Fall 2013, Issue 10

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ARMA E-NEWSLETTER

Edited and published by
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Summary of the 47th U.S. Rock Mechanics / Geomechanics Symposium

Laura J. Pyrak-Nolte, Jamal Rostami, Joe Morris, Alvin Chan and Russ Ewy

The 47th U.S. Rock Mechanics / Geomechanics Symposium was held in San Francisco, California this year on 23 - 26 June, 2013. This was one of the most successful symposia to date, with more than 350 papers, four keynote speakers, 44 technical sessions, two poster sessions, four short courses, three workshops, 15 exhibitors, three technical tours and a large number of exciting special activities. This multidisciplinary international annual meeting is the focal event for the rock mechanics and geomechanics communities, bringing together professionals and students from civil, geological, mining, geophysical and petroleum engineering. The symposium focused on new and exciting advances in rock mechanics and geomechanics that cut across disciplines and span the globe with more than half of the papers from 39 countries including the U.S. The keynote speakers provided insights into pore pressure in deep water (Peter Fleming), a perspective on current and future directions in carbon sequestration (Larry Myer), a fascinating description of the technical, political and socio-aspects of constructing a water tunnel from the Mediterranean Sea to restore the Dead Sea (Chris Breeds) and the current state of the art in monitoring landslides and other large-scale ground movements (Erik Eberhardt).

Technical Session Summaries

The technical sessions spanned a range of topics from civil, mining and petroleum engineering as well as cross-disciplinary topics that involved experts from many branches of science and engineering.

Mining - Jamal Rostami

Mining-related topics were presented in seven oral sessions as well as one poster session that included topics in coal mining, numerical modeling, ground control, mine seismicity, deep hard-rock mining, weak rocks and evaporate, and production-related rock mechanics issues. The Symposium sessions provided opportunity for about 48 presentations and nine posters. The increased use of mine seismicity and monitoring of the seismic events to improve the working conditions in deep mines and prevent rock burst were discussed by the pertinent experts in the industry. Gabriel Esterhuizen discussed the strength parameters for modeling of the roof strata, and Kanaan Hanna presented the geotech-geophysical mapping of foamed-sand used as backfill in Colorado. Shivakumar Karekal from Australia reviewed design issues related to extraction of coal from multi-seam layers by highwall mining, and Biao Qiu reviewed his findings on the subsidence prediction for coal mining.

Ground control for underground and surface coal and metal mines was also addressed. This included a range of subjects from the use of close range photogrammetry in monitoring of open pit mines by Saeed Rezaei to the use of ground support measures including shotcrete and backfill by Arunkumar Rai, modeling of ground-support interaction by Catherine Banton, to a discussion of ground support in frozen ground by Sheila Ballantyne and a look at the sustainability in ground support by Boris Amusin. On the issue of rock mass characterization, Steve Rogers presented his findings about the Volumetric Fracture Intensity Measurement for improved rock mass characterization in block caving operations and Laura Olson presented her findings on 2-D and 3-D imaging of core for fracture mapping in Canada, followed by the discussion of rock mass characterization and conceptual modeling of caving in the Malmberget Mine by Sraj Umar from Sweden.

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SYMPOSIUM Results

Summary of the 47th U.S. Rock Mechanics / Geomechanics Symposium (continued)

Numerical modeling of mining operation received a healthy treatment. Presentations included modeling of cable bolts and examination of active versus passive bolts by Michael Murphy and Anil Ray, simulation of mine floor properties from pillar behavior by Douglas Tesarik, modeling of caving in coal mines and other forms of failures by Feng Cui, and finally numerical modeling of bio-stabilization of dump slopes was discussed by Dr. Vishal. Other topics dealt with cutting of limestone by Rasit Altindag, drilling with diamond bits by Masood Mostofi, reliability analysis of slope design (Ali Keneti), replacing of barrier pillar with backfill by Hamid Maleki, and accounting of confinement in stability of foliated rocks by Sanjive Narendranathan. Overall, the topics were of interest to many mining operations and to the ongoing efforts to address the complexity of mining applications in various environments.

Interdisciplinary - Joe Morris

A diverse collection of topics -- ranging from CO_2 storage and utilization to rock heterogeneity and scaling, from coupled processes in intact and fractured rock to the challenges facing high-performance computing, and from geophysics to uncertainty quantification -- was covered during the interdisciplinary sessions. In all, approximately 100 papers of an interdisciplinary nature were presented either at the podium or by posters at this year's conference.

Wrestling with the challenges of geothermal energy proved to be a popular topic this year with 12 podium presentations and five poster presentations. The papers covered topics that addressed not only the fundamentals, but also included many case studies of specific locations such as Newberry Volcano (Cladouhos, et al), Hengill Area in Iceland (Sveinbjornsson, et al.), Soultz-sous-Forets in France (Gentier, et al.), Northwest Geysers in California (Rutqvist, et al.) and more (Dempsey, et al.).

Improving our understanding of coupled processes, both within rock continua and within rock interfaces, received much attention with two dedicated podium sessions and six poster presentations spanning both experimental and modeling work. In the acoustic emission session, both passive and active techniques for monitoring the approach to failure were presented, demonstrating the blending of geomechanics and geophysics. Sergei Stanchits presented laboratory results that showed an increase in acoustic emission activity during the early stages of fracturing,related to the onset of volumetric rock deformation. Ahmad Hedayat showed from laboratory measurements that active geophysical monitoring yields signatures of precursor to failure along single joints.

The topic of CO_2 sequestration was expanded this year to included utilization, in keeping with the shift in emphasis that we are observing in this area. Many ongoing case studies were presented from around the world that included efforts in the Netherlands, India, Norway and others.

Civil Engineering

The civil engineering sessions focused on rock slopes, constitutive models, laboratory-scale rock mechanics, tunnels and caverns, dams and foundations, and discrete geomechanics. Many fascinating case studies were presented. In the dams and foundations session, Schlotfeldt, et al. discussed designed methods used for bridge piers in the presence of an unfavorably oriented joint set in the Kicking Horse Canyon in British Columbia. Hanna, et al. described emergency sinkhole mitigation using both high-and low-mobility grout to stabilize U.S. 24 at Tennessee Pass in Colorado.

Participants viewing geothermal vents at the Geysers. (Photos by Hill Montague for ARMA)

Two sessions were devoted to understanding rock with discontinuities such as fractures, joints and cracks through discrete geomechanics involving theoretical and numerical approaches. Gen-hua Shi discussed the importance of understanding and implementation of the mathematical concepts needed to simulate multiple contacts between blocks formed by discontinuities. Sitar used block theory to assess the stability of dams from hydraulic erodibility by identifying removable blocks and potential failure modes.

As landslides cause billions of dollars of damage throughout the world, two civil engineering sessions focused on rock slopes. Other presentations examined the effect of earthquakes on slope failure, fault models and design challenges of retaining walls and rock anchors.

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SYMPOSIUM
Results

Summary of the 47th U.S. Rock Mechanics / Geomechanics Symposium (continued)

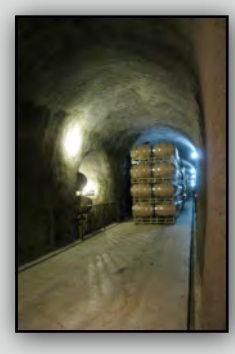
Petroleum - Alvin Chan

Participation from the petroleum community continued to see growth in the symposium. A large number of high-quality papers were submitted on topics such as experimental rock mechanics, fracture mechanics and geomechanics for conventional and unconventional resources. An increased interest was observed in coupled process modeling and a re-introduction of pore pressure modeling. The petroleum poster sessions also benefited both in terms of quantity and quality. Two sessions were dedicated to reservoir geomechanics with topics that ranged from post-depletion subsidence to intensely faulted reservoir -- as well as fault reactivation and natural fracturing processes. Three sessions focused on coupled-processes, from modeling to experiments. Izadi, et al. discussed the evolution of permeability, seismicity and heat production in geothermal reservoirs. Other topics included the scaling relationship between fluid flow and fracture specific stiffness, stress effects on flow partition in fractured reservoirs, fluid-driven fractures and other fluid-mechanical coupling. Three petroleum sessions (two podium and one poster) were on experimental rock mechanics related to shale, mudrocks, chalk and sand. Fjaer and Nes discussed the strength anisotropy of Mancos shale based on extensive uniaxial and triaxial testing and found the weakness of bedding plane strongly impacts the strength. Other shale-related topics included novel methods for measuring the elastic properties of shale and coupled thermo-hydro-mechanical behavior of shales. Holt, et al. gave an interesting presentation on static versus dynamic moduli and on discrepancies between the two.

Technical Tours - Russ Ewy

A technical tour was organized to The Geysers geothermal field. The Geysers cover some 45 square miles, 388 wells, 15 power plants with 725 megawatts capacity, 80 miles of steam pipelines, and 69 miles of injection water lines. The Geysers has been producing geothermal energy since 1920, and currently accounts for 39% of total U.S. geothermal power. One particular area has been recently used for an Enhanced Geothermal Systems demonstration project. Yet water injection has actually been going on for many years at The Geysers, and they currently have 53 injection wells. Reclaimed municipal wastewater is used for injection; they treat and inject over 16 million gallons of water per day.

Two other technical tours rounded out this year's offering. J. Casey Moore, Professor at UC Santa Cruz, along with his associate Bob Garrison, conducted a tour of several interesting and unique features along the coastline near Santa Cruz. Attendees were able to view (and understand) sandstone intrusions, paleostress indicators, hydrocarbon fronts, dike sill complexes, and carbonate cold seep structures. The third technical tour was the ever-popular geological engineering tour of the San Francisco peninsula, led by Prof. Richard Goodman and his associates Dale Marcum and John Wallace.



Future Leader Initiatives

Two new events were held at the Symposium this year thanks to the efforts of the Future Leaders of ARMA (Alvin Chan, Amie Hows, Haiying Huang, Thierry Lavoie, Michael Murphy, Marisela Sanchez-Nagel, Maria-Katerina Nikolinkakou, Azadeh Riahi, David Scarpato, and Karim Zaki). The first event was a career center where students/members posted resumes and industry/ academia posted job openings.

Left. Rock engineered wine caves at Rutherford Hill Winery.

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Future Leaders Program

The ARMA Future Leaders group was organized with a number of purposes in mind. Primary goals were to provide for continued relevance to rock mechanic and geoengineering issues as they emerge over time, and to ensure that the organization has an enduring foundation as it evolves to be representative and useful to its members. These purposes are demonstrated in recent activities by members of the program.

Future Leaders have been fully engaged in supporting ARMA annual symposia through participating in the organizing committee, developing and chairing sessions, reviewing papers, and selecting awards for papers and posters.

At the recent San Francisco Symposium, members of Future Leaders were active in a number of other ways. Many of these activities were summarized in a preceding article (e.g. Career Corner, Trivial Pursuit contest). In addition, a Linked-In and email site was set up to facilitate communications. A second class of ARMA young members were elected as additional members to the group and will be expected to help serve in future events and activities.

Finally, another activity has been to expand the reach of rock mechanics/ geomechanics professionals and academics by collaborating with external societies. Future Leaders initiated an ARMA co-sponsorship of the AAPG Geosciences Technology Workshop on Geomechanics and Reservoir Characterization of Shales and Carbonates, held 16-17 July 2013 in Baltimore, MD.

New Future Leaders, nominated by current Leaders and approved by the Board of Directors are: Dale Walters (Taurus Reservoir Solutions), Sherif Alk (Cairo University), Ivan Gil (BP), Chloé Arson (Georgia Institute of Technology), Chi Hyun Park (Schnabel), Matt Pierce (Itasca), and Gang Li (FTS International).

This article is based on reports submitted by Gang Han, Mike Hardy, Haiying Huang, and others.

Above. Students and potential employers gather at the ARMA Career Center organized by the Future Leaders at the San Francisco Symposium. (Photo by Hill Montague for ARMA.)

SYMPOSIUM Results

Summary of the 47th U.S. Rock Mechanics / Geomechanics Symposium (continued)

Future Leader Initiatives (continued)

The second event was a student trivia contest held on Monday night. Students competed for a team prize by answering 33 trivia questions such as "What is the minimum grade that can be mined at a profit?", "In a thrust faulting stress regime, which direction will a hydraulic fracture propagate?" and "What type of seismic wave travels the fastest: P-wave, S-wave or surface wave?". The winners were a two-member team: Luca Urpi, a PhD student from the Freie Universitat in Berlin, Germany and Luke P. Frash from the Colorado School of Mines.

Above Left. J. Casey Moore and participants on the carbonate technical tour; Above Middle. Discussions at the Career Center.; Above Right. Winners of the student trivia contest, Luca Urpi and Luke P Frash with Marisela Sanchez-Nagel. (Photos by Hill Montague for ARMA)

ARMA News Briefs

Unconventional Geomechanics Workshop

A workshop organized by Prof. Azra N. Tutuncu on Unconventional Geomechanics was held prior to the 47th U.S. Rock Mechanics / Geomechanics Symposium in San Francisco; the session featured distinguished speakers sharing their research as well as fruitful discussions. Workshop presentation material can be viewed at http://ungi.mines.edu/events.html.

Future Event: ARMA in Minneapolis

The 48th US Rock Mechanics and Geomechanics Symposium will be held in Minneapolis, 1-4 June, 2014. The Organizing Committee, led by Joseph Labuz and Emmanuel Detournay, is already working to ensure an exciting and quality program for ARMA members. The theme they have selected will be "Rock Mechanics Across Length and Time Scales." They have issued the Call for Papers, with a deadline for submission of abstracts on 1 November, 2013. For further information or to submit your abstract, see www.ARMAsymposium.org.

Future Event: Brazilian Symposium of Rock Mechanics (SBMR)

The Brazilian Rock Mechanics Committee and ARMA are co-hosting the sixth Brazilian Symposium of Rock Mechanics (VI SBMR) to be held in the city of Goiania, Brazil, on 9-13 September 2014. The symposium will be held in parallel to the Brazilian Congress of Soil Mechanics and Geotechnical Engineering. The website is: www.gtep.civ.puc-rio.br/sbmr2014. Abstract submission deadline is 11 November 2013. Please submit to: http://www.qeeventos.com.br/qeeventos/site/html_include/Edital_Ingles_Cobramseg2014.pdf.

Future Event: Discrete Fracture Network Engineering Conference

The International Conference on Discrete Fracture Network Engineering will be held in Vancouver, Canada in October 2014. The theme of the Conference is Engineering Characterization of Fractured Rock Masses: Applications of Discrete Fracture Network Engineering. The DFNE 2014 website is now in place at www.dfne2014.ca. DFNE practitioners are invited to submit abstracts of up to 400 words by 31 January, 2014. All abstracts and papers must be submitted electronically at www.dfne2014.ca/abstract- submission.php.

FEATURED Article

My Career in Rock Mechanics

Charles Fairhurst, Professor Emeritus – University of Minnesota, Senior Consultant, Itasca Consulting Group; Minneapolis, Minnesota

Editor's Note: As a new initiative of the Publications Committee, we will ask some of the pioneers in the field of Rock Mechanics to tell their stories of how they started their careers in rock mechanics. The first of such featured articles is on Dr. Charles Fairhurst. The first installment in the series was published in Issue 9 of the ARMA e-Newsletter and told of his life and career path prior to developing the rock mechanics program at the University of Minnesota. The second article presented in this issue continues to cover his time at Minnesota from the 1950's to the present era.

Part Two: How I Came Into Rock Mechanics

The first part of the story of my Minnesota adventure in rock mechanics[1] ended at the beginning of 1957. I had arrived at the University of Minnesota in summer 1956 and in Spring 1957[2] had accepted Professor Pfleider's invitation to develop a graduate rock mechanics program in the School of Mines and Metallurgy.

Although there was, at the time, no established U.S. graduate program to use as a guide, it was a time of considerable research activity within the U.S. and internationally. The first U.S. Symposium on Rock Mechanics, sponsored by the Colorado School of Mines (CSM)[3] had been held at CSM, 23-25 April, 1956 and was about to become an annual event.

My undergraduate studies and practical experience indicated that prospective graduate students arriving with a similar background in mining engineering would require considerably better preparation in mechanics, if they were to contribute to the emerging discipline of rock mechanics. Civil engineers might have some knowledge of soil mechanics – but they, too, would require additional preparation in mechanics.

I could not provide this background alone.

At the time, the University of Minnesota had a Department of Mechanics and Materials (M&M), where graduate courses in continuum mechanics, elasticity, plasticity, viscosity, wave propagation, experimental stress analysis etc. were taught by distinguished colleagues. I decided to approach them for help. Professors Al Blatherwick, Roger Fosdick, C.C. Hsiao, Larry Goodman, Phil Hodge, Bob Plunkett, and Bill Warner all responded enthusiastically. They indicated a willingness to introduce supplementary material to some courses, serve as Ph.D. co-advisors to students, etc. The courses also required additional preparation in Applied Mathematics.

Eventually, this strong fundamental preparation in mechanics became the hallmark of rock mechanics at Minnesota -- with much of the credit due to our colleagues in M&M (now the Department of Aerospace Engineering and Mechanics).

At the same time, I started to prepare courses to focus on the specific application of mechanics to rock.

Texts and publication in classical theoretical and experimental mechanics were abundant, but applications to rock were relatively sparse. Several relevant books and papers were beginning to appear. Some that I found informative included:

- H.Kolsky (1953) Stress Waves in Solids, Clarendon Press (Oxford).
- J.C.Jaeger (1956) Elasticity, Fracture and Flow, with Engineering and Geological Applications Methuen (London).[4]
- R. V. Proctor and T. L. White (1946) Rock Tunneling with Steel Supports, with an Introduction to Tunnel Geology by Karl Terzaghi, Commercial Shearing & Stamping Co.
- H. Labasse, (1949) Les pressions de terrains dans les mines de huiles. Revue Universelle des Mines. Liege, Belgium, Series 9, Vol. 5, No. 3, 78-88.
- J. Talobre (1957) La mécanique des roches: appliqueé aux travaux publics, Dunod (Paris).
- E. de St Q. Isaacson (1958) Rock Pressure in Mines, Mining Publications (London).
- J. Mandel (1959) Les calculs en matière de pression de terrains Rev.de L' Industrie Minerale Jan-Fev.[5]
- D.S. Berry and T.W. Sales (1960-62) An Elastic Treatment of Ground Movement due to mining: Part I, Isotropic Ground, Vol. 8 – 4, pp.280-292, 1960; Part II, Transversely Isotropic Ground, Vol.9 -1 pp. 52-92, 1961; Part III, Three-Dimensional Problem-Transversely Isotropic Ground, Vol.10 -1, pp.73-83, 1962.

[1] See ARMA Newsletter, Spring 2013
[2] The date of 'Spring 1956', given in Part 1, was incorrect.
[3] Part 1 of my notes failed to note the central role of Dr. Howard L. Hartman in helping to establish the Symposium series, i.e. 1956, 1957, 1959 at the Colorado School of Mines, and 1961 at The Pennsylvania State University.
[4] This excellent and concise text (152 pages) provided much of the fundamental rock mechanics for the classic J.C. Jaeger and N.G.W. Cook (1969) "Fundamentals of Rock Mechanic" Methuen (London).
[5] Translation - C. Fairhurst.. 'Rock Pressure Calculations' Nottingham Univ, Mining Mag., 67-81 (1964).

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FEATURED Article

My Career in Rock Mechanics (continued)

Kolsky -- a classic text -- was clearly relevant to the ongoing research on drilling of hard rock and to studies of rock blasting.

Proctor and White described the standard procedure in the U.S. for design of tunnel supports,especially in civil engineering. Terzaghi described the empirical 'Terzaghi Rock Load' method of calculating the (constant) load to be carried for various ground conditions. This reflected the U.S. tradition in which the steel support was designed by structural engineers based on a constant load, prescribed for them by geotechnical engineers. The Rock Load method was derived from soil mechanics.[6]

Labasse, Professor of Mining Engineering at the University of Liège, Belgium, had published a series of papers in which he describes what is now referred to as the Convergence-Confinement Method of support design -- the principle behind the NATM (New Austrian Tunnelling Method) now in general use for tunnel support design. I translated the papers and provided copies to all students. The Introduction to the first paper describes well the practical constraints in support design:

> *"First, the types of support to be used [in the mine] must be limited to one or two in order not to disrupt the material supply operations underground. This standardization makes precise calculation of a support for each section [of tunnel advance] useless. Further, the need to install the support immediately after excavation does not allow time to make calculations and fabricate the support. In order to arrive at a precise determination it would be necessary, in fact, to study each section separately because it would differ from neighboring sections with respect to the rock layers encountered, their dip and their disposition. It would be necessary to take a test specimen from each layer, determine its properties and the influence of these properties on neighboring layers. This would require a series of experiments and mathematical analyses whose solution, assuming that a solution is possible, would take up precious time during which the excavation would certainly have collapsed."*

Thus, a good support design is one that (1) will stabilize the excavation for the conditions to be expected, and (2) is capable of being adapted to deal with changes from these conditions as they are revealed at the face during excavation. [Note also that time is mentioned as a factor.] The terms design-as-you-go and the observational approach are sometimes used to describe this method implied by Labasse.

Talobre's text provided valuable insights into the European approach to application of rock mechanics in civil engineering. Isaacson,[7] an English physicist, had relocated to India and became affiliated with the Kolar Gold Mines[8] in Southern India, in charge of the Rockburst Research Unit. Together with the Gold Mines of the Witwatersrand, the mines in Kolar (closed in 2001) were the deepest in the world. Rockbursts were a major hazard in both mining regions, and remain so in South Africa[9]. The book provides an interesting account of the practical insights that Isaacson gained from basic elasticity theory. Unfortunately, it also contains an example of a serious mis-application of elasticity theory to design in rock. On page 34, (first paragraph) it is stated: *"Thus, we have the important result: when the axes of a tunnel of elliptical cross-section are in the same ratio as the principal stresses, and if the major axis is in the same direction as the major principal stress, then maximum stability will be achieved."* While it is true that in an ideal isotropic material, the tangential stress around the boundary of an elliptical opening of this shape and orientation will be constant., the strain energy distribution behind the boundary is far from uniform. If the elastic limit is exceeded, as in the event of a rockburst (e.g. from dynamic slip on a fault), which creates a stress wave that impinges on the tunnel and overloads the boundary, it is seen that this shape is far from stable. A photograph of the consequences of such a rockburst on an elliptical tunnel excavated at Kolar is shown (without explanation) in the Frontispiece to the book[10]. The same erroneous design principle, sometimes referred to as the *Harmonic Hole* concept, has appeared in more recent discussions. (This topic is discussed in detail in footnote 5.) It is argued that an ellipse oriented at 90° to that suggested by Isaacson would be preferable in the event of a burst, as would be a (more practical) circular tunnel.

Mandel's paper was another that I translated and distributed to students.

Berry and Sales' papers provide a very good example of using elasticity theory to develop important insights into the behavior of rock, in this case surface subsidence due to longwall coal mining. (Surface manifestation of the underground extraction involves significant time dependence, but these were secondary to the goals of this study.) This group of papers stimulated an exchange with Dr. Berry during my sabbatical years in Nottingham (1963-64) and Dr. Berry's follow-up return visit and lecture series at the UMN in 1965.

Preparation of lecture material implied that there were students interested and available to study rock mechanics at the University of Minnesota. In fact, students did not appear automatically. A one page announcement outlining the rock mechanics program and a general curriculum for both Master's and Ph.D. students with details of three (one–quarter) courses in rock mechanics had been circulated to all U.S. mining and civil engineering departments.

[6] See detailed discussion in Fairhurst, C. and C. Carranza-Torres. (2002) "Closing the Circle — Some Comments on Design Procedures for Tunnel Supports in Rock," Proc 50th Annual Geotech. Conf. (Feb.), pp. 21-84. Minneapolis: University of Minnesota.
[7] He visited the UMN and lectured to students in the early 1960's.
[8] The Kolar Mines are about 70km east of Bangalore. When closed in 2001, the deepest mine reached a depth of approx. 3.2 km. The world's deepest mine Tau Tons Gold Mine in South Africa is currently at 3.9 km.
[9] In South Africa, "The Leon Commission (1994) reported that more than 69,000 mineworkers had lost their lives from 1900-1994 while a million had been injured. The biggest contributors to fatalities and injury were rockfalls, rockbursts and seismicity." Mining Weekly, Feb.1,2008. D. Ndaba.
[10] Several pictures of damaged roadways can be found in Caw, J. M. (1956). "The Kolar Gold Field". Mine and Quarry Engineering 22, 306–316. London.

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FEATURED Article

My Career in Rock Mechanics (continued)

The results were very disappointing. Rock mechanics – or at least the version described in the flyer – seemed to be of little interest to U.S. students in the late 1950's and early 1960's.

We decided to cast our net wider. A modified version of the flyer was sent to civil, mining, and geological engineering departments internationally. This proved to be more successful, and students began to arrive from a variety of countries. By early 1960-61 we had assembled a group of graduate students -- mostly mining and civil engineering undergraduates from around the world, including a few from the United States. They accepted the challenge of a demanding series of courses with enthusiasm. More than one faculty member in M&M remarked "I have never seen such a hard-working group." A truly exceptional group, they deserve much of the credit for helping to establish the Minnesota program and its tradition in rock mechanics.

The 'tempo' and tight camaraderie developed by the early group was carried forward to the later arrivals, and continues at Minnesota today. Many of these graduates are now recognized for their contributions to rock mechanics internationally, both in academia and industry. (See Appendix 1 for a list of all of the Ph.D. graduates for whom I served as primary Adviser).

This group was augmented over the years by a substantial number of other students and international visitors -- Post–Doctoral students and Master's students (many of whom completed Ph.D. studies at other universities, while others developed prominent careers in industry); and still others, already faculty members at other universities, who came to the University of Minnesota to spend one or two years to update their skills and then return home. Mr. Dong Kie Kim of Seoul National University (SNU), Korea was in this category. Dong Kie arrived at almost the same time as I did, under the auspices of the FAO (Foreign Operations Administration)[11]. He was one of the first students to take a course in rock mechanics and assist with the drilling research. He returned to Korea in 1959. I lost contact with Dong Kie for some years, only to learn the tragic news in 1969 that he had lost his life while preparing to climb Mount Everest. It was only in 2012, at the ISRM Congress in Beijing that I learned from SNU Professor (now Emeritus) Chung-In Lee that it was Dong Kie who introduced rock mechanics to Korea in 1960 "as a new and a promising research field in mining engineering [gained] through his study experience in the University of Minnesota. It was a great stimulation and motive in my life for me to begin the study of Rock Mechanics." Professor Lee, former ISRM Vice–President for Asia, is recognized as the person who has led the development of rock mechanics in Korea.

As mentioned earlier, Professor Pfleider had been active, even before he had invited me to develop the rock mechanics program, in inviting international researchers to visit Minnesota and deliver a series of lectures. One of the first to arrive in early 1957 was Professor E (Ted) L. J. Potts of King' College, Newcastle-upon-Tyne, England[12], an authority on rock mechanics instrumentation and experiments in underground mines. He was eager also to attend the Second U.S. Symposium on Rock Mechanics, 21-24 April, 1957 at the Colorado School of Mines.

I had just purchased my first car, an Oldsmobile 88, and planned to drive to the meeting. Since this was Prof. Potts first visit to the U.S., he was keen to see the mid-West and accepted my invitation that we drive out together. A keen driver, he 'took the wheel' for most of the trip- exhilarated by the long open roads across the Central plains[13].

The Second Symposium, "Behavior of Materials of the Earth's Crust," signaled recognition of the importance of understanding the behavior of rock on both the laboratory and field scale. It was here that I first met Alistair Black, then Professor of Mining at the University of the Witwatersrand, Johannesburg. Professor Black later moved to Imperial College, London. He persuaded Dr. Evert Hoek to move from CSIR[14] Pretoria, South Africa to Imperial College, where Hoek established the Post-graduate School of Rock Mechanics in 1966.

The Third Symposium on Rock Mechanics, again at CSM in Golden, took place on 20 -22 Aprl, 1959. This attracted U.S. and international speakers on a broader variety of topics, both theoretical and applied. Professor Leopold Müller, of Salzburg, Austria, spoke on *The European Approach to Slope Stability Problems in Open Pit Mines*.[15] Dr. Nils Hast of Sweden, an authority on in-situ stress determination -- using a high modulus overcoring technique[16] -- also participated. It was at the Third Symposium also that I met Mr. Ken S. Lane of the U.S. Army Corps of Engineers. Ken became an invaluable ally in supporting the rock mechanics research program at the UMN.

[11] In September 1954 the University of Minnesota entered into a contract with the Foreign Operations Administration (FAO), designed to assist in strengthening and developing the educational and research programs of the Seoul National University (SNU) of Korea. SNU had been badly damaged during the Korean War. FAO evolved into today's U.S.AID (Agency for International Development).

[12] In 1963, King's College became the University of Newcastle upon Tyne, and today, Newcastle University.

[13] This was the period of the Suez Canal crisis and Potts had left England where gasoline had been severely rationed for many months. Prof. Potts took special delight to drive into the gas station en route, new Stetson hat on his head, roll down the car window, and cry out, "Fill' er up!"

[14] Council for Scientific and Industrial Research.

[15] This led subsequently to a dialog with Adolph Soderberg and Donald Rausch of Kennecott Copper in Salt lake City for whom stability of open pit slopes was a serious issue. Don Rausch later participated with me, at the invitation of Prof. Müller, as the other U.S. Member of the Salzburg Circle (discussed later in these notes).

[16] Nils Hast (1958) The measurement of rock pressure in mines. Norstedt, Stockholm.

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FEATURED Article

My Career in Rock Mechanics (continued)

Professor Müller visited the UMN on his return from the symposium. We had several very stimulating discussions concerning the challenges of rock engineering in both Civil and Mining Engineering. This was the start of a long and valuable interaction with Professor Müller.

He invited me to join a group of Austrian colleagues, the 'Salzburger Kreis' (Salzburg Circle), concerned about the need for international attention to practical problems of engineering design in or on rock. The collapse of the Malpasset Dam in France in December 1959 and difficulty of tunneling in the Alps[17] were major concerns in Europe. The coal mine disaster in January 1960 at Coalbrook, South Africa[18] underlined the need for a better understanding of rock mass behavior.

The discussions culminated in the decision to establish the International Society for Rock Mechanics (ISRM), in Salzburg, in May 1962, with Professor Müller as President, and his colleagues as founding members.[19] Don Rausch of Kennecott also participated in several of the meetings. With most in attendance twenty years or more my senior, I learned a great deal from the 'Circle' members and their colleagues of the major challenges of engineering in rock. Most of the Circle members transferred to the ISRM, as can be seen in the 'first twenty' list in Appendix 2.

Dr. Müller also invited me to join him as co–editor of the journal (originally Geologie und Bauwesen) founded by his teacher Josef Stini, which he renamed Rock Mechanics and Engineering Geology (Appendix 2). This is now known as Rock Mechanics and Rock Engineering, co-edited by Prof. Herbert Einstein and Giovanni Barla.

At the UMN, experimental research on rock drilling was progressing. We had been successful in receiving research support from the Petroleum Research Fund (PRF). Research progress was evaluated on the basis of presentations and discussions at a meeting in Biloxi, Mississippi, attended by senior researchers from the petroleum industry and other recipients of PRF support. Discussions at this meeting led to an invitation to spend the summers of 1959 and 1961 at the Jersey Production Research (JPR) Company in Tulsa, Oklahoma. While at JPR, I had several discussions with Dr. Ralph Kehle -- a recent Ph.D. graduate in Mechanics and Geology from the UMN. Dr. Kehle was working on the mechanics of hydraulic fracturing. These discussions stimulated subsequent work at the UMN, leading to the development of hydraulic fracturing as a technique for in-situ stress determination.

The hydraulic fracturing research was part of a broader program on in-situ stress determination, stimulated in part by Prof. Samuel (Sam) S. Goldich, a geochemist at UMN. Sam had drawn my attention to difficulties being experienced in the Cold Spring Granite quarries, near St. Cloud, Minnesota. Apparently the rock was fracturing during the process of cutting blocks for dimension stone. I drove with Professor Goldich to the Rockville quarry where we were met by Mr. Alexander, the quarry owner. Walking briskly with his cane, Mr. Alexander led us down a long stairway into the quarry. Striding over to one corner of the quarry, he pointed his cane onto the rock surface. "There, young man, is where the pressure is! How do we deal with it?"

And so began a long and rewarding interaction with the Cold Spring Granite Company, resulting in research to develop in-situ stress determination techniques, field experiments, and Rock Mechanics Short Courses – conducted initially on the UMN campus, and later at St. John's University, Collegeville, near St. Cloud, MN. These short courses became popular in the mid 1960's, with an internationally distinguished faculty. (See Figure 1.)

Professor Jaeger was a regular participant in these courses. He became a close friend of the Alexander family, who had learned that Jaeger was fascinated by steam threshing engines. Threshing competitions with these vintage machines were held every summer near Cold Spring -- and the Alexander sons would try to ensure that Professor Jaeger could be there during the competitions. He and Mrs. Jaeger collected these machines, which they kept on their farm in Tasmania.

Right - Figure 1. Faculty- Rock Mechanics Short Course, Minnesota, 1966.

Left to Right: A.M. Starfield, R.E. Goodman, C. Fairhurst, P. Hackett, N.J. Price, N.G.W. Cook, J. C. Jaeger,. E. Hoek. (Faculty not shown – W.F. Brace, M.D.G.Salamon, T.A Lang)

[17] The New Austrian Tunneling Method was undergoing field development by Dr. Rabcewicz and Dr. Franz Pacher in Austria.
[18] Over 400 lives were lost at Malpasset and also at Coalbrook.
[19] See Appendix 2.

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FEATURED Article

My Career in Rock Mechanics (continued)

The U.S. Bureau of Mines opened the Twin Cities Research Center at Fort Snelling in the early 1960's.[20] This was a boon to the university graduate program -- especially since the Bureau was allowed to handle and use explosives, something not permitted on the university campus. The Bureau sponsored research, and several Ph.D. studies were carried out in collaboration with colleagues -- led by Tom Atchison -- at the Center.

In May 1962, the Fifth U.S. Symposium on Rock Mechanics was held at the University of Minnesota. I was co-Chairman with Professor Pfleider. One of my duties was to make a preliminary review of papers submitted for the symposium.

One of the papers, "The Seismic Location of Rockbursts" by N.G.W. Cook[21] of the Bernard Price Institute for Geophysical Research, University of the Witwatersrand, Johannesburg, South Africa caught my attention. It was clearly a significant contribution. I wrote to tell Dr. Cook that the paper had been accepted for presentation.

Dr. Cook wrote to thank us for accepting the paper, but expressed regret that he would be unable to attend the symposium.

This was particularly disappointing to me, since I was planning to spend my first sabbatical year, 1963-64, at the University of Nottingham, UK to interact with Dr. Peter Hackett, Mining Engineer, and Dr. Denis Berry, Applied Mathematician, both active in rock mechanics research. Dr. Cook seemed like the ideal person to replace me at the University of Minnesota for the 1963-64 academic year. I decided to telephone him. To my delight, he told me that he was available and agreed to come to Minnesota, beginning in September 1963, for the academic year. Although we 'overlapped' for just a few days after his arrival with his wife Jennifer, this was the start of a lifetime friendship between Neville, Jennifer, their children Anne-Marie[22] and Paul, and our family.

In 1965, at the invitation of the University Student Society, I made the first of many visits to Johannesburg, to the University of the Witwatersrand, Chamber of Mines & Mining Research Laboratory, the Centre for Scientific and Industrial Research in Pretoria -- all together, a very vigorous and stimulating group.

Together with several colleagues from the UK and the U.S., the South African group of researchers played a major role in bringing the latest international developments in rock mechanics to the staff and students of the University of Minnesota, and to rock mechanics professionals.

My sabbatical year (1963-64) at the University of Nottingham had been very beneficial, both professionally and personally. I became acquainted with Dr. Peter Hackett (later to become Dean of the Camborne School of Mines in Cornwall) and with Dr. Denis Berry.

My wife, Margaret, and our five children became acquainted with the English contingent of relatives, and we learned how to turn a large house[23] with no central heating into a happy home. Our neighbors, a local dentist and his wife, also with five children, welcomed us. They had removed the central heating system from their home when they purchased it, considering this innovation to be 'unhealthy.' On our return to Minnesota, we received several comments admiring the rosy complexions of our children.

Denis accepted my invitation to spend some months at the UMN, where he presented lectures on his research on rock deformation and mining induced subsidence to the rock mechanics group.

By 1965, I was allowed to add another faculty member to Rock Mechanics at UMN. During my visits to Johannesburg, I had come into contact with a young Applied Mathematician at the University, Dr. Anthony (Tony) M. Starfield. He had just completed his Ph.D. on heat transfer and ventilation cooling in hot and humid deep mines. I invited Tony to join the UMN to develop courses on 'modeling' in rock mechanics. To my delight, he accepted.

[20] The Center closed in 1995 when the U.S. Bureau was closed by Act of Congress –a consequence of the general perception that mining brought serious damage to the environment.

[21] This was Dr. Cook's first publication. It describes his Ph.D. studies at the Bernard Price Institute of Geophysical Research, University of the Witwatersrand, Johannesburg, South Africa.

[22] Anne Marie was born during this period in Minnesota.

[23] This was a remarkable Victorian 'stately home' –with large entrance gates, carriage house, tennis court, greenhouse, fruit and vegetable gardens –all rundown and overgrown. The kitchen included a 'servant call-bell' system, a coke-fired Aga stove, etc. The home was to be demolished and replaced by apartments. We were allowed to rent, mainly as a guard against vandalism.

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C. Fairhurst Appointed to French Legion of Honor

On 15 July, 2013, Charles Fairhurst was notified that he had been named an officer in the National Order of the Legion of Honor by the French government. He was cited for his "exemplary personal commitment to French-American relations as symbolized by (his) exceptional cooperation with French companies and contribution to many public-private partnerships in the field of rock mechanics." Further, he was recognized that his "commitment to training the next generation of engineers in this field is also a valuable contribution to a sustainable approach to geology." They stated that this decoration was a source of deep joy for those who admire (his) scientific leadership.

FEATURED Article

My Career in Rock Mechanics (continued)

He arrived in February 1966, greeted by the bitter cold of a Minnesota winter. Fortunately he was taken under the wing of a close friend, Dr. W.D. (Dave) Lacabanne, who steered this warm-weather South African safely through the remainder of the winter. Dr. Lacabanne had taught undergraduate classes in petroleum engineering, but collaborated with me on drilling research as well as setting up and taking charge of the rock mechanics laboratory. Every student benefitted from his help and learned quickly the rules of good laboratory practice!

The latter half of the 1960's saw a steady development of the rock mechanics program. Research on rock drilling, blasting, in-situ stress determination, design of tunnel supports, and the mechanics of rock fracture -- all were topics where progress was being made, thanks to the dedicated efforts and drive of the graduate students and to financial support from several agencies. The first group of Ph.D. students, whom I now counted as friends, was ready to graduate. Hassan Imam accepted a rock mechanics position at the University of Cairo, followed, in short order, by our first two U.S. students: Paul Gnirk, who returned to South Dakota, where he founded the rock mechanics company, RESPEC; and Bill Pariseau who started what would be a very distinguished career in rock mechanics applied to mining engineering, much of it spent as a Professor at the University of Utah. (Appendix I shows the complete list.) It is to this exceptional group that much of the credit is due for 'launching' rock mechanics at the University of Minnesota.

The 1970's opened with a major development. The School of Mineral and Metallurgical Engineering, of which I was now Head, was to be dissolved. Mineral Engineering and Process Metallurgy were to be joined with Civil Engineering to become the Department of Civil and Mineral Engineering. Physical Metallurgy was to be joined with Chemical Engineering. Another eventful phase for rock mechanics at Minnesota was about to begin –but that story must wait!

Appendix I

Ph.D. Graduates advised by Dr. Charles Fairhurst, University of Minnesota, 1965-2000.

Year	Graduate	Thesis Title
1965	Imam, Hassan F.	A Viscoelastic Analysis of Mining Subsidence in Horizontally Laminated Strata
1966	Gnirk, Paul F	An Investigation of Some Aspects of Contained Explosion Phenomena in Rock
1966	Pariseau, William G.	The Gravity Induced Movement of Materials in Ore Passes Analyzed as a Problem in Coulomb Plasticity [Advisor, Prof. E. P. Pfleider.]
1967	Kutter, Herbert K.	The Interaction Between Stress Wave and Gas Pressure in the Fracture Process of an Underground Explosion in Rock, with Particular Application to Pre-Splitting
1968	Wawersik, Wolfgang R.	Detailed Analysis of Rock Failure in Laboratory Compression Tests
1968	Haimson, Bezalel	Hydraulic Fracturing in Porous and Nonporous Rock and its Potential for Determining In-Situ Stresses at Great Depth
1968	Hustrulid, William	Theoretical and Experimental Study Of Percussive Drilling of Rock
1970	Crouch, Steven L.	The Influence of Failed Rock on the Mechanical Behavior of Underground Excavations
1970	Von Schônfeldt, Hilmar A	An Experimental Study of Open-Hole Hydraulic Fracturing as a Stress Measurement Method –with Particular Emphasis on Field Tests
1971	Porter, Darrell D.	A Role of the Borehole Pressure in Blasting: the Formation of Cracks
1971	Hudson, John A.	A Critical Examination of Indirect Tensile Strength Tests for Brittle Rocks
1973	Ash, Richard L.	The Influence of Geological Discontinuities on Rock Blasting
1973	Hardy, Michael P.	Fracture Mechanics Applied to Rock
1974	Roegiers, Jean –Claude	The Development and Evaluation of a Field Method for In-Situ Stress Determination Using Hydraulic Fracturing
1974	Van Eeckhout, Edward M.	The Effect of Moisture on Coal Mine Shales
1975	Cornet, François, H.	Analysis of the Deformation of Saturated Porous Rock in Compression
1975	Daemen, Jaak J.	Tunnel Support Loading Caused by Rock Failure
1978	Voegele, Michael D	An Interactive Graphics Based Analysis of the Support Requirements of Excavations in Jointed Rock Masses
1983	Detournay, Emmanuel	Two-Dimensional Elastoplastic Analysis of a Deep Cylindrical Tunnel Under Non-Hydrostatic Loading
1985	Leonard, Gideon	Fracture Mechanics Analysis of the Validity of Hydraulic Fracturing as a Technique of In-Situ Stress Determination
1992	Fakhimi, Ahmad Ali	The Influence of Time Dependent Deformation of Rock on the Stability of Underground Excavations
1992	Lin, Dezhang	Elements of Rock Block Modeling
1993	Santurbano, Robert B	An Experimental and Analytical Study of the Mechanics of Rock Particle Fragmentation During Impact Crushing
1996	Damjanac, Branko D	A Three-Dimensional Numerical Model of Water Flow in a Fractured Rock Mass
1998	Carranza-Torres, Carlos M.	Self-Similarity Analysis of the Elasto-Plastic Response of Underground Openings in Rock and Effects of Practical Variables
2000	Whyatt, Jeffrey D	Influences of Geologic Structures on Stress Variation and the Potential for Rockbursting in Mines with Particular Reference to the Lucky Friday Mine, Idaho

Note. Although William G. (Bill) Pariseau was advised by Professor Pfleider, he was a central member of the initial group of rock mechanics students, and so is included in the list above.

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My Career in Rock Mechanics (continued)

Appendix 2
International Society for Rock Mechanics –Early Members (1962)

1. Prof. Leopold Müller, Austria
2. Mr. F. Pacher, Austria
3. Prof. L.V. Rabcewicz, Austria
4. Mr. C. Lorber, Austria
5. Prof. F. Kahler, Austria
6. Dr. W. Zanoskar, Austria
7. Mr. W. Finger, Austria
8. Dr. A. Fuchs, Austria
9. Prof. F.K. Müller, Austria
10. Mr. P. Reska, Austria
11. Dr. K. Waschek, Austria
12. Prof. G.B. Fettweis, Austria
13. Dr. Georg Beurle, Austria
14. Neue-Reformbaugesellschaft MbH, Austria (Supporting Member)
15. Dr. Alois Kieser, Austria
16. Prof. H. Seelmeier, Austria
17. Dr. Adolf Bretterklieber, Austria
18. Mr. W. Wessiak, Austria
19. Prof. A. Watznauer, East Germany
20. Prof. Charles Fairhurst, U.S.A.

IN Memoriam

Obituary: Don Banks

Provided by Kelle Banks Barfield

Don Charles Banks, an ARMA Fellow, died August 11, 2013, at home in his library. He was 73.

Dr. Banks was born on March 17, 1940, in Dardenelle, Ark., and graduated valedictorian and class president of Russellville High School. He earned his bachelor's and master's degrees in civil engineering from the Georgia Institute of Technology and a doctorate of philosophy in civil engineering from the University of Illinois at Urbana-Champaign. He began a 35-year career at the U.S. Army Corps Waterways Experiment Station (WES) in Vicksburg, Mississippi, in 1962. During his long tenure, he became Chief of Engineering Geology and Rock Mechanics Division; he was later named Chief of Soil and Rock Mechanics Division, Geotechnical and Structures Laboratory. His leadership resulted in the Corps being recognized as pre-eminent in the field of rock mechanics.

In addition to being an ARMA Fellow, Dr. Banks was named a Fellow of the American Society of Civil Engineers. In 2012 he was admitted to the WES Gallery of Distinguished Civilian Employees for projects that included the following: Panama Canal stability surveillance; development of computer code capable of predicting behavior of soil, rock and groundwater; perfection of discontinuous deformation analysis computer modeling; and a study of U.S. Army Corps of Engineers' ability to build a permanent Moon habitat. After retirement, he continued his civil service to the United States as a contractor to the U.S. Department of Defense specializing in military applications of rock mechanics. He was also an international contributor to the field of rock mechanics, including co-authoring a book on rock-based construction and offering global instruction and mentoring for Engineers Without Borders. He authored or co-authored some 40 reports and papers throughout his career. The last was presented at the Hindu Kush Geoscience Conference at Kabul University, Afghanistan in 2011.

One of Dr. Banks' greatest joys was having lengthy debates about all things possible. Every subject was worthy of his passion, and every theory deserved greater exploration; he was always in mid-sentence. While humble, Dr. Banks inspired greatness through his own achievements and keen, insatiable curiosity. He instilled a drive for educational excellence, especially in his children and grandchildren. To him, no part of the world was inaccessible, and no idea was unachievable.