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In this issue

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Editor's Notes

*You probably noticed that our ARMA periodical has a new title: **ARMA Letters.** It replaces our original title: **ARMA e-Newsletter.** Over time we realized that the nature of our tri-annual written communication to members does not follow the usual format of a typical newsletter. We do not limit ourselves to just announcing forthcoming meetings, publications, deadlines, and other occasional brief articles of interest to ARMA members. Rather, our emphasis is on the newest developments in the field of rock mechanics/geomechanics — soliciting technical articles, often prior to publication in reviewed journals. We strive to keep our readers aware of what is new in the field of rock mechanics, emphasizing the advances made in the U.S., as well as internationally. At the same time, we also inform ARMA members of current and future events, such as conferences, workshops, short courses, and other events of interest. As for precise announcements of dates and venues of future ARMA or related events, our official ARMA periodic email fulfills that job quite efficiently.*

This issue is dedicated to reports on three major rock mechanics/geomechanics-related conferences held in 2018, as follows:

- *Richard A. Schultz presents a concise summary of the important issues covered by the diverse topics of the 52nd annual US Rock Mechanics/Geomechanics Symposium, held in Seattle, WA.*
- *Tom Doe reports on highlights of the 2nd Discrete Fracture Network Engineering Conference (DFNE2018).*
- *Kate Baker critically reviews URTeC 2018, the Unconventional Resources Technology Conference, held in Houston, TX.*

—Bezalel Haimson, Chair
ARMA Publications Committee

52nd US Rock Mechanics/Geomechanics Symposium, June 2018

Submitted by Richard A. Schultz, Technical Program Committee Chair

The 52nd US Rock Mechanics/Geomechanics Symposium was held in Seattle, Washington from 17-20 June, 2018. This symposium brought together more than 736 professional scientists, engineers, and students from academia, industry, and government in the areas of civil, environmental, geological, mining, geophysical, geothermal, and petroleum engineering; there were attendees from 38 nations. The symposium is the premier annual event organized by ARMA and has become one of the most recognized and important venues for rock mechanics and geomechanics worldwide.

In many ways the Seattle symposium was a proving ground for new approaches consistent with the remarkable growth of the symposium as a major event. In addition to more than 400 technical presentations, the venue hosted five plenary keynote lectures, two technical tours, two short courses and one workshop. The symposium was followed by the 2nd DFNE Conference which shared one day of presentations and exhibits with the symposium. (See following article for a summary.) This year all poster presentations were up and available for viewing and discussion during every day of the symposium; this and co-location in the exhibit hall were widely regarded as successful innovations, to be repeated at future symposia. Given the increasing size and complexity of the symposium, printed copies of the program were minimized and reliance placed on the mobile app, which was updated continuously and became the document-of-record for participants to use in navigating through the week's activities.

Charles Fairhurst, University of Minnesota, delivered the 2nd ARMA Distinguished Lecture with an exciting and thought-provoking presentation on "Rock Engineering–Where is the Laboratory?" The 10th Annual MTS Lecture, "Reliability-Based Hazard Analysis and Risk Assessment for Rock Slopes," was given by Sebnem Düzgün, Professor and Banfield Chair, Colorado School of Mines; she spoke on how applied probabilistic approaches can aid decision-making for hazard and risk evaluations. Tony Dell, SNC Lavalin, discussed "Rock Mechanics Aspects of the John Hart Generating Replacement Project" in a keynote address that described how the hydroelectric power facility in British Columbia is being upgraded. The Early Career Keynote Address was delivered by Fengshou (Frank) Zhang, Professor, Tongji University, who gave a wide-ranging presentation on the important topic: "Hydraulic Fracturing in Naturally Fractured Reservoirs: Aspects from Multi-Scale Numerical Modeling." The final keynote address,"The Making of a Hydraulic Fracture Swarm," was delivered by Andrew Bunger,Associate Professor, University of Pittsburgh; he stressed the need to include viscous energy dissipation and time-dependent deformation to explain the growth, interaction, and spacing of hydraulic fractures.

Figure 1. Pre-symposium tour of the Snoqualmie Powerhouse and inspection of I-90 Rock Slope Stability issues. Photo by Hill Montague

One workshop and two short courses preceded the symposium. Technical tours visited the Snoqualmie Powerhouse, the I-90 Rock Slope Stability project, and Whidbey Island to view landslides, lahars, tsunamis, and earthquakes as they affect rock engineering in the Pacific Northwest. The day-long short courses focused on "Microstructural Modeling of Rock Fracture: Bonded-Particle Modeling with PFC and Bonded-Block Modeling with 3DEC" and "2D and 3D Mod-

Figure 2. Charles Fairhurst presenting the 2nd ARMA Distinguished Lecture, Photo by Hill Montague

eling of Rock Fracturing Processes in Geomechanics;" both of these topics demonstrate the on-going importance of computation and software development in solving geomechanical issues. The day-long workshop covered "Characterizing Induced Seismogenic Potential" which is of critical importance to applications such as: hydraulic fracturing design and assessment; reservoir and top-seal geomechanics; wastewater injection; underground projects including carbon dioxide sequestration, natural gas, fuel, and compressed-air storage; and geothermal energy extraction.

The technical sessions provided exciting opportunities to present and discuss the newest fundamental findings and applications obtained through analytical and numerical modeling, laboratory experiments, and field-scale studies. Some 476 papers accepted from more than 800 abstracts were scheduled for presentation in podium and poster formats including 218 in petroleum geomechanics, 45 in civil and environmental engineering, 98 in mining engineering, and 115 in interdisciplinary topics including geothermal. One of the strengths of the symposium was its ability to bring together rock- and geo-mechanicists from a wide range of disciplines to focus on problems, potential solutions, and innovative applications that were recognized as critical and need-

Figure 3. Andy Bunger and Gang Han discussing the finer points of hydraulic fracturing with ARMA participants. Photo by Hill Montague.

ed across the field. Many of the presentations were selected for recognition as best papers, to be re-reviewed for publication in Rock Mechanics and Rock Engineering along with additional papers written expressly from several keynote speakers for this journal's special ARMA issue.

Many of our members were honored for their contributions to ARMA and our field. Steve Glaser, Professor, University of California, Berkeley was inducted as ARMA Fellow. Twelve members were inducted in the Class of 2018 ARMA Future Leaders, many of whom served in leadership capacities in the symposium's technical program committee. The NGW Cook Ph.D. Dissertation Award was given to Anahita Modiriasari from Purdue University for "Geophysical Signatures of Fracture Mechanisms." The MS Thesis Award was presented to Andrew LeRiche for "Stress Estimation from Borehole Scans for Prediction of Excavation Overbreak in Brittle Rock." The Applied Rock Mechanics Award was bestowed on Messrs. Naeimipour, Rostami, Buyuksagis, and Forough for "Estimation of Rock Strength Using Scratch Test by a Miniature Disc Cutter on Rock Cores or Inside Boreholes." ARMA President Laura Pyrak-Nolte presented ARMA Presidential Citations to Sergio A.B. da Fontoura for his service as International Representative on the ARMA Board of Directors and Richard Schultz for his successful efforts as Technical Program Committee Chair of the Seattle symposium.

The importance and on-going success of the symposium was evidenced by the strong support of six corporate sponsors and 15 exhibitors, all recognizing the opportunities presented by the assembly of like-minded and professionally engaged academics, researchers and practitioners, corporate representatives, and others that make up ARMA's world-wide membership. Corporate sponsors included Golder Associates, Inc.; MTS Systems Corporation; Schlumberger; Agapito and Associates, Inc.; Rocscience, Inc.; and Itasca Consulting Group, Inc. Exhibitors included Floxlab; Frac Tech Laboratories; GCTS Testing Systems; GDS Instruments; Geomechanica, Inc.; Geo-Slope International Ltd.; Golder Associates, Inc.; IDS GeoRadar; Itasca Consulting Group, Inc.; MetaRock Laboratories, Inc.; MTS Systems Corporation; Rocscience, Inc.; Sandia National Laboratories; Schlumberger; and TRE Altamira, Inc. Sponsors and exhibitors are thanked for their contributions to making the Seattle Symposium a success.

Figure 4. ARMA President Laura Pyrak-Nolte addresses symposium participants at the Awards Banquet. Photo by Hill Montague

2nd Discrete Fracture Network Engineering Conference (DFNE2018)

Submitted by Thomas Doe (Conference Organizing Committee member)

The second Discrete Fracture Network Engineering conference, DFNE2018, occurred as a follow-on meeting to the 52nd US Rock Mechanics/Geomechanics Symposium, held in Seattle 20-22 June, 2018. The success of the first DFNE conference, held in Vancouver in 2014, indicated a significant worldwide interest in tactical interactions on this topic and led to this second conference on the subject.

One of the most important original contributions of rock mechanics to engineering has been the theory and practice of working in discontinuous materials -- that is, materials that contain fractures. Unlike other engineering, which usually throws away things after they break, people who deal with rock often have a material that is already broken.

Discrete fracture network approaches have been a significant outgrowth of advances in rock mechanics since the 1970s. Initially discrete fracture network models developed as probabilistic methods of rock slope design that used stochastic generations of fracture networks. This work drew on new probabilistic methods for describing fracture orientation, size, intensity, and other hydraulic and mechanical properties developed by Greg Becker, John Hudson, and Stephen Priest, among others. Later stochastic models of fractures were coupled to flow simulators, providing a major breakthrough in studying fluid flow through fractured rock both for hydrogeology and for oil and gas. In addition to these applications, discrete fracture methods have also found significant applications in mining and underground construction.

The DFNE program included 114 papers presented over two and a half days of oral and poster sessions covering wide ranging applications from radioactive waste disposal, mining, geothermal energy, oil and gas development, and groundwater hydrology, among others. In addition to practical applications, several sessions were devoted to DFN theory and computational approaches including relationships between fracture networks and geophysical properties.

In addition to the regular sessions, each day included one keynote address, and there were two interactive panel seminars. The first keynote address was presented by Prof. Philippe Davy of the French National Research Council (CNRS) on DFN concepts, theories, and issues with particular focus on the upscaling

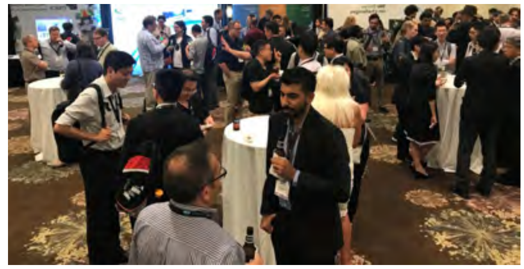

Figure 1. Reception for attendees at DFNE conference, 2018. Photo by Hill Montague

of small-scale measures to site scale, intrinsic variability versus geologic determinism, incorporating a priori knowledge, and critical characteristics involving length scales and scaling laws. Professor Davide Elmo of the University of British Columbia spoke on DFN analysis and modeling for better understanding rock mass behavior for rock engineering problems. The third plenary session talk was given by Dr. Lee Hartley of Golder Associates providing an overview of the landmark applications of DFN modeling to the geological repository programs in crystalline rock in Sweden and Finland. The work on these projects has been the culmination of nearly 30 years taking DFN modeling from a research tool to being the fundamental basis of site characterization and licensing.

In addition to the keynote talks, there were two seminars, one on DFN approaches for naturally fractured and stimulated oil and gas reservoirs, and a second seminar on the characterization of that particularly challenging parameter, fracture size.

The participation by over 150 attendees from all parts the world shows how DFN has matured from a set of academic research tools to accepted and widely applied components of the rock engineering toolkit.

The rock mechanics community owes particular thanks to the conference co-chairs Bill Dershowitz of Golder Associates and Thomas Flottmann of Origen Energy, who were ably assisted by Seth Busetti (ConocoPhillips), Caroline Darcel (Itasca), Tom Doe (Golder), Davide Elmo (University of British Columbia), Herbert Einstein (MIT), Lee Hartley (Golder), and Jan-Olof Selroos (SKB). The conference would not have been possible without the generous support of platinum sponsors Golder Associates, MTS, and Schlumberger and the contributions of lanyards and delegate bags from Rocscience and Itasca. The organizational efforts of the ARMA staff are also gratefully acknowledged.

Conventional Resources Technology Conference (URTeC),

Submitted by Kate H. Baker, ARMA Fellow

Introduction

As a result of the shale boom, U.S. crude oil production now exceeds 11 million barrels per day, behind only Russia. Total US oil and gas production is 27.5 MBOE/D (million barrels oil equivalent per day), more than that of any other country. The U.S. still imports oil, but for the first time since 1957 is now a net exporter of natural gas. This energy abundance has changed the country's geopolitical reach. Rock mechanics and geomechanics are the foundation for much of the technical decision-making in unconventional resource development, including such diverse matters as subsurface imaging, ultimate recoverable reserves estimation, and wellbore design for life-of-well integrity.

Given today's technology, considering current oil and gas prices relative to development costs, transportation infrastructure and regulatory regime, it is generally estimated that about 10% of the unconventional in-place hydrocarbon resource can be recovered. Scott Tinker offered a perspective on the challenges as follows: Shale development is bad for the local environment but good for the global one -- it lessens dependency on more carbon-intensive energy sources while lifting people out of poverty. Shale production economics are poor but the overall economy benefits from lower cost energy and more diversified supply. All forms of energy, at scale, require work to be environmentally sustainable.

This was the context for the URTeC Conference convened in Houston on 23-25 July, 2018.The conference offered nine sessions on geomechanical topics, organized by SPE, SEG, AAPG and ARMA members. These included more than forty papers focused on measurements and techniques for improving the effectiveness and safety of operations. There was also a session on how to access some of the capabilities of the 17 National Labs run by the US Department of Energy[1], and multiple sessions presenting results from the full-scale hydraulic fracture test site (HFTS) in the Wolfcamp Shale (Reagan County, Texas), as well as lessons learned from the Collab Enhanced Geothermal Site[2]. The DOE's Collab Sigma V initiative is an intermediate-scale (10's of meters) project designed to elucidate basic relationships among in situ stress, induced seismicity and permeability enhancement in engineered geothermal systems (EGS).

Selected Field Test Site Results

The results from a number of test sites were presented and discussed at the conference.

At the HFTS, more than 400 stimulation stages were mapped by Stegent and Candler (URTeC 2902311) using microseismic monitoring. Because multiple fracturing crews were on location on this multi-well pad at the same time, there is some uncertainty about event assignment. Nonetheless, interpretation of the data suggest that timing between zipper fracturing[3] completion sequences does not appear to make a difference as revealed by microseismic response. In addition, microseismic data could not determine whether three or five clusters/stage was "better" in terms of creating the propped, stimulated volume. Fluid-created fracture height is believed to be about 800 feet; the propped extent may be less. While the stage length (the distance from toe-most perforation to heel-most perforation in a set of perforation clusters) was roughly 250 feet on average, the microseismic cloud width was double that. There was no obvious evidence of fracturing induced parallel to the wellbore direction and emanating from the wellbore itself. Such fracturing has been observed elsewhere on occasion as a result of fracturing fluid leakage into the space between the formation and the well casing or liner beyond the intended treatment zone.

Based on two sets of cores taken in a specially-drilled slant well following the stimulation of the 6U and 6M wells, Fairfield et al. (URTeC 2937221) reported a positive correlation between likely hydraulic fractures observed in the core and areas of highest microseismic density in the stage of the neighboring horizontal nearest to the Upper Wolfcamp cored interval. This demonstrates that microseismic density can be a reliable indicator of hydraulic fracture density and complexity around the stimulated well.

Using a surface seismic array, Kumar et al (URTeC 2902789) recorded multiple low frequency (10-40 Hz) events of long time duration during hydraulic fracturing of two horizontal Middle Wolfcamp wells on the pad. They believe including such long-period, long-duration (LPLD) events may be important to improving seismically-based predictions of well production. These events may indicate permeability-enhancing deformation mechanisms not captured by microseismic analysis (which dominantly records shear failure of brittle rock). These mechanisms include: 1) movement along pre-existing discontinuities such as bedding planes and fractures/faults, 2) deformation of ductile rocks with high clay content, and 3) jerky tensile opening of hydraulic fractures.

Kneafsey commented that the first stimulation (a mode 1 hydraulic fracture) has successfully met its target flow circulation goal once. Flow occurred out of a multiplicity of fractures in the production well, suggesting the importance of natural fractures as contributors to flow.

Other Matters of Note

Operators remain divided as to whether the propped, connected volume of an induced or stimulated fracture set can be ascertained from measurements and/or modeling available today. Concho Resources says no; Bhattacharya (URTeC 2902106), with Shell, presented what her company considers to be a reasonable automated geomechanics/reservoir simulation algorithm that captures stress shadow effects, completion design and geometrical effects (i.e. proppant type, proppant volume, cluster spacing, perforations per cluster), and the effect of multiple fractures in multiple wells. Shell also has a software agnostic workflow for deciding economic criteria, deciding fracture design variables, gathering data, selecting a field or play region to simulate, and calibrating their models for that region.

Damjanac (URTeC 2901800) and co-authors used a bonded particle model to examine the Stress Shadowing Effect on Fracture Initiation and Interaction. They conclude that fractures are more complex than generally predicted not just because of rock mass variability, but also because of stress shadow effects and the hydraulic connection between perforation clusters. The modeling code allows the hydraulic fracture to "find" its path based on the stresses generated within the model, including perforation pressure drop. Bunger et al (2012, SPE-140426-PA) had previously discovered that there is a critical spacing below which fractures attract one another and above which they repel.

These findings raised some questions. Do we have the data needed to inform sophisticated models – or even relatively simple ones? Opinion seemed to be divided here. Also, while there was general consensus that relatively thin but persistent laminae can act as barriers to fracture propagation, high resolution properties are seldom measured. The degree of cementation in naturally occurring fractures is seldom fully known, but it is clear that in some instances, a more complicated formulation is needed rather than merely treating them mechanically as frictional interfaces. The type of cement in the fracture may also matter. Wang (URTeC 2902343) found in his PhD work that for natural fractures cemented with relatively "soft" cements, increasing natural fracture thickness in models promotes hydraulic fracture diversion along the frictional interface. A higher stress ratio and a larger coefficient of friction are required for a hydraulic fracture to cross the cemented natural fracture than would be the case with a stiffer mineralizing cement. Weng (URTeC 2962607) affirmed the dominant effect of in situ stress on fracture height growth and containment, while observing that thin layers may not provide a sufficient barrier, depending on stress contrast relative to net pressure, pumping parameters, and even the vertical distance of the thin layer from the perforations. Modulus contrast, toughness, leak-off and interface properties can also come into play. Weak interfaces are probably least well understood.

Sharma (URTeC 2962612) picked up on complexity and interface crossing themes. He noted that layer boundary crossings may involve branching, kinking or T-ing into the interface in addition to going right through. He noted that kinking is actually quite common. He included in complexity aspects of fluid-proppant complexity, and proppant transport within the wellbore and through the perforations as part of the integrated system that must be analyzed. He observed, for example, that fluid leaks off into perforations, but the proppant particles disproportionately remain within the wellbore moving toward the toe. The toe screens out, so most of the proppant goes into the heel. Staging, perforations and proppant placement need to be optimized to get a better (more uniform) distribution.

As one might expect with SEG co-sponsorship of URTeC, there was a good deal of attention given to the use of microseismic data for fracture location and net stimulated volume assessment. Maxwell (URTeC 2900807) compared two end-member models: one in which microseismically active fractures representing the entire flow system and second consisting of an aseismic, tensile hydraulic fracture that activates pre-existing fractures. The model containing the aseismic, tensile fracture represents the lowest energy state and is most consistent with typical microseismic and injection pressure characteristics. Maxwell believes that microseismic response illuminates the activated pre-existing fractures, but that is not the complete flow system. He further opines that proppant distribution within the stimulated region will have to be determined through modeling; it cannot be extracted from the microseismic data alone.[4] In his modeling, most of the proppant stays in the mode I fractures. Nonetheless, coupled with fluid flow or fluid pressure information, microseismic data modeling can assist with cluster spacing and well spacing decisions in multi-well development plans.

Numerous questions remain: Is bedding plane slip a common mechanism for generating microseismicity? If injection "triggers" seismicity (including felt earthquakes) by raising pore pressure on pre-existing critically stressed faults and releasing tectonic stress, why should moment release have anything to do with the amount of energy emplaced into the subsurface by a pumping schedule?

Zoback (URTeC 2882313) reported on the work of one of his graduate students in a tectonically active area of the Sichuan Basin to better understand fault slip and casing deformation and what might be done to avoid it. 32 of 101 wells drilled and completed in the Changning and Weiyuan shale gas blocks experienced casing deformation. One well in particular was chosen for study, a toe-up horizontal with 12 fracture stimulation stages planned (of which 10 were performed). A large fault was found near the toe of the well and casing deformation was observed post-stimulation about 100 m from the located fault seismicity. This activity included a number of magnitude 2.5 to 3.5 events. The shear displacement of the casing was estimatedat 1 to 3 cm, a displacement consistent with a M= 3 event on a 1 km^2 slip surface. The discrepancy between the largest seismic event locations and the casing displacement measured depth could be due to fault location errors. Alternatively, the Longmaxi shale has a high-enough clay content that aseismic slow slip could occur, as the fault's resistance to slip would increase with slip rate on the fault. In either case, he supposed that casing deformation might be reduced or avoided in future wells by stimulating only those portions of the wellbore that are not near known faults and by ensuring that the intervals stimulated are properly isolated from any wellbore-fault intersections in drilling and completion design and execution. This could be accomplished by cement, packers or other fluid pressure barriers in the annulus between the formation and the well production casing or liner.

Nagel (URTeC 3044072) observed that more proppant per foot equates to better wells. In the US in the last 12 months there has been a 30% increase in proppant per foot and a 10-50% increase in production.

Is that just acceleration of hydrocarbons that would eventually be economically recovered anyway, or is it tapping resources that would otherwise remain unproduced? It depends what you think. If it is that more entry points are creating the increased production, it suggests a greater number of strongly cemented natural fractures are being stimulated. If more sand is going out per cluster, then weakly cemented fracture or partially open perforations are suggested, and it's all about acceleration. Planar microseismic clouds suggest that the rock fabric (including bedding planes, natural fractures and other features of the contacted subsurface volume, in addition to any intrinsic anisotropy of the depositional, igneous or metamorphic geobodies within the volume) was not effectively mobilized or utilized in the stimulation. He asked, "Do I want mode I fractures or do I want to stimulate fabric as the main source of enhanced flow?"

Footnotes

1 The National Labs projects highlighted at URTeC had less to do with rock mechanics and big data applications and more to do with physical tools and materials science: development of high temperature downhole motors, multiphase metering using swept-phase interferometry, a special spacer with a negative coefficient of thermal expansion useful for mitigating temperature-induced annular pressure increases during drilling, and advanced corrosion monitoring.

2 Papers on the Collab Sigma V initiative have been presented at ARMA meetings by the same set of authors as at URTeC. The project is now in its 17th month and is still very much a work in progress.

3 Zipper fracturing involves simultaneous stimulation of two parallel horizontal wells close enough one to the other so that the induced stresses owing to the fractures created in the one well influence fracture propagation in the other well, improving reservoir contact.

4 Sherman (URTeC 2900760) looked at low-frequency, long-durations signals using downhole distributed acoustic sensors (DAS) and came to a similar conclusion: DAS can be used to constrain fracture geometry but not to identify proppant location.