american rock mechanics association

ARMA e-NEWSLETTER 19

AMERICAN ROCK MECHANICS ASSOCIATION • ISSUE 19 • FALL 2016

In this issue

ANNOUNCING A NEW SPECIAL ISSUE

The ARMA Publications Committee is pleased to announce a call for contributions to the e-Newsletter's third Special Issue. Special Issues are devoted to a single topic of great interest to a large number of ARMA members. Two such special issues have already been published, ***"Geomechanics of Hydraulic Fracturing in Shale Formations"*** and "***Imaging and Remote Sensing in Rock Mechanics***".

The topic for this third Special Issue (to be published in the Winter, 2017 issue) is:

Discrete Fracture Network (DFN) Modeling in Rock Mechanics

The use of Discrete Fracture Network (DFN) models has become an important tool in rock mechanics in hydrocarbon extraction applications as well as in the mining and civil works design.

This topic will be of interest to anyone involved with rock mass modeling, mass mining, and fluid flow in jointed rock. Consequently, it should appeal to mining engineers, petroleum engineers, and geological engineers interested in such subjects as caving, design of support systems, hydraulic fracturing, underground excavations, geological disposal of waste, carbon sequestration, slope stability assessments in highly fractured rock mass, and others.

CALL FOR CONTRIBUTIONS

Please submit a "technical note" or a "case study" related to the topic above, no later than 24 December 2016.

Message to potential contributors:

ARMA e-Newsletter solicits original contributions that stand alone, but that commonly can be later developed into refereed journal papers, or summaries of previously published papers in journals not commonly read by many ARMA members. There are two kinds of contributions:

Technical Notes are original contributions on basic or applied innovative research related to a timely topic.

Case Studies are reports on investigations undertaken in field projects. Important scientific findings, major issues encountered, and lessons learned should be reported in some detail.

We welcome your submissions and all submittals will be considered. Manuscripts submitted to the ARMA e-Newsletter are reviewed by the ARMA Publications Committee, and their acceptance is based on the contents and the technical quality. Manuscripts containing commercial advertisements will not be published. Thank you.

Bezalel Haimson
Chair, ARMA Publications Committee

Houston Highlights

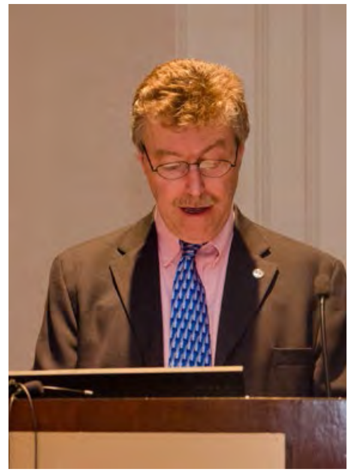
Submitted by Peter H. Smeallie, Executive Director, ARMA

The audience at one of the plenary sessions, ARMA Symposium, Houston, 2016.

The largest US Rock Mechanics/Geomechanics Symposium to date took place in June in Houston, Texas. At the 50th annual meeting of ARMA, over 700 delegates participated in presentations of 400 papers (oral and posters), four keynote lectures, two short courses and six workshops. The technical program focused on the interdisciplinary nature of rock mechanics/geomechanics.

Two papers were cited for distinction.[1] Anahita Modiriasari, Antonio Bobet, and Laura Pyrak-Nolte presented *Monitoring Rock Damage Caused by Cyclic Loading Using Seismic Wave Transmission and Reflection,* which describes the evolution of damage in prismatic Indiana limestone specimens when those samples were subjected to repeated cycles of uniaxial loading. The second paper by Shiva Esna Ashari, Giuseppe Buscarnera, and Arghya Das, titled *Evaluation of a Modeling Framework Capturing the Evolution of Permeability in Crushable Granular Solids,* describes the progression of rock fragmentation and the resulting loss of porosity and increasing surface area that is evaluated using the Breakage Mechanics theory of Einav (2007).

The Eighth MTS Lecture was delivered by Peter Kaiser from Laurentian University (Canada). Titled *Underground Rock Engineering to Match the Rock's Behavior: Challenges of Managing Highly Stressed Ground in Civil and Mining Projects*, the lecture advocated that underground mining or construction engineering solutions must "...respect the complexity and variability of the geology, consider the practicality and efficiency of construction, and provide safe and effective rock support." (See accompanying article.)



ARMA Fellow Derek Elsworth delivers his presentation at ARMA Symposium, Houston, 2016.

Richard Goodman, University of California, Berkeley (Emeritus), delivered the first ARMA Distinguished Lecture, *Comments and Observations on the Analysis of Discontinuous Rock Masses in Rock Engineering.* Jean-Claude Roegiers, University of Oklahoma, Norman (Emeritus), presented case studies that demonstrated the rapid growth of rock mechanics applications in the energy sector from exploration to abandonment. *Managing the Hazard of Induced Earthquakes in a Changing World* was the subject of keynoter William L. Ellsworth, Stanford University. The lecture described industrial activities that have the potential to induce earthquakes as an unintended consequence.

Prior to the symposium, in conjunction with the American Association of Petroleum Geologists (AAPG), ARMA sponsored the SedHeat Workshop on Successful Engineering of Sedimentary Geothermal Systems. The purpose of the workshop was to examine crucial issues impacting the successful development of sedimentary geothermal resources from an engineering standpoint. The third in a series, the workshop was organized by Texas Christian University with support from the National Science Foundation. Speakers and participants identified impediments to making sedimentary geothermal reservoirs a commercial reality.

According to Kate Baker, a participant at the session, the workshop put forward at least the following assertions:

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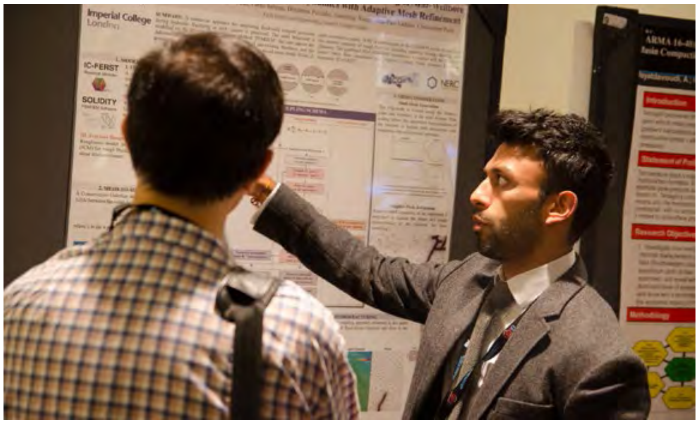
[1] Papers are available at a special rate for ARMA members through OnePetro: http://armarocks.org/resources/one-petro-digital-library/ or by purchase of the complete proceedings: http://armarocks.org/resources/bookstore



Poster session, ARMA Symposium, Houston, 2016.

- ◆ Horizontal wells and massive hydraulic fracturing are techniques that can be applied to Sed-Heat.
- ◆ We need to understand better the reservoir rocks and in-situ stresses. Effective heat extraction requires careful thought about the well geometry.
- ◆ Wells in sedimentary formations can be prolific; 50 kg/sec can be achieved in many formations. But hot water or steam is currently worth about 25cents/bbl; step changes are needed for geothermal to be a commercially viable energy source.
- ◆ Chemical effects still have not been adequately studied.
- ◆ Numerical models can forecast seismic hazard and maximum magnitude, but one needs event catalogues of about 1,000 events for each fault modeled. Earthquakes per mass injection are low when extraction occurs concurrently, and when the injection formation is not crystalline rock.

Other workshops took place over the course of the symposium: Workshop on Hydraulic Fracturing (See accompanying article); Geomechanics in Unconventionals Workshop for Asset Teams; How Laboratory Geomechanics Testing Adds Value to Exploration and Production; Microseismic Geomechanics from Laboratory to Field Scale Across All Industries; and ARMA Future Leaders/Students Open Discussion: "What's Your Problem?"

Continued success of the symposium was evidenced by the strong support of five corporate sponsors and 18 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 membership.

ARMA President John McLennan reported on the state of the association with mention of the continued growth as a professional society and in a discipline that continues to gain recognition and stature. He noted that the association was known as a place where innovative ideas and inter-disciplinary subjects were given free rein.

Underground Rock Engineering to Match the Rock's Behavior: Challenges of Managing Highly Stressed Ground in Civil and Mining Projects

Submitted by Peter K. Kaiser, Laurentian University, Sudbury, Ontario, Canada. This paper was presented as the keynote MTS Lecture at the 50th US Rock Mechanics / Geomechanics Symposium held in Houston, Texas, USA, 26-29 June 2016.

Preamble

Consistent with the theme of the symposium, "new exciting advances in rock mechanics," this lecture introduces several recent advances that are awaiting application in engineering practice and aims at opening new paths of discovery by questioning implicit assumptions in standard engineering approaches. The discussion is underscored by two principles: "No challenge is too big for rock specialists with the right know-how and skill." And relatedly, by reference to Figure 1, the same applies to safety, "If you put your mind to safety, you get safety and good performance, too."

Figure 1. Rock climbers or rock specialists at work on El Capitan in Yosemite National Park (CA) (Insert courtesy of G. van Aswegen)

The Storyline

A robust rock engineering solution in underground mining or construction must respect the complexity and variability of the geology, consider the practicality and efficiency of construction and provide safe and effective rock support.

For this purpose it is essential to anticipate the rock mass and excavation behavior early in the design process, i.e., at the tender stage before excavation techniques are chosen and designs are locked in through construction contracts.

Whereas it is possible in most engineering disciplines to select the most appropriate material for a given engineering solution, in rock engineering, a design must be made to fit the rock, not vice versa.

Lessons learned from excavation failures (Figure2) tell us that stressed rock at depth is less forgiving and that advances in rock mechanics demand a full comprehension of the behavior of stress-damaged rock near excavations.

Figure 2. Examples of excavation instabilities in stressed rock.

Comprehension in this context means explaining all observations such that fiction can be separated from reality and our engineering models and methods become congruent with the actual behavior of a rock mass. This article presents a discussion of aspects of underground rock engineering where dichotomies exist and gaps between reality and current practices have to be closed by the application of recent advances in rock mechanics to arrive at sound rock engineering solutions.

Excavation behavior

It is well-known that the excavation behavior depends on the rock mass quality or strength (horizontal axis in Figure 3) and the mining-induced stress (vertical axis on the right [9]). What is often ignored in practice, particularly when using empirical methods, is that mining-induced stress changes or variations in stress paths may drastically alter the excavation failure mode. During the life span of an excavation, the behavior mode may therefore change and with it the applicable engineering models may have to be changed accordingly.

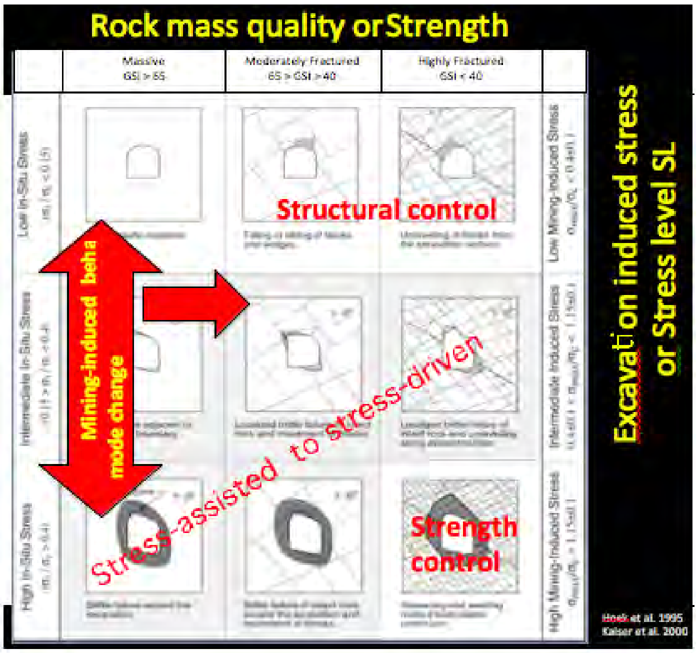


Figure 3. Excavation behavior matrix with indication of anticipated failure mode changes resulting from mining-induced stress-paths (after [3] and [8]).

As was illustrated by reference to field measurements from a caving operation, the stress level index SL = $(3\sigma_1 - \sigma_3)$/ UCS may change rapidly over the life span of an excavation from an initially rather favorable condition with $k=\sigma_1/\sigma_3$ ranging from 0.5 to 2 to very unfavorable conditions for k exceeding 3 with high stress concentrations (tangential stresses exceeding $8\sigma_1$) and simultaneous relaxation (σ_3 less than zero).

At greater depths, the behavior of underground excavations is therefore often affected or dominated by stress-fracturing (gray boxes in Figure 3) and may change drastically over its life span as stress changes will alter instability mechanisms. Because rock mass models typically only reflect one behavior mode they become frequently deficient when changes occur. A robust engineering design has to respect these behavioral changes.

Design-basis: fiction or reality

Whereas it is always necessary to make some simplifications for most engineering designs, as paraphrased by R. Sessions after A. Einstein, they should be as simple as possible but not simpler – or, in engineering terms "a little fiction is ok but not too much".

By exploring dichotomies between fiction and reality in engineering approaches, including numerical modeling and empirical methods, deficiencies in designs can be identified and eventually overcome, advances in rock engineering can be implemented, and new advances can be made. There is a need to close such gaps by matching designs to the actual rock mass and excavation behavior. Dichotomies between fiction and reality are explored for brittle failing rock with respect to:

- Failure criteria (peak and residual);
- Depth failure around excavations;
- Volumetric behavior of broken rock;
- Characterization for rock mass strength determination; and
- Rock mass heterogeneity.

For details related to rock mass characterization and for implications with respect to support design, the reader is referred to the on-line ISRM lecture [4] and the Sir Muir Wood lecture [5].

Failure criteria for brittle rock

Tensile stresses induced during loading in heterogeneous rock lead to Griffith-type extension fracturing with the consequence of depressing the failure envelope (Figure 4.) in the low confinement zone (at approximately s3 < UCS/10) where fracture propagation causing spalling cannot be suppressed by the available confining pressure.

The resulting failure envelope for rock affected by stress-fracturing is s-shaped or tri-linear, not linear (Mohr-Coulomb) or continuously curved (Hoek-Brown) ([7]).

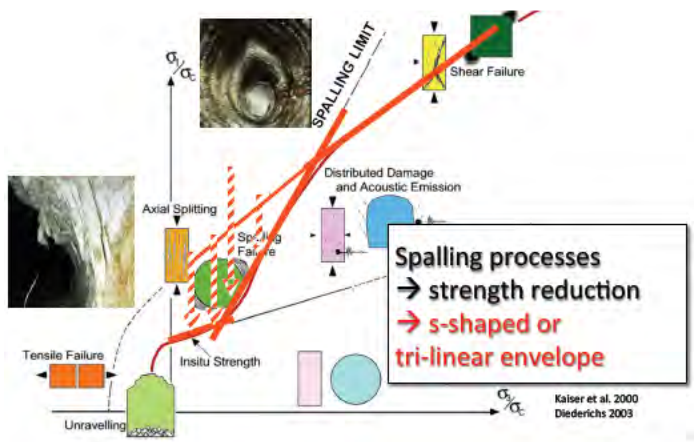


Figure 4. Principal stress space showing depressed failure envelope in low confinement range and related excavation failure processes: spalling, notching, and shear rupture.

The Mohr-Coulomb error

Schofield [11], by reference to Taylor's work and to Terzaghi's use of the Mohr-Coulomb (MC) criteria, pointed out that it is a serious error to assume that the cohesional and frictional strength components are simultaneously mobilized.

Supported by [9], it is now well-understood that the mobilization of the cohesive and frictional components of rock and rock mass strength is strain-dependent as reflected in the following revised version of the MC strength equation with cohesion, effective stress internal to the rock and the dilation angle depending on the plastic strain:

$$\tau = c(\varepsilon) + \sigma'(\varepsilon) \quad \tan(\varphi + i(\varepsilon))$$

Rock mass failure forecasting thus becomes highly sensitive to the assumed stress-strain characteristics, rendering many frequently adopted models (e.g., elastic, perfectly brittle plastic models) as fiction, i.e., far from reality.

Post-peak strength (PPS)

It is frequently assumed that the post-peak strength (PPS) is defined by the residual strength. This assumption becomes fiction and is not congruent with reality when the actual induced plastic strain is less that the strain needed to reach the residual strength. This is the case in most engineering problems, particularly for civil engineering applications. By considering Marble (Figure 5.) as an analogue for a rock mass, it can be seen that the PPS is strain-dependent, leading to a bi-linear PPS envelope with a cohesion intercept and a change in slope at the brittle ductile transition (σ_3*).With increasing strain, the mobilized PPS (m PPS) decreases and eventually reaches the residual PPS. The cohesion intercept and the location of the transition point of the mPPS are strain-dependent and the residual strength is, for most rocks, only reached at large strains (strains larger than typically encountered in underground structures)

Rock mass failure simulations utilizing purely frictional post-peak strength envelopes, with the PPS set equal to the residual strength, tend to underestimate the mobilized PPS and consequently lead to excessively large depth of yield predictions.

Strength degradation

When adopting GSI-based rock mass strength equations [3], it is implicitly assumed that the degree of interlock is sufficiently small such that rock block formed by open joints can rotate during the failure process. In massive to moderately jointed rock this is not the case and the strength is controlled by

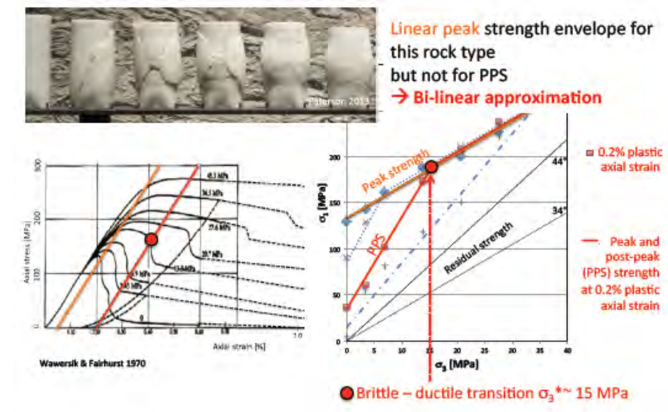


Figure 5. Marble as rock mass analogue indicating strain-dependent bi-linear post-peak strength (PPS) envelopes with brittle-ductile transition at σ_3 (modified after [12]). The peak strength and three mobilized PPS envelopes are shown in blue and red.*

stress-fracturing of rock blocks, rock bridges and asperities, and by the dilation of highly interlocked rock fragments. Hence, the strength degradation from the intact rock strength is much less at elevated confining pressures than conventionally assumed, at least at strains typically imposed in practice.

Consequently, the rock mass is much stronger than anticipated by the standard models (see [1]).

Failure envelopes for brittle rock

If the s-shaped peak strength envelope introduced in Figure 4 is fitted as an approximation by Hoek- Brown or Mohr-Coulomb parameters, unconventionally high m_b- and a-values emerge (see [4] and Figure 6).

Furthermore, the post-peak strength (see Figure 5) should rarely be set equal to the residual strength because of high initial post-peak rock mass dilation (see [4] and Figure 6).

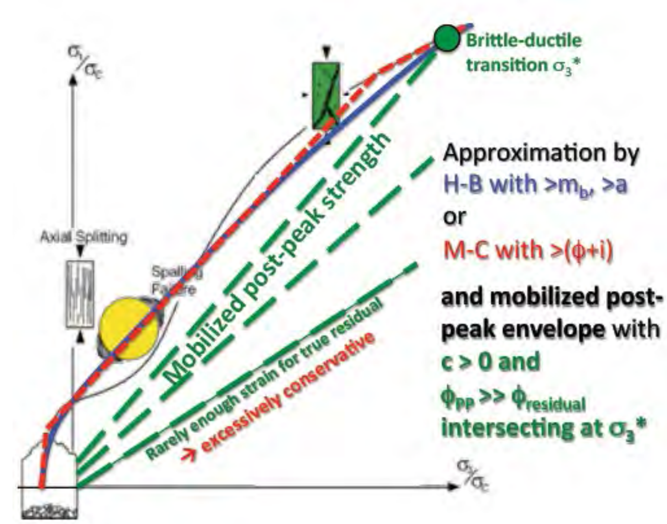


Figure 6. Illustration of means for approximation of s-shaped failure criterion and mobilized post-peak strength envelope.

It is recommended that the PPS envelope has to honor four points on the s-shaped envelope of the rock mass: the tensile strength, the unconfined compressive strength, the the midpoint of the spalling limit, and the brittle-ductile transition point at σ_3^*.

Inner versus outer shell behavior

From a practical perspective, the consequence of the above findings on the rock mass behavior and engineering design is a need to differentiate between engineering problems dominated by stress-fracturing (in the inner shell) and by shear rupture (in the outer shell). The threshold between the inner and outer shell is typically at about s3 = UCS/10 as shown in Figure 7.

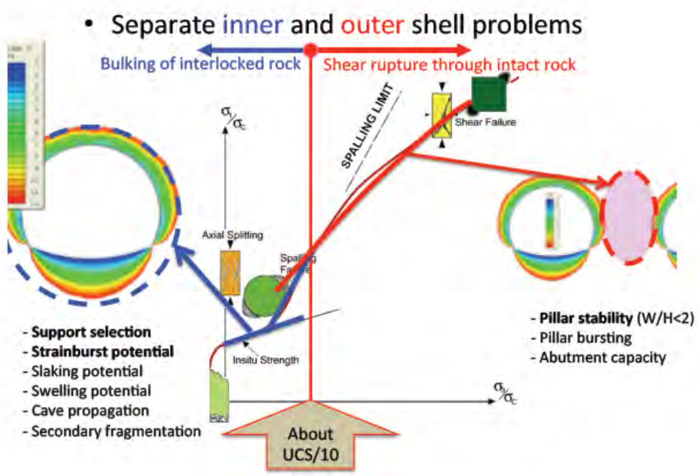


Figure 7. Zoning of stress space for inner and outer shell

Inner shell engineering problems are those dominated by the behavior of the rock mass in the immediate zone surrounding an excavation where the confinement is low, i.e., in the zone where stress-fracturing can occur and block/fragment rotation is possible. Engineering challenges of support design, strainbursting, etc. fall into the class of inner shelf problems.

On the other hand, engineering problems related to pillar instability fall in the outer shell class where shear rupture dominates due to sufficiently high confinement.

Depth of yield versus depth failure

Continuum models typically show indicators of yield and thus can be used to establish the depth of yield around an excavation (x in Figure 8; also shown are confinement contours for 0 to 10 MPa).

The three coloured points in Figure 8 indicate that the rock at these locations has a substantial cohesive strength and thus, while yielded, will not fall apart and fail under gravity loading alone (will not unravel). The depth of yield is therefore not the same as

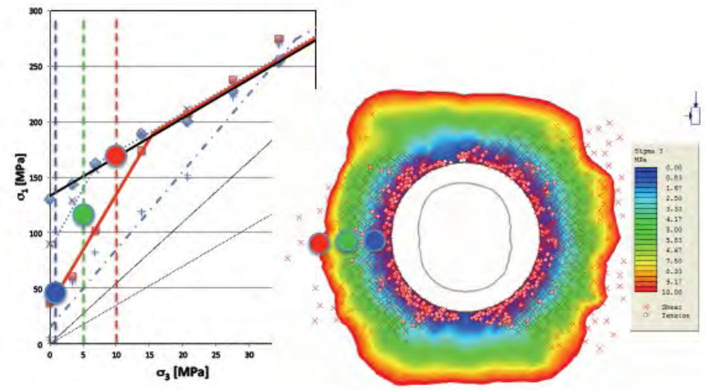


Figure 8. Right: Continuum model of tunnel showing yield locations (x and o) for k_o = 0.5 and confinement contours; Left: Illustration of three states at locations indicated by circles in principal stress space for marble (Figure 5).

the depth of failure defined as the depth to which a rock mass fails and unravels if unsupported.

The extreme normalized depth of failure d_f/a, defined as the maximum depth of notch formation or rock mass unravelling recorded in a tunnel domain with otherwise equal properties, increases linearly as a function of stress level index (up to SL = 1 or σmax = UCS as shown in Figure 9 in blue)

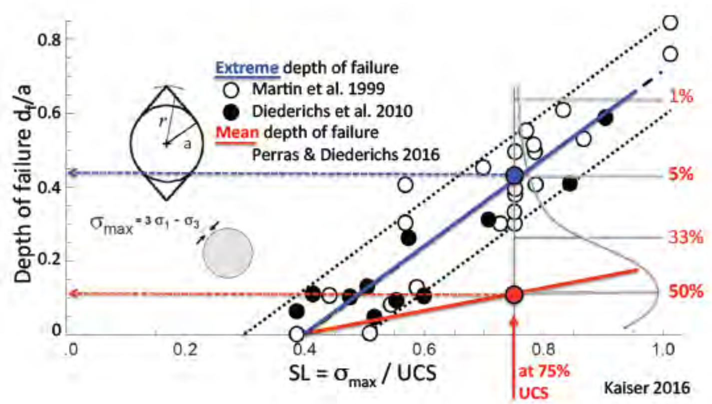


Figure 9. Depth of failure chart for extreme and mean conditions; also shown is an approximate frequency distribution at SL = 0.75; a = tunnel radius.

Recent work by Perras and Diederichs [10] indicates that the mean depth of failure is much smaller as indicated in red in Figure 9. Based on an assumed normal distribution shown for SL = 0.75, 50% of this tunnel will experience no failure or a depth of failure of less than 0.1a. Only 5% of the tunnel in the same domain will experience an extreme depth of failure of 0.45a or larger. Unless local conditions deviate from the norm (e.g., due to stress variability as will be discussed below), it is highly unlikely that the depth of failure exceeds 0.65a.

Based on the empirical data presented in Figure 9, it is today possible to not only anticipate the mean and extreme depth of failure in brittle failing rock but also to estimate the percentage of a tunnel that will experience such failure characteristics.

Dilation versus geometric bulking

Stress-fractured rock bulks due to a geometric non-fit of rock fragments when deformed past peak and loosing strength. This leads to omnidirectional bulking deformations that are controlled by the excavation geometry and the imposed tangential deformation. This bulking process is not fully captured by dilation models relating strength to the volumetric strain (Figure 10). Contrary to common constitutive laws, broken rock does not gain strength despite its high dilation characteristics.

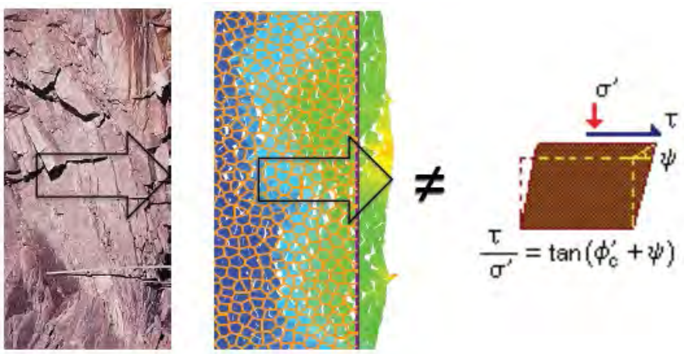


Figure 10. Unidirectional rock mass bulking due to stress-fracturing (left) reflected in Voronoi model (cartoon-like model in center) and non-representative dilation model (right).

The geometric bulking deformation can be estimated following the semi-empirical approach outlined in [5].

Rock mass characterization

Conventional rating systems such as RMR, Q and GSI were developed and calibrated for conditions that were not dominated by large mining-induced stress changes and stress-fracturing of rock blocks bound by open joints. Hence, they are often, for example in defected rock and large strain environments, not applicable, particularly when the rock mass is massive to moderately jointed.

For example, if the GSI is indiscriminately applied to conditions other than those used to develop the GSI approach, the resulting rock mass strength tends to be underestimated. This is applicable to all rating systems and is addressed in the author's ISRM online lecture on "Challenges of rock mass strength determination" [4].

Homogeneity versus heterogeneity

Despite today's computational capabilities many engineers (and researchers) still resort to homogeneous stress models and, if not, only consider strength heterogeneities. The impact of modulus and strength heterogeneity on the in-situ and mining-induced stresses is rarely considered. Furthermore, over-simplistic statements are frequently found in GBR's or in tender documents often suggesting that "the stress field can be approximated by the overburden weight and a stress ratio k near unity or possibly ranging from <1 to 2". Such simplistic conditions are rarely valid, particularly along tunnels crossing various geological domains. They often represent non-conservative baseline assumptions.

The influence of rock mass heterogeneity on the in situ stress variability in a tectonically strained setting (e.g., the Canadian Shield) is presented in [2]. The corresponding mining-induced minimum and maximum tangential stress profile for tunnels at various depths or for a tunnel progressing from surface to depth of 1600 m is presented in Figure 11.

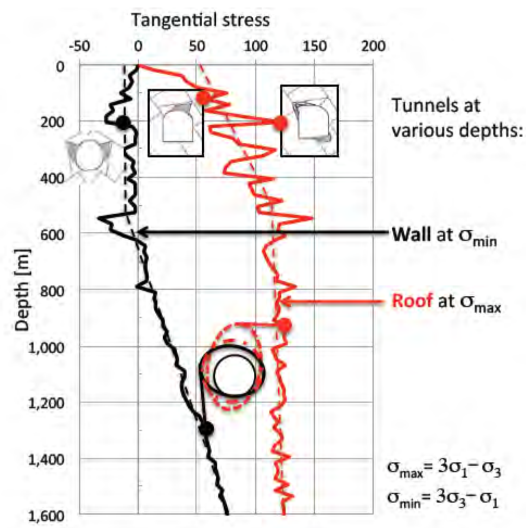


Figure 11. Example of mining-induced minimum and maximum tangential stress profiles for a circular tunnel in a tectonically strained environment. Also shown are various failure modes reflected by the behavior matrix of Figure 3.

For a tunnel progressing in a given rock mass domain to greater depth, the minimum stress indicates stress relaxation ($\sigma_{min} \leq 0$) to a depth of about 600 m whereas the maximum stress is highly variable. At greater depth, the maximum tangential stress is more or less constant and the minimum stress gradually increases. The variability in stress decreases with depth for the underlying heterogeneous rock mass model that only varies in modulus at depth.

As a consequence of the stress variability, highly variable failure mechanisms are to be expected as shown by the inserts. Structurally controlled failures and overbreak together with potential stress-fracturing are to be expected at shallow depth (<600 m). At greater depth, the potential for roof and floor fracturing remains more or less constant whereas the tendency for wall fracturing gradually increases as indicated by the changing overbreak profiles in the insert. In other words, the actual tunnel behavior cannot be anticipated without due consideration of the anticipated stress variability. The impact of strength variability is also discussed in [2].

Two case histories in support of the high impact of stress heterogeneity can be found in [5].

Deformation-based support selection

In stress-fractured ground, two mechanisms affect the excavation performance during construction:

(a) ravelling of broken rock resulting in short stand-up times and construction difficulties with open TBMs, and (b) large deformations caused by geometric bulking imposing large radial deformations on the support system.

The challenge of managing this highly stressed brittle rock in civil and mining projects can best be managed by the application of deformation compatible support systems. The reader is referred to the detailed analysis presented in the written version of the Sir Allan Muir Wood lecture entitled "Ground Support for Constructability of Deep Underground Excavations" [5].

It is recommended that support systems be selected based on allowable displacement criteria (i.e., Factor of Safety in terms of deformation capacity and demand, or the probability of displacements exceeding a supports displacement capacity).

The underlying principles of a deformation-based support design lead to two fundamental but practical support design axioms:

1. Control the driver of or cause for bulking, i.e., minimize the tangential straining of the rock in the immediate vicinity of evacuation; and
2. Control the geometric bulking of stress-fractured ground by rock reinforcement and the application of confining pressure.

For detailed explanations, the reader is referred to [5] and [6].

Conclusion

The various examples presented in this article illustrate the wide gaps between assumed and observed rock mass behavior. Much progress has been made in recent years and these findings are available now for better and more robust engineering designs, i.e., designs that match the rock mass and excavation behavior and thus can be constructed without undue delays and costs.

Furthermore, observations of rock behavior to verify the applicability of design approaches are essential for sound and robust engineering. With systematic observations and correct interpretations, fiction can be replaced by models of reality and solutions can be found that fit the rock.

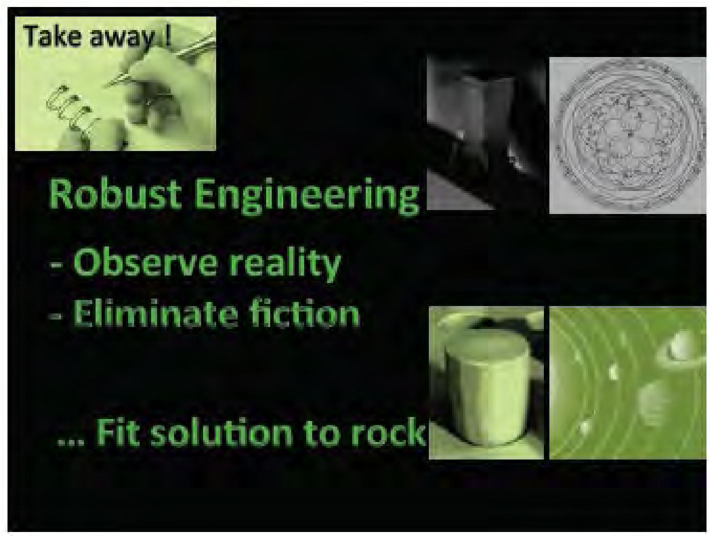


Figure 12. Fit solution to the rock (Illustration from brettellis.net).

In closing, the icons in Figure 12 indicate that "if we try to fit a solution or design to the rock as a square peg into a round hole, we cannot succeed!" Whereas one perspective, based on observations in 100 A.D., suggested that the earth is the center of our planetary system, and another, based on calculations by Copernicus in 1540, suggested that the sun is the center, there is only one reality: "What we thought was right yesterday may be flawed today".

References

[1] *ARMA 16-890* Bahrani N, PK Kaiser 2016. Strength degradation approach (SDA) for estimation of confined strength of micro-defected Rocks.

[2] *ARMA 16-571* Kaiser PK, S Maloney and S Yong 2016. Role of large scale heterogeneities on in-situ stress and induced stress fields.

(continued on page 12)

The 2016 ARMA Hydraulic Fracturing Workshop

Submitted by ARMA Technical Committee on Hydraulic Fracturing

The ARMA Technical Committee on Hydraulic Fracturing (TCHF) held its first hydraulic fracturing workshop on 24 June in Houston, TX. Attendance was limited at the event to encourage discussion, participation, and candor. In total there were 79 attendees representing 56 organizations from six continents.

The one-day workshop consisted of three 2-hour sessions focusing on the fundamental physics involved in hydraulic fracturing processes such as initiation, propagation, and closure. Each session featured three speakers in the first hour, and opened the floor for discussions in the second. As many as 10 discussion participants prepared 5-minute presentations and shared their understandings in each fracturing process.

The technical challenges discussed in the workshop included:

- Longitudinal vs. transverse fractures: Why do longitudinal fractures often occur?
- Bigger and denser vs. smaller and fewer perforations: Does perforating have a negative effect on fracture initiation?
- Toe vs. heel fractures: Why do fractures at the heel appear to be better developed?
- Converging vs. diverging adjacent fractures: Can models really predict whether one or the other phenomenon takes place?
- Lab, wellbore vs. field scales: Can heterogeneity, natural fractures, fracture toughness be upscaled and effectively characterized for model inputs?
- Rock toughness vs fluid transport and leak-off: Can lab tests and field data help verify and quantify fracture propagation behaviors?
- Traditional vs. new Diagnostic Fracture Injection Training (DFIT) analyses: How is fracture closure impacted by its surface mechanical characteristics and how does this affect the selection of closure pressure for the minimum in-situ stress?
- Proppant flowing vs. settling: Where do proppants go?

While model development has been thriving in recent years, developers are more or less faced with similar shortages of genuine calibrations and verifications. In consequence the industry largely has not accepted the "new models" as means of optimizing hydraulic fracture design, or as means of interpreting microseismic or post-fracture stage performance. Lab investigations and field observations become critical to fill in the gap. These subjects will be discussed in future TCHF workshops.

Group Photo of TCHF members (from left to right): Mark Mack, Mukul Sharma, John McLennan, Joe Morris, Xiaowei Weng, Sau-Wai Wong, Gang Han, Maurice Dusseault, Ahmad Ghassemi, Jon Olson.

ARMA News Briefs

ARMA Status

Membership now numbers over 800 with an estimated 70 new members in the past year; there are four technical committees with a range of activities and interests, and five student chapters. Twenty of ARMA's most distinguished and dedicated members have been recognized by election as ARMA Fellows, and the energy and continuity of the organization have been assured through the addition of Future Leaders.

Call for Abstracts for 51st Symposium in San Francisco.

ARMA invites you to its 51st US Rock Mechanics/Geomechanics Symposium to be held in San Francisco, California, on 25-28 June 2017. The 2017 program will focus on new and exciting advances in all areas of rock mechanics and geomechanics. San Francisco is one of the country's most dynamic cities. Home to some of the world's most innovative companies (Silicon Valley is nearby), San Francisco is known for its beautiful hills and views, its world-class restaurants, and its sophisticated cultural institutions. The symposium will be held at the Westin St. Francis on Union Square in the heart of the city. Technical tours and field trips are being planned. Sightseeing tours will include various city landmarks, social activities and other attractions. Short courses and workshops will be held immediately prior to the symposium and will be listed as they are confirmed.

Members are encouraged to submit abstracts of 250-500 words, in English, online at http://submissions.mirasmart.com/ARMA2017. Abstracts should include a brief description of work performed, results, and significance. Figures may be included as necessary to explain the abstract. All abstracts and accepted papers will be peer-reviewed by experts in respective subject areas through an online process. To facilitate travel arrangements, invitation letters to attend and participate in the symposium may be issued upon request after acceptance of an abstract. A presentation slot will be tentatively assigned at that time, with final confirmation after approval of the paper.

Deadlines for abstract and paper submission are as follows:

1 November 2016: Abstract submission

6 January 2017: Notification to authors

Bobet Elected ARMA Fellow.

Antonio Bobet, Professor of Civil Engineering at Purdue University, was elected as ARMA Fellow and inducted at the Houston 2016 symposium. Dr. Bobet was cited for his experimental, analytical and numerical work on cracking processes in rock. He has made major contributions in the analysis and design of underground structures in areas specifically related to drainage, the performance of bolts, and dynamic effects. He received the ASCE Ralph E. Peck Award for his paper on dynamic effects on a subway station. Dr. Bobet serves on the ARMA Board of Directors as Immediate Past President and was chairman of the 2012 46th US Rock Mechanics/Geomechanics Symposium in Chicago.

ARMA Future Leaders.

Nine ARMA members were inducted in the 2016 fourth class of the ARMA Future Leaders. This program recognizes motivated ARMA members of outstanding promise, relatively early in their careers, to ensure the continual development of ARMA. New future leaders are: Ingrid Tomac, University of California San Diego; Kan Wu, Texas A&M University; Jesse Hampton, New England Research; Hiroki Sone, University of Wisconsin-Madison; Andrew Rathbun, Chevron Energy Technology Company; Mahdi Heidari, University of Texas at Austin; Xiaochun Jin, University of Utah; and Andrea Lisjak, Geomechanica, Inc.

ARMA Awards.

One of the highlights of the annual symposium is the announcement of the ARMA awards. At the ARMA 2016 Houston symposium, the following awards were presented: N.G.W. Cook Ph.D. Dissertation Award: Qinghua Lei, Imperial College London, "Characterisation and Modelling of Natural Fracture Networks: Geometry, Geomechanics and Fluid Flow." Nominated by Chin-Fu Tsang, University of California-Berkeley. Outstanding Contributions to Rock Mechanics Award: Jean-Claude Roegiers, University of Oklahoma. Nominated by Ahmad Ghassemi, University of Oklahoma.

2017 Rock Mechanics/ Geomechanics Symposium

The Westin St. Francis, Union Square

San Francisco, California

25-28 June 2017

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