ARMA e-NEWSLETTER FALL 2012

Volume 11, Issue 3
Fall 2012

Inside this issue:

ARMA E-NEWSLETTER

Edited and published by
ARMA PUBLICATIONS COMMITTEE

Bezalel Haimson
Chairman

Assistant Editors
Peter Smeallie
ARMA

Jim Roberts
ARMA

Layout Designer
Wendy DiBenedetto

New Frontiers and Challenges in Reservoir Geomechanics

Submitted by Ahmad Ghassemi, Texas A&M University and Jean-Claude Roegiers, University of Oklahoma

Rock mechanics continues to play an important role in energy resources development and sustainability. In many parts of the world, important potential petroleum resources occur in unconventional shale formations that are characterized by low permeability and high heterogeneity, or in deep-water sandstone reservoirs with complex geological settings subjected to high temperatures (>150° C) and pressures (>69 MPa). In addition, the majority of high-grade geothermal resources exist in low permeability naturally fractured rock systems in diverse tectonic settings with potential for induced seismicity. Harvesting these renewable resources is predicated on the ability to "engineer" and/or create a reservoir that can safely operate for a life expectancy of 20-25 years. This note highlights some pertinent geomechanical issues in each of these areas.

Shale Reservoirs

Unconventional petroleum reservoirs tend to have extremely low permeability (of the order of nanoDarcys or nD) and possess heterogeneities that pose challenges to economic energy production. Fracture conductivities of 10 mD-ft (milliDarcys-ft) or higher appear to be necessary for economic gas production. This is often achieved by multiple hydraulic fracturing treatments in order to generate a fracture network. But such stimulations are often poorly predictable, in part because of the resulting complex fracture geometry that arises from pertinent rock mass textural characteristics and pre-existing in-situ stress conditions. This complexity not only impacts permeability enhancement but also the containment of the stimulated volume within the zone of interest (with significant environmental consequences). At times, simple variations in depth interval appear to yield completely different fracturing styles resulting in different stimulation outcome and containment responses. These phenomena are often attributed to lack of in-situ stress contrast, or rock brittleness, shear reactivation of mineralized fractures, and textural heterogeneity. Therefore, establishing the role of rock mechanical parameters on the nature of fracturing is essential to optimize production.

Improved numerical modeling strategies are needed to account for fracture complexity related to rock texture and fabric. Fracture re-orientation and steering models developed to date are unable to account for rock heterogeneity. Thus, analyses using models that more realistically capture the rock rheological characteristics are needed. In addition, stress-dependent permeability models are necessary to better assess the stimulated rock volume and its dynamics with production. Finally, sustaining the conductivity of generated fracture networks requires a better understanding of proppant pack diagenesis while considering rock and fluid interactions.

Deep Water

Deep water high-temperature and high-pressure reservoirs are usually characterized by low permeability and high effective stress changes during production; such changes pose new challenges and magnify previously encountered rock mechanics related problems. For example, optimum well design, well operation issues such as casing deformation or sand production, and hydraulic fracturing activities must rely on à priori knowledge of the state of stress and of its evolution over the field's production life. The latter is a function of thermo-chemo-poro-mechanical processes that are set in motion by mass and heat flows due to drilling/stimulation/production. Therefore, coupled analyses and modeling -- where the interactions among transport phenomena, rock stress and deformation are taken into account -- are needed to assist in drilling, completions and production design. But, more importantly new rock properties need to be measured to satisfy the required input data. Whereas two parameters suffice in elasticity, poroelastic and thermo-poroelastic treatments need five and nine rock parameters, respectively. And even more constants need to be determined under simulated downhole conditions if the chemical coupling becomes important. Recent field experience has proven the importance of the mud temperature in affecting the stability of deep-seated boreholes. In addition, classical concepts such as effective stress need be revisited in view of very high pore fluid pressure and variable fluid chemistry (e.g., while drilling through shale formation) .

- *Continued on Page 2* -

TECH Note

New Frontiers and Challenges in Reservoir Geomechanics (continued)

Geothermal Systems

Hot rocks and geofluids can be an abundant source of renewable energy in the form of heat or electricity. A total of 24 countries now generate electricity from geothermal resources. The total installed capacity is 10,898 MW which corresponds to approximately 67,246 GWh of electricity. Most commercial geothermal systems are of the hydrothermal type. These systems have sufficient permeability and reservoir fluids, so that large amounts of hot water and steam are extracted from pores and fractures. But such hydrothermal systems constitute only a small fraction of the resources as most geothermal systems are either deficient in water or permeability, or both -- the so-called "hot dry rock." The production of geothermal energy from these generally dry and low permeability reservoirs can be achieved by "engineering" fracture networks consisting of man-made and enhanced pre-existing fractures (joints, faults). This is often referred to as enhanced or engineered geothermal systems (EGS).

An important step towards removing technical and economical impediments to EGS development is minimizing uncertainties in reservoir structure and dynamics. This effort must rely on reservoir geomechanics principles conditioned to geothermal settings. Therefore, rock mechanics/geomechanics experiments, modeling, and analysis dealing with fluid/rock interactions constitute an integral part of a comprehensive approach to geothermal reservoir characterization and development. The stress state in the reservoir and its variation with time is of fundamental importance to many aspects of geothermal energy development such as borehole instability, stimulation, production, and safety. Data such as intact rock and natural fracture mechanical properties and their dependence on coupled processes are needed for reservoir modeling and analysis; this will enhance energy recovery by sustaining flow into the production well while minimizing hydraulic and thermal drawdown. Coupled constitutive equations for rocks need to be evaluated and chemo-mechanical relations that address the multi-scale nature of the processes should be developed for intact rock and fracture permeability. Strain localization (within intact rock, fractures, and faults), and its interactions with fluid flow and heat transport is manifold and complex; understanding this interaction and its role in reservoir development and induced seismicity is critical to the success of EGS. Therefore, the relation between size of micro-seismic events and its distribution within the reservoir during injection/extraction operations must be further studied in order to develop a relationship between seismic energy release, injected fluid volume and pressure, and geological setting. It is worth noting that very similar problems arise in CO_2 storage and sequestration using aquifers and depleted petroleum reservoirs.

In the past, rock mechanics practitioners employed by resource development companies dealt mainly with homogeneous "blanket" reservoirs that required, at best, approximate input data in order to consider their economic feasibility. Those times are over, and more challenging formations have now become the rule rather than the exception. However, such challenges should excite our new generation of rock engineers.

ARMA Symposium Report

The 46th US Rock Mechanics/Geomechanics Symposium

Submitted by Antonio Bobet, Purdue University & Symposium Chair

The 46th US Rock Mechanics/Geomechanics Symposium took place in Chicago on 22-28 June 2012, at the Westin Michigan Avenue Hotel. The focus of the Symposium was on new and exciting advances in rock mechanics and geomechanics, and it encompassed all aspects of rock mechanics, rock engineering and geomechanics. It attracted more than 600 participants from more than 30 different countries.

The symposium offered many opportunities to learn about recent advances in rock mechanics and geomechanics and share new knowledge and new methodologies. The meeting started with two excellent workshops. The first one, "2nd Unconventional Resources Geomechanics Workshop: Geomechanics Solutions for Environmental and Technical Challenges in Unconventional Resources," was organized by Azra Tutuncu and sponsored by Unconventional Natural Gas and Oil Institute (UNGI) and ARMA. It brought together more than 70 national and international researchers from the energy industry, academia and federal and state government organizations to explore technical and environmental challenges and to showcase the findings from ongoing field studies on unconventional reservoirs. (Editor's note: A more detailed report on the workshop follows this article.) The second workshop, "1st ISRM-ARMA Workshop on Petroleum Geomechanics Testing," was organized by Tony Addis, Russ Ewy, Axel Makurat and Maurice Dusseault and was sponsored by ISRM and ARMA. More than 100 participants discussed how to efficiently obtain quality rock properties relevant to field development planning and for design issues.

The symposium comprised 44 technical sessions and two poster sessions, with a total of more than 350 papers. The symposium has become, following a growing pattern from past events, multinational, with just over 50% of the papers from countries outside the US.

All papers were peer reviewed, and a special issue of *Rock Mechanics and Rock Engineering Journal* will include a representative sample of the contributions made at the symposium. The presentations at the meeting were loosely grouped into four tracks: petroleum, mining, civil, and interdisciplinary. It is interesting to note that the majority of the sessions were truly multidisciplinary, with presentations and participation of professionals from different industries. This follows a trend observed in the last ARMA symposia where the problems, and many times the approaches taken and the solutions proposed, cut across disciplines. The range of topics covered was very broad, including "classical problems" such as rock mass characterization or stability and support of caverns and tunnels, to name a few, to more recent challenges such as carbon sequestration and geothermal energy. Another trend is the greater involvement of rock mechanics/geomechanics in addressing new societal demands for water, energy, and sustainability. The search for new sources of energy is turning towards geothermal energy and unconventional resources, where mechanics, temperature, fluid flow, and chemistry issues all fall into the realm of our profession.

The symposium also included five plenary lectures. The lectures were intended to cover topics from theory and fundamentals to applications, from micro to planetary scales, thus mirroring the great diversity in rock mechanics/geomechanics. Fundamental and theoretical issues were addressed by Paul Young in his lecture, "Rock Fracture Dynamics and Induced Seismicity," where he shared his experience at the University of Toronto on experimental rock deformation and geophysical imaging, and by John Rudnicki with his lecture, "Formation and Extension of Localized Compaction in Porous Sandstones," where he proposed theoretical considerations for the formation and extension of compaction bands as observed in the laboratory and in the field.

Applied rock mechanics was the focus of the lectures by Luis Alfaro, "The Panama Canal Expansion," where he described the project for the widening of the Panama Canal -- one of the most iconic projects in geomechanics, and by Paul La Pointe in his lecture, "It's the Cracks that Matter: DFN Modeling of Everything Rock," an exploration of the wide range of applications of discrete fracture network approaches and synthetic rock mass models.

- Continued on Page 4 -

ARMA Symposium Report

46th US Rock Mechanics/Geomechanics Symposium (continued)

Jay Melosh, the MTS lecturer, took rock mechanics to planetary scale with his lecture, "Dynamic Fragmentation, Asteroid Impacts and Meteorites from Mars," where he discussed the formation of meteorite craters and the possibility of transfer of life across planets. (Editor's note: These lectures and more can be found on the ARMA website at www.armarocks.org under the "resources" page.)

Two short courses complemented the symposium: "Floor Stability in Underground Coal Mines: The Illinois Basin Experience," given by Murali Gadde, and "Monitoring and Modelling Seismic Rock Mass Response to Mining," taught by Richard Lynch from the Institute of Mine Seismology. Three technical tours were available: Urban Underground Limestone Mine, Fermilab, and Chicago's Tunnel and Reservoir Project (TARP).

The success of the 46th ARMA Symposium was the result of the efforts and dedication of a number of individuals. They include the organizing committee chaired by Antonio Bobet and members Steve Brandon, Bill Dershowitz, Chuck Dowding, Russ Ewy, Murali Gadde, Giovanni Grasselli, Bezalel Haimson, Haiying Huang, Joe Labuz and Peter Smeallie. Peter A. Dickson, MWH Global, was instrumental in putting together the technical tours, and Kathryn Greco, Hill Montague, Katharine Smeallie, and Wayne Gibson provided the technical support for the symposium. The sponsors, Agapito Associates, Inc., Chevron, ConocoPhillips, Golder Associates, Inc., Haley & Aldrich, Inc., Itasca International Inc., MTS Systems Corp., MWH Global, and TerraTek contributed to the economic success of the symposium.

The 46th Symposium reflects the continuous growth of the US Rock Mechanics/Geomechanics symposia over the past few years. While we look back at its success as a testimony of the increasing interest in rock mechanics/geomechanics in the US and around the world, we also need to look forward for the new and exciting things to come in June 2013, in San Francisco, with the 47th US Rock Mechanics/Geomechanics Symposium.

Workshop Report

ARMA Symposium Workshop Report

Submitted by Azra Tutuncu, Colorado School of Mines

Topic: Geomechanics Helps in Solving Technical, Environmental and Economic Challenges in Shale Reservoir Development and Production

The 2nd Unconventional Reservoir Geomechanics Workshop, held in conjunction with ARMA Symposium in Chicago, 2012, was attended by nearly 80 domestic and international geomechanics specialists. The speakers covered a wide range of technical, environmental and economic challenges in the development of shale reservoirs, with an emphasis on how geomechanics contribute to solving many of these challenges. Some of the presentations at the workshop are highlighted as follows:

Brian Crawford (ExxonMobil) introduced preliminary results of a database for evaluation of shale anisotropy using discontinuous single plane of weakness and continuously variable strength models. Marte Gutierrez (Colorado School of Mines) reported on the relationship between the over consolidation ratio and ductile-to-brittle transition in shales. Tom Bratton (Schlumberger) discussed the complexity in unconventional reservoirs with strong heterogeneity and anisotropy. Derek Elsworth (Penn State University) discussed the coupling of the exfiltration of CH_4 and infiltration of CO_2 in fractured coals and shales for storage. John Rutqvist (Lawrence Berkeley National Laboratory) presented a numerical modeling study related to the potential for injection-induced fault reactivation and notable seismic events associated with both CO_2 sequestration and shale-gas hydraulic fracturing operations.

Marshall Sundberg (ExxonMobil) presented results of a research study for proppant embedment in shales and its effect on hydraulic fracture conductivity. Neal Nagel (Itasca) discussed some critical issues impacting the geomechanics of hydraulic fracture stimulation in shale gas and shale oil reservoirs. Norm Warpinski (Pinnacle Technologies) emphasized the many uncertainties related to the source of microseismicity and the relationship to the fracture and the fracturing fluid. Azra Tutuncu (Colorado School of Mines) discussed the stress anisotropy and associated formation of mechanical, acoustic and transport properties. Anthony Iannacchione (University of Pittsburgh) covered well integrity issues, one of the greatest threats to environmental protection, safety, and production for Marcellus Shale development.

Other speakers included Ramana Graves (Colorado School of Mines), Will Pettitt (Ithasca), Charles Fairhurst (University of Minnesota), Antonio Bobet (Purdue University), Patrick Leahy (AGI), and David Wunsch (National Groundwater Association).

ARMA Student News

ARMA Student Chapters

Colorado School of Mines

The Colorado School of Mines (CSM) Student Chapter of the American Rock Mechanics Association (ARMA) celebrates its first anniversary this year. Since its founding in March 2011, the chapter has grown significantly, serving the CSM geomechanics community and students with numerous activities. The ARMA/Unconventional Natural Gas and Oil Institute (UNGI) Lecture Series initiated in the inaugural year drew attention campus-wide and was well attended by the students and faculty. Five distinguished speakers from the industry and academe covered various applications of geomechanics. They were Dr. Omer Aydan (Tokai University, Japan), Dr. Philip Nelson, Dr. Mark Zoback (Stanford University), Dr. Johathan McKenna (Microseismic, Inc.), and Dr. Neal Nagel (Itasca).

Above: ARMA/UNGI speaker Dr. Johathan McKenna with CSM ARMA student chapter members after his lecture.

Other Chapters

Students from several universities have been interested in establishing ARMA student chapters. This interest was advanced through a student meeting during this summer's Chicago symposium. About 15 graduate students from Colorado School of Mines, Louisiana State University, Montana Tech, Penn State and University of Minnesota attended the meeting to explore how to organize and run a student chapter of ARMA. As an action item, the group recommended that a student link be set up in the ARMA website. Peter Smeallie, ARMA Executive Director, emphasized the significance of establishing student chapters of ARMA and recommended the CSM ARMA Student Chapter as a model in setting their organizational by-laws, officer election and other formal processes. It should be noted that Louisiana State University, recently established an ARMA Student Chapter.

ARMA Fellow Named

Ed Cording Elected ARMA Fellow

The Fellows of ARMA are pleased to announce the election of Ed Cording, a distinguished member of the geomechanics community and a life member of ARMA, as a Fellow.

Dr. Cording is an emeritus professor at the University of Illinois at Urbana-Champaign where he taught and conducted research in geotechnical engineering, focusing on rock engineering, soil-structure interaction and underground construction. His research in rock engineering and underground construction is documented in about 90 publications. He has served on the U.S. Nuclear Waste Technical Review Board (appointed by the President for oversight of Yucca Mountain project). He was instrumental in the planning and analysis for the Washington DC Metro system, the New York subways, and many other urban transit projects. Recently he served as a member of the Large Cavity Review Board for the potential large detector at DUSEL/SURF, Homestake.

He is an elected member of the National Academy of Engineering (1989) and recipient of the ASCE Martin S. Kapp Award, the Moles Non-member award for Outstanding Achievement in Construction (2003), and the Geo-Institute Harry Schnabel, Jr. Award for Career Excellence in Earth Retaining Structures. More recently, he was awarded the Underground Construction Association of SME 2012 Outstanding Educator Award.

In Memorium

Obituary: John Alan Franklin 1940-2012

Submitted by Maurice Dusseault, Waterloo Ontario

It is with great sadness that we announce that Dr. John A. Franklin, a former member of the Department of Earth and Environmental Sciences at the University of Waterloo, Ontario, and a primal force in the world of rock engineering, passed away on 6 July 2012.

Dr. Franklin served as the President of the International Society for Rock Mechanics from 1987 to 1991. He was a premier consulting engineer involved in fascinating projects such as the foundations of the CN Tower in Toronto (the highest tower in the world for several decades), the Sudbury Science North Centre (seated across a major fault), the 2100 meter deep Neutrino Observatory (SNOLAB) in Sudbury, a rock breakwater at the end of the world (Tierra del Fuego), and many other rock engineering projects. In the international rock mechanics world, he is known, among others, for his contributions to design engineering, rock testing methods, monitoring, rock fragmentation, and joint fabric analysis through imagery. John profoundly understood the intersection between geosciences and rock engineering, an attitude that pervaded his professional career.

John passed away after an unusually long and determined fight against Parkinson's, which eventually defeated his physical body but never his spirit. Kersty, his wife, helped John as much as possible through the last decade.

The single-minded dedication that John brought to rock mechanics and rock engineering in the broadest sense reminds us that the world is built on the ideals of a few visionaries who lead us forward. He was such a visionary and remained intellectually active long after his physical disability restricted his movements and travel opportunities. Last year, he travelled for the last time to the International Society for Rock Mechanics quadrennial Congress in Beijing. He was saying goodbye, though he would never have admitted it.

If our International Society for Rock Mechanics has become an important professional organization, it is in part because of John Franklin. Those who were fortunate to know him personally remain delightfully aware of his irrepressible elfish humor, his profound skill at bridge, and his eclectic and wide-ranging knowledge of just about everything (a genuine Trivial Pursuit champion).

Let us extend our appreciation for his life and contributions, as well as our condolences for her loss, to his wife, Kersty, and to his friends and professional associates.

ARMA News Briefs

ARMA 48th Announced

For those of you making long-range plans, the ARMA 48th US Rock Mechanics/Geomechanics Symposium will be convened in **Minneapolis in 2014**. But come to San Francisco for the 47th, so you will not miss out.

ARMA Annual Awards

ARMA issues annual awards to recognize outstanding contributions and careers in the profession of rock mechanics and rock engineering that are of benefit to the US rock mechanics community. The purposes of the awards program are:

- to encourage teaching, research, and advancement of knowledge in rock mechanics;
- to encourage collaboration and exchange of ideas and information between rock mechanics practitioners; and
- to promote high standards of professional practice among rock engineers so that civil, mining, and petroleum works might be safer, more economic, and less disruptive to the environment.

ARMA recognizes outstanding contributions in naming recipients of the following six awards:

- Rock Mechanics Research Award;
- Applied Rock Mechanics Research Award;
- Case History Award;
- Dr. N.G.W. Cook Ph.D. Dissertation Award;
- M.S. Thesis in Rock Mechanics Award; and
- Outstanding Contributions to Rock Mechanics Awards

Further information on the awards can be found at: http://www.armarocks.org/awards.html. Please send your nominations to Steve Brandon, sbrandon@lachel.com, Chair of the ARMA Awards Committee, by 31 December 2012.

Seeking Corporate Memberships

ARMA corporate memberships are encouraged. Such memberships will connect you to the broader rock mechanics and geomechanics community, including industry, academia, and government; demonstrate your support for professional practice in rock mechanics and geomechanics; augment ARMA's promotion of rock mechanics and geomechanics as a discipline, especially with students; present communication opportunities with ARMA and associated societies; and recognize your support of and participation in the activities and discussions of ARMA and rock mechanics/ geomechanics. Corporate members can have access to a dedicated portal through the ARMA website at www.armarocks.org.

Award of Merit Presented to ARMA's Touseull

One of ARMA's members, **Jack Touseull**, has distinguished our profession through receiving the Award of Merit from the ASTM International Committee on Soil and Rock Standards. This award is the highest organizational recognition for contributions to the standards work of ASTM. Mr. Touseull is a geological engineer at the US Department of Interior, Bureau of Reclamation in their Denver office.

Changes Announced to GEOTECHNIQUE

The professional journal, **Geotechnique** (through ICE Publishing) wishes to alert ARMA members of changes in its editorial procedures to significantly decrease publication times for selected articles. Contact lisa.oliver@icepublishing.com for more information or visit their site at www.icevirtuallibrary.com.

ARMA Call for Papers

Deadlines Set for Call for Papers

ARMA will convene its 47th US Rock Mechanics/Geomechanics Symposium from 23-26 June 2013 in San Francisco, California, USA. The organizing committee, chaired by Laura Pyrak-Nolte (Purdue University), has begun its work with a call for papers to be reviewed and presented at the meeting. The committee is inviting scientific and engineering papers in civil engineering, geology and geophysics, mining engineering, petroleum engineering, underground construction, and other relevant topics. Papers that are accepted will be featured in presentations and displays during the symposium and compiled into proceedings available following the meeting.

Abstracts of 250-500 words, in English, can be submitted online at http://www.armasymposium.org. Abstracts should include a brief description of work performed, results, and significance. Figures may be included as necessary to explain the abstract. All abstracts and accepted papers will be peer-reviewed by experts in respective subject areas through an online process.

Deadlines for abstract and paper submittal are as follows:

- ***1 November 2012–Abstract submittal***
- ***15 December 2012–Notification to authors***
- ***15 February 2013–Paper submittal***

Information on symposium registration, exhibition, accommodation and sponsorships can be found at www.armasymposium.org or by contacting Peter Smeallie, Executive Director, ARMA, info@armarocks.org, 703-683-1808.

The focus of the Symposium is on fundamental, practical and educational issues facing our profession. Topics are listed on the right.

47th US Rock Mechanics/Geomechanics Symposium
San Francisco
June 23-26, 2013

Symposium Topics include but are not limited to:

- Rock mass characterization
- Rock physics and geophysics
- Unconventional resources development
- In-situ stress and pore pressure prediction and measurements
- Geomechanics for injection, production and depleting reservoirs
- Drilling and wellbore stability
- Reservoir monitoring technologies
- Carbon sequestration and utilization
- Induced seismicity and monitoring micro-seismicity
- Hazards & hazard mitigation, rock slides
- Geothermal and hydrothermal advancements
- Waste disposal, seal integrity, underground storage
- Complexity of subsurface reservoirs/fault zones/fractured media
- Fracture mechanics and fracture propagation
- Deep rock mining, mining in evaporites & weak rocks
- Rock mechanics of coal, salt, and metal mines, quarrying
- Stability/support of underground openings and slopes
- Numerical/analytical/ constitutive modeling of rock and rock processes
- Discrete Element Method (DEM) and Discontinuous Deformation Analysis (DDA)
- Discrete Fracture Network (DFN) Analysis for Geomechanics and Flow
- Rock mechanics and sustainable development
- Pore-scale processes and visualization
- Weak rocks, shales, problem geomaterials, granular materials
- Fluid flow and transport through fractured porous media
- Coupled heat, flow and transport
- Geochemical/biogeochemical influences on rock properties and fluid flow
- Rock tunneling and grouting
- Dams, abutments and foundations
- GIS methods for rock mechanics