TRIP REPORT
ROCK MECHANICS SYMPOSIUM

The 26th U. S. Symposium on Rock Mechanics was held in Rapid City, South Dakota from June 26 to June 28, 1985. At NRC's request, SNLA sent a representative (Krishan Wahi) to attend the symposium.

A keynote address was delivered at the start of the symposium by Dr. Evert Hoek, an international expert on rock mechanics. The talk was titled, "Rock Mechanics: A Scientific Curiosity or a Practical Engineering Tool?" A number of case-histories were discussed that used a variety of ways to solve the problem. The main message was that no one method (numerical, analytical, common sense, etc.) could be applied to all situations. Application of probabilistic techniques was shown to be useful in one instance but not appropriate in another.

There were numerous sessions on important topics. Three sessions took place at any given time so that it was only possible to participate in roughly one-third of the talks given. Abbreviated session titles are listed below for quick reference.

Wednesday, June 26:

Slope Stability	Rock Properties	Fracture (Numerical)
Subsidence	Deep Boreholes (Panel discussion)	Numerical Modeling

DEBATE: Acceptability of risk of failure of excavations in or on rock

Thursday, June 27:

Weak Rock	Hydraulic Fracture	Constitutive Modeling of Rock
Ground Support	Fracture Mechanics	Model Verification

Poster Session A

Friday, June 28:

Underground Mine Design	Seismic Studies	Field Testing For Nuclear Waste
Heat and Fluid Flow	In-situ Testing Results	Rock Drilling and Cutting

Poster Session B

Instrumentation	Case Histories	Rock Blasting
Underground Excavation	Stress Measurements	Physical Modeling

Saturday, June 29:

Underground Tour of Homestake Mine

Two volumes of the Symposium proceedings were given to each participant. Copies of all the technical papers are included in those volumes. Highlights of most of the presentations that Krishan Wahi was able to attend are given next.

A comparison of rock mass classification approaches was presented by John Udd of Canada Center for Mineral and Energy Technology. The study was conducted at a mine in Quebec and used four different classifications to obtain numerical index values that represent local conditions in the rock mass. The four methods are: (1) Deere, (2) Russian, (3) CSIR, and (4) NGI. The authors believe that for their case, the NGI method was the most appropriate. Both the NGI and CSIR approaches were found to be easy to use in the field. The weaker and the stronger rocks were consistently identified through all of the approaches. The recommendation by the authors that operators establish their own classification system seems contrary to quality assurance goals from NRC's perspective.

D. Cregger gave a paper on the influence of geological factors on the mechanical properties of rock in the Palo Duro Basin. The authors suggest that diagenesis (geochemical transformation) of the deposits results in profound changes to the mechanical properties of the rock compared to structural deformation of the salt. Lithology is the major geological factor governing the mechanical properties. Nearly 200 measurements of dynamic Poisson's Ratio are available from the laboratory strength testing program, and the variability of this property decreases as the results are grouped into more refined lithologic categories. An approach to characterization is suggested in which rock mechanics test results would be grouped by lithologic rock type and by formation. Modeling parameters must reflect such geological factors as lithology, texture, depositional and diagenetic history, structural history and in-situ stress conditions. A fracture frequency versus depth chart was shown for the Palo Duro Basin. Two to four fractures per 100 ft exist in the host rock.

An equivalent continuum approach was proposed by E. Detournay of Agbabian Associates for large scale modeling of rock masses. Failure and limitations of existing empirical and semi-empirical procedures in the context of numerical modeling were outlined. The proposed alternative involves two levels of definition of the rock mass. The first level (global) corresponds to the continuum representation at the scale of resolution (i.e., coarseness of mesh). The second level (macroscopic) is one at which the discontinuities and inhomogeneities of the rock can be treated. The global level solution is obtained by conventional finite-element or other numerical schemes. The macroscopic level requires an explicit definition of the discontinuities implemented by associating with each finite element a discrete model such as Cundall's discrete element method or the displacement discontinuity method. The proposed scheme is rigrous and can be implemented in any non-linear finite-element code that does not require reformulation of the stiffness matrix.

R. Price (SNLA) presented his analysis of the elastic strength properties of Yucca Mountain tuff. a large data base was analyzed that resulted in empirical expressions relating elastic properties and strength with "functional porosity" (i.e., total porosity plus clay content). In earlier work, the author had tried to relate elastic and strength properties with porosity (without clay content) and obtained a fit that is inferior to the present model. The following relationships predict the Young's modulus (E) and the unconfined compressive strength (σ_u):

$$E = ae^{bn}$$

$$\sigma_u = cn^d$$

where n is the functional porosity and a, b, c, d are empirical constants. Simple theory for elastic composite materials was applied to explain the observed variation of bulk modulus with functional porosity in terms of a uniform model.

Results of rock motion modeling of oil shale cratering experiments were presented by E. Gorham-Bergeron of SNLA. In in-situ retorting of oil shale, best oil yields occur when the permeability across the rubble bed is uniform. To achieve these uniform permeabilities, the blasing process must be optimized by adjusting parameters such as explosive properties, borehole spacing and blast timing. The blasting effects need to be modeled in two major stages; namely, fragmentation and fragment motion. The first stage represents a process on the order of a few milliseconds while the second stage occurs over a few seconds. The computer model DYNA2D was used to model the first stage, and CAROM was used to model the motion during the second stage. Good quantitative agreement was obtained with experimental measurements of a cratering test. Two primary conclusions are that: (1) the size of the excavated crater is determined by the rock motion, which is a function of the extent and shape of the fractured zone, and (2) the effect of late-time explosive gas pressure on the cratering in single borehole tests is secondary to the shape of the fractured zone.

The use of an empirical subsidence prediction method, as applied to Saskatchewan potash mines, was described by C. Steed of Queen's University in Ontario. The data base consisted of five producing potash mines. In general, an initial subsidence is followed by a constant subsidence rate. The proposed method, labeled the zone area method, uses influence functions in correlating subsidence with extraction. A knowledge of three site functions from existing data is necessary to use this method: (a) relative contribution of extraction within zones to the total subsidence of an overlying point, (b) the function relating the influence of extraction to the long-term subsidence rate, and (c) the function relating the influence of extraction to the initial subsidence of a point. Subsidence was found to be site-specific and depended on the mining method, the mining seam, and the overburden rheology. A larger initial contribution to subsidence was observed for the chevron panel mining as compared to pillar mining.

Charles Fairhurst (Itasca) presented a comparison of numerical modeling results with field observations of deformation in a potash mine in Brazil. Representative mechanical properties of the main evaporites were established from lab testing and used in FE (finite element) and DD (Displacement discontinuity) models to predict the deformation behavior for the mine excavations and pillars. Since the DD method allows non-linear (creep) behavior only in the seam, the evaporitic rock mass over the roof and below the floor was considered to behave as linearly elastic in both models. A series of simple compression, indirect tension, shear, and uniaxial and triaxial creep tests were performed in the lab. The field instrumentation program was developed with the objective of comparison with predicted deformation behavior. Good agreement between predicted and measured closure in the mine gallery was seen. This paper offers valuable insight in the planning and placement of field instrumentation for creep measurements.

A paper by Nelson and Fossum (RE/SPEC, Inc.) was included in the program, but was not presented at the symposium. In any event, the proceedings do include this paper titled, "Salt Pressure on Defense High-level Waste Packages." The paper is of interest in that it represents a more in-depth analysis of an issue that was addressed inadequately in the salt EA's. The issue concerns the stresses induced in the waste package overpack once the initial air-gap between the borehole wall and the package closes. Bounding calculations presented in the paper show that the stress in the overpack can be very high (>70 MPa, or >10,000 psi) if no initial air-gap is present. An initial gap mitigates the peak stress which can still be substantial. The results are for a thermal loading of 21 W/m^2. For higher thermal loadings, even higher stresses would result.

Two- and three- dimensional FE analyses of room-pillar mining systems with flat and rolling coal seams, authored by Wang et al., were presented. Effects of several parameters on stress distribution in flat or rolling coal seams with multiple openings were investigated. These parameters include mine depth (overburden), layered rock properties, in-situ stress, pillar size, number of openings, wave amplitude and length, and location of openings. The 2-D, plane strain model gave equally acceptable results as compared to the more complex (and expensive) 3-D model. Guidelines for choosing proper numerical model dimensions are given. The magnitude and distribution of stresses are strongly affected by the in-situ stresses and the curvature of the roll. Design criteria used for flat coal seam mines must be modified when the in-situ stress ratio and the amplitude/wave-length of the rolling seam are high.

An interesting debate on the possible role of risk analysis for rock structures was moderated by Don Banks. Compelling arguments were presented both in favor of and against requiring a risk evaluation associated with rock excavations. The audience seemed equally divided on this issue. A tour of the RE/SPEC, Inc. Rock Mechanics Laboratory was conducted on Wednesday evening. Several salt creep tests, under different conditions of applied load and temperature, are currently in progress. In the U.S., RE/SPEC, Inc. appears to have done a majority of the creep testing and model development work.

P. Senseny of RE/SPEC, Inc., presented a talk on non-associative constitutive laws for Algerie granite. Conventional treatment of low-porosity rocks assumes a pressure-dependent strength model and an associative flow rule. Two constitutive models were presented for Algerie granite that "accurately reproduce the observed behavior." Both laws include strain hardening between yield and peak stress as well as non-associative plastic straining. The Mohr Coulomb and the Mises Schleicher yield criteria were considered and the appropriate parameters were determined by least-squares fitting of the lab data. The constitutive laws are considered by the authors as significant improvements over classical constitutive models.

Constitutive modeling of rock joints with dilation was discussed by M. Plesha of University of Wisconsin. The underlying assumption of the model is that the joint interface contains an infinitesimally thin layer of elasto-plastic material in which the elastic deformations are related to change of stress and the plastic deformations correspond to permanent sliding and other features (e.g., dilatancy). Degradation of asperities can also be included in the model. "Numerical" direct shear tests give results that qualitatively match the observed experimental behavior. The simplicity of the model makes it amenable for numerical implementation.

D. Mraz, a consultant from Saskatchewan, Canada described test procedures for salt rock for obtaining high-quality design parameters. The primary message of this talk was that high-quality testing of intact salt must consist of undisturbed sampling combined with careful sample preparation and rigrous control of boundary conditions. The author believes that such control is only possible under triaxial conditions. Before testing granular halite backfill, initial density, water content, and grain size must be determined. The NRC should make its consultants aware of the recommendations made by Mraz because they will be useful in evaluating DOE test plans and procedures for site characterization.

Physical and numerical simulations of fluid-filled cavities in salt were discussed by D. Preece (SNLA). The physical simulation consisted of centrifuge experiments on scaled models constructed from plasticine. A more extensive presentation on this subject was given by Herbert Sutherland (SNLA) in early June at NRC. The combination of physical and numerical models represents a powerful capability that can assist, among other things, in the validation of computer codes.

L. Wardle, from CSIRO in Australia showed results of his comparison study between predicted and measured stresses in an underground coal mine. A three-dimensional numerical stress analysis method was validated by comparison with stress measurements during panel extraction. The DD method employed in this analysis uses much less computer time than a comparable FE analysis. By choosing appropriate anisotropic properties for the rock strata, good agreement was obtained between the predicted and observed values of vertical stress and surface displacements. Both the material anisotropy and the three dimensionality of the model were found to be essential ingredients for a successful prediction for the configuration of interest. The vibrating wire stressmeters gave reliable results for this study.

An energy analysis of hydraulic fracturing was presented by J. Shlyapobersky of Shell Development Company. The two common hydraulic fracture models (KGK and PKN) have two main shortcomings: (1) they neglect rock strength, and (2) they cannot predict the fracture height growth. The proposed approach includes rock toughness characteristics which can be determined from field pressure data. The fracture toughness coefficient (K_{1c}) is considered as a free matching parameter. The laboratory K_{1c} measurements cannot quantify rock fracture toughness of large hydraulic fractures. A variational principle of the minimum energy dissipation rate is proposed for inclusion in classic hydrofrac models.

R. Zimmerman from SNLA described the thermal-cycle testing of the G-Tunnel heated block. A rock mechanics program is being conducted for the NNWSI Project to support the design of underground facilities for a HLW repository in tuff. The thermal-cycle testing consisted of three heating periods. The maximum temperature rises were 76°C (to actual temperature of 94°C) at the center of the block and 127°C at the boundaries. Thermal expansion coefficients were determined from HSX (horizontal surface extensometers) and MPBX (multiple borehole extensometers) measurements. Plane stress elastic equations were used in the calculations. Fracture permeability measurements were made at select times to record responses to the variable temperature and pressures. The thermal-expansion coefficient had a range of 5.0 to 8.7 x $10^{-6}/^{\circ}C$ as compared to a laboratory range of 6.4 to 8.0 x $10^{-6}/^{\circ}C$. Single fracture permeabilities were relatively insensitive to stress and slightly sensitive to temperature change under representative in-situ conditions. The surface of the block could not be levelled which caused a problem in applying a uniform load. The average permeability varied by an order-of-magnitude. Most of the dewatering during heating cycles occurred from 70°C to 120°C.

An analysis of the basalt block test, being conducted at the Hanford Site, was presented by R. Hart of Itasca Consulting Group. The objective was to characterize the elastic and inelastic behavior of the rock. A set of transversely isotropic elastic parameters was derived using the SVD (Singular Valve Decomposition) Method from the known stresses and strains. Joint stiffness properties were estimated using equations from literature for continuum characterization of jointed rock. The UDEC code was used to simulate the observed response. The major finding was that an adequate mechanical description of the basalt rock mass must take account of rotation and slip of the basalt columns. Another observation was that non-linear behavior can occur at very low strain levels even in the simple joint law used in this analysis.

H. Morgan from SNLA described the efforts to improve drift response models for WIPP by using field data. A comparison of computed and measured room closures for the "South Drift" at WIPP was presented. A two-dimensional plane-strain model was used to compute the South Drift response with SANCHO, a FE code. Over thirty calculations have been performed in attempts to understand the discrepancy between computed and measured closure. The result indicate a significant unresolved discrepancy. some modeling issues that remain to be addressed include other elastic property variations, microcracking of salt, and alternate forms of the creep law.

The in-situ load-deformation characterization of the CSM/OCRD jointed test block was described by A. Richardson of Colorado School of Mines. The block is a two-meter cube of precambrian Gneiss cut by three continuous vertical fractures that effectively divide it into four sub-blocks. The test matrix consisted of uniaxial and biaxial loads at ambient temperature with an applied stress range of 0-5.2 MPa. A tilt correction had to be made to reduce the apparent hysteresis in the displacement data. Some of the tests had to be repeated with very strict calibration procedures. The tests indicate that boundary effects influence the behavior of a block test.

T. Chan of AECL made a presentation on the mechanical response of jointed granite during shaft sinking at the Canadian Underground Research Laboratory (CURL). A rectangular access shaft was sunk last year. The shaft has a 2.8m x 4.9m cross section and a depth of 255m. Displacements and stress changes were monitored as the excavation face advanced. The displacements and stress changes at the instrumented locations were calculated using a three dimensional FE Code, MARC, prior to the start of shaft sinking. Excavation-induced displacements in the relatively intact portion of the rock mass agreed well with the model predictions. Natural fractures need to be modeled as discrete fractures. Small temperature changes lead to displacements comparable to the mechanical response. Therefore, air and rock temperatures should be carefully monitored during the experiment. More accurate extensometers with closely spaced anchors are necessary for reliable measurements.

W. Hustrulid (CSM) presented results of laboratory and field deformation modulus of the sedimentary foundation rock for a nuclear power plant in northeastern U.S. The foundation mat is approximately 60m in diameter. Uniaxial, biaxial, and triaxial laboratory tests were performed. In-situ measurements of Young's modulus were made using an Oyo borehole dilatometer in 12 boreholes to a depth of 54m. It was necessary to introduce several "factors" to estimate the in-situ moduli, which lowers the level of confidence in the final results. A series of large-scale jacking tests are recommended to properly estimate the in-situ rock mass behavior, especially for critical structures.

A strategy for future laboratory rock mechanics programs was outlined by B. Butcher of SNLA. The strategy is based on advances in structure stability analysis and on new developments in load path control of laboratory stress-strain tests. A major constraint of the proposed strategy is that for laboratory simulation any in-situ joint features and sample size effects must be ignored.

Some problems associated with near surface in-situ stress measurements by the overcoring method were described by I. Farmer from University of Arizona. Although sound in principle, the overcoring method can give erroneous results due to several factors related to the test environment or instrument design. Environmental factors include magnitude of in-situ stress, rock temperature and its effect on interfacial adhesion, rock type, and rock anisotropy. Instrument design factors are circuit design, compensation for temperature change, resistance of connections, and gauge/crystal interaction. Measurements at shallow depths or in low stress environments are difficult because the magnitude of errors can exceed the magnitude of strain due to stress relief. The authors have proposed a method of measuring these errors. The detection of glue yield is difficult (even at depth) unless two or more holes of different orientation are used.

Estimates of in-situ stresses at Yucca Mountain were provided by S. Bauer of SNLA. Using regional geologic studies, stress measurements in Yucca Mountain and nearby Rainier Mesa, and FE calculations, estimates of in-situ stresses were obtained. Values of horizontal to vertical stress ratio in the range of 0.3 to 0.8 are considered reasonable for repository depths according to Bauer's analyses.

H. Swolfs from USGS presented results of plane-strain solutions to analyze the influence of topography on the state of stress at Yucca Mountain. The results are in good agreement with hydrofrac measurements in drill holes directly beneath the crest of the ridge. The stresses are thought to be gravitationally induced. Vertical faults and fractures impart a vertical transverse isotropy that results in unequal horizontal stresses.

An underground tour of the Homestake Mine near Lead City, S. Dakota was conducted at the end of the Symposium. Carl Schmuck, Homestake's Chief Mine Engineer was the main guide. Brief descriptions of core sampling, mining, and ore-processing were also given.

<u>Review of DOE's Position Paper on Retrievability and Retrieval</u>

- On p. 4, Section 2.2 (<u>Reasons for Retrieval</u>); If the NRC considers the DOE's decision to retrieve for resource recovery reasons as posing an undue risk to public health and safety, does it have the authority to refuse permission to retrieve?

- On p. 5, first paragraph under <u>Public Health and Safety and the Environment</u>; I recommend that the third line should be changed to read: ". . . health and safety of the public <u>could</u> otherwise be adversely affected <u>beyond permissible levels</u> by the . . . ."

- On p. 6, the last sentence of the last paragraph under Section 2.2; ". . . any regulations, standards, or requirements . . ." should be changed to ". . . any requirements . . . ."

- On p. 7, the middle paragraph, last sentence refers to a period of no more than 50 years; exceptions need to be made to increase this period since construction delays or court-ordered interruption could reduce the "effective" retrieval period to much less than 50 years. The other point is that NRC may want to receive assurance of minimal delays when construction authorization is granted if the 50-year limit is difficult to alter.

- On p. 9, Section 2.4 (<u>Time for Retrieval</u>), the second sentence refers to the state of readiness. Whereas it should not be required "that all equipment, systems, and procedures must be designed, constructed and operated in a constant state of readiness for the retrieval of the complete inventory," the NRC may want to specify a time-frame to achieve readiness once a decision to retrieve has been made.

- On p. 13, first paragraph; it is not clear what is meant by "designed to <u>minimize</u> . . . hazard . . ." since the 10CFR20 limits should apply anyway. Is this, perhaps, a reference to the ALARA concept?

- On p. 13, Section 3.1 (<u>Current Technology</u>), the position could preclude the long-horizontal borehole emplacement concept since there is considerable debate in the technical community about the capability to drill long holes or retrieve multiple canisters from such holes.

- On p. 16, the "proof of principle" needs to be defined. Furthermore, will the mock-up demonstrations be host-rock specific or not?

- On p. 17, the first paragraph under "<u>Development of Prototypical Equipment</u>" refers to conditions approximating those of the repository environment. The stress environment (in-situ and thermomechanical) is not included among the listed conditions nor are aggravated or accident conditions (such as flooding) mentioned in this context.

- On p. 20, Section 4, the last sentence of the first paragraph refers to maintaining the retrieval equipment in working condition. This appears contradictory to statements elsewhere. For example, on p. 9 (Section 2.4) the intention <u>not</u> to keep . . . equipment in a state of readiness is made clear.

- On p. 20, Section 4.1, in the first paragraph " . . . retrieval of any or all of . . . " should be changed to "retrieval of any of . . ." for logical consistency.

- On p. 20, Section 4.1, the following should be appended at the end of the second paragraph: " . . . and as long as no waste remains in those rooms."

- On p. 20, Section 4.1, the statement, " . . . no further protection of the integrity of geologic barriers is necessary" is extremely bothersome!

- On p. 21, the discussion in Section 4.2 (Backfilling) does not address as to what happens if early backfilling is not planned, but becomes necessary as emplacement progresses? Will new and immediate demonstration of retrievability in backfilled areas be performed if that were the case?

- On p. 23, Section 4.4 (Access Maintenance) the second paragraph discusses the time required to retrieve. It is suggested that DOE include plans to provide a fair estimate of how long it might take to start retrieval (after a need to do so is identified).

- On p. 24, the top paragraph mentions that backfilled portions of the repository need not be available for quick entry. The term quick should be changed to "immediate" because the entry may have to be as quick as possible, depending on the reason for making the retrieval decision.

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