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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: 35th U.S. Symposium on Rock Mechanics (20-5702-623)

DATE/PLACE: June 4–7, 1995, Lake Tahoe, Nevada

AUTHOR: A. Ghosh

PERSONS PRESENT: Approximately 250 technical professionals, professors, researchers, and students representing different areas of mining, civil, petroleum, and related industries. The list of participants is given in APPENDIX A.

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BACKGROUND AND PURPOSE:

35th U.S. Symposium on Rock Mechanics was organized by the University of Nevada, Reno. It was held at South Lake Tahoe, in the heart of Sierra Nevada, a place rich in rock engineering works and challenges: slopes, landslides, tunnels, dams, and mines. The aim of the symposium was to present state-of-the-art and ongoing research, progress, and applications in rock mechanics. The purpose of attending the symposium was to present four technical papers, organize and chair the session "Rock Fragmentation by Blasting," and to interact with professionals in the broad field of rock mechanics and to become familiar with most recent and mostly unpublished advances in this field, many of which are highly relevant to the repository program of the U.S.

SUMMARY OF PERTINENT ACTIVITIES:

A. ROCK MECHANICS SYMPOSIUM

The author of this trip report developed and chaired the session on *Rock Fragmentation by Blasting* and also presented four papers in this symposium. The papers are listed below:

(i) *Tensile Strength of Welded Apache Leap Tuff: Investigation of Scale Effects.* A. Ghosh, K. Fuenkajorn, and J.J.K. Daemen.
(ii) *A Scale Model Study of Seismic Response of an Underground Opening in Jointed Rock.* D.D. Kana, S.M. Hsiung, and A.H. Chowdhury.
(iii) *Rock Fragmentation in Bench Blasting--A Numerical Study.* A. Ghosh and J.J.K. Daemen.
(iv) *On Natural Rock Joint Profile Characterization Using Self-Affine Fractal Approach.* S.M. Hsiung, A. Ghosh, and A.H. Chowdhury.

First two papers were presented on June 6. Other two papers were presented on June 7.

Each day of the symposium started with an invited keynote lecture, followed by the organized technical sessions. Three sessions were held in parallel on every day. On June 5, the first keynote lecture was delivered by Professor Richard Goodman. Professor Jean-Claude Roegiers presented the second keynote lecture on June 6. On June 7, Dr. Laura Pyrak-Nolte, recipient of the fourth Schlumberger award, delivered the Schlumberger lecture. Brief descriptions of the keynote lectures and the paper presentations that I have attended are given below. Schedule of technical sessions is given in APPENDIX B. During the award luncheon, it was announced that the 36th U.S. Symposium on Rock Mechanics will be held at New York city and will be hosted by the Columbia University.

Block Theory and Its Application
Richard E. Goodman (University of California, Berkeley)

Professor Goodman explored the current state of block theory in this keynote lecture. Block Theory is a geometric approach for evaluating the possibilities of *in situ* rock blocks to move into the geometric space created by the excavation. In general, the methods of block theory cannot be applied to nonblocky rock mass. In simplest analysis with block theory, each joint set is represented by a single nominal orientation and a friction angle. A joint is defined as an open discontinuity which lacks tensile strength or significant cohesion. Volume of rock that can be observed in exploration of a site is very much smaller than the volume of the rock mass potentially supplying the key blocks to an excavation. In a rock mass, most joints belong to a set. Minimum sample size is required for stochastic characterization of joint orientation, persistence and spacing. However, except important mappable features, actual location of any joint is not determinable. When joints in one or more joint sets are highly dispersed, characterization by a single nominal orientation may be misleading. In those cases, statistical block theory may be applied up to some degree of randomness.

Key block theory assumes all the blocks to be rigid. Another inherent assumption of block theory is that failure of an excavation starts at the boundary with movement of a block into the excavated space. Loss of the first block allows removal of additional blocks with continued degradation leading up to the massive failure. Intersection of preexisting joints by surfaces of the excavation generates the key blocks. A true key block is that rock block whose removal causes degradation of a larger mass of blocks. In block theory, a key block is such a rock block that would become unstable when intersected by an excavation. Prevention of loss of a key block assures stability. By varying the actual location of a joint plane with fixed orientation, the maximum key block can be determined such that any similar block larger than this is not removable. Friction angles of joints diminish with increasing block weight. Therefore, the largest key block (largest of a set of similar blocks) will be least stable. It is a common practice using the Austrian Tunneling Method to specify in the tunneling contract calculation of the maximum possible key block along the whole length of the tunnel.

Block theory can be used in several design problems for estimating probable support requirements for tunnels, minimum safe distances between parallel tunnels, evaluating the effect of tunnel or shaft size on the support cost, determining the minimum length of rockbolts to assure anchorage behind key blocks of tunnels and excavations, predicting the most stable orientations for a shaft or tunnel, and assessing safety of rock foundations and rock slopes with potential key blocks.

Recent Rock Mechanics Developments in the Petroleum Industry
Jean-Claude Roegiers (University of Oklahoma)

Professor Roegiers discussed the recent rock mechanics advances in the petroleum industry in this second keynote lecture. The renewed interest in rock mechanics in the last fifteen years was due to problems associated with the development of difficult reservoirs at great depths, high pore pressures, unusual tectonic stress regimes, deep water, etc. Rock mechanics concepts developed for and by the mining industry had to be extended to include coupled behavior and poroelasticity. Using the fracture mechanics principles, new fundamental failure mechanisms were detected.

The main recommendation of the Committee on Advanced Drilling Technologies of the National Academy of Sciences was the development of a 'smart drilling system' which is capable of detecting and adapting to rock conditions around and ahead of the drill bit in real time. Preliminary experimental results of Ziaja and Roegiers show that both amplitude and frequency of forced vibration may be used to detect different lithologies and dynamic conditions of rock drilling.

In the past, most of the holes were vertical or near vertical and consequently, parallel to one of the principal stress directions. Stability is becoming a fully three dimensional problem as the petroleum industry has started developing more structurally complex formations requiring highly deviated boreholes. Redrilling to remove dislodged blocks in long holes is extremely difficult. In case of anisotropic formations, prediction of stability trend becomes almost impossible. Recent results show that the extent of stable region is dependent on formation anisotropy. However, attempts to validate this theoretical prediction using servo-controlled polyaxial tests were not successful. It was thought for a long time that the characteristic 'dog-ears' failure pattern was due to shear failure. However, underground observations as well as laboratory tests on thick cylinders indicated tensile failure. Current understanding using pervasive randomly-oriented microcracks suggest initiation of microfracture and propagation through intersections with other microcracks govern the breakage. Final stable geometry is related to the ratio of the applied principal *in situ* stress components.

Renewed interest is now placed on the application of Biot's theory of pore pressure distribution with reservoir deformation. Any load perturbation in a fluid saturated porous medium will introduce a time dependency. Biot's original theory has been extended to include anisotropy and viscoporoelasticity. Poroelastic effects are extremely important in every aspects in reservoir analysis.

Change in effective stresses due to production, stimulation treatments, or secondary/tertiary recovery methods affects the overall behavior of a reservoir. Pore collapse and sand production are presently studied in detail by the industry.

Conventional simulation models of hydraulic fracturing (KGD and PKN models) were not capable to simulate the stimulation of more complex reservoirs. New models have been developed which are three dimensional and also include poroelastic effects.

Fracture and Shatter Zone Inflow into Hard Rock Tunnels -- Case Histories
J.Y. Kaneshiro (Parsons Engineering Science) and B. Schmidt (Parsons Brinkerhoff Quade & Douglas)

Ground water inflows in tunnels are dependent upon the local geologic and hydrologic conditions. In tunnels excavated in low permeability and low porosity intact rocks, water inflow will be controlled by the joints and fractures with heavier influx associated with the shear zones. Identification of minor fractures and joints is necessary to estimate the water flow zones as the exact flow paths within a fractured rock mass are often very intricate and unpredictable. Case histories from 17 tunnelling projects, representing 24,364 m of tunnel in crystalline rocks with covers ranging from 15 to hundreds of meters, show that larger inflows are associated with shear zones or open and closely spaced joints. In blocky to massive rock, water inflow was low, less than 6.3 l/s. The San Jacinto tunnel was constructed in 1935 to 1939 for Metropolitan Water District of Southern California. The tunnel was driven through four major faults and about 20 minor fractures. There were 8 to 10 instances when peak flow of about 1000 l/s with water pressure of 4 MPa with average being 1 to 2.4 MPa was measured. Maximum flow measured from all tunnel headings was about 2500 l/s. Ground water that originally fed springs located as much as 4.8 km from the tunnel was lowered during and after tunnel construction. Historical records indicate that large inflows occurred when passing through major fault zones, such as the Goetz fault. It should be noted, however, that when crossing another major fault, the McInnes fault, the inflow was less than 6.3 l/s. There were indications that water had been previously present. Drainage had occurred perhaps largely through the Goetz fault encountered six months earlier.

The Stanley Canyon tunnel in Colorado (1990-1991) is 3.3 m in diameter and about 5,000 m long. It was excavated using a tunnel boring machine (TBM). This is an interesting case study as it demonstrates the unpredictability and complexicity of estimating groundwater quantities and duration of inflow. The TBM encountered a major shear zone, consisted of brittle fractured rock with open and clean fractures, bearing water. Peak flow of 150 l/s was measured at peak water pressure of 3.4 to 4.1 MPa. TBM operation was stopped. Probing ahead of the tunnel detected a softer clay gouge. A consulting team calculated future inflows of 315 to 500 l/s and lasting for months, based on head of water, effective yield and storage coefficients, effective porosity, and size of storage basin. Attempt to grout against such high water head failed. TBM operation started eventually and the problematic water bearing area was over with 15 m of tunnel advance. The water inflow into the tunnel was primarily from one shear zone. It leveled off to about 110 l/s one year after the fault was first encountered.

Constitutive Representation of Damage Healing in WIPP Salt

K.S. Chan (Southwest Research Institute), A.F. Fossum (RE/SPEC), S.R. Bodner (Southwest Research Institute), and D.E. Munson (Sandia National Laboratories)

In the Waste Isolation Pilot Plant (WIPP), the excavated rooms in rock salt are projected to be used for emplacement of nuclear waste. It is presumed that the closure of these rooms by creeping of rock salt would ultimately encapsulate the waste resulting in effective isolation. The presence of damage in the form of microfractures can increase the permeability and, therefore, the potential for fluid flow around the sealing system. Recently developed constitutive laws for salt incorporate time-dependent, damage-based fracture characteristics. Recent work has shown that healing of damage can lead to inelastic flow in salt under hydrostatic compression. None of the available constitutive models incorporate this damage healing effect on inelastic and failure responses. This paper describes a continuum mechanics based approach, the MDCF model, for incorporating damage healing in a coupled creep and fracture constitutive model by treating it as a physical mechanism which contributes to macroscopic strain rate along with creep and damage mechanism. Anisotropy of healing by multiple mechanisms is treated in this model in terms of a power-conjugate equivalent stress measure. A scalar damage model describes both damage growth and healing. Appropriate power-conjugate equivalent stress and strain rate measures are developed for the healing component along with the corresponding flow law, kinetic equation, and damage evaluation equation. This model was used to predict the experimental results at 20°, 46°, and 70° C. The result of this analysis showed that damage healing in WIPP salt occurred by two mechanisms with different characteristic time constants and anisotropies. The model predicted very well the axial, lateral, and volumetric strains during healing of WIPP salt under hydrostatic compression. The short characteristic times of the healing mechanisms indicate that the creep will dominate the closure of the rooms in salt.

Correlation of Theoretical Calculations and Experimental Measurements of Damage Around a Shaft in Salt

D.E. Munson & D.J. Holcomb (Sandia National Laboratories) K.L. De Vries & N.S. Brodsky, (RE/SPEC) and K.S. Chan (Southwest Research Institute)

Fracture process generates microcracks in the salt around the sealing system of a shaft. Potentially these microfractures can increase the permeability and deteriorate the integrity of the sealing system. The MDCF model is based on the coupled micromechanical description of creep and evolution of microcracks in the salt. It uses the maps of fracture and deformation mechanisms in formulating the model. The strains from microfractures and creep are additive. A stress dependent damage evolution equation describes the tertiary creep. The coupling includes an effect of strain rate on fracture strain and an effect due to reduction of fracture area which increases the effective creep stress. This paper describes the comparison of damage predictions determined by the MDCF model with *in situ* ultrasonic wave speed measurements obtained around the Air Intake Shaft of WIPP. Arrays of ultrasonic piezoelectric transducers were installed at three different instrument stations in the shaft. Each array consisted of 40 transducers. The velocities for waves propagating tangentially and radially to shaft axis were measured. The velocities show a drop at the shaft wall which then increases with radial distance from the shaft and ultimately reach the compressional wave velocity in undamaged salt. These results show that the cracks are opening in the radial, tangential, and axial directions. Model results show reasonable agreement with experimental results although the model predicts a smaller zone of damage.

Variability of the Physical Properties of Tuff at Yucca Mountain, NV

P.J. Boyd & R.J. Martin, III (New England Research) and R.H. Price (Sandia National Laboratories)

Lateral and vertical variabilities of bulk and mechanical properties of tuff, measured on recovered cores from boreholes along the Exploratory Studies Facility/North Ramp, at the proposed nuclear waste repository site at Yucca Mountain have been evaluated. The properties include dry and saturated bulk densities, average grain densities, porosity, compressional and shear wave velocities, elastic moduli, and compressional (both unconfined and triaxial) and tensional strength. 250 core intervals from three boreholes (UE25 NRG-5, USW NRG-6, and USW NRG-7/7A) that have penetrated the TSw2 unit were examined. 106 uniaxial compression, 141 Brazilian, and 43 triaxial tests were performed. Substantial variability in all properties of tuff at Yucca Mountain resulted from the differences in the mode of deposition, the cooling history, the composition, and distance from the source vent. The variability among the thermo-mechanical units is particularly evident and is directly associated with the change in lithology. For example, the generally nonwelded PTn unit has significantly higher porosity and lower strength, elastic moduli, grain density, and P wave velocity than the welded units. The concentration of data was such that contacts between the units can be accurately located using only bulk and mechanical properties. The contact between typically lithophysal TSw1 unit and the generally nonlithophysal TSw2 unit (both welded) is not as easily distinguishable. Within each unit, the properties also vary in a consistent manner. Generally strength, elastic moduli, and P wave velocity increase with decreasing porosity. Core intervals where this relationship is not obvious or reversed, can be explained by the size, shape, and orientation of the pores and/or altered zones. Lateral variability within the same unit would most likely be due to the difference in distance from the source vent. The flow direction in Yucca Mountain was north to south, and thinning of various units would be expected in the same direction with modifications due to topography and erosional activities. Available bulk and mechanical properties data show that there is small lateral variability normal to flow direction. Due to small separation distances between the boreholes (less than a kilometer) and the relative east-west orientation of the boreholes, a through evaluation of the lateral variability in bulk and mechanical properties was not possible. There are some observable differences in the property data that can be attributed to the variability of specific properties such as porosity and internal structures.

Application of DDA to Block-in-Matrix Materials
Te-chih Ke (Chung-Yuan Christian University, Taiwan)

In many field situations, rock blocks are within a matrix of soft/weak rock, for example, melange, breccia, conglomerate, and tillite. These materials are called block-in-matrix (bimrocks). Generally, the mechanical properties of bimrock are taken as those of the weaker matrix. This assumption has proven to be over-conservative. This paper attempts to describe the bimrock response in terms of matrix, blocks, and interfaces using Discontinuous Deformation Analysis (DDA) program. Factors affecting the bimrock response are: i) volume proportion of blocks, ii) shape and orientation of blocks, iii) arrangement of blocks, iv) size and distribution of blocks, v) property contrast of block and matrix, and vi) strength of interfaces. Numerical simulation using the DDA code hows that although block volumetric proportion plays an important role, other factors such as block geometry, block arrangement, deformability contrast of block and matrix, and interface strength may become dominant in certain cases.

Sliding Stability of Prismatic Blocks
M. Mauldon (University of Tennessee) and J. Ureta (Universidad Tecnologica de Panama)

Wedge and plane sliding stability analyses have been widely used in rock slope stability analysis. These classic methods, based on limiting equilibrium, assume shear stress on the contact plane(s) directly opposes the motion. Certain geological environments produce blocks that cannot be adequately modeled as either wedge or plane slides. An example is blocks forming in cylindrically folded sedimentary rocks where the surface of sliding is curved which cannot be modeled as a single or a double plane. This type of blocks may be idealized as prismatic blocks with multiple (**m**) sliding planes (**$m \to \infty$**) with parallel lines of intersection. A new analytical model for stability analysis of prismatic blocks is given which include plane and wedge slides as special cases. This model used the potential energy of the system to derive the solution. Potential energy is minimum at equilibrium. Contact forces are modeled using the elastic springs. Shear stresses are assumed to be along the sliding direction, as at the moment of initiation of sliding the shear forces will turn towards the sliding direction. The calculated factor c. safety when three or more discontinuity planes form the sliding surface is significantly lower than the case assuming a wedge.

Modification of the DDA for Elasto-Plastic Analysis with Illustrative Generic Problems
Y. Ohnishi and M. Tanako (Kyoto University) and T. Sasaki (Kajima Corporation, Japan)

This paper describes the modifications to DDA code carried out by authors, followed by the application of this new code to some rock slope stability problems. The first modification deals with the algorithm of penetration of one block into another is handled in the original DDA. The new formulation uses penalty function in both normal and shear directions as opposed to only in normal direction in the original DDA. The block element in the modified code can deform as an elasto-plastic material following the Drucker-Prager associated constitutive law to take into account block yielding to simulate soft rock behavior subjected to various loading conditions. A rockbolt element has been developed which fuses two blocks representing shotcrete in a tunnel. The modified DDA code was validated by comparing with laboratory model tests. Subsequently, this code was used to analyze stability of rock slope and a tunnel, and rockfall on a very steep slope.

Joint Shear Displacement-Dilation Analysis Using In-Situ Opposing Profiles
B. B. Thapa (Lawrence Berkeley Laboratory)

This paper describes a Borehole Scanner System (BSS) capable of unrolled true color digital image of the borehole wall at a resolution of 0.10 mm. Data from a 3.5 in diameter borehole were used to determine the *in situ* opposing roughness profiles of a joint. Results of this analysis are presented along with a comparison of predicted shear strength of the same joint using DDA and laboratory direct shear test. Results of kinematic analyses of the roughness profiles measured from BSS match closely with DDA simulation and laboratory results. Both DDA and kinematic analyses failed to produce peak shear stress observed in the laboratory test. Predicted residual shear strengths are higher than actual and show unrealistic oscillations. The predicted shear stiffness of the joint by this method is also lower than actual.

Geomechanical Investigations and Analyses of the Large Rock Sculptures at Mount Rushmore and Stone Mountain
T. J. Vogt (RE/SPEC) and W.J. Boyle (US DOE)

This is a very interesting paper dealing with the application of the key block theory to two high-profile and practical cases, namely, the analyses of stability of the large rock sculptures at Mount Rushmore, South Dakota, and Stone Mountain, Georgia. The National Park Service and the Mount Rushmore National Memorial Society commissioned RE/SPEC, Inc. to perform site investigations and analyses of the sculpture and the nearby unfinished Hall of Records that is part of the Memorial. The sculptures were completed more than 50 years ago. Natural joints in the rock mass dictated major and minor changes of Borglum's design and development of the four presidential faces. Borglum initiated a program to seal the discontinuities against water penetration during the period of sculpting (deterioration of rock joint strength due to presence of water). A database of more than 100,000 points located on the surface of the sculpture was created using aerial and terrestrial photogrammetry. From these points, maps of the surface of the sculpture were created which also included the geology and the discontinuities. The maps were examined to find those areas of the sculpture bounded by discontinuities for possible key blocks. There were 22 completely bounded or very nearly bounded blocks in the sculpture; 10 blocks of which are removable. Of these 10 blocks, only two blocks would tend to move out of the sculpture under their own weight. One of these blocks is in the forehead and face of the Lincoln and has still rock bridges between the joints. The other block on top of the head of the Roosevelt sculpture is held in place by friction and also possibly by rock bridges not visible beneath the block. A silicon-based sealant with good adhesive and elastic properties was selected for sealing water out of the existing fractures. Fractures were prioritized for treatment with the sealant emphasizing large vertical fractures in horizontal surfaces.

There are no key blocks in the existing Hall of Records that can move into the Hall or into the immediate surrounding area largely due to small size of the Hall compared to joint spacing.

Site investigation at Stone Mountain of the Confederate Memorial Carving revealed essentially no through-going fractures. Most of these surface discontinuities have limited length. Consequently, only a few cases of mutually intersecting joints forming *in situ* blocks. Only one block can possibly move out from its current position if the mortar and metal pins fail. Freeze and thaw cycles are not a factor in the long-term stability of this almost two-dimensional structure.

WAVE: A Computer Program for Investigating Elastodynamic Issues in Mining
M.W. Hildyard & A. Daehnke (CSIR, South Africa), and P.A. Cundall (Marine on St. Croix, Minnesota)

A finite difference computer program WAVE has been developed in CSIR-MiningTek as part of its elastodynamic research in the Rock Mass Behavior project. The activities in this project include dynamic fault slip and rockburst mechanisms; interaction of seismic waves with tabular stopes and geological structures, such as dyke; determination of geometric factors which influence the magnitude of motions in stopes; influence of local and regional support, such as backfill, on dynamic motions; and wave propagation in and dynamic response of stope fracture zone.

WAVE can model mining geometries in two-dimensional plane strain or in three dimensions. Using the explicit finite difference scheme, it solves the system of first-order wave equations on a staggered mesh. The mesh is regular and orthogonal. Geologic features must be aligned along a grid. Zones with different material properties can be arbitrarily positioned in the mesh. Crack element in this code can be used to represent tabular stopes, seams, or faults. Seam or joint stiffnesses may be specified and may also be used to model backfill in stopes with linear stiffness. The program can model stope advance, Mohr-Coulomb failure on faults, and opening and closure of joints and stopes. Parameters, such as stiffness, friction, and cohesion, can be varied arbitrarily throughout a fault.

Absorbing boundaries can be used to simulate approximate wave propagation through an infinite rock mass. A static solution is obtained through asymptotic solution of the wave equations, and by applying viscous damping in the mesh.

WAVE's restriction to an orthogonal regular mesh allows for efficient solution and storage. Consequently, three dimensional modeling is a possibility on a PC. Maximum model size is limited by the computer memory. This paper gives two validation examples. The first example is a static one and deals with the convergence of a tabular stope. Convergence of the results given by WAVE agrees quite well with the results from DIGS, a boundary element program. WAVE also has been successfully used to back-analyze dynamic photoelastic experiments for three geometries. The paper also discusses the application of WAVE to study the influence of backfill under dynamic extraction and the triggering of a larger event by the wave motion from a slip on a nearby fault.

Blasting Induced Fracturing and Stress Field Evolution at Fracture Tips
J. Song and K. Kim (Columbia University)

This paper discusses the results from the study carried out using the Dynamic Lattice Network model to examine the dynamic stress state ahead of the crack tips caused by blasting. The numerical model consists of particles and springs. The particles posses the lumped mass based on the material density and are interconnected with each other through springs arranged in triangular lattices. Stiffness and failure thresholds of each spring are assigned randomly. Numerical simulation showed emergence of 10 to 12 radial cracks out of the pressurized hole. A process zone forms ahead of a radial crack. Microcracks, formed in this zone, relieve the stresses. Propagation of both P and S waves, and the corresponding reflected waves can be accounted for in the analysis.

Investigation of Interface Wave Propagation along Planar Fractures in Sedimentary Rocks
A. Ekern (NTH, Norway), R. Suarez-Rivera (IKU Petroleum Research), and A. Hansen (IKU Petroleum Research and NTH, Norway)

Rough interfaces play an important role in determining the productivity and final recovery of hydrocarbon reservoirs. Change of state of stress on the fractures caused by the reservoir depletion may considerably affect the hydraulic properties. Presence of these interfaces and their mechanical and hydraulic properties can be evaluated using seismic waves. Predominance of fast and slow modes of interface waves and their velocities are strongly dependent on the stress applied across the interface and the interface stiffness. Interface wave velocity is equal to Rayleigh wave velocity at zero normal load and equal to shear wave velocity at high normal load. Experimental measurements carried out on Anstrude limestone along with the comparison of the results with analytical and numerical studies of others are focus of this paper.

A fracture surface created on the limestone block (154 mm long, 66 mm wide, and 103 mm high) was scanned along 7 parallel lines with a resolution of 0.8 mm. Fracture surface showed self-affine scaling properties. A uniform normal stress was applied on the top surface. Spring-loaded piezoelectric transducers having 1 MHz central frequency were used to measure S-wave. Rayleigh wave was measured using a single half of the specimen. Measurements of the Rayleigh wave along smooth and rough surfaces indicate that fracture roughness induces attenuation and velocity dispersion. The attenuation is approximately 100 db/m at 100 kHz and increases linearly with frequency. Interface waves were measured for normal stress 0 to 10 MPa. Both zero cross-over velocity and phase velocity increased with increasing stress from a value approximately equal to Rayleigh wave velocity to S-wave velocity. Amplitude of interface wave increased with increasing stress, in contradiction to the theory.

B. ARMA (American Rock Mechanics Association) and U.S. National Committee for Rock Mechanics (USNC/RM)

There was a special session on Monday, June 5, afternoon to discuss the status of U.S. National Committee for Rock Mechanics and the mission of the newly formed ARMA. USNC/RM has been relocated within the National Academy of Sciences to the Board on Earth Sciences and Resources (BESR) in the Commission on Geosciences, Environment, and Resources (CGER). Dr. Jane C.S. Long is currently the Chairperson of USNC/RM. Dr. Priscilla Nelson, President of ARMA, spoke about the new organization and its current and planned activities. "ARMA is a private organization owned by its members to serve its members. Its interests are to promote and act as an advocate for the profession, to develop communications links for interactions with other societies and for enhanced resource and educational services, and to generally improve the states of the art and practice." Being a private organization, ARMA can carry out many activities that is not possible under the National Academy of Sciences. A letter, written jointly by Drs. P.P. Nelson and J.C.S. Long, explaining the two organizations of Rock Mechanics, is attached in APPENDIX C. ARMA has started a new newsletter with Dr. Bernard Amadei as the editor. The first issue, dated June 5, 1995, is also attached in APPENDIX C. ARMA is actively looking for new members. ARMA is now on the information superhighway. A World Wide Web home page entitled "RockNet" has been established on a server at the Sandia National Laboratories. The URL is:

http://sair019.energylan.sandia.gov:70. The home page is also attached in APPENDIX C.

IMPRESSIONS/CONCLUSIONS:

The 35th U.S. Symposium on Rock Mechanics was well-attended and a success by every measure. In every session, good discussion on the subject after formal presentation of each paper was very fruitful. There is a possibility that these discussions will be published in near future. The proceedings of the symposium are available from the author of this trip report for those interested.

PROBLEMS ENCOUNTERED:

None to report.

PENDING ACTIONS:

None to report.

SIGNATURES:

AGhosh — July 6, 1995

Amitava Ghosh
Senior Research Engineer

DATE

CONCURRENCE SIGNATURES AND DATE:

7/6/95

Asadul H. Chowdhury
Manager, RDCO

DATE

7/7/95

Budhi Sagar
Technical Director

DATE

/yl

APPENDIX A

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
June 4, 1995

Participant List by Name

---

1. Younane Abousleiman
Univ. of Oklahoma
Sarkeys Energy Center
100 E. Boyd, Rm. T301
Norman, OK 73019
USA

2. James Adams
Western Technologies, Inc.
2528 W. Windrose Dr.
Phoenix, AZ 85029
USA

3. Tirso Alvarez
Univ. of Illinois
2206 Newmark Civil Eng. Lab.
Urbana, IL 61801
USA

4. Bernard Amadei
Univ. of Colorado
Dept. of Civil Eng., CB428
Boulder, CO 80309
USA

5. Garry Anderson
ASARCO Ray Complex
P.O. Box 8
Hayden, AZ 85235
USA

6. J.Guadalupe Arguello
Sandia Nat'l Lab, Orgn. 1517
P.O. Box 5800 - MS 0443
Albuquerque, NM 87185
USA

7. Michel Aubertin
Ecole Polytechnique
P.O. Box 6079
Stat. "Centre-Ville"
Montreal, Quebec H3C 3A7
CANADA

8. Tim Avery
Nicholson Const. Co.
12 Panoramic Way
Berkeley, CA 94704
USA

9. Mao Bai
Univ. of Oklahoma
Sarkeys Energy Center
100 E. Boyd, Rm. T301
Norman, OK 73019
USA

10. Colleen Barton
Stanford Univ.
Dept. of Geophysics
B57 Mitchell
Stanford, CA 94305
USA

11. William Bawden
Queen's University
103 Marclen Dr.
Kingston, Ontario K7L 5H6
CANADA

12. Wes Bender
Wesley Bender & Assoc.
P.O. Box 310
Nevada City, CA 95959
USA

13. Brad Bessinger
Lawrence Berkeley Lab
1 Cyclotron Rd., Bldg. 50E
Berkeley, CA 94720
USA

14. Susan Bird
Call & Nicholas, Inc.
3625 E. 42nd Stravenue
Tucson, AZ 85123
USA

PARTICIPANT LIST
35th U.S. Rock Mechanics Sympc ium
XC202
Embassy Suites Resort
June 4, 1995

Participant List by Name

---

15. Stephen Blair
Lawrence Livermore Nat'l Lab
P.O. Box 808, L-201
Livermore, CA 94551
USA

16. Brad Boisen
Slope Indicator Co.
P.O. Box 300316
Seattle, WA 98103
USA

17. Amarin Boontun
Michigan Tech. Univ.
Dept. of Mining Eng.
Houghton, MI 49931
USA

18. Seymour Bortz
Wiss, Janney, Elstner Assoc.,
330 Pfingsten Rd.
Northbrook, IL 60062
USA

19. Peter Boyd
New England Research, Inc.
76 Olcott Dr.
White River Jct., VT 05001
USA

20. William Boyle
US Dept. of Energy
101 Convention Center Dr.
Las Vegas, NV 89109
USA

21. Marco Brignoli
AGIP
P.O. Box 12069
Milano, 20120
ITALY

22. Nancy Brodsky
RE/SPEC Inc.
P.O. Box 725
Rapid City, SD 57701
USA

23. Scott Burch
US Army Corps of Eng.
P.O. Box 4970
Jacksonville, FL 32232
USA

24. Tarcisio Celestino
Themag Engenharia
Rua Bela Cintra 986
Sao Paulo, SP 01415-906
BRAZIL

25. Arif Cetintas
Univ. of Nevada, Reno
Mining Engineering
Mails Stop 173
Reno, NV 89557
USA

26. Hulya Cetintas
Univ. of Nevada, Reno
Mining Engineering
Mails Stop 173
Reno, NV 89557
USA

27. Kwai Chan
Southwest Research Inst.
6220 Culebra Rd.
San Antonio, TX 78238
USA

28. Neil Chandler
AECL
Underground Research Lab
Pinawa, Manitoba R0E 1L0
CANADA

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
June 4, 1995

Participant List by Name

---

29. Gang Chen
Univ. of Alaska, Fairbanks
P.O. Box 755800
Dept. of Mining & Geological
Fairbanks, AK 99775
USA

30. Alexander Cheng
Univ. of Delaware
Dept. of Civil Eng.
Newark, DE 19716
USA

31. Dai Choi
Consol Inc.
4000 Brownsville Rd.
Library, PA 15129
USA

32. Mark Christianson
Itasca Consulting Group,
708 So. 3rd St., #310
Minneapolis, MN 55415
USA

33. Yang Chun He
Univ. of Nevada, Reno
Mining Engineering
Mails Stop 173
Reno, NV 89557
USA

34. Kenneth Cole
Caltrans
5900 Folsom Blvd.
Sacramento, CA 95819
USA

35. Edward Cording
Univ. of Illinois
2221 Newmark CE Lab.
Urbana, IL 61804
USA

36. Laurence Costin
Sandia Nat'l Laboratories
P.O. Box 5800, MS 1325
Albuquerque, NM 87185
USA

37. David Crouthamel
Stone & Webster Eng.
28 Hundred Oaks Ln.
Ashland, MA 01721
USA

38. Don Cruickshank
Univ. of Oklahoma
Sarkeys Energy Center
100 E. Boyd, Rm. T301
Norman, OK 73019
USA

39. Lizheng Cui
Univ. of Delaware
Dept. of Civil Eng.
Newark, DE 19716
USA

40. Jaak Daemen
Univ. of Nevada, Reno
Mail Stop 173
Reno, NV 89557
USA

41. Robin Datta
Woodward Clyde Federal Svc.
4080 Paradise Rd., #15
Las Vegas, NV 89109
USA

42. Hans DePater
Delft Univ. of Tech
Mijnbouwstraat 120
Delft, 2628RX
NETHERLANDS

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
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Participant List by Name

---

43. W.Raynor Dean
Univ. of Arizona
5561 N. Ft. Yuma Trail
Tucson, AZ 85715
USA

44. Becky Dees
Haro, Kasunich & Assoc.
116 E. Lake Ave.
Watsonville, CA 95062
USA

45. H.J.R. Deketh
Delft Univ. of Technology
Mijnbouwstraat 120
Delft, 2628RX
NETHERLANDS

46. Emmanuel Detournay
Dept. Civil Eng, Univ. of Min
500 Pillsbury Dr. SE
Minneapolis, MN 55455
USA

47. Helio Dos Santos
Univ. of Oklahoma
418 Rosewood Dr.
Norman, OK 73069
USA

48. Charles Dowding
Northwestern Univ.
Dept. of Civil Eng.
Evanston, IL 60208
USA

49. John Dudley
Shell E&P Technology
3737 Bellaire Blvd.
Houston, TX 77025
USA

50. Judy Ehlen
USA TEC
7701 Telegraph Rd.
Alexandria, VA 22315-3864
USA

51. Herbert Einstein
MIT
77 Mass Ave., 1-342
Cambridge, MA 02139
USA

52. Steve Ericksen
Kennecott Utah Copper
P.O. Box 232
Bingham Canyon, UT 84006
USA

53. Russell Ewy
Exxon Production Research Co.
P.O. Box 2189
Houston, TX 77252
USA

54. Charles Fairhurst
Univ. of Minnesota
500 Pillsbury Dr., SE
Civil Engineering
Minneapolis, MN 55455
USA

55. Jianli Fan
UC Berkeley
2600 Bancroft Way
Berkeley, CA 94704
USA

56. Robert Ferriter
DOL, MSHA
P.O. Box 25367
Denver Safety/Health Tech. Ce
Denver, CO 80225-0367
USA

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
June 4, 1995

Participant List by Name

---

57. Gerald Finfinger
US Bureau of Mines
P.O. Box 18070
Pittsburgh, PA 15236
USA

58. Ray Finley
Sandia Nat'l Labs
HS-B25, P.O. Box 5800
MS 1325
Albuquerque, NM 87185
USA

59. Andrea Fori
Univ. of Nevada, Reno
Geological Eng.
Reno, NV 89557
USA

60. Chris Francke
Westinghouse-WIPP
P.O. Box 2078
Carlsbad, NM 88221
USA

61. Kai Front
VTT/YKI
P.O. Box 15041
VTT, Fin 02044
FINLAND

62. Kittitep Fuenkajorn
Rock Eng. International
7226 W. Rivulet Dr.
Tucson, AZ 85743
USA

63. James George
Sandia Nat'l Labs
P.O. Box 5800
MS 1325
Albuquerque, NM 87123
USA

64. Leonid Germanovich
Univ. of Oklahoma
100 E. Boyd, T301
Norman, OK 73019-0628
USA

65. Amit Ghosh
Southwest Research Inst.
6220 Culebra Rd.
San Antonio, TX 78238-5166
USA

66. M. Giezen
Univ. Leiden
Verversdijk 122
Delft, 2611N1
NETHERLANDS

67. Kirstin Girdner
Univ. of Arizona
Dept. of Mining/Geological En
Tucson, AZ 85721
USA

68. Steven Glaser
Colorado School of Mines
Div. of Engineering
Golden, CO 80401
USA

69. Maria Gracia Fustino
Intevep
APDO 76343
Caracas, 1070A
VENEZUELA

70. R.Larry Grayson
W.Virginia Univ.
P.O. Box 6070, COMER
Morgantown, WV 26506
USA

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
June 4, 1995

Participant List by Name

---

71. RG Gurtunca
CSIR Mining Technology
P.O. Box 91230
Auckland Park
Johannesburg, 2006
AFRICA

72. Robert Guyer
Los Alamos Nat'l Lab
MS-C305
Los Alamos, NM 87545
USA

73. Bezalel Haimson
Univ. of Wisconsin
1509 Un. ersity Ave.
Madison, WI 53706
USA

74. Frank Hansen
Sandia Labs
P.O. Box 5800/MS 1322
Albuquerque, NM 87185
USA

75. Michael Hardy
Agapito & Assoc., Inc.
715 Horizon Dr., #340
Grand Junction, CO 81506
USA

76. F.P. Hassani
McGill University
3450 University, FDA20
Montreal, QUEBEC H3A 2A7
CANADA

77. Yossef Hatzor
Ben Gurion Univ.
P.O. Box 653
Berr Sheva, 84105
ISRAEL

78. Steve Hencher
Univ. of Leeds
Dept. of Earth Sciences
Leeds LS2 9JT
UNIT KINGDOM

79. Galen Hesler
UC Berkeley
Dept. of Mineral Eng.
570 Evans Hall
Berkeley, CA 94720
USA

80. Francois Heuze
LLNL
L-200
Livermore, CA 94551
USA

81. L.Brun Hilbert
Lawrence Berkeley Lab
Earth Sciences Div., Bld. 50E
1 Cyclotron Rd.
Berkeley, CA 94720
USA

82. M Hildyard
CSIR Mining Technology
P.O. Box 91230
Auckland Park
Johannesburg, 2006
AFRICA

83. Kang Hongpu
Central Coal Mining Research
Hepingli, Beijing 100013
CHINA

84. Deborah Hopkins
Lawrence Berkeley Lab
MS 90/3147
Berkeley, CA 94720
USA

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
June 4, 1995

Participant List by Name

---

85. Cliff Howard
Re/Spec Inc.
302 Mariposa
Carlsbad, NM 88220
USA

86. Jingkun Hu
Univ. of Nevada, Reno
Mining Engineering
Mails Stop 173
Reno, NV 89557
USA

87. Nicholas Hudyma
UNLV
4505 Maryland Pkwy, Box 45401
Dept. of Civil/Envir Eng.
Las Vegas, NV 89154
USA

88. Taylor Hwong
UC Berkeley
Berkeley, CA 94720
USA

89. Anthony Iannacchione
US Bureau of Mines
P.O. Box 18070
Cochrans Mill Rd.
Pittsburgh, PA 15236
USA

90. Roger Ilsley
R.I. Geotechnical Inc.
3494 N. Shepard Ave.
Milwaukee, WI 53211
USA

91. Violeta Ivanova
MIT
77 Mass Ave., Rm. 5-330B
Cambridge, MA 02139
USA

92. Seokwon Jeon
Univ. of Arizona
Tucson, AZ 85705
USA

93. Russell Jernigan
Univ. of Colorado, Boulder
230 S. Lark Ave.
Lonuville, CO 80027
USA

94. J.L. Jethwa
CMRI, Dhanbad
CMRI Regional Centre
54-B Shankar Nagar
Nagpur, Maharashtra 440 010
INDIA

95. Peter Kandaris
Salt River Project
P.O. Box 52025
Phoenix, AZ 85072-2025
USA

96. Jon Kaneshiro
Parsons Eng. Science
9404 Genesee Ave., #140
LaJolla, CA 92037
USA

97. Murat Karaca
Miyazaki Univ.
Faculty of Engineering
Miyazaki, 889-21
JAPAN

98. Moses Karakouzian
UNLV
4505 Maryland Pkwy, Box 45401
Dept. of Civil/Envir Eng.
Las Vegas, NV 89154
USA

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
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Participant List by Name

---

99. Mario Karfakis
Virginia Tech
100 Holden Hall
Mining & Minerals Eng.
Blacksburg, VA 24061
USA

100. John Kemeny
Univ. of Arizona
Dept. Mining/Geological Eng.
Tucson, AZ 85721
USA

101. Frances Kendorski
Weir Int'l Mining Cons.
2340 River Rd., Ste. 203
Des Plaines, IL 60018
USA

102. Aziz Khan
Univ. of Oklahoma
Sarkeys Energy Center
100 E. Boyd, Rm. T301
Norman, OK 73019
USA

103. Kunsoo Kim
Columbia University
811 SW Mudd
New York, NY 10027
USA

104. M. Kathryn Knowles
Sandia National Labs
P.O. Box 5800 - MS1322
Albuquerque, NM 87185
USA

105. Nicholas Kripakov
US Bureau of Mines, DRC
Bldg. 20, Denver Federal Ctr.
Denver, CO 80225
USA

106. Geetha Krishnan
Univ. of Oklahoma
Sarkeys Energy Center
100 E. Boyd, Rm. T301
Norman, OK 73019
USA

107. P.H.S.W. Kulatilake
Univ. of Arizona
Dept. of Mining/Geological En
Tucson, AZ 85721
USA

108. Andrew Kurkjian
Schlumberger
110 Schlumberger Dr.
Sugar Land, TX 77478
USA

109. Sangki Kwon
Univ. of Missouri-Rolla
1006 Kingshighway
Rolla, MO 65401
USA

110. Joseph Labuz
Univ. of Minnesota
Dept. of Civil Eng.
Minneapolis, MN 55455
USA

111. Lewis Lacy
BJ Services Company
11211 FM 2920
Tomball, TX 77375
USA

112. Victor Langhaar
Law/Crandall, Inc.
200 Citadel Dr.
Los Angeles, CA 90040
USA

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
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Participant List by Name

---

113. Moo Lee
Sandia Nat'l Lab
P.O. Box 238
Mercury, NV 89023
USA

114. Jiang Li
Univ. of Nevada, Reno
NV Bureau of Mines & Geology
Mails Stop 178
Reno, NV 89557
USA

115. Dezhang Lin
Univ. of Oklahoma
Sarkeys Energy Center
100 E. Boyd, Rm. T301
Norman, OK 73019
USA

116. Jane Long
LBL, Earth Sciences Div.
1 Cyclotron Rd.
Berkeley, CA 94720
USA

117. Terry MacDonald
Sandia National Laboratories
115 N. Main St.
Carlsbad, NM 88220
USA

118. Mary MacLaughlin
UC Berkeley
440 Davis Hall
Berkeley, CA 94720
USA

119. Mark Mack
Schlumberger Dowell
P.O. Box 2710
Tulsa, OK 74101
USA

120. Stephen Mackwell
Penn State Univ.
405 Deike Bldg.
Geosciences
University Park, PA 16802
USA

121. Randolph Martin
New England Research, Inc.
76 Olcott Dr.
White River Jct., VT 05001
USA

122. R.J. Matetic
US Bureau of Mines
P.O. Box 18070
Cochrans Mill Rd.
Pittsburgh, PA 15236
USA

123. Matthew Mauldon
UT-Knoxville
Civil/Environmental Eng.
223 Perkins Hall
Knoxville, TN 37996
USA

124. Katherine McCall
Los Alamos Nat'l Lab
P.O. Box 1663, MS F665
Los Alamos, NM 87545
USA

125. Edmund Medley
Geological Engineer
36C Denbigh Rd.
W. Ealing, London
UNITED KINGDOM

126. Maugeri Michele
Univ. of Catania
Viale Andrea Doria
Catania, 95125
ITALY

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
June 4, 1995

Participant List by Name

---

127. Hamish Miller
Univ. of Missouri-Rolla
1006 Kingshighway
Rolla, MO 65401
USA

128. Mike Miller
Woodward Clyde Cons.
20 S. Ogden #206
Denver, CO 80209
USA

129. Stan Miller
Univ. of Idaho
Geological Engineering
Moscow, ID 83844
USA

130. Terry Miller
Exxon Production Res. Co.
P.O. Box 2189
Houston, TX 77252-2189
USA

131. Fersheed Mody
Baroid Drilling Fluids
P.O. Box 1675
Houston, TX 77251
USA

132. Moe Momayez
McGill University
3450 University, FDA20
Montreal, QUEBEC H3A 2A7
CANADA

133. Andreas Momber
Univ. of Kentucky
Center for Robotics
Lexington, KY 40506
USA

134. James Monsees
Parsons Brinckerhoff
834 Millcreek Cr.
Lancaster, TX 75146
USA

135. Jason Moore
Univ. of Nevada, Reno
Geological Eng.
Reno, NV 89557
USA

136. Zissis Moschovidis
AMOCO
P.O. Box 3385
Technology Center
Tulsa, OK 74102
USA

137. Darrell Munson
Sandia National Labs
P.O. Box 5800
MS 1322
Albuquerque, NM 87185
USA

138. Larry Myer
Lawrence Berkeley Lab
Mailstop 50E
Berkeley, CA 94720
USA

139. Seiji Nakagawa
UC Berkeley
1835 Delaware #2
Berkeley, CA 94703
USA

140. Pawel Nawrocki
Univ. of Waterloo
Dept. of Earth Sciences
Waterloo, Ontario N2L 3G1
CANADA

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
June 4, 1995

Participant List by Name

---

141. Justo Neda
Intevep
APDO 76343
Caracas, 1070A
VENEZUELA

142. Edris Negion-Perez
Corpoven S.A.
Ed SEDE, Mod B, 21, Ofc 38
Puerto La Cruz, ANZ
VENEZUELA

143. Priscilla Nelson
Nat'l Science Foundation
4201 Wilson Blvd., Rm. 545.17
Arlington, VA 22230
USA

144. Gregory Neumann
Johns Hopkins Univ.
E/PS Olin Hall
Baltimore, MD 21218
USA

145. Tung Nguyen
Univ. of Nevada, Reno
NV Bureau of Mines & Geology
Mails Stop 178
Reno, NV 89557
USA

146. Mark Nickerson
Univ. of Arizona
Eng/Mines Bldg.
Tucson, AZ 85721
USA

147. Kurt Nihei
Lawrence Berkeley Lab
1 Cyclotron Rd., 50E
Berkeley, CA 94720
USA

148. Kevin O'Connor
US Bureau of Mines
5629 Minnehaha Ave.
Minneapolis, MN 55417
USA

149. Gregory Ohlmacher
Univ. of Texas, El Paso
El Paso, TX 79968
USA

150. Vincke Olivier
Institut Francais du Petrolr
1 et 4, Avenue de Bois Preau
Rueil-Malmaison, 92 500
FRANCE

151. Bibhuti Panda
Univ. of Arizona
Dept. Mining/Geological Eng.
Tucson, AZ 85721
USA

152. Euripides Papamichos
IKU Petroleum Research
N-7034 Trondheim
NORWAY

153. Panos Papanastasiou
Schlumberger Cambridge Res.
High Cross-Madingley Rd.
Cambridge, CB3 OEL
UNITED KINGDOM

154. William Pariseau
Univ. of Utah
315 WBB
Salt Lake City, UT 84112-1185
USA

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
June 4, 1995

Participant List by Name

---

155. Adam Pawelek
FERC
230 S. Dearborn St.
Chicago, IL 60604
USA

156. David Pentz
Golder Associates
One Bellevue Center
411 108th Ave. NE, Suite 1920
Bellevue, WA 98004
USA

157. Pauel Peska
Stanford Univ.
Dept. of Geophysics
B57 Mitchell
Stanford, CA 94305
USA

158. Paul Piscoran
Univ. of Nevada, Reno
Geological Eng.
Reno, NV 89557
USA

159. Thomas Plona
Schlumberger-Doll Research
Old Quarry Rd.
Ridgefield, CT 06877
USA

160. Dave Poppler
2367 Utley Rd.
La Crescenta, CA 91214
USA

161. Ronald Price
Sandia National Labs
P.O. Box 5800
MS 1325
Albuquerque, NM 87185-1325
USA

162. Sunthorn Pumjan
Michigan Tech Univ.
1908 E. Woodmar Dr.
Houghton, MI 49931
USA

163. Gangerico Ramos
ARCO Exploration & Production
2300 W. Plano Parkway
Plano, TX 75075
USA

164. Chongwei Ran
Univ. of Nevada, Reno
Mining Eng./173
Reno, NV 89557
USA

165. Joe Ratigan
RE/SPEC Inc.
P.O. Box 725
Rapid City, SD 57701
USA

166. Rodney Read
AECL
Whiteshell Lab., STN91, URL
Pinawa, Manitoba R0E 1L0
CANADA

167. MKC Roberts
CSIR Mining Technology
P.O. Box 91230
Auckland Park
Johannesburg, 2006
AFRICA

168. Eugene Robertson
US Geological Survey
National Center, MS 922
Reston, VA 22092
USA

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
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Participant List by Name

---

169. Jean-Claude Roegiers
Univ. of Oklahoma
Sarkeys Energy Center
100 E. Boyd, Rm. T301
Norman, OK 73019
USA

170. David Ropchan
DOL, MSHA
P.O. Box 25367
Denver Safety/Health Tech. Ce
Denver, CO 80225-0367
USA

171. H.P. Rossmanith
Technical Univ. Vienna
Inst. of Mechanics
Wiedner Hauptstr. 8-10/325
Vienna, A-1040
AUSTRIA

172. Sanjit Roy
Univ. of Notre Dame
156 Fitzpatrick Hall
Notre Dame, IN 46556
USA

173. Thomas Ryan
Call & Nicholas, Inc.
3625 E. 42nd Str.
Tucson, AZ 85713
USA

174. Pierre Santoni
Northwestern Univ.
Dept. of Civil Eng.
Evanston, IL 60208
USA

175. Andrew Schaffer
US Army Corps of Eng.
1000 Liberty Ave.
Pittsburgh, PA 15222
USA

176. Birger Schmidt
Parsons Brinckerhoff
303 2nd St., Ste. 700N
San Francisco, CA 94402
USA

177. Richard Schultz
Mackay School of Mines
University of Nevada, Reno
Reno, NV 89557
USA

178. Thomas Scotese
Woodward-Clyde
101 Convention Center Dr.
Las Vegas, NV 89109
USA

179. Gregg Scott
US Bureau of Reclamation
P.O. Box 25007
ATTN: Marge Wagner/D-8311
Denver, CO 80225
USA

180. Robert Sharon
Barrick Goldstrike Mines
P.O. Box 29
Elko, NV 89803
USA

181. Robert Sharp
Los Alamos Nat'l Lab
28 Sage Hill Dr.
Placitas, NM 87043
USA

182. Zhuping Sheng
Univ. of Nevada, Reno
NV Bureau of Mines & Geology
Mails Stop 178
Reno, NV 89557
USA

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
June 4, 1995

Participant List by Name

---

183. Jacob Shlyapobersky
Shell E&P Technology
3737 Bellaire Blvd.
Houston, TX 77025
USA

184. Liu Shuqing
Qiwu Coal Mine
Weishanhu, Shandong Province
CHINA

185. Peter Smeallie
American Rock Mechanics Assn.
600 Woodland Ter.
Alexandra, VA 22302
USA

186. William Smith
Un . of Texas, El Paso
Ge ogical Sciences
El aso, TX 79968
USA

187. John Song
Columbia University
834 SW Mudd
New York, NY 10027
USA

188. Catherine Stafford
Univ. College London
Dept. of Geological Sciences
Gower St.
London, WCIE6BT England
UNITED KINGDOM

189. John Steighner
US Bureau of Reclamation
P.O. Box 25007
Denver, CO 80225
USA

190. Charles Stone
Agapito Assoc., Inc.
3841 W. Charleston, Ste. 203
Las Vegas, NV 89102
USA

191. Wen Su
Univ. of Missouri-Rolla
1006 Kingshighway
Rolla, MO 65401
USA

192. Xiaoqing Sun
AAC International
P.O. Box 1093
Lebanon, NH 03766
USA

193. F.T. Suorineni
University of Waterloo
Dept. of Earth Sciences
Waterloo, Ontario N2L 3G1
CANADA

194. Robert Swift
Los Alamos Nat'l Lab
P.O. Box 1663, MS F665
Los Alamos, NM 87545
USA

195. Makoto Tanaka
Kyoto Univ.
School of Civil Eng.
Yoshida-Hommachi
Sakyo-ku, Kyoto 606-01
JAPAN

196. Stephen Taylor
Univ. of Nevada, Reno
Dept. of Mining Eng.
Sparks, NV 89431
USA

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
June 4, 1995

Participant List by Name

---

197. Bhaskar Thapa
Lawrence Berkeley Lab
1 Cyclotron Rd., Bldg. 50E
Earth Sciences Div.
Berkeley, CA 94720
USA

198. Thomas Tharp
Purdue University
Dept. of Earth/Atmos. Sci.
W.Lafayette, IN 47907
USA

199. Alan Thompson
Csiro Exploration & Mining
P.O. Box 437
Nedlands, WA 6009
AUSTRALIA

200. Scott Thurman
Univ. of Oklahoma
Sarkeys Energy Center
100 E. Boyd, Rm. T301
Norman, OK 73019
USA

201. Joe Tillerson
Sandia National Labs
P.O. Box 5800, Org. 6121
MS 1322
Albuquerque, NM 87185
USA

202. Z Toper
CSIR Mining Technology
P.O. Box 91230
Auckland Park
Johannesburg, 2006
AFRICA

203. Azra Tutuncu
Univ. of Texas, Austin
Dept. of Petroleum Eng.
Austin, TX 78712
USA

204. Ed Van Eeckhout
Los Alamos Nat'l Lab
P.O. Box 1663
MS C335
Los Alamos, NM 87545
USA

205. P.J. Van den Hoek
Shell Research B.V.
P.O. Box 2463
ATTN: Henrietta Jones
Houston, TX 77252
USA

206. Andres Vega
Soil Conservation Svc.
131 W. Timberview Ln.
Arlington, TX 76014
USA

207. Tim Vogt
RE/SPEC Inc.
P.O. Box 725
Rapid City, SD 57701
USA

208. Lewis Wade
US Bureau of Mines
5629 Minnehaha Ave. So.
Minneapolis, MN 55417
USA

209. Thomas Watters
Smithsonian Inst.
CEPS, NASM, MS315
Washington, DC 20560
USA

210. Wolfgang Wawersik
Sandia Nat'l Lab
Geomechanics Dept., MS0751
Albuquerque, NM 87185
USA

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
June 4, 1995

Participant List by Name

---

211. Xiaowei Weng
ARCO Expl. & Production Tech.
2300 W. Plano Parkway
Plano, TX 75075
USA

212. Gerald Wieczorek
US Geological Survey
National Center, MS 922
Reston, VA 22092
USA

213. John Wilson
Univ. of Missouri, Rolla
226 McNutt
Rolla, MO 65401
USA

214. P. Edward Wilson
US Bureau of Mines, DRC
Bldg. 20, Denver Federal Ctr.
P.O. Box 25086
Denver, CO 80225
USA

215. Robina Wong
Hong Kong Polytechnic Univ.
Hung Hom
HONG KONG

216. Yue Wu
Univ. of Nevada, Reno
Mining Engineering
Mails Stop 173
Reno, NV 89557
USA

217. Aiguo Xu
Univ. of Nevada, Reno
NV Bureau of Mines & Geology
Mails Stop 178
Reno, NV 89557
USA

218. David Yale
Mobil Exploration & Producing
13777 Midway Rd.
Dallas, TX 75244
USA

219. Gemei Yang
Lawrence Berkeley Lab
1 Cyclotron Rd.
Berkeley, CA 94720
USA

220. Ronald Yeung
Montana Tech
Dept. of Geol. Eng.
1300 W. Park St.
Butte, MT 59701
USA

221. Nobuyuki Yoshida
Kyoto University
Dept. of Civil Engineering
Yoshida
Sakyo, Kyoto 606
JAPAN

222. Dae Young
Michigan Tech Univ.
1400 Townsend Dr.
Houghton, MI 49931
USA

223. Musharraf Zaman
Univ. of Oklahoma
Sarkeys Energy Center
100 E. Boyd, Rm. T301
Norman, OK 73019
USA

224. David Zeuch
Sandia Nat'l Lab
Geomechanics Dept., MS0751
Albuquerque, NM 87185
USA

PARTICIPANT LIST
35th U.S. Rock Mechanics Symposium
XC202
Embassy Suites Resort
June 4, 1995

Participant List by Name

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225. Mark Zoback
Stanford Univ.
Dept. of Geophysics
Stanford, CA 94305
USA

Participant List Addendum

Ayden, Omer
Tokai University
Orido 3-20-1
Shimizu, Shizuoka, 424
JAPAN

Banks, Don
USAE Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
USA

Carbonell, Roberto
University of Minnesota
1170 Cushing Circle Apt. 211
St. Paul, MN 55108
USA

Cook, John
Schlumberger Cambridge Research
High Cross Madingley Road
Cambridge
ENGLAND

Cook, Neville
U.C. Berkeley
Berkeley, CA 94720
USA

Dai, Shongtao
Civil Engineering Dept, U. of Minn.
500 Pillsbury Dr.
Minneapolis, MN 55455
USA

Damjanac, Branka
Dept. of Civil Eng. - U. of Minn.
500 Pillsbury Drive
Minneapolis, MN 55455
USA

Desroches, J.
Schlumberger Cambridge Center
215 The Sycamores
Milton, UZ 6B6 G2D

Drussel, Steve
Reliable Geo LLC
241 Lynch Road
Yakima, WA 98908
USA

Edalatpour, Kamran
Shiraz University
85 Hang St.
Shiraz, Fars
IRAN

Elsworth, Derek
Penn. State University
Dept. of Mineral Engineering.
University Park, PA 16802
USA

Filho, Adolfo Polillo
Petrobras S.A.
Av. Chile 65 Room 1460
Rio De Janero, RJ 20035-900
BRAZIL

Ghaboussi, Jamshid
Univ. of Illinois at U.C.
3118 Newmark Civil Eng. Lab
Urbana, Il 61801
USA

Goel, R.K.
Central Mining Research Inst.
5413 Shankar Nagar
Nazpur
INDIA

Goodman, Richard
Univ. of California - Dept. of C.E.
Berkeley, CA 94720
USA

Hovem, Knut
Statoil
N-4035 Stavange
Stavange
NORWAY

Huang, Pingan
U.C. Berkeley
927 Riley Drive
Albany, CA 94706
USA

Hustrulid, Bill
LKAB
S-98186 Kiruna
SWEDEN

Iwano, Masahiro
Taisei Corporation
SCB15F 1-25-1 Nishi-Shinguku
Shinguku
Tokyo
JAPAN

Jagannath, Dr. Banad
U.S. Nuclear Regulatory Commission
G. Halifax CT
Rockville, MD 20850
USA

Jingen, Deng
University of Petroleum, China
Changping Beijing, P.R. China
102200

Ke, Te-Chin
Chung Yuan University, Taiwan R.O.C.
Chung-Li, Taiwan 32023

LaPointe, Paul
Golder Associates
19711 N.E. 185th St.
Woodinville, WA 98052
USA

Lindquist, Eric
Jacobs Associates
500 Sansome St.
San Fransisco, CA 94111
USA

Mazariegos, Ruben
Texas A&M University
College Station, TX 77840
USA

Nicholson, Glenn
Army Corp. of Engineers
3909 Halls Ferry Road
Vicksburg, MS 39180
USA

Park, Chul-Wan
Kigam
30 Kajung Dong
Yusungku, Taejon
KOREA

Steiger, Ron
EXXON
P.O. Box 2189
Houston, TX 77252
USA

Stormont, John
Sandia Labs
MS 0719
P.O. Box 5800
Albuquerque, NM 87185
USA

Thomas, Andrew
Golder Associates Inc.
4104 148th Ave NE
Redmond, WA 98052
USA

Wu, Lansun
Qiwu Coal Mine of Shandong
Weishan 227606
CHINA

Yi, Weidong
U.C. Berkeley
980 Riley Dr.
Albany, CA 94706
USA

APPENDIX B

UPDATED SCHEDULE OF TECHNICAL SESSIONS

Monday, June 5 — *Harrah's - South Shore Room*

8:30-9:00 Opening Session
9:00-10:00 Keynote Lecture: Block Theory and Its Application.
Dr. R.E. Goodman

First Sequence — *Harrah's - South Shore Room*

10:20-Noon Construction Engineering
Chair: F. Heuze
1:30-3:10 Surface Excavation Case Studies
Chair: G. Scott
3:30-4:30 Stability and Shear Strength of Fractured Rock
Chair: M. Mauldon and B.A. Grenoble

Second Sequence — *Embassy Suites - Stanford/Blaisdel Rooms*

10:20-Noon Laboratory Testing
Chair: W.R. Wawersik
1:30-3:10 Rock Dynamics
Chair: S. Glaser
3:30-4:30 Planetary Rock Mechanics
Chair: R. Schultz, S.J. Mackwell

Third Sequence — *Embassy Suites - Emerald/Nevada Rooms*

10:20-Noon Stress Measurements
Chairs: B. Haimson and K. Kim
1:30-2:50 Tunnels and Groundwater Flow
Chairs: B. Schmidt and J. Kaneshiro

ARMA — *Embassy Suites - Emerald/Nevada Rooms*

4:30-5:00 ARMA (American Rock Mechanics Association)

Poster Presentations — *Embassy Suites - Meteor/Mamie Rooms*

5:00-6:30 Poster Presentations
Chair: R. Schultz

Tuesday, June 6 — *Harrah's - South Shore Room*

8:00-9:00 Keynote Lecture: Recent Rock Mechanics Developments in the Petroleum Industry. J.-C. Roegiers

First Sequence — *Harrah's - South Shore Room*

9:20-10:20 Hydraulic Fracturing in Oil and Gas Production
Chair: R. Steiger
10:40-Noon Borehole Stability
Chairs: Y. Abousleiman and J. Shlyapobersky
1:30-3:10 Mechanics of Tool-Rock Interaction
Chair: E. Detournay

Second Sequence — *Embassy Suites - Stanford/Blaisdel Rooms*

9:20-10:20 Building Stone Durability
Chairs: M. Mauldon and B.A. Grenoble
10:40-Noon Rock Reinforcement, Verification, and Instrumentation
Chairs: D. Banks and W. Boyle
1:30-3:10 Tunneling and Underground Construction
Chair: H. Einstein

Third Sequence — *Embassy Suites - Emerald/Nevada Rooms*

9:20-10:20 Fracture Mechanics I
Chairs: J. Kemeny and L. Costin
10:40-11:40 Fracture Mechanics II
Chairs: L. Costin and J. Kemeny
1:30-3:10 Radioactive Waste Disposal
Chair: J. Tillerson

Panel Discussion — *Harrah's - South Shore Room*

3:30-5:00 Educational Requirements for Future Graduates in Rock Mechanics
Coveners: F. Heuze and J. Long

UPDATED SCHEDULE OF TECHNICAL SESSIONS

Wednesday, June 7 — *Harrah's - South Shore Room*

8:00-8:45 Schlumberger Lecture: L.J. Pyrak-Nolte

First Sequence — ***Embassy Suites - Stanford/Blaisdel Rooms***

9:00-10:00 Dynamic Rock Behavior in Underground Mining
Chair: M.P. Hardy

10:30-11:30 Rock Fragmentation by Blasting
Chair: A. Ghosh

1:00-2:20 Underground Mining
Chair: M.P. Hardy

3:00-4:20 Underground Coal Mining
Chairs: N. Kripakov and F. Kendorski

Second Sequence — ***Harrah's - South Shore Room***

9:00-10:00 Hydrology I
Chairs: J. Long and P.R. LaPointe

10:30-Noon Mechanical and Hydraulic Properties of Rock Joints
Chairs: B. Amadei and K. Kulatilake

1:00-2:40 Stochastic Approaches in Rock Mechanics and Rock Engineering
Chairs: K. Kulatilake and B. Amadei

3:00-4:40 Hydrology II
Chairs: P.R. LaPointe and J. Long

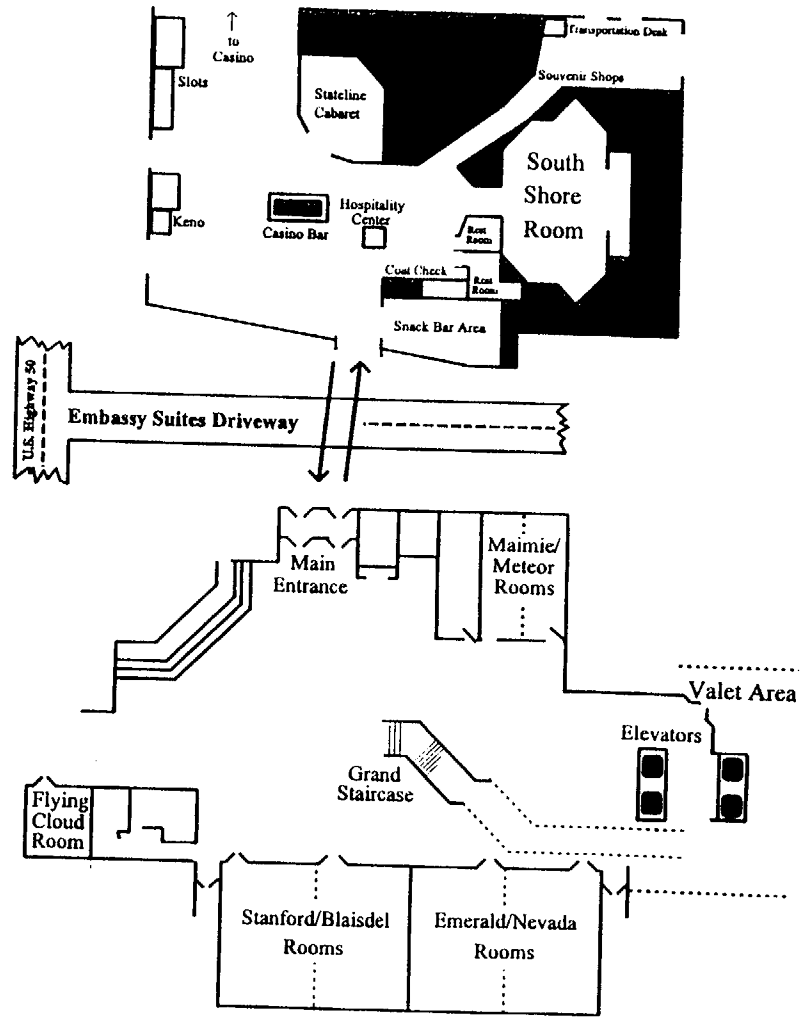
Third Sequence — ***Embassy Suites - Emerald/Nevada Rooms***

10:30-11:50 Rock Creep, Damage, and Healing
Chair: K. Fuenkajorn

3:00-4:00 Discontinuity Model Verification
Chair: M. Karakouzian

4:00-4:40 Analytical and Numerical Modeling of Discontinuities
Chair: M. Karakouzian

Harrah's Hotel/Casino Foor Plan



Embassy Suites Floor Plan

APPENDIX C

AMERICAN ROCK MECHANICS ASSOCIATION
600 Woodland Terrace, Alexandria, VA 22302 703.683.1808 Fax 703.683.1815
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NATIONAL RESEARCH COUNCIL
COMMISSION ON GEOSCIENCES, ENVIRONMENT, AND RESOURCES
Phone: (202) 334-2744 BOARD ON EARTH SCIENCES AND RESOURCES FAX: (202) 334-1377
2101 Constitution Avenue Washington, D.C. 20418

June 5, 1995

Dear Friends and Colleagues in Rock Mechanics,

There have been a lot of changes for the U.S. rock mechanics community this year. In brief summary, the U.S. National Committee for Rock Mechanics (USNC/RM) has been relocated within the National Academy of Sciences, and we have a new professional organization for rock mechanics the American Rock Mechanics Association (ARMA). The purpose of this letter is to let you know how and why these changes took place, what importance these changes have for you, and where we expect things to go in the future.

The USNC/RM was formed in 1967 by the National Academy of Sciences/National Research Council with three kinds of activities planned: to provide U.S. representation to the International Society for Rock Mechanics (ISRM); to respond to government needs for expert advice with respect to technical and policy issues related to rock mechanics; and to promote the health of the scientific and engineering aspects of rock mechanics. Last year, the Committee was affiliated with the Commission on Engineering and Technical Services (CETS) but organizational changes within CETS meant that it was not clear that CETS would continue to support the USNC/RM.

In June of 1994, at the Austin NARMS meeting, many of you attended meetings that Barry Brady held as the outgoing chairman of the USNC/RM to discuss the events and uncertainties. I (Jane) had been nominated as the next chairman and I was confirmed by NAS shortly thereafter. As the incoming chair, I was particularly concerned that the Rock Mechanics Symposium was at risk if the USNC/RM were dissolved, as was under active discussion within CETS. Consequently, I asked Priscilla Nelson and Bernard Amadei to think about alternative ways to run the Symposium.

Bernard organized a meeting in Boulder, Colorado, during July, 1994. About 12 people attended, invited to include perspectives from academia, research laboratories, federal agencies, and industry. This group reached a consensus that a new organization should be established that could promote and develop expanded opportunities for individuals working in the areas of rock mechanics and rock engineering activities which would not be appropriately accomplished within the NAS committee system. We decided to incorporate a new association, ARMA, with particular goals of:

* fostering increased participation of U.S. scientific and engineering community in ISRM activities. While the USNC/RM has been an excellent representative for our country in ISRM, the founders of ARMA believe the U.S. technical community would benefit from and is ready for an organization of individual and corporate members.

* being actively involved in supporting and organizing the U.S. and North American rock mechanics symposia. These meetings have grown to over 400 attendees and future symposia would benefit from a continuing and steady administrative presence.

* creating a focus for developing new activities and resources within the United States.

The formation of the American Rock Mechanics Association and its sister organization, the ARMA Foundation, was accomplished before the end of 1994, and the first meeting of the Board of Directors was held in Boulder in January, 1995. The current officers were elected at that time.

Meanwhile, within the NAS, the affiliation of the US National Committee for Rock Mechanics has been moved to the Board on Earth Sciences and Resources (BESR) in the Commission on Geosciences, Environment, and Resources (CGER). This proposal has been accepted by the NRC and we have been welcomed enthusiastically by BESR. Ina Alterman has been appointed to staff our committee and we are currently charting a revitalization of the USNC/RM. Within CGER, we will be associated with other committees such as the Committee on Seismology and related boards such as the Board on Radioactive Waste Management. In addition, we will maintain our long-standing association within the Academy complex with the engineering-oriented boards such as BEES and the Board on Infrastructure and Constructed Environments. The USNC/RM looks forward to a sharper focus on national issues in an environment that recognizes the expertise and importance of rock mechanics.

Last year at this time we had one faltering USNC/RM. This year we have two organizations, ARMA and a newly organized USNC/RM. How should these two organizations relate to each other and where are we going in the future?

The NRC has always had the primary mission to provide special studies that address technical, and especially policy, needs for the government, and the U.S. National Committee for Rock Mechanics has actively and successfully pursued such studies. In addition, USNC/RM has sponsored the Rock Mechanics Symposium, collected membership dues for ISRM, and managed the rock mechanics awards.

ARMA is a private organization owned by its members to serve its members. Its interests are to promote and act as an advocate for the profession, to develop communications links for interactions with other societies and for enhanced resource and educational services, and to generally improve the states of the art and practice. As a private organization, ARMA can carry out many activities that can not be done at the NRC. In fact, the charters of ARMA and USNC/RM are in many respects quite complementary. It is possible that ARMA could begin to take over many of the professional activities currently done by USNC/RM, as well as adding professional activities never done by anyone for rock mechanics. As chairman of USNC/RM and President of ARMA, we see any shifting of responsibilities as an evolutionary process. For example, we want to avoid the confusion of having both organizations collect dues. In the last meeting of USNC/RM, it was decided to delegate collection of next year's ISRM dues to ARMA because ARMA can perform this function more efficiently. We also expect that Columbia University and ARMA will jointly propose to run the 1997 Rock Mechanics Symposium.

Differences of opinion exist about what USNC/RM and ARMA should be and do. We are committed to continuing the discussion of the roles of ARMA and USNC/RM, and to finding other logical and efficient ways to work together. It is our view that the process will lead to a USNC/RM that acts more effectively as a policy/technical resource for the government and that ARMA will take over some of the responsibilities previously taken by USNC/RM, add others, and look to the USNC/RM to establish vision with the authority derived from its assembled expertise and the stature of the National Academies of Sciences and Engineering.

The evolution of the two organizations, USNC/RM and ARMA, will continue as each expands into its responsibilities. We welcome input from any and all of you. We are certain that together we will be able to ensure an increasingly bright future for rock mechanics and rock engineering in the United States and abroad.

As President of ARMA and Chairman of USNC/RM. we must continue to invest in the success of both organizations. We are committed to this process because we see that it is in the interest of you, the rock mechanics community.

Very Truly Yours,

Priscilla P. Nelson
President, ARMA

Very Truly Yours,

Jane C. S. Long
Chairman, USNC/RM

****

Dr. Priscilla P. Nelson
Program Director
G3S/CMS, Directorate for Engineering
National Science Foundation
4201 Wilson Boulevard, Room 545.17
Arlington, VA 22230
Tel: (703) 306-1361
Fax: (703) 306-0291
pnelson@nsf.gov

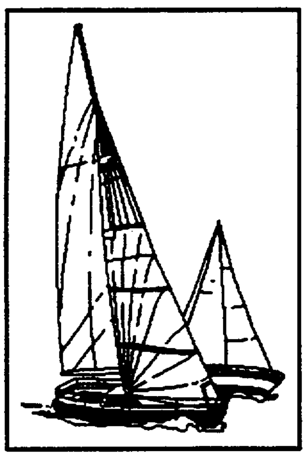
Dr. Jane C.S. Long
Bldg 50 C
Lawrence Berkeley Laboratory
Berkeley, CA 94720
Tel: (510) 486-6697
Fax: (510) 486-4159
jcslong@lbl.gov

ARMA
AMERICAN ROCK MECHANICS ASSOCIATION

ARMA NEWSLETTER

Bernard Amadei, Editor VOL. 1 No.1, June 1995

ARMA IS SAILING



It has now been a year since some of us met at the University of Texas at Austin to explore the idea of a new organization devoted to the field of Rock Mechanics and Rock Engineering. A year later and after much work, we are pleased to present to you a new association, called the American Rock Mechanics Association (ARMA). The concept of ARMA was born on July 08, 1994 on a beautiful afternoon on the University of Colorado, Boulder campus.

ARMA is a national membership-based-organization devoted to the promotion of our profession. It regroups scientists and engineers interested in various aspects of rock mechanics and rock engineering. It is entirely separate from the U.S. National Committee for Rock Mechanics (USNC/RM). The objectives of ARMA can be summarized as follows:

• to promote the development of rock mechanics and rock engineering in the U.S;

• to act as an advocate for organizations and individuals who practice rock mechanics and rock engineering;

• to provide a communications link and educational services among members and other related organizations;

• to be a repository for information on the development and use of rock mechanics and rock engineering;

• to improve the states of the art and practice and to disseminate knowledge through symposia, publications, and other means;

• to work with other professional societies and organizations which have rock mechanics and rock engineering interests; and

• to promote international cooperation in the development of rock mechanics and rock engineering technology, and encourage involvement of U.S. scientists and engineers in ISRM activities.

We believe that in launching ARMA, we have identified a unique sense of purpose for our new organization. So far, ARMA has been received with great enthusiasm and expectations. Since, we are a member based organization, it must be kept in mind that the success of ARMA and how ARMA can serve your needs depend greatly on your participation.

If you feel that our profession is at risk, that changes need to be made in the professional, research and educational aspects of rock mechanics and rock engineering, then we want to hear from you. Act now and join the ARMA !

Bernard Amadei, Secretary.

WANT TO BECOME AN ARMA MEMBER ?

ARMA offers individual and corporate memberships.

Individual:

Lifetime: $ 1,000
Charter: $ 100
Individual: $ 45 ($65 if outside US)
Student: $ 15

Corporate:

Igneous: $ 1,000
Metamorphic: $ 2,500
Sedimentary: $ 5,000

In addition, for a period of one year, you can become an ARMA Founder for $ 250. Founders contributions will be used for start-up purposes for ARMA and its parallel scientific and educational organization, the ARMA Foundation. ARMA Founders will have an early voice in the formative stages of ARMA and the ARMA Foundation. ARMA Founder's contributions are tax deductible as charitable donations.

To become a member contact Peter Smeallie, Executive Director, ARMA, 600 Woodland Ter., Alexandria, VA 22302. Tel: (703) 683-1808, Fax: (703) 683-1815.

ARMA ON THE INFORMATION SUPER HIGHWAY

One of the services of ARMA is to provide a computer based forum and clearinghouse for information on rock mechanics and related topics. A new Mosaic home page entitled "RockNet" has been established on a server at Sandia National Laboratories in Albuquerque, New Mexico. Rocknet is open to all and can be accessed via Mosaic by opening the URL: http://sair019.energylan.sandia.gov:70. For more information or comments and on how to contribute to RockNet contact Stephen Brown at srbrown@sandia.gov or call him at (505) 844-0774.

FROM THE PRESIDENT

Managing Rock Fall Hazards

I attended the one-day Transportation Research Board (TRB) Symposium on "Managing Rock Fall Hazards: Identification, Prioritization, and Mitigation" held May 14, 1995 in Charleston, WV. This symposium immediately preceded the 46th Highway Geology Symposium, May 15-18. There were no proceedings from the TRB sessions, and the room was dark and crowded. However, I did take some notes which may be correct and which are summarized below.

Barry Seil of FHWA described the NHI (National Highway Institute) workbook, produced mainly by Oregon DOT people, on establishing a methodology for rock fall management. The report is evidently available (not verified by me at the FHWA Report Center (Tel: 703-285-2144, Fax: 703-285-2919) as document FHWA-SA-93-057, titled something like "Rock Fall Hazard Mitigation Methods and Rock Fall Hazard Rating System, Participants Manual".

Richard Andrew of Colorado DOT discussed rock fall management efforts, and commented on the Glenwood Canyon (I-70) experience. From a peak of 35 rock fall-related accidents per year during construction (1980), rates are now down to about 2 per year. Upslope stabilization included removal (scaling), and retention systems (bolts, cable lashing, concrete buttresses. Downslope techniques included flexible fencing Richard gave a nice discussion on flexible vs. rigid fencing -- the performance improvements with flexible designs are clear), barriers and ditches, and geosynthetic barriers (Richard called them "buttress burritos"), capable of absorbing one million lbft of energy.

Skip Watts, from Radford University in Virginia (the Institute for Engineering Geosciences) discussed VDOT experience including the current legal environment where the difference between "fallen" and "falling" rock will have an impact on case outcome. He also recommended as a great reference a three-volume set titled "Slope Stability Reference Guide for National Forests in the United States," 1994, Hall, D.E., Long, M.T., & Remboldt, M.D., eds; Prellwitz, R.W., Koler, T.E., & Steward, J.E., coordinators, $44 for 3 volumes from: Superintendent of Documents, U.S. Government Printing Office, Mail Stop SSOP, Washington, DC. 20402-9382, Tel: (202) 512-1800, GPO stock number 001-001-00655 -6. ISBN: 0-16-045307-0.

Michael Vierling of New York DOT described a "Hazard Rating Procedure" under evolution. The NY research identifies a "Relative Risk" factor which is evaluated as the product of three factors: GF or "Geological Factor"; SF or "Section Factor" evaluated using Ritchie's ditch geometry comparisons and slope geometry; and HF or "Human Exposure Factor" evaluated statistically and empirically to include traffic, velocity, and active ("falling") vs passive ("fallen") rock hazards. The "Relative Risk" is intended only as a tool for prioritization and considering options for remediation. Stay tuned to NYDOT for further developments.

The Oregon DOT people (esp. Larry Pierson, Steve Davis and Tim Pfeiffer) have certainly done a lot of work on slope inventory, prioritization, and remediation management. The ODOT presentation included results of experiments where the accepted "standard" designs for ditches were revisited. They have produced new design charts, and develop a methodology which is readily applicable to risk-based assessments of designs. You can get a copy of the full report by contacting Liz Hunt, Tel: 503 - 986-2848, and asking for a report titled something like "Rock Fallout Design Criteria".

John Duffey reported on the CALTRANS experience with fences and barriers using a fantastic set of slides showing successes and failures. He is definitely a convert to flexible barrier systems (including submarine ring nets - capable of handling very high energy falls - to 1000 ft-tons), and John has analyzed California experience to produce additional guidance on design and construction of drapery systems.

Duncan Wyllie of Golder Associates (Canada) described the makings of a data base on rock slope conditions which has been under construction for a private railroad company for several years. The methodology is public domain, but the data ain't. The data is accessed by a probabilistic simulation software package which includes decision analysis on remediation measures, life-cycle cost, and contracting requirements and specifications. Someday the data may be available, but we wait now for a clear demonstration of cost-effectiveness so that we can convince more owners that data base investment is worth the cost because of the money saved in the long run. We will be able to demonstrate this, won't we?

The presentations continued with a discussion (led by Jerry Higgins and Keith Turner of Colorado School of Mines) of CRSP (Colorado Rockfall Simulation Program - and, yes, sometimes people use rockfall, and sometimes rock fall!), now out as CRSP-3, version 3.0a, available only as PC software through the Colorado Geological Survey, 303-866-2611 for some nominal charge less than $50. The graphics were nice - but there was much discussion on selection or evaluation of slope"roughness" and boulder size-scale dependence of roughness. Final presentation was by George Hearn from the University of Colorado, Boulder, who has had success with assembling numerical models of fences and barriers, calibrating the modes results with real experiments (even you will believe this verification!), and therefore producing a modeling tool which can be used directly in design optimization (now all you need to know is how big is the boulder, of what shape, and how fast it is moving).

Overall - a nice meeting with lots of opportunity for discussions in close quarters. If you get the chance, consider attending one of the Highway Geology Symposia - we'll keep you informed of future meeting plans via the RockNet home page: http://sair019.energylan.sandia.gov:70/0/RockNet/rocknet.html.

Priscilla P. Nelson, President.

ASCE ROCK MECHANICS COMMITTEE

The American Society of Civil Engineers (ASCE) supports a Rock Mechanics Committee whose official purpose is: "to carry out the following general functions as appropriate to rock mechanics: (1)

evaluation of current research and literature; (2) preparation of state-of-the-art reports; (3) organization of technical programs; (4) liaison with related organizations; (5) preparation of Manuals of Practice; (6) advising the Society and other agencies in the specialty area of the committee." The committee currently has 26 members; 9 from universities, 13 from private industry, and 4 from Government agencies. The main focus of the committee for the past several years has been the sponsoring of technical sessions that promote the practical use of rock mechanics. This has included sessions at ASCE conferences and the U.S. Symposia on Rock Mechanics, including sessions on Tunnels, Rock Socketed Piers, Dam Engineering, Excavations Near the Rock/Soil Interface, Surface Excavations in Rock, and Environmental Remediation in Rock Masses. The committee is in the process of establishing a formal liaison with ARMA, and looks forward to collaboration on future projects. For additional information, contact me at (303) 236-3922.

Gregg A.Scott, Committee Chairman.

FUTURE ROCK MECHANICS SYMPOSIA

- *NARMS'96*: "Tools and Techniques in Rock Mechanics", Montreal (Canada), June 19-21, 1996. Abstracts due August 1, 1995. For more information contact Prof. Michel Aubertin, Ecole Polytechnique, Tel: 514-340-4046, Fax: 514-340-4477.

- *36TH U.S. ROCK MECHANICS SYMPOSIA:* "Earth Engineering Through Rock Mechanics" is the theme of the symposium proposed by Columbia University and ARMA. The symposium will be held in New York city in June 1997 on the campus of Columbia University with sessions held at the Lamont-Dogherty Laboratory, ten miles North of New York on the banks of the Hudson River.

"ROCKS AS GOD'S SCULPTURES"

So says 88-year old painter and rock collector C.C. Wang, who, according to an article in the New York Times (April 9, 1995) is donating and selling his treasure trove of natural rock sculptures, some dating from the 16-th century Ming Dynasty. As a painter, Mr. Wang often used the rock sculptures as models for mountains in his landscape paintings. The shapes and forms of his rocks evoke tantalizing images: one sedimentary rock, shaped by wind and water, has been likened to a ship's figurehead of a woman with chest to the wind and torso bent back at the waist. Mr. Wang has donated a handful of his prized rocks to the Metrolopitaan Museum where they have been on exhibit in the museum's Dillon gallery. He is selling others at the New York's Frankel Gallery where the prizes have ranged from $1,000 to $20,000.

Peter Smeallie, Executive Director.

TEACHER "FIELD TESTS" HANDS-ON ROCK TEXT

"I had to introduce the idea of properties before we talked about the rocks. We were doing Venn diagrams with attribute blocks at the time, so it dovetailed nicely", wrote third-grade teacher John Usher in the margin notes of Rocks and Minerals as he and other teachers field-tested the soon-to-be released elementary text. Mr. Usher's margin notes appear with permission in the Spring 95 issue of National Sciences Resource Center Newsletter. The margin notes provide an interesting look into the challenges and rewards of teaching hands-on "outdoor" science.

Peter Smeallie, Executive Director.

RockNet Home Page

presented by the American Rock Mechanics Association

The "ARMA" Organization

Announcement: Foundation of ARMA
Announcement: Election of First President
Board of Directors
Constitution
Bylaws

Membership Information and Forms

Societies and Meeting Information

American Association for the Advancement of Science (AAAS)
American Association of Petroleum Geologists (AAPG)
American Geological Institute (AGI)
American Geophysical Union (AGU)
Environmental and Engineering Geophysical Society (EEGS)
Geological Society of America (GSA)
Minerals and Geotechnical Logging Society (MGLS)
Society of Exploration Geophysicists (SEG)
Society of Petroleum Engineers (SPE)
Other Professional Societies and Consortia

1995 Gordon Conference on Rock Deformation
1995 U.S. Rock Mechanics Symposium: Lake Tahoe
1996 ASCE Conference: "Uncertainty in the Geologic Environment"

Edinburgh Castle - Virtual Meeting Place

On-line Publications

Our Very Own Publication Archive
Center for Wave Phenomena: Samizdat Press, etc.
Claerbout's Classroom
Carnegie Mellon Quake Project Papers and Reports
'94 Physical Properties of Earth Materials Newsletter (postscript file)

Civil Infrastructure Systems: a new NSF Announcement

Earth Science/Engineering Resources on the Internet

Clearinghouse for Internet Resource Guides
WWW Virtual Library (All Subjects)
Earth Sciences Index
Engineering Index
Environment Index
Geophysics Index
Virtual Earth: Earth Science Links
Soft Earth: Earth Science Software Links
Rice University Geology and Geophysics Gopher Server
United States Geological Survey Server
Edinburgh University Geology and Geophysics Links
Prospectings of Geophysics and Tectonophysics
Hydrology-Related Internet Resources
MineNet -- Mining-Related Internet Resources
Undergraduate Engineering Education Resources
Physics Servers and Services Around the World
Bill Beaty's Science Hobby Homepage

Scott's Earth Science Site of the Week

Other Useful Information

- Guide to the Internet
- Planet Earth Home Page
- Yahoo
- Fedworld
- On-Line Job Services
- Geoscience Jobs Classified Ads
- Our Very Own Job List

Comments/suggestions about anything in the "RockNet" Homepage?
Email me (Stephen Brown) at *srbrown@sandia.gov*

(RockNet currently resides at the Sandia National Laboratories Geoscience and Geotechnology Center)