

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: 4th North American Rock Mechanics Symposium (20.01402.671)

DATE/PLACE: July 31 - August 3, 2000, Seattle, Washington

AUTHORS: R. Chen

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PERSONS PRESENT:

Participants included the author and rock mechanics from around the world. Authors of papers and workshop attendees are provided in attachment A.

BACKGROUND AND PURPOSE OF TRIP:

This is the premier rock mechanics symposium in North America. The author presented a paper at the symposium. The author also attended various segments of the symposium.

SUMMARY OF PERTINENT POINTS:

The 4th North American Rock Mechanics Symposium, also known as Pacific Rocks 2000, was held July 31 - August 3, 2000, following a few workshops and short courses during the proceeding weekend. The theme of Pacific Rocks 2000 was "Rock around the Rim." There were eight keynote lectures addressing the contribution of rock mechanics to the civil, mining, and petroleum industries. The technical program consisted of 29 sessions and, at a given time, four sessions were held in parallel. Following is a brief summary of the sessions (or parts of sessions) that the author attended. The proceedings of the symposium is available in one single volume and can be obtained by contacting the author or Amit Ghosh.

Discrete Element Modeling

The session on discrete element modeling was chaired by Mary McLaughlin of Montana Tech School of Mines and Geology. Five papers were presented on use of discontinuum analysis tools or development of such tools. Two of these papers are related to investigations for the proposed Yucca Mountain geological repository and two of them used Universal Distinct Element Code (UDEC).

M.R. Yeung (San Jose State University) presented "*DDA back analyses of large block test data.*" The paper is coauthored by S.C. Blair of Lawrence Livermore National Laboratory (LLNL). Discontinuum Deformation Analysis (DDA) was used to back calculate the global deformation distribution and fracture displacement in the Large Block Test (LBT) at Yucca Mountain based on measurements of the multiple point borehole extensometers (MPBXs). It was shown that the results of back calculation are rather sensitive to input fracture properties.

Rui Chen (Center for Nuclear Regulatory Analyses, Southwest Research Institute) presented “*Effects of thermal and dynamic loads on underground stability at Yucca Mountain, Nevada.*” The title of the talk is modified from that of the paper that has been published in the symposium proceedings to reflect more recent analysis results. The study emphasized those aspects of rock mass deformation that distinguish a thermal-stress controlled problem from conventional mining and tunneling problems under ambient conditions. Modeling results show that thermal loading alters stress state significantly and thermal load mainly causes slip along subhorizontal fractures in roof and floor areas. Modeling results also show that thermally induced rock mass deformation and load acting on ground support system are greater in a higher quality rock mass. Consequently, a higher quality rock mass needs stronger ground support under heated conditions. These results indicate that empirical design approaches based on rock mass classification may not be applicable to the heated condition at Yucca Mountain.

Joel Kuzmaul (University of Mississippi) talked about “*The effect of varied joint set orientations on keyblock size.*” He introduced the extension of the unit-cell method to consider the effect of variations in joint-set orientation in estimating the size of keyblocks. Unit-cell method was described in a three-dimensional form considering joint set spacing. In some cases, the importance of considering variations in joint-set orientation is clearly demonstrated.

Joseph P. Morris [Geophysics and Global Security Division, Lawrence Livermore National Laboratory(LLNL)] talked about “*An efficient displacement discontinuity method using fast multipole techniques.*” His coauthor is Stephen C. Blair, also from LLNL. Morris introduced a modified Fast Multipole Method (FMM) that performs the necessary calculations in optimal time and with reduced memory usage. He claims that the FMM solves large discontinuum mechanical problems much more efficiently.

Martin Grenon (University of Laval) presented “*An investigation of drift stability in moderately jointed rock mass.*” The paper was coauthored by J. Hadjigeorgiou, J.P. Harrison, and R. Banas. Grenon introduced the results of numerical studies on drift stability using UDEC. His modeling demonstrated the relative importance of parameters such as joint orientation, spacing, and stress state on drift stability.

Nuclear Wastes

This session was chaired by Bill Thompson from Golder Associates. Thompson is often involved in review of various reports generated by the DOE for the proposed Yucca Mountain repository and therefore he is fairly familiar with the Yucca Mountain project. He announced that the Organizing Committee for the Second International Workshop on Geomechanics of Nuclear Waste Repositories is soliciting written comments to be included in the workshop proceedings to be published later. Such comments should be sent to ctaimon@sandia.gov or bthompson@golder.com. It was also announced that there will be a technical session on nuclear waste at DC Rocks 2001. Nancy Brodsky of Sandia National Laboratory will organize the session. She could be contacted at nsbrods@sandia.gov.

Five papers were submitted to the session. However, only three papers were presented. Dwayne Kicker of Morrison Knudsen Corp presented “*Probabilistic key block analysis at Yucca Mountain.*” His coauthors are M. Lin, J.M. Kemeny, and C.A. Stone. Kicker introduced an attempt for probabilistic assessment of the likely formation of key blocks within the potential repository horizon based on orientations of discontinuities present in the Exploratory Studies Facilities at Yucca Mountain using the DRKBA software. The analysis has considered various emplacement drift orientations. Seismic loading was considered by reducing friction

present in the Exploratory Studies Facilities at Yucca Mountain using the DRKBA software. The analysis has considered various emplacement drift orientations. Seismic loading was considered by reducing friction angle, which has generated a lot of questions and doubts. There are also questions about the effect of thermal loading that is not currently included in Kicker's calculation.

Nasser Hoteit of ANDRA, France presented "*Geological radioactive waste disposal project in France: conceptual model of a deep geological formation and underground research laboratory in Meuse/Haute-Marne Site.*" His coauthors are O. Ozanam and K. Su. Hoteit introduced a plan to establish a geomechanical conceptual model in argillite formation studied by ANDRA in the framework of feasibility study of underground waste disposal in France. A underground research laboratory (URL) will be constructed. He presented some preliminary numerical modeling results for the design of the URL.

Neil Chandler (Atomic Energy of Canada Limited) presented an interesting talk on "*An integrated approach to excavation design - a project within Canada's used fuel disposal program*" The paper was coauthored by R. Read (BGG Engineering), P. Cundall and D. Potyondy (Itasca Consulting Group, Inc.), E. Detournay (University of Minnesota), R. P. Young (University of Liverpool) and J.S. O. Lau (Mining and Mineral Sciences Laboratories, Canada). Chandler talked about how the excavation design process for potential application in construction of a nuclear fuel waste disposal in Canada encompassed a wide range of geotechnical skills and technologies. He emphasized the role of Particle Flow Code (PFC) in understanding the micro-mechanical phenomena leading to time-dependent cracking in situ and quantifying rock mass damage.

Joint Distributions and Analysis

This session was chaired by Scott Huang (University of Alaska, Fairbanks). Six papers were presented. Kiyoshi Kishida (Department of Civil Engineering, Kyoto University, Japan) talked about "*Experimental study on the dilatancy behavior of single joints under constant loading conditions.*" He introduced experiments for measuring dilatancy properties of rock joints, a proposed constitutive model for rock joints, and comparison between model prediction and experimental results.

R.E. Hammah (Golder Associates, Limited) presented "*Standardization and weighting of variables for the fuzzy K-means clustering of discontinuity data.*" He summarized the vulnerability of cluster analysis tools to the presence of noise variables and acknowledged that variable standardization can be used to filter such noise effect. He further discussed issues surrounding variable weighting and standardization and proposed algorithms for addressing the difficulties in fuzzy K-means cluster analysis.

N.H. Maerz (Rock Mechanics and Explosives Research Center, University of Missouri-Rolla) presented "*Discontinuity data analysis from oriented boreholes.*" He talked about attempts in improving analytical tools for the characterization of rock masses from oriented borehole discontinuity data using automated multivariate cluster analysis and the three dimensional stereonet.

John Hadjigeorgiou (Université Laval, Canada) presented two papers: "*A practical application of borehole data to determine in situ block size distributions*" and "*Development of a methodology for the automatic construction of discontinuity trace maps based on digital images.*" In the first paper, he used a case study whereby oriented borehole data were used to characterize a rock mass. The influence of random joints in the resulting block size distribution is investigated and its implications discussed. The analysis was used to evaluate

the caving potential of a particular mine project. In the second paper, Hadjigeorgiou described his efforts to develop a methodology for automatic construction of discontinuity trace maps. Digital images of exposed rock surfaces were collected and analyzed using various algorithms.

Jae-Joon Song (Seoul National University of Korea) presented "*Study on the estimation of joint length distribution using window sampling in statistical joint modeling.*" He adopted a window sampling method and derived a number of equations for estimating joint trace length distribution within a selected window and claimed that his method is more efficient than those using semi-trace length distribution from a scanline survey.

Plasticity, Creep, and Time-Dependent Phenomenon

The session was chaired by William G. Pariseau (University of Utah) and N.D. Cristescu (University of Florida). Five papers were submitted and four papers were presented at the symposium. Dr. Derrell E. Munson presented "*Spall formation in solution mined storage caverns based on a creep and fracture analysis.*" Munson used the Multimechanism-Deformation Coupled Fracture (MCDF) model to predict salt creep and fracture in the Strategic Petroleum Reserve (SPR) storage caverns in salt domes in Gulf Coast.

D.F. Malan (CSIR Division of Mining Technology, South Africa) presented "*Modeling the post-failure relaxation behavior of hard rock.*" He examined post-failure relaxation behavior of some typical hard rocks found in the South African gold mines. Laboratory tests were performed using quartzite and lava specimens. It was observed that the quartzite specimens undergo more significant relaxation than the lava specimens. A continuum elasto-viscoplastic model was proposed as a numerical tool to simulate such relaxation behavior.

W.G. Pariseau (Department of Mining Engineering, University of Utah) presented "*Equivalent properties approach to jointed viscoplastic rock slopes.*" He applied an equivalent properties approach to time-dependent behavior of jointed rock masses to mine slope stability problems. A non-representative volume element (NRVE) was used as an approximation to account for joints without explicit representation. Applications to a simple open pit mine model using both elastic-plastic and elastic-viscoplastic material models for two joint sets of different dips demonstrated the method.

N.D. Cristescu (Department of Aerospace Engineering, Mechanics and Engineering Science, University of Florida) presented "*On creep flow of natural slopes.*" He presented a new model for describing creep flow of natural slopes with non-homogeneous Bingham type materials. The model accounts for the effect of gravitational compaction of the geologic material and allows for the variation of density and yield stress with depth. The model was used to predict the field behavior of several natural slopes in Europe. It was found that the predicted displacement profiles correlated well with field observations.

Laboratory: Physical Modeling

The session was chaired by Scott G. Johnson (MTS Systems Corporation). Five papers were presented. P.H.S.W. Kulatilake (University of Arizona) talked about "*Physical and numerical modeling study of jointed rock block strength under uniaxial loading.*" Laboratory testing was performed on jointed model material blocks and results were used to develop a non-linear relation between the fracture tensor component and the jointed model mass strength.

M.Sagong (Purdue University) presented "*Coalescence of multiple flaws in uniaxial compression.*" Laboratory experiments were performed to investigate crack initiation and coalescence. The produced crack patterns were observed to be affected strongly by the preexisting flaw arrangement. Some geometry factors were introduced to explain such dependency.

Robina H.C. Wong (The Hong Kong Polytechnic University) presented "*Experimental study on failure behavior of tunnel in jointed rock mass under excavation.*" Failure behavior in disturbed zone around an underground opening in non-persistent jointed rock masses was investigated by laboratory testing. It was found that failure time does not necessarily increase due to increase in confinement.

R.M. Holt (NTNU and SINTEF Petroleum Research, Norway) presented "*Discrete particle and laboratory modeling of core mechanics.*" Particle Flow Code (PFC) was used to simulated previous experiments on synthetic sandstone to understand the mechanical behavior due to stress release during coring. The simulation confirmed the physical understanding of core damage mechanisms and demonstrated how core damage effects could be quantified and corrected.

S. Nakashima (Kyoto University, Japan) presented "*Experimental study on the stability of dam foundation in consideration of the effect of the concrete plug treatments.*" A gravity dam testing machine was developed and tests were carried out to investigate the stability of dam foundations with faults and the effect of the concrete plug treatment on the stability of dam foundations. Modeling results show that the effect of faults on stress distribution is small. Concrete plugs are helpful in redistributing stresses and reducing the deformation of dam foundations.

Rock Mass Characterization

The session was chaired by Dick Robbins (Robbins Group) and Don Deer (Rocky Mountain Construction). Four papers were presented on rock mass characterization. D.H. Park (Sambo Engineering Company, Korea) presented "*Application of mechanical crack model to numerical study of rock mass behavior.*" Mechanical crack models were used to simulate the non-linear behavior of rock masses.

L. Zhang (MIT) presented "*Estimating the deformation modulus of rock masses.*" A new set of relations between the rock mass deformation modulus and RQD was developed based on additional data that cover the entire range of $0 \leq RQD \leq 100$. Reasons for the large scatter of the data were discussed and suggestions for using the new relations to estimate the rock mass deformation modulus were presented.

M.L. Rucker (AGRA Earth and Environmental Incorporated) presented "*Estimating earthwork factors for roadcuts using surface geophysics.*" A method was developed to utilize surface refraction seismic geophysical measurements to estimate earthwork factors involving large rock cuts in weathered, fractured rock masses and associated embankments. The method uses Percolation Theory concepts to relate rock mass modulus values to rock mass porosity values.

M. Mauldon (University of Tennessee) presented "*Borehole estimate of fracture size.*" A procedure was developed to estimate fracture size from rock core or borehole images. The method is applicable to circular fractures perpendicular to the borehole axis.

Ground Support

Ground Support

The session was chaired by Steve Signer (NIOSH, Spokane) and John Goris (Thiessen Team). Five papers were presented. Marek Mrugala (Morrison Knudsen Corporation) presented "*Steel set loads analysis.*" Steel sets strain gage data collected from the Exploratory Studies Facility at the proposed Yucca Mountain repository were used to assess the magnitude of ground loads acting on an individual set. Numerical modeling utilizing the FLAC program was used to examine steel set response to such factors as the installation procedure and the design value of jacking load, impact of non-uniform lagging, and range of possible design tolerances.

Xinping Li (Wuhan University of Technology, P.R. of China) presented "*Overall elastic properties of support system of rock mass and rockbolts.*" An equivalent homogeneous elastic model of orthorhombic layers was established to simulate the support composite system that consists of rock mass, rockbolts, and grout. Expressions and computations for equivalent properties of support composite system were given in terms of elastic properties of constituent materials, spatial and geometrical arrangements of rockbolts, etc.

J.H. Synn (Korea Institute of Geology) presented "*Design of ground reinforcement and support of shallow tunnel in heavily fractured rock mass.*" A case history for design of ground support in a "bad" geological condition was presented. It was suggested that the reinforcement be installed preceding the excavation and design patterns were laid out. The stability of opening with the suggested design pattern was demonstrated numerically using FLAC.

Chunlin Li (Luleå University of Technology, Sweden) presented "*Analytical study of the behavior of rock bolts.*" Models were developed for bolts in pullout test and bolts installed in uniformly deformed rock masses.

W.F. Bawden (University of Toronto, Canada) presented "*Lessons in control of mine costs from instrumented cable bolt support case studies.*" Professor Bawden reviewed the use of instrumented cable bolt support (SMART - Stretch Measurement for Assessment of Reinforcement Tension - cables) in Canada over the past three years. He also discussed the database developed using SMART cables, SMART MPBX's and SMART contractometers under a wide array of mining situations and ground conditions and the positive economic impact of this technology in mining industry.

The author also attended some sessions on weak rocks, particularly Weak Rocks II: Tunneling in Weak Rocks and Weak Rocks III: Panel. These sessions are not summarized in this trip report since they have limited implication in our overall objectives. Interested readers are referred to the one-volume proceedings of the symposium.

Keynote Lectures

Priscilla Nelson (National Science Foundation) talked about "Space, Scale, Time, and Rocks." She gave her opinions on the role of rock engineering in general in the past, present, and future. With reference to the Yucca Mountain project, she mentioned that people have to realize that there are lithophysae and non-lithophysae rocks and that they are different. She shared the opinion that more data are needed for the lower lithophysal unit.

“Putting All of Your Tools to Work” was offered by Frank Kendorski of Weir International Mining Consultants. He presented a few case histories in mining in which rock mechanics played important roles in mining safety, safety evaluation, and various court cases on mining related accidents.

Prof. Herbert H. Einstein (MIT) gave a comprehensive lecture titled “Puzzles in Rock.” He reviewed the development of various tools in solving the “puzzles in rock” and in “putting the puzzle pieces back together.” His lecture covers a wide range of topics from fracture initiation and coalesce to fracture network modeling, from the stability of open pit to underground mining, and from mining safety to risk analyses. He also introduced tools and software developed recently at MIT.

Derek Martin of the University of Alberta talked about “The Challenges of Deep Excavations” His lecture was largely based on his experience during design, construction, and research at the Underground Research Laboratory in Canada. He emphasized understanding the deformation mechanism at particle scale by means of laboratory testing and numerical simulation. Examples were given using the Particle Flow Code.

The last keynote lecture was titled “*Rock Mechanics in the Pacific Rim: Reports from 3 Countries*” and was given by Ashinnichi Akutagawa from Japan (Kobe University), Seokwon Jeon from Korean (School of Civil, Urban, and Geosystem Engineering, Seoul National University, Korean), and Jian Zhao from Taiwan (School of Civil and Structural Engineering, Nanyang Technological University, Taiwan). The highlights of Rock mechanics research and practices in each of these three regions were briefly reviewed and discussed.

CONCLUSIONS:

The following conclusions are made based on the information obtained at the workshop and symposium.

1. Following the trend of Vail Rocks’ 99, there was extensive use of animation (e.g., using the Powerpoint presentation software) in the presentations. A good example is the keynote lecture by Prof. Herbert H. Einstein. In most cases, the animation enhanced the quality of the presentations. In other cases, small font text and inappropriate mix of background and foreground colors render the images unreadable.
2. Similar to the U.S. Rock Mechanics Symposium, the North American Rock Mechanics Symposium has grown into one of the most comprehensive and widely attended forums for the exchange of ideas in rock mechanics and engineering. The participants in this year’s symposium were drawn from all over the world and the breadth of the technical program was quite impressive.

PROBLEMS ENCOUNTERED:

None.

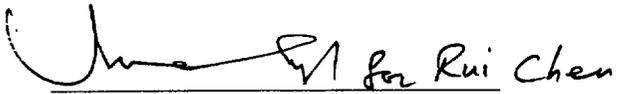
PENDING ACTIONS:

The staff became aware of a number of concepts and new approaches to modeling in rock mechanics. Specific follow-on actions will be delineated in the context of CNWRA operations plans for FY2001.

RECOMMENDATIONS:

Staff should continue to be actively involved in participating in and making presentations at this Symposium.

SIGNATURES:

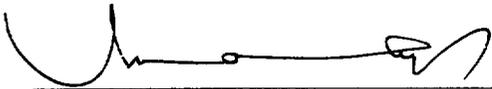
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Senior Research Engineer

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Attachment A

Pacific Rocks 2000 Full Attendance Roster

Attachment A

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Pacific Rocks 2000

Pre-Registration Attendance Roster
July 30 - August 2, 2000

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