CONDITION ASSESSMENT, DURABILITY AND CORROSION OF ROCK REINFORCEMENTS

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Session #6
“Rock Reinforcement”
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TOPICS

1. Rock Reinforcement Types and Installation Details
2. Chronology of Rock Reinforcement Types
3. Corrosion & Corrosion Protection
4. Existing Performance Data
5. NDT
6. Service Life Modeling
7. Conclusions
# 1. TYPES OF ROCK REINFORCEMENTS

<table>
<thead>
<tr>
<th>System Type</th>
<th>Tendon Type</th>
<th>Anchorage Type</th>
<th>Corrosion Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock Anchors</td>
<td>Strands or Bars</td>
<td>Cement Grout in Bonded Zone</td>
<td>Class I or Class II Protection</td>
</tr>
<tr>
<td></td>
<td>High Strength Steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock Bolts</td>
<td>Bars Strands</td>
<td>Mechanical, resin grout or cement grout</td>
<td>Epoxy coating, galvanized, grout cover. May have no protection other than grout cover.</td>
</tr>
<tr>
<td></td>
<td>Mild Steel or 150 ksi</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ROCK BOLTS

- Mechanical anchorage
- Grouted anchorage
Sledge & Wedge Rock Bolt
Expansion Shell Anchorage
Cement-Grouted Anchorage
Resin-Grouted Anchorage

1. Place predetermined quantity of resin cartridges.
2. Insert deformed reinforcing bar and spin through cartridges to mix hardener and catalyst in cartridge.
3. Fast resin sets to develop tensioning anchorage in about 5 minutes.
4. After fast resin sets, tension the bar (by direct pull or torquing the nut) and complete nut tightening operation.
5. After tensioning, "slow" resin sets to provide continuous bond over full length of reinforcing element.

NOTES:
1. "Thread bar" (see fig. 5-1) may be used in place of bar shown.
2. If "thread bar" is used, only direct pull tensioning is recommended.
Ground Anchor

Diagram of a ground anchor showing:
- Anchor Head
- Bearing Plate
- Anchor Bond Length
- Tendon Bond Length
- Unbonded Length
- Trumpet
- Sheath
- Unbonded Tendon
- Anchor Grout
- Bonded Tendon
- Anchor Diameter

Photo of a ground anchor in the ground.
2. CHRONOLOGY

Rock Bolts

- 1900: Slot and wedge rock bolts in mining industry.
- 1930: Carbide tipped drills.
- 1940: First expansion shell anchorages.
- 1950: Uses fully grouted unthreaded deformed bars.
- 1960: Mostly groutable anchors used for tunneling and slope stability.
- 1970: Propackaged polyester resin systems.
- 1980: European Practice
  - Corrosion-protected tiebacks.
  - Drilling techniques. Steel strength improves.
  - Tieback installed using grout pumped under high pressure.
  - Pressure grouting adopted as U.S. regular practice.
  - Tiebacks installed using drilled holes.

Tiebacks
3. TYPES OF CORROSION

- Uniform corrosion
- Pitting corrosion
- Crevice corrosion
- Stress corrosion cracking
- Hydrogen embrittlement
- Stray-current induced corrosion
- Micro-bacterial induced corrosion
CORROSION PROTECTION SYSTEMS
Class II (PTI, 2007)
Class I (PTI, 2007)
4. LONG TERM PERFORMANCE OF ROCKBOLTS (Baxter, 1987; Kendorski, 2003)

**Finish Rockbolt Research (Sundholm, 1987)**

- Cracks, voids and lack of material were found in both cement grouted and resin grouted bolts.
- Large pieces of resin cartridge cover were seen between the grout and the borehole wall.
- Cement grouting of rebar seemed to offer the best protection against corrosion.
- For cement-grouted bolts damage from corrosion only occurred at the proximal end of the bolt, where the cement grout was often very poor.
- Uncovered parts of resin-grouted rebar were very badly corroded within two years.
LONG TERM PERFORMANCE OF ROCKBOLTS (CONT.)

Swedish Rockbolt Research (Helfrich and Finkel, 1989)

• Approximately 50% of cement grouted bolts had reduced or insufficient grouting.
• Severe pitting corrosion was observed in cement grouted rockbolts.
• General surface corrosion was observed from uncoated bolts.
• Resin-grouted bolts indicated increasing rust formation with age.
• Cement-grouted bolts had no or poor grout quality at the distal end.
• Resin-grouted bolts showed no or poor grout quality at the proximal end.
Ground Anchor Performance

Case Studies
• 35 case studies reported by FIP (1986)
• Rock bolt experience in mining industry
• NCHRP 24-13 survey
  – Several reported incidents in transportation sector

History of Performance
• In general performance has been satisfactory
• Some corrosion problems- near anchor head, MIC, stray currents
• Creep
• Loads not anticipated in design- ice loads, poor drainage, cyclic loads
5. NDT
UTILITY OF NDT

• Electrochemical Tests
  – Half cell
  – Polarization

  Indicate integrity of corrosion protection systems.

• Wave Propagation Techniques
  – Impact Test
  – Ultrasonic Test

  Assess the current condition of an element, i.e., severity of corrosion.
APPROACH

1. A number of monitoring techniques are included in the test protocols for NDE of rock bolts.

2. The SE, IR, UT, and ECT techniques are applied to evaluate the condition of grouted rock bolts.

3. Installation details can be distinguished with NDE, and these details are useful for condition assessment and service life modeling.

4. Reliability and durability are affected by lock-off loads, and whether the design load is determined by geotechnical or structural considerations.
SIGNAL ATTENUATION

40 Kips

Normal - $L_T = 20$ ft, $L_b = 5$ ft

Distressed = $L_T = 10$ ft, $L_b = 3$ ft

10 Kips
## LIFT-OFF TEST RESULTS

<table>
<thead>
<tr>
<th>BOLT #</th>
<th>LIFT-OFF (Kips)</th>
<th>NDT RESULT</th>
<th>CORRECT NDT</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>36</td>
<td>GOOD</td>
<td>Y</td>
</tr>
<tr>
<td>4</td>
<td>38</td>
<td>GOOD</td>
<td>Y</td>
</tr>
<tr>
<td>7</td>
<td>17</td>
<td>GOOD (?)</td>
<td>N (?)</td>
</tr>
<tr>
<td>8</td>
<td>22</td>
<td>GOOD</td>
<td>N</td>
</tr>
<tr>
<td>9</td>
<td>20</td>
<td>NG</td>
<td>Y</td>
</tr>
<tr>
<td>G1</td>
<td>7</td>
<td>NG</td>
<td>Y</td>
</tr>
<tr>
<td>6</td>
<td>LOOSE</td>
<td>NG</td>
<td>Y</td>
</tr>
<tr>
<td>17</td>
<td>LOOSE</td>
<td>G/NG</td>
<td>Y (?)</td>
</tr>
</tbody>
</table>
VERIFICATION OF NDT
MOBILITY CURVES

Total Length = 15 Feet

![Graph showing mobility curves for normal and distressed conditions.](image-url)
Bruceton SRCM

SE Test Results

UT Results
HALF-CELL POTENTIALS

- NH I-93 (NB)
- NH I-93 (SB)
- NC I-240
- Bruclon Mine
- Dam Tie-Downs
- NH I-93 (tendons)
- PA Anchors (NR)
- PA Anchors (R)

$E_{corr} \text{ (mV)}$

-1000
-900
-800
-700
-600
-500
-400
-300
-200
-100

Resin Grout
Portland Cement Grout
CORROSION RATES OBSERVED WITH LPR
DAM TIE DOWNS - BUTTON HEAD ANCHORAGES
LOCH ALVA DAM - IMPACT TEST RESULTS
Grout Condition Assessment for Rock Bolts & Ground Anchors

![Graph showing the intensity of reflections from impact test for different conditions.](image-url)
6. SERVICE LIFE MODELING
## CORROSIVENESS OF SOILS

<table>
<thead>
<tr>
<th>Corrosiveness</th>
<th>Resistivity (ohm/cm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>2000 – 5000</td>
<td>5–10</td>
</tr>
<tr>
<td>Aggressive</td>
<td>700 – 2000</td>
<td>5–10</td>
</tr>
<tr>
<td>Very Aggressive</td>
<td>&lt; 700</td>
<td>&lt; 5</td>
</tr>
</tbody>
</table>
### Recommended Parameters for Service-Life Prediction Model
(Withiam et al., 2002)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal</th>
<th>Aggressive</th>
<th>Very Aggressive</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K (\mu m)$</td>
<td>35</td>
<td>50</td>
<td>340</td>
</tr>
<tr>
<td>$r$</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Effect of Time on Metal Loss for Rock Bolts & Ground Anchors
**SERVICE-LIFE MODEL**

\[ X \left( \frac{\mu m}{side} \right) = A \left( \frac{\mu m}{side} \right) \times t^{0.8} (yr) \]

**Statistics for A**

\[ \mu = 60 \, \mu m/yr \]
\[ \sigma = 40 \, \mu m/yr \]

PDF - lognormal
7. CONCLUSIONS

- The type of rock reinforcement and installation details have a significant effect on condition assessment and durability.
- Older installations may not incorporate the same level of details and corrosion protection afforded to more modern applications.
- Existing data on performance and service life are useful to identify vulnerabilities of different systems.
- In general, systems are most vulnerable to deterioration near the anchor heads.
- NDT are useful tools for condition assessment.
- Generalized service-life models are available from the literature.
- More data are needed from condition assessment to incorporate affects of climate and site conditions on performance.