U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO
THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT:  IN SITU MECHANICAL PROPERTIES TESTING

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IN SITU MECHANICAL PROPERTIES STUDY
(STUDY PLAN 8.3.1.15.1.7)

PURPOSE:
OBtain In Situ measurements of mechanical properties of the rock mass on an intermediate scale

SCP APPROACH:
- Plate loading testing
- Rock mass response experiment
POST-SCP MODIFICATIONS

- EXTEND TESTING TO CALICO HILLS
  - DESIGN INFORMATION FOR LONG-TERM SUPPORT OF OPENINGS
  - ADDITIONAL MODEL VALIDATION DATA

- TESTS IN UNITS ABOVE TSw2
  - UPPER DBR
  - OFF-BLOCK FAULTS

- ROCK MASS RESPONSE EXPERIMENTS
  - UNIAXIAL RESPONSE
  - AMBIENT BLOCK TESTS (BIAXIAL)
  - SLOT TESTS
PLATE LOADING TESTS

OBJECTIVES

- MEASURE DEFORMATION MODULI
- EVALUATE FRACTURING AROUND OPENING
- OBTAIN SEVERAL MEASUREMENTS
  - 10 TO 20 TESTS
  - UPPER DBR, MAIN TEST LEVEL, AND CALICO HILLS
PLATE LOADING TESTS
(CONTINUED)

DESCRIPTION OF TEST

* ISRM AND USBR STANDARD TEST

* UNIAXIAL SURFICIAL LOADING WITH FLAT JACKS

* DISPLACEMENTS WITH MPBX AND ROD EXTENSOMETERS
PLATE LOADING

DESCRIPTION OF TEST

- 34.2 in. (87 cm) dia. flat jack
- Concrete pad
- Particle board pad
- (4) 10 in. (25.4 cm) dia. aluminum columns
- Tunnel, dial gage
- Tunnel rock surface
- Base plate
- 20 ft (6.1 m) long he
- 3 in. (7.6 cm) dia. drill hole
- Measuring anchors (5 per hole)
- Sensor head 7-LVDT's
- Rubber sleeve over lead wires
- 28 conductor transducer lead wire
- Data acquisition system
- 10,000 psi (700 kPa/cm²)
- Hydraulic pump
- Hydraulic hose
- (4) screws for set up and removal

10,000 PSI (700 kPa/cm²) HYDRAULIC PUMP
PHOTOGRAPH OF MULTIPoint BOREHOLE EXTENSOMETER (MPBX)
PHOTOGRAPH OF PLATE LOADING TEST
PLATE LOADING TESTS
(CONTINUED)

DATA ANALYSIS AND USE

● FROM ELASTICITY THEORY

\[ W_{z=0} = \frac{2(1 + \nu^2)}{E} qa \]

- \( W_z \) = DISPLACEMENT IN DIRECTION OF APPLIED PRESSURE
- \( \nu \) = POISSON'S RATIO
- \( E \) = MODULUS OF ELASTICITY (DEFORMATION)
- \( q \) = PRESSURE
- \( a \) = RADIUS OF LOADED AREA

● CORRECTION FOR THE CENTRAL HOLE CAN BE MADE AND DEFORMATION MODULUS BETWEEN ANY TWO POINTS CAN BE OBTAINED
PLATE LOADING TESTS
(CONTINUED)

PREVIOUS EXPERIENCE

- NO PROTOTYPE TESTS PLANNED
- TEST PARAMETERS IMPORTANT FOR ESF
  - GEOMETRY
  - LOAD CAPACITY
  - OBSTRUCTION AND TIME
ROCK MASS RESPONSE EXPERIMENTS

OBJECTIVES

- MEASURE ROCK MASS RESPONSE THROUGH INTERMEDIATE-SCALE FIELD EXPERIMENTS
- EVALUATE SCALE EFFECTS
- EFFECT OF JOINTS
- PROVIDE DATA FOR PRELIMINARY MODEL VALIDATION STUDIES
- MULTIPLE TESTS
  - MAIN TEST LEVEL AND CALICO HILLS
- DUPLICATION OF INFORMATION FROM DIFFERENT TESTS
ROCK MASS RESPONSE EXPERIMENTS
(CONTINUED)

EXPERIMENTS INCLUDE:

- COMPRESSION TESTS
- BLOCK TESTS
- SLOT TESTS
TEST DESCRIPTION

COMPRESSION TEST

• SLOTS - ISOLATE 1.0 x 1.0 x 2.0 M BLOCK

• INSTRUMENTS
  - FIVE AXIAL BOF-EX MPBXs
  - ACOUSTIC EMISSION
  - DISPLACEMENT TRANSDUCERS AT RIGHT ANGLES TO THE BLOCK

• LOADING FRAME
  - LOAD APPLIED BY FLAT JACKS
  - MAY INCLUDE CONFINED TESTS AS SECOND STAGE
UNIAXIAL ROCK MASS STRENGTH TEST

REINFORCED CONCRETE REACTION PAD

GRILLAGE

ROLLERS

INSTRUMENTATION HOLES

SLOTS

INSTRUMENTATION HOLES

SLOTS
TEST DESCRIPTION
(CONTINUED)

BLOCK TEST

• SLOTS - ISOLATE 1.0 x 1.0 x 2.0 M BLOCK

• INSTRUMENTS
  - SURFACE DISPLACEMENT GAGES
  - STRESS GAGES
  - ACOUSTIC EMISSION

• LOADING
  - FOUR FLAT JACKS, INDEPENDENTLY PRESSURIZED
  - MAY BE COMBINED WITH AXIAL LOADING
TEST DESCRIPTION
(CONTINUED)

SLOT TESTS

- SINGLE SLOT 1 x 1 x 1

- INSTRUMENTS
  - SURFACE DISPLACEMENT GAGES
  - CROSS-DRIFT DISPLACEMENT GAGES
  - ACOUSTIC EMISSION

- SINGLE OR MULTIPLE (SANDWICH) FLAT JACKS
G-TUNNEL SLOT TEST

0.2 m DIAMETER BOREHOLE

ACOUSTIC EMISSION INSTRUMENTS
4 LOCATIONS

A CROSS DRIFT MEASUREMENT
FLATJACK (SHADED)

SLOT WIDTH = 16 mm

SCALE
0.25 m
ROCK MASS RESPONSE EXPERIMENTS

PREVIOUS EXPERIENCE

- PROTOTYPE TESTS
  - BLOCK TEST
  - SLOT TESTS

- IMPORTANT TEST PARAMETERS
  - GEOMETRY - ORIENTATION WITH RESPECT TO JOINT SETS
  - LOAD CAPACITY
ROCK MASS RESPONSE EXPERIMENTS
(CONTINUED)

EXAMPLE - SLOT TEST

- G-TUNNEL WELDED TUFF
- ORIENTATION - 30° TO PRINCIPAL JOINT STRIKE
- STARTER HOLE FOR CHAIN SAW
- 30 MPA MAXIMUM FLAT JACK PRESSURE

ANALYSES
- 2-D JOINTED ROCK MASS (CONTINUUM) MODEL
- 3-D DISCRETE JOINT MODEL
G-TUNNEL SLOT TEST

0.2 m DIAMETER BOREHOLE

ACOUSTIC EMISSION INSTRUMENTS
4 LOCATIONS

CROSS DRIFT MEASUREMENT

FLATJACK (SHADED)

SLOT WIDTH = 16 mm

SCALE
0.25 m

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CROSS-SECTIONAL VIEW OF SLOT TEST

SLOT STRIKES N30°W

FRACTURES STRIKE N60°W

FLATJACK

B

B'
PLAN VIEW OF SLOT TEST

DEMONSTRATION DRIFT

APPROX 20' 9"
AT SPRINGLINE

SLOT AT N 30° W

30°

PRINCIPAL VERTICAL JOINT
SET AT N 60° W

30°
RESULTS OF 2-D FINITE ELEMENT ANALYSIS
DISPLACEMENT AT GAGE LOCATION A - A'

PDM 71-042

- Exp Data
- Analysis 1
- Analysis 2
- Analysis 3
- Analysis 4

Displacement (inches) (×10^-1)

Time (hours)
PHOTOGRAPH OF G-TUNNEL SLOT TEST
3-D FINITE ELEMENT RESULTS

MAGNIFIED BY 1.000

ELEMEN BLOCKS ACTIVE:
34 OF 34

SMAX

\[ R = -0.500 \times 10^3 \]
\[ B = 0.500 \times 10^3 \]
\[ C = 1.500 \times 10^3 \]
\[ D = 2.500 \times 10^3 \]
\[ E = 3.500 \times 10^3 \]
\[ F = 4.500 \times 10^3 \]
\[ \Theta = -1.160 \times 10^3 \]
\[ \Phi = 3.637 \times 10^3 \]

TIME 5.328
DISPLACEMENT AT GAGE LOCATION A - A'

- Exp Data
- NO FRICTION Small Model
- $\mu=0.3$ Small Model
- $\mu=0.6$ Small Model
- $\mu=0.3$ Large Model

Displacement (inches) ($\times 10^{-1}$) vs. Time (hours)
## Site Characterization - Rock Mechanics

### Parameter Values
- **Laboratory**: Many
- **Field**: Few

### Statistical Confidence
- **Laboratory**: X
- **Field**: Maybe

### Spatial Variability
- **Laboratory**: X
- **Field**: Few

### Code Validation
- **Laboratory**: Few
- **Field**: X
PLANNED LAB PROPERTIES TESTS

- LABORATORY DETERMINATION OF MECHANICAL PROPERTIES OF INTACT ROCK
  - COMPRESSIVE MECHANICAL PROPERTIES AT BASELINE EXPERIMENT CONDITIONS
  - EFFECTS OF VARIABLE ENVIRONMENTAL CONDITIONS

- LABORATORY DETERMINATION OF MECHANICAL PROPERTIES OF FRACTURES
  - MECHANICAL PROPERTIES AT BASELINE EXPERIMENT CONDITIONS
  - EFFECTS OF VARIABLE ENVIRONMENTAL CONDITIONS

- LABORATORY THERMAL PROPERTIES
  - DENSITY AND POROSITY
  - VOLUMETRIC HEAT CAPACITY
  - THERMAL CONDUCTIVITY

- LABORATORY THERMAL EXPANSION TESTING
SAMPLING FOR THERMAL AND MECHANICAL PROPERTIES

- COORDINATED WITH OTHER SAMPLING/DRILLING NEEDS

- DESIGNED TO PROVIDE STATISTICAL AND SPATIAL INFORMATION

- TAKE INTO ACCOUNT
  - EXISTING DATA (HIGH NATURAL VARIABILITY, UNITS, etc.)
  - DESIRED GOALS AND CONFIDENCE LEVELS OF DESIGNERS/ANALYSTS
  - NEED FOR A REALISTIC INITIAL PROGRAM
LABORATORY THERMAL PROPERTIES

- PARAMETERS MEASURED
  - GRAIN DENSITY, POROSITY, THERMAL CONDUCTIVITY, HEAT CAPACITY

- MEASUREMENT LOCATIONS
  - SIX CORE HOLES, TWO RAMP ACCESSES AND DRIFTS (TBD) IN ESF, VICINITY OF IN SITU TESTS

- SITE CHARACTERIZATION CONTRIBUTIONS
  - ROCK-MASS THERMAL CONDUCTIVITY FOR HEAT-TRANSFER CALCULATIONS, HEAT-FLOW ESTIMATES
  - ROCK-MASS HEAT CAPACITY FOR HEAT-TRANSFER CALCULATIONS
  - ROCK-MASS BULK DENSITY FOR HEAT-TRANSFER CALCULATIONS, ESTIMATION OF VERTICAL IN SITU STRESS, ESTIMATION OF RADIOLOGICAL SHIELDING PROPERTIES
LABORATORY THERMAL EXPANSION

• PARAMETERS MEASURED
  - COEFFICIENT OF LINEAR THERMAL EXPANSION

• MEASUREMENT LOCATIONS
  - SIX CORE HOLES, TWO RAMP ACCESSES AND DRIFTS (TBD) IN ESF, VICINITY OF IN SITU TESTS

• SITE CHARACTERIZATION CONTRIBUTIONS
  - ROCK-MASS THERMAL-EXPANSION BEHAVIOR FOR ESTIMATION OF THERMALLY INDUCED STRESSES AND RELATED STABILITY ANALYSES
LAB MECHANICAL PROPERTIES OF INTACT ROCK

PARAMETERS MEASURED
- YOUNG'S MODULUS, POISSON'S RATIO, STRENGTH, COHESION, INTERNAL FRICTION ANGLE

MEASUREMENT LOCATIONS
- SIX CORE HOLES, TWO RAMP ACCESSES AND DRIFTS (TBD) IN ESF, VICINITY OF IN SITU TESTS

SITE CHARACTERIZATION CONTRIBUTIONS
- INTACT-ROCK MECHANICAL PROPERTIES FOR ESTIMATION OF ROCK-MASS RESPONSE TO IN SITU AND THERMAL LOADS AND FOR STABILITY ANALYSES
LAB MECHANICAL PROPERTIES OF FRACTURES

- PARAMETERS MEASURED
  - NORMAL STIFFNESS, SHEAR STIFFNESS, COHESION, COEFFICIENT OF FRICTION, SURFACE ROUGHNESS

- MEASUREMENT LOCATIONS
  - SIX CORE HOLES, TWO RAMP ACCESSES AND DRIFTS (TBD) IN ESF, VICINITY OF IN SITU TESTS

- SITE CHARACTERIZATION CONTRIBUTIONS
  - FRACTURE MECHANICAL PROPERTIES FOR ESTIMATION OF ROCK-MASS RESPONSE TO IN SITU AND THERMAL LOADS AND FOR STABILITY ANALYSES