ARMA e-NEWSLETTER WINTER 2011

Welcome 2011!

american rock mechanics association

Volume 1, Issue 2, Winter 2011

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Congratulations to ARMA on Their Inaugural e-Newsletter

The United States National Group, as represented by ARMA, of the International Society for Rock Mechanics (ISRM) is a most valued ISRM National Group—and it is encouraging to note the continuing development of ARMA through this initial issue of the ARMA e-Newsletter. Congratulations on the initiative, and we look forward to reading the contents every three months.

Over the years, I have been particularly impressed by ARMA's organisational capabilities, most recently demonstrated in June by the well-managed ARMA /CARMA meeting in Salt Lake City, so I am sure that this ARMA e-Newsletter will also be a great success. Well done and good luck!

ISRM

John A Hudson
ARMA Fellow
Emeritus Professor, Imperial College, United Kingdom
President, International Society for Rock Mechanics, 2007-2011

Photo courtesy of Ahmed S. Abou-Sayed

Reminders

Don't FORGET!

45th ARMA Rocks
PAPER SUBMITTAL
Deadline
3/01/2011

e-Newsletter

YOUR contributions are NEEDED for the ARMA e-Newsletter! Send us your-

- Technical Notes
- Case Studies
- Policy issues
- Latest ARMA news
- Announcements of interest to members
- Miscellaneous items

newsletter@armarocks.org

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Bezalel Haimson
Chairman

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ARMA News

ARMA Fellow Memberships

By Sidney Green, ARMA Board Member

The "Fellow" title, which is granted to a selected few ARMA Members, is recognition of outstanding achievements in the field of Rock Mechanics, and is evidence of the individual's expertise, judgment, and wisdom. Fifteen ARMA Members have been elected to Fellow.

By the nature of their accomplishments and wisdom, Fellows tend to represent ARMA, and the entire rock mechanics/ geomechanics communities, in an exemplary manner. The Fellows are dedicated to the ARMA vision to be the recognized representation of multi-disciplinary rock mechanics/geomechanics advancements and applications. Fellows may be called upon as advisors for ARMA or requested to participate in various ARMA projects, and may be suggested to Agencies where rock mechanics/ geomechanics expertise is required. Fellows regularly participate in the ARMA Annual Symposium, and look forward to meeting and to discussions with ARMA Members.

Below: *The first class of Fellows was elected in 2008 and inducted at the Annual Symposium in San Francisco. (Left to Right) Charles Dowding (Northwestern University), Herbert Einstein (MIT), Charles Fairhurst (University of Minnesota), Richard Goodman (UC Berkeley), Sidney Green (TerraTek/Schlumberger), Bezalel Haimson (University of Wisconsin), Francois Heuze (Retired LLNL), Jean-Claude Roegiers (University of Oklahoma), Bernard Amadei (University of Colorado) (Not shown is Dr. Priscilla Nelson of New Jersey Inst. of Technology.)*

Additional ARMA Fellows

Five additional fellows were elected and inducted at the Annual Symposiums in 2009 and 2010.

Above: From Left to Right are Don Banks (Rtr. Army WES), Sidney Green (TerraTek/Schlumberger)—currently serving as Chair of the Fellows, Ahmed Abou-Sayed (Advantek International Corp.), Derek Elsworth (Penn State University), Jean-Claude Roegiers (University of Oklahoma, Current Fellow). *(Not shown in the photos are Dr. John Hudson of Imperial College and Dr. Wolfgang Wawersik, retired from Sandia National Laboratory.)*

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TECH Notes

Massive Multi-Stage Hydraulic Fracturing: Where are We?

By Maurice Dusseault, University of Waterloo with contributions from John McLennan, University of Utah

Massive multi-stage hydraulic fracturing (MMHF) in long horizontal wells has unlocked vast gas resources in low permeability strata – "shale" – in plays such as the Marcellus Shale, PA, and the Barnett Shale, TX.

The importance and increased utilization of MMHF calls for improvements in our ability to simulate the process realistically. I'll try to summarize some difficulties and point to some things we can do, some we can't, and where we might go. An expanded version of this synopsis, with a list of references, is posted on the ARMA web site at www.armarocks.org/resources.

The Technology

MMHF is intended to maximize drainage volume around a well and is executed at perforated locations along a cased well, usually drilled parallel to σ_{hmin} to maximize fracture length extension normal to the well axis (Fig. 1). The well is placed close to the base of the zone because fractures rise when $d\sigma_{hmin}/dz > d\rho_f/dz$ (HF fluid density is ρ_f). If $\sigma_v = \sigma_3$, even "horizontal" fractures will rise at a shallow angle to the principal stress directions as it propagates away from the injection point.

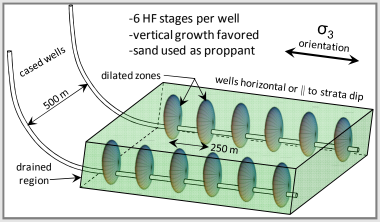

***Figure 1**: Multiple HF stages for shale gas stimulation.*

The current record appears to be 45 separate fracturing stages along a well, each being a high-rate, high-proppant-concentration treatment to create a region of sand-propped fractures. Hopefully, this "sand-zone" is surrounded by a much larger region where natural fractures have been opened permanently or propped by shear displacements - the "dilated zone" (Fig. 2).

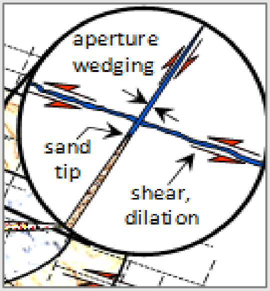

***Figure 2**: Fracture opening (dilation) created by wedging and shear displacement.*

Geomechanics of MMHF

MMHF is performed in stiff, low-permeability strata of low to moderate porosity (5-15%). They may be naturally fractured, but also contain "incipient" fractures consisting of vertical and bedding planes of low tensile strength.

MMHF effectiveness in shale is attributed to four geomechanics mechanisms. (1) On the injection zone flanks, high injection pressures ($p_{inj} \geq \sigma_v$) result in permanent flow channels by "self-propping" slip of natural fractures. (2) Proppant placement opens fractures well beyond the sand-filled tips, a process called "wedging." (3) The local sand-placement zone near the well (sand-packed fractures) creates general dilation far out into the naturally fractured rock because of volume-linked stress changes. - continued on page 4 -

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TECH Notes

Geomechanics of MMHF continued

(4) Block rotations and attendant slip along block edges produce self-propped openings, even in the absence of proppant sand. Large volume changes produce large local stress changes that drive these processes. The stress changes then interact with the rock fabric to generate an array of induced fractures and opened natural fractures, but only fractures close to the wellbore are propped with sand. Factors such as leak-off rate, fluid viscosity, injection rate and time, proppant concentration, and so on can be modified to achieve the best results.

MMHF involves elevated pressures so effective stresses during MMHF are low, making slip easy. Moreover, shale formations subjected to MMHF have low permeability, and elevated pore pressures travel far beyond the sand zone. This facilitates shear and promotes growth of the stimulated zone with natural fractures that are wedged open, self-propped because of slip, and opened because of rigid block rotations. Maximum reach of the effect of MMHF likely is achieved with high water volumes without viscosifiers.

Key questions concerning the best approach to MMHF in specific cases (rock type and properties, depth, well orientation, stress magnitudes…) probably will be found with a combination of better analysis, field monitoring, and compilation of post-treatment well performance history. Is it better to maximize injection rate and use a high proppant concentration continuously for several hours, or is it best to inject more slowly for many days at a low proppant concentration? Should we try for short fat fractures near the wellbore, or long extended fractures of larger surface area? Is slick water (with friction reducers) or viscous water better in pressurizing a large rock volume to maximize shearing of surrounding block interfaces? Will slick water lead to premature sand drop-out? Should we inject water aggressively for many hours before introducing sand? Can we reliably characterize the dilated zone and calibrate it to the volume of sand injected? In staged fracturing, do the stress changes induced during previous stages significantly affect the success of the current HF activity?

Given these and additional questions, it would be highly desirable to have a mathematical model good enough at least for sensitivity analyses, if not actual design. Ideally, such a model could be calibrated in real cases and used to predict behavior for the next stage or adjacent wells. A comprehensive physics-based model is too much to hope for, and monitoring is and always will be needed for model calibration, verification and optimization.

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OPINIONS:
Hydraulic Fracturing Gets a *BUM RAP*

Hydraulic fracturing for the purpose of production stimulation has been practiced by the oil and gas industry since the 1940's. Reservoir fracturing has been an astonishing success story, enhancing hydrocarbon extraction in general, and in particular in zones otherwise considered depleted. In 1957 two scientists working in the industry, King Hubbert and David Willis, published a seminal paper in which they demonstrated that the fluid pressures required to create, and then extend hydraulic fractures were directly related to the local state of stress in the rock formation. A decade later, Hubbert and Willis theory served as the basis for the development of a new and revolutionary method of measuring the in situ state of stress. Appropriately, this method was also named "hydraulic fracturing".

Since then hydraulic fracturing for stress measurements has been used in thousands of boreholes all over the globe, and has been a major contributor to the World Stress Map. The method is used routinely in a variety of fields such as the design of hydroelectric plants, underground mine pillar stability, oil field well layout, regional crustal stress, and much more.

Recently, however, the reputation of hydraulic fracturing has been badly tarnished in the media. Hydraulic fracturing for boosting production has been under severe criticism in conjunction with the extraction of gas from the Marcellus Shale, which is found mainly in Pennsylvania and southern New York. Unfortunately, hydraulic fracturing for stress determination carries the same name, and to the uninitiated the difference is not clear.

Because shales ordinarily have insufficient permeability to allow significant fluid flow to a well bore, most shales are not commercial sources of natural gas unless artificially fractured to provide avenues for fluid (or gas) escape. *- continued -*

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TECH Notes

Monitoring

Three monitoring methods can lead to better understanding of MMHF. (1) Microseismic monitoring shows the spatial distribution and magnitude of seismicity associated with bedding plane slip as well as slip of natural and incipient fractures; the dilated volume limits are thought to be contiguous with the region emitting microseismicity. (2) Deformation monitoring using tilt-meters allows decomposition of the fracturing process into vertical and horizontal components and provides insights into the shape and magnitude (ΔV, shear) of the stimulated zone. (3) Pressure tests during and after MMHF allow insight into the process, estimates of permeability, and estimates of the open volume generated. Pressure tests can involve simply post-MMHF decay, but can also use pulses or build-up and decay methods. Sophisticated analyses give insight into the stimulated zone extent, its deformability, and flow properties. These approaches can be implemented in "real-time" and in principle used to track and optimize treatments. Of course, this requires rapid analysis methods, excellent graphical capability, and a robust conceptual model of the mechanisms.

Mathematical Modeling

The MMHF process in stiff fractured rock has these physical, non-linear, and coupled attributes:

1. Strong coupling between fluid flow and deformations, even neglecting ΔT effects.
2. Strong influence of the natural fracture fabric, including incipient fractures.
3. Packing of sand into fractures with liquids propagating far beyond the sand zone in a filtration/separation process with friction of sand/water slurries in thin channels.
4. Wedging open of sand-filled fractures near the wellbore as well as wedging other fractures without proppant because of large volume changes.
5. Fracture slip and self-propping along fractures and bedding planes.
6. Block rotations and elastic compression affecting fracture apertures.
7. Massive alterations in fracture permeability as wedging, shear, and propping occur throughout the dilation zone.

MMHF analysis will have to rely on judicious simplifications and large scale averaging that will not degrade the physics beyond recognition, but permit some credible calibration by means of available field data. Field data reflect the MMHF process interacting with the stratigraphic, mechanical and fabric characteristics of the rock mass 1-3 km deep.

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OPINIONS:
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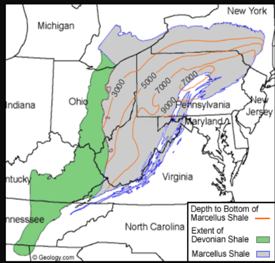

Above: Marcellus Shale extent and depth (in ft).

The shale gas boom in recent years has resulted from the use of production-stimulating hydraulic fracturing to create extensive man-made cracks around well bores. However, unlike the technique used for in situ stress determination, which utilizes small quantities of clean water (measured in liters), extracting gas entrapped in shale requires hydraulic fracturing of horizontal wells using many thousands of gallons of fluids. In addition, the aspect of production-related hydraulic fracturing (also called 'fracing') that concerns environmentalists is the use of chemicals in the fluids.

A recent Vanity Fair article is representative of the many publications in the mass media criticizing the use of chemicals in fracing the Marcellus Shale. Here is an excerpt:

> *"The Delaware is now the most endangered river in the country, according to the conservation group American Rivers. That's because large swaths of land—private and public—in the watershed have been leased to energy companies eager to drill for natural gas here using a controversial, poorly understood technique called hydraulic fracturing. "Fracing," as it's colloquially known, involves injecting millions of gallons*

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TECH Notes

Mathematical Modeling continued

We have much to learn about history-matching and model calibration from the petroleum reservoir engineers.

Continuum mechanics simulators (finite difference, finite element, boundary element, and displacement discontinuity formulations) experience severe difficulties in representing actual complex fractures systems with opening and closing apertures, propagating fractures, block rotation, slip, and self-propping. For example, how would you represent the massively changing permeabilities associated with block rotation and opening of a fracture? Can this be done using volume averaging methods with a large "unit volume"?

Can discrete element methods (DEM) come to our rescue as opposed to continuum modeling? A discrete particle code such as 3-DEC has exceedingly long execution times for massive numbers of blocks that are free to rotate. Such codes are also ill-equipped to handle fluid flow in fracture networks with simultaneous sand emplacement (filtration). As an alternative, can sand emplacement be treated entirely separately, simply generating an input file to the DEM simulator? What are the transport properties of sheared, self-propped fractures?

Despite these difficulties, at this point DEM methods offer the best hope in generating better MMHF models. As part of a hybrid approach, for example, a discretized portion of a representative continuum could be imbedded in a finite-element (FEM) region whose surrounding, in turn, is represented by a displacement discontinuity formulation, reducing the number of degrees of freedom by a factor of 3 to 5, compared to FEM alone.

Closure

The economic impact of MMHF activity will be huge, involving trillions of dollars. Better analysis is needed, but realistically, MMHF modeling requires decomposition of the problem into its simplest elements, and seeing how we can cope with first one, then another; I even recommend going back to 2-D DEM models before jumping to 3-D.

Progress in understanding and prediction needs monitoring to generate high-quality data to calibrate and verify models, and there is considerable value in the concept of calibrated models that are simplified, yet robust enough for use in subsequent, predictive analyses. This is in the best spirit of our discipline: do "hard" analysis when we can and when it is of benefit, use common sense, monitoring data and simplifications as we must to address real-world issues.

OPINIONS:
Hydraulic Fracturing Gets a *BUM RAP*

of water, sand, and chemicals, many of them toxic, into the earth at high pressures to break up rock formations and release natural gas trapped inside."

Just today, February 1, 2011, New York Times reports that Congressional investigators have charged that from 2005 to 2009 "tens of millions of gallons of diesel fuel were used by drillers as part of a contentious process known as hydraulic fracturing, or fracing", raising concerns "over the potential for fracing chemicals — particularly those found in diesel fuel — to contaminate underground sources of drinking water."

The use of the same term for both fracturing methods is truly unfortunate. I have received inquiries in my office from journalists and others, requesting that I list the chemicals we use in hydraulic fracturing, although as I stated above, only small amounts of tap water are employed in fracing for stress measurements.

Changing the name of the in situ stress method now is a bit too late. However, it is important for everyone to realize that the procedure involved in measuring stress has little in common with production-related hydraulic fracturing practiced by the oil and gas industry.

Bezalel Haimson
University of Wisconsin

WORKSHOPS & CONFERENCES

THIS YEAR IN SAN FRANCISCO:

The 45TH U.S. Rock Mechanics/ Geomechanics Symposium

By Peter Smeallie, ARMA Executive Director

"If you're alive, you can't be bored in San Francisco. If you're not alive, San Francisco will bring you to life." (William Saroyan)

In 2008, the highly successful 42nd U.S. Rock Mechanics Symposium was held in San Francisco. Its success was due to a combination of San Francisco's breathtaking beauty and a program that featured key topics and speakers. In 2011, we invite you to again visit one of the great cities of the world and participate in a program that focuses on new and exciting advances in rock mechanics and geomechanics in the fields of geology and geophysics, civil engineering, mining engineering, petroleum engineering, and underground construction.

The focus of the 2011 symposium is on both fundamental and practical issues facing our profession. We received a record number of abstracts and have accepted 430 from 34 nations for podium or poster presentations. A special technical session will be devoted to rock mechanics in Afghanistan with invited Afghan scholars delivering papers.

World-renowned experts have been invited to address the symposium. Priscilla Nelson, NJIT, will deliver the third MTS Lecture on underground urban sustainability and rock mechanics. Mark Zoback, Stanford, will discuss achieving global CO_2 emissions reductions utilizing unconventional natural gas instead of large-scale carbon sequestration. He will also present findings from the National Academy of Engineering report on the causes of the Deepwater Horizon accident. Challenges involved and the behind-the-scene stories of the Chilean Mine rescue operation will be described by David Singleton, Layne Christensen Company. Rick Fragaszy, National Science Foundation, and Bill Roggenthen, South Dakota School of Mines and Technology, will address the future of the Deep Underground Science and Engineering Laboratory (DUSEL). Incoming ISRM President Professor Xia-Ting Feng will talk about his visions for ISRM and the upcoming 2011 Beijing Congress.

Technical tours are being planned to the U.S. Geological Survey in Menlo Park, San Andreas Fault visits, geological tours of the Sierra foothills, and the Geysers Geothermal site. "California Dreaming: The Very Best Field Trips" will feature tours of the California Wine Country, Alcatraz, Highlights of San Francisco, Golden Gate Bridge Experience, Dinner on the Waterfront Pier 39, Muir Woods and Sausalito, Lunch in Chinatown, North Beach Java Walk, and a special Dinner-Dance Cruise on San Francisco Bay.

The symposium will host an exhibition for companies and organizations to display and network with participants. Sixteen booths are available in the main symposium meeting room.

A block of hotel rooms has been reserved for symposium attendees at the Westin San Francisco Market Street. The Westin is located in the lively South of Market district, close to Union Square and the Financial District. Guests can walk to cable cars and trolleys that go to Chinatown, Fisherman's Wharf, and the Alcatraz ferry. The San Francisco Museum of Modern Art is also nearby. The San Francisco and Oakland Airports are easily accessible from the hotel by train. The Westin has made rooms available to symposium delegates at a very favorable rate.

Further information on the symposium can be found at www.armasymposium.org.

2011 SME Annual Meeting "Shaping a Strong Future Through Mining" will be held on Feb. 27 - March 2, 2011 at the Colorado Convention Center in Denver click here for details.

Two full sections on **Tues., March 1** are scheduled on applications of rock mechanics to open pit and underground mines.