SUBJECT: EXCAVATION INVESTIGATIONS

PRESENTER: DR. LAURENCE S. COSTIN

PRESENTER'S TITLE AND ORGANIZATION:
SUPERVISOR,
PERFORMANCE ASSESSMENT APPLICATIONS DIVISION
SANDIA NATIONAL LABORATORY
ALBUQUERQUE, NEW MEXICO

PRESENTER'S TELEPHONE NUMBER: (505) 846-0488

REGISTRY HOTEL, DENVER, COLORADO
JUNE 25-27, 1991
EXCAVATION INVESTIGATIONS STUDY

OBJECTIVES OF THE STUDY
(STUDY PLAN 8.3.1.15.1.5)

- PROVIDE DATA TO HELP VALIDATE MODELS USED TO PREDICT ROCK MASS MECHANICAL BEHAVIOR
  - LARGEST SCALE
  - EXTENT OF STRESS-ALTERED REGION

- DEMONSTRATE CONSTRUCTABILITY OF THE REPOSITORY
DISTURBED ZONE AROUND AN UNDERGROUND OPENING

UNDISTURBED ROCK

STRESS REDISTRIBUTION ZONE

DAMAGED ZONE

TRANSITIONAL AREA

STRESS ALTERED REGION

UNDISTURBED ROCK
EXCAVATION INVESTIGATIONS STUDY

(CONTINUED)

SCP APPROACH

- SHAFT CONVERGENCE EXPERIMENT
- DEMONSTRATION BREAKOUT ROOMS EXPERIMENT
- SEQUENTIAL DRIFT MINING EXPERIMENT
POST-SCP MODIFICATIONS

• SHAFT CONVERGENCE - ACCESS CONVERGENCE
  - LESS EMPHASIS ON SHORT-TERM RESPONSE
  - MORE EMPHASIS ON EXTENT OF ALTERED REGIONS NEAR FAULTS AND IN UNITS ABOVE THE TSw2
  - RAMP TO CALICO HILLS
  - IN SITU STRESS MEASUREMENTS FROM ANGLED BOREHOLES

• DEMONSTRATION BREAKOUT ROOMS
  - LOWER ROOM MAY NOT BE NECESSARY EXCEPT TO PROVIDE SPACE FOR OTHER TESTS
  - MECHANICAL EXCAVATION DEMONSTRATION

• SEQUENTIAL DRIFT MINING
  - MECHANICAL EXCAVATION
ACCESS CONVERGENCE EXPERIMENT

OBJECTIVES

- MEASURE IN SITU STRESS AND STRESS CHANGES
- MEASURE DEFORMATION OF ROCK MASS SURROUNDING THE OPENING
ACCESS CONVERGENCE EXPERIMENT

(CONTINUED)

TEST DESCRIPTION

- MEASUREMENT STATIONS
  - EACH MAJOR UNIT
  - NEAR FAULTS

- EACH MEASUREMENT LEVEL INCLUDES THE SAME MEASUREMENTS

- IN SITU STRESS MEASUREMENTS USING OVERCOVERING TECHNIQUE AT EACH STATION

- 6-MPBXs, 12 TAPE EXTENSOMETER ANCHORS WILL BE USED AT EACH STATION
ACCESS CONVERGENCE MEASUREMENTS

UPPER MEASUREMENT LEVEL

LOWER MEASUREMENT LEVEL
SHAFT CONVERGENCE

PREVIOUS EXPERIENCE

PROTOTYPE

- NO FORMAL PROTOTYPE EXPERIMENT

- INSTRUMENTS HAVE BEEN EVALUATED IN:
  - G-TUNNEL
  - MPBX
  - TAPE EXTENSOMETER
  - HYDRAULIC PRESSURE CELLS

ANALYSES

- PRE-TEST ANALYSES FOR THE SHAFT WERE COMPLETED

REVISIONS

- RAMP ACCESS
- MACHINE BORING
FINITE ELEMENT MESH FOR SHAFT EXCAVATION ANALYSIS

(a)

X-AXIS METERS

Y-AXIS METERS

Fixed (z)

Symmetry

Fixed (r)

Pressure
EXCAVATION SEQUENCE FOR THE SHAFT

(b)
EXCAVATION SEQUENCE ANALYSIS
RESULTS

Stresses Normalized to Vertical In Situ Stress at Each Depth (MPa)

- PTn (-2.12)
- TSw1 (-4.66)
- TSw2 (-7.21)

Stresses Normalized to Vertical In Situ Stress at Each Depth (MPa)

- PTn (-2.12)
- TSw1 (-4.66)
- TSw2 (-7.21)
EXCAVATION SEQUENCE ANALYSIS
RESULTS

Displacements Normalized to
Maximum Wall Convergence (mm)

PTn  ○ UU(2.09)  + SSD(2.48)
TSw1 □ UU(0.65)
TSw2 ◊ UU(0.53)

1 Excavation Round = 2.5m

Excavation Passes
Measurement Station
EXCAVATION INVESTIGATIONS - DEMONSTRATION BREAKOUT ROOMS

OBJECTIVES

- PROVIDE EARLY DATA ON ROCK MASS RESPONSE TO EXCAVATION

- DEMONSTRATE CONSTRUCTABILITY OF REPOSITORY-SIZE OPENINGS IN THE HOST ROCK
  - HIGH AND LOW LITHOPHYSAE CONTENTS
  - EARLY FEEDBACK ON EFFECTIVE CONSTRUCTION TECHNIQUES

- PROVIDE SPACE TO CONDUCT OTHER TESTS
EXCAVATION INVESTIGATIONS - DEMONSTRATION BREAKOUT ROOMS (CONTINUED)

TEST DESCRIPTION

- SELECT CRITICAL ORIENTATION BASED ON FRACTURE GEOMETRY AND IN SITU STRESSES

- EXCAVATE REPOSITORY-SIZED ROOMS BY BLASTING AND INSTALLING INSTRUMENTS IN SEQUENCE. MONITOR:
  - ROCK MASS MOVEMENT
  - ROCK BOLT LOADS OR STRAINS
  - EXCAVATION TECHNIQUES

- CONTINUE TO MONITOR DISPLACEMENTS AND LOADS UNTIL STEADY-STATE CONDITION IS REACHED
EXCAVATION INVESTIGATIONS - DEMONSTRATION BREAKOUT ROOMS
(CONTINUED)

CONDITIONS

- **LOCATIONS**
  - DENSELY WELDED TUFF, HIGH AND LOW LITHOPHYSAL CONTENT

- **ORIENTATION**
  - COINCIDENT WITH THE MOST CRITICAL OF THE TWO ORTHOGONAL ORIENTATIONS PLANNED FOR THE REPOSITORY DRIFTS

- **TIMING**
  - MINE BOTH DBRs PRIOR TO REMAINDER OF MAIN TEST LEVEL

- **DIMENSIONS**
  - CROSS SECTION: REPOSITORY SCALE
  - LENGTH: 6 X WIDTH

- **MINING**
  - MECHANICAL METHODS
**INSTRUMENTATION**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>INSTRUMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROCK MASS MOVEMENT</td>
<td>MULTIPLE-POINT BOREHOLE EXTENSOMETER (MPBX)</td>
</tr>
<tr>
<td>CROSS-DRIFT CONVERGENCE</td>
<td>TAPE EXTENSOMETER</td>
</tr>
<tr>
<td>ROCK BOLT LOAD</td>
<td>LOAD CELL, ULTRASONICS OR STRAIN GAUGES</td>
</tr>
</tbody>
</table>
DEMONSTRATION BREAKOUT ROOM

PLAN VIEW

SECTION A - A

- CROSS-DRIFT CONVERGENCE PIN
- MULTIPLE-POINT BOREHOLE EXTENSOMETER (MPBX)
EXCAVATION INVESTIGATIONS - DEMONSTRATION BREAKOUT ROOMS

(CONTINUED)

PREVIOUS EXPERIENCE

- DEMONSTRATION DRIFT IN G-TUNNEL

  - MEASUREMENT OF RESPONSE TO EXCAVATION USING MPBXs, TAPE EXTENSOMETER, AND ROCK BOLT LOAD CELLS

  - INVESTIGATION OF TECHNIQUES FOR CONTROLLED BLASTING AND GROUND SUPPORT
EXCAVATION INVESTIGATIONS - SEQUENTIAL DRIFT MINING

SEQUENTIAL DRIFT MINING EXPERIMENT

Diagram showing sequential drift mining steps with labels 1, 2, and 3.
EXCAVATION INVESTIGATIONS - SEQUENTIAL DRIFT MINING

OBJECTIVES

- PROVIDE DETAILED INFORMATION ON EXCAVATION RESPONSE
  - SUPPORT MODEL VALIDATION
  - DELINEATE EXTENT OF EXCAVATION DAMAGE AND STRESS REDISTRIBUTION
- DEMONSTRATE CONSTRUCTABILITY OF REPOSITORY-SCALE OPENING
- PROVIDE SPACE AND BASELINE CONDITIONS FOR HEATED ROOM EXPERIMENT
EXCAVATION INVESTIGATIONS - SEQUENTIAL DRIFT MINING

(CONTINUED)

USE OF DATA

- VALIDATE MECHANICAL MODELS AT LARGEST SCALE
- DEFINE CHARACTERISTICS AND EXTENT OF BLAST-DAMAGED ZONE AND STRESS-ALTERED REGION
- VERIFY CONSTRUCTABILITY OF UNDERGROUND REPOSITORY AS DESIGNED
  - IMPACT OF LITHOPHYSAE
  - ORIENTATION
  - GEOMETRY
  - TECHNIQUES
EXCAVATION INVESTIGATIONS - SEQUENTIAL DRIFT MINING
(CONTINUED)

TEST DESCRIPTION

● MINE INSTRUMENTATION DRIFTS

● DRILL HOLES INTO CENTRAL AREA AND CHARACTERIZE ROCK MASS USING
  - CORE LOGGING AND BOREHOLE INSPECTION
  - BOREHOLE PERMEABILITY MEASUREMENTS
  - CROSS-BOREHOLE AND CROSS-DRIFT SEISMICS

● ESTABLISH BASE CONDITIONS USING
  - BOREHOLE EXTENSOMETERS
  - BOREHOLE STESSMETERS
  - BOREHOLE DEFLECTOMETERS
EXCAVATION INVESTIGATIONS - SEQUENTIAL DRIFT MINING

(Continued)

TEST DESCRIPTION (Continued)

● EXCAVATE CENTER DRIFT

- MONITOR INSTRUMENTS CONCURRENTLY

- INSTALL BOREHOLE EXTENSOMETERS, CROSS-DRIFT CONVERGENCE PINS, AND ROCK BOLT LOAD CELLS ALONG CENTER DRIFT

- MONITOR MINING ACTIVITIES

● REPEAT CHARACTERIZATION OF ROCK MASS AFTER EXCAVATION
EXCAVATION INVESTIGATIONS - SEQUENTIAL DRIFT MINING

(CONTINUED)

CONDITIONS

- LOCATION
  - MAIN TEST LEVEL

- ORIENTATION
  - COINCIDENT WITH REPOSITORY

- DIMENSIONS OF CENTER DRIFT
  - CROSS SECTION: REPOSITORY SCALE
  - LENGTH: 6 X WIDTH

- MINING OF CENTER DRIFT
  - SAME METHOD AS REPOSITORY

- SUPPORTS
  - ROCK BOLTS, WIRE MESH
EXCAVATION INVESTIGATIONS - SEQUENTIAL DRIFT MINING

(CONTINUED)

INSTRUMENTATION

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>INSTRUMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROCK MASS MOVEMENT</td>
<td>BOREHOLE EXTENSOMETER</td>
</tr>
<tr>
<td>CROSS-DRIFT CONVERGENCE</td>
<td>TAPE EXTENSOMETER</td>
</tr>
<tr>
<td>ROCK BOLT LOAD OR STRAIN</td>
<td>LOAD CELL, ULTRASONICS, OR STRAIN GAUGES</td>
</tr>
<tr>
<td>BOREHOLE DEFLECTION</td>
<td>DEFLECTOMETER</td>
</tr>
<tr>
<td>PERMEABILITY</td>
<td>STRADDALE PACKER/INJECTION APPARATUS TO BE FABRICATED</td>
</tr>
<tr>
<td>STRESS CHANGE</td>
<td>UNDECIDED; PROTOTYPE EXPERIMENT USED RIGID INCLUSION BSMs</td>
</tr>
</tbody>
</table>

HGEILCSP.125 NWTRB/6-27-91
SEQUENTIAL DRIFT MINING EXPERIMENT

**PLAN VIEW**

- **MULTIPLE-POINT BOREHOLE EXTENSOMETER (MPEX)**
- **BOREHOLE DEFLACTOMETER (BD)**
- **BOREHOLE PERMEABILITY MEASUREMENTS (BP)**
- **BOREHOLE STRESSSENSOR (BSS)**

**SECTION A - A**

- **MPB anchor (TD)**
- **Convergence measurements (TD)**

---

HGEILC5P.125.NWTRB/6-27
EXCAVATION INVESTIGATIONS - SEQUENTIAL DRIFT MINING

(CONTINUED)

PREVIOUS EXPERIENCE

PROTOTYPE TEST COMPLETED: DEMONSTRATION DRIFT IN G-TUNNEL

- SINGLE INSTRUMENTATION DRIFT
- MEASURED
  - ROCK MASS DISPLACEMENT
  - CROSS-DRIFT CONVERGENCE
  - ROCK BOLT LOADS
  - BOREHOLE DEFLECTION
  - PERMEABILITY CHANGES
  - STRESS CHANGES
PLAN VIEW OF DEMONSTRATION DRIFT EQUIPMENT

- 29.6 m
- 8.6 m
- 9.1 m
- 3.0 m

GROUT INSERT
MAJOR FRACTURES
FAULT
DEMONSTRATION DRIFT
INSTRUMENT CUTOUT

STATIONS

(a)
PHOTOGRAPH OF DEMONSTRATION DRIFT
TAPE EXTENSOMETER MEASUREMENTS
DEMONSTRATION DRIFT
MODEL OF DEMONSTRATION DRIFT EXPERIMENT

UNIT C

5 deg.

UNIT B

RUBBLE

DEM Onstration ROOM

1.52 m

VITROPHYRE

3.68 m

3.05 m

6.10 m

3.68 m

E

E

DRIFT 12

TUNNEL BED TUFF

8 MPa

2 MPa
DEFORMED FINITE ELEMENT MESH
COMPARISON OF CALCULATED DISPLACEMENTS vs DATA

![Graph comparing calculated vs measured displacements.](image)

- **MPBX Station C7**
- **MPBX Station E7**
- **Average Measured MPBX Displacements**
- **Calculated**

**S-DISTANCE (meters)** vs **S-DISPLACEMENT (mm)**

**Collar**
COMPARISON OF CALCULATED DISPLACEMENTS vs DATA

---

- MPBX Station C1
- MPBX Station E1
- Average Measured MPBX Displacements
- Calculated

END ANCHOR

S-DISTANCE meters vs S-DISPLACEMENT mm