – The experimental information was and is used to develop the predictive model, FROCK, which, incorporated in a boundary element model, showed satisfactory coincidence of numerical and experimental results. – While all this work was done to gain fundamental understanding and provide satisfactory predictive models, most recent work is now more narrowly related to energy: The fracture process in shale including the influence of bedding is being investigated and modeled. Very importantly, laboratory experiments and analytical models to better understand hydraulic fracturing are underway in the context of both tight shale and EGS.

EGS Well Construction

Drilling wells is the major cost and time factor for petroleum and gas extraction but also for EGS. This not only requires technologies that can speed up and reduce the cost but methodologies for representative cost and time estimation. Such methodologies have to represent the fact that much of what a well will encounter is uncertain, i.e. the cost and time estimates will be in form of distributions.

Using preceding work on tunnel cost and time estimation under uncertain conditions, it was possible to develop a tool to estimate well cost and time under uncertainty. Specifically geologic uncertainties (rock strength and abrasivity), temperature variation, trouble events (casing failure, stuck drill pipe, “fishing”), cementing - and equipment cost variation can be incorporated. The result is not only an eminently practical tool for decision making but it also allows researchers to determine which new drilling technologies would be most beneficial.

Conclusions

This keynote paper will describe experimental and theoretical research in rock mechanics conducted over many years by the author and his collaborators. The emphasis is, therefore, on fractured rock characterization and performance, behavior of shale, as well as on design and construction in rock. All this is of generic interest but has been and is related to many issues of energy production. The author hopes, therefore, to contribute a bit to the understanding of rock mechanics and rock engineering, in general, and to the increasingly important energy issues.