Rock Anchors for Dams: The Need for Common Sense and Clarity

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What’s Wrong with this Picture?
1. The Background to the National Research Program

The main project tasks were to:


2. Research and compile all technical papers written about North American dam anchoring projects. (over 230).

3. Collect hard copies of information, and create database of all dam anchoring projects in North America (over 400).
2. The Bibliography
Collection and Analysis of Published Technical Papers

- Hard copy and electronic versions of each published paper have been collected.
- A total of 235 papers have so far been found relating to over 200 dams.
- Data used to populate database.

3. The Database of Projects

Histogram of US Dam Construction (1960-2004)

Interim Release
Work in Progress

Notes:
1. Source of Data - National Inventory of Dams, USACE, 70777 Dams Total
2. Does not include MDC dams where the year completion was not specified on record
3. Total number of dams (not including 1950 with an unspecified start date) = 70777
Numbers of dams anchored/numbers of masonry and concrete dams, per state

No. of Dams Anchored:
- 0-5
- 6-10
- 11-15
- 16-20
- 21-25
- 26-30
- >30

Notes:
1) Source of data – National Inventory of Dams USACE
2) Statistics may be skewed based on how states classify their dams.

Numbers of dams anchored/numbers of large dams, per province

No. of Dams Anchored:
- 0-5
- 6-10
- 11-15
- 16-20
- 21-25
- 26-30
- >30
2. Geotechnical Design

Traditional Approach:
- Uniform bond distribution
- $T_w = 100$ to $130$ psi
- “Volume of rock cone” theory for overall stability

Assumption

Stress distribution of a simple design approach

Ultimate load $= \pi d L T_{ult}$

This means load $\propto$ fixed length

This is not a true statement.
However, it is a conservative approach, and is most unlikely to change.

3. Construction
3.1 Drilling

Then:
- Diamond drilling in concrete
- Rotary or rotary percussive in rock
- Deviation monitoring (< 1 in 100)
- Pressure grouting
- Maintain full logs
3.1 Drilling

Now:
- Diamond drilling only for reinforced concrete or very weak structures
- Use down-the-hole hammer
  - Deviation control
  - Speed
  - Vibrations/pneumatic fracture
- MWD

3.2 Water Pressure Testing

Then:
- Full length
- 0.5 gpm at 60 psi (more typical 0.001 gal/inch diameter/ft/min at 5 psi)
- Very conservative criterion
3.2 Water Pressure Testing

Now:
- Knowledge of fissure control on permeability
- 2.5 gal at 5 psi excess
- Testing of corrugated protection also

3.3 Grouting

Then:
- Proprietary non-shrink grout for first stage
- Water:cement ratio ≤ 0.45
- Pre-construction testing
- High speed, high shear mixer
- Tremie grout
3.3 Grouting

Now: Same except:
- No use of preblend cements
- Focus on fluid property testing
- Often single stage grouting
- Preproduction testing

3.4 Tendon Evolution
1960s – 1970s
Bare Strand/Wire Throughout

- Tendon proposed/selected by Contractor/PT Supplier (wire, strand, bar).
- Grout conceived to be the only protection: 2 stages essential.
- Fully bonded, and so no long-term load monitoring capability.

1970s – 1980s
Greased and sheathed free lengths, bare strand on bond length.
1980s Onwards
Corrugated Sheathing on Bond Length (1980s) Extending to Full Length Protection by 1990s

Greased and sheathed protection on individual strands, permitting single stage grouting.

1990s Onwards
Epoxy-coated and filled strand with or without grease sheathed free length. Typically require special handling and installation methods.
## Corrosion Protection Requirements

<table>
<thead>
<tr>
<th>CLASS</th>
<th>PROTECTION REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ANCHORAGE</td>
</tr>
<tr>
<td>I</td>
<td>ENCAPSULATED TENDON</td>
</tr>
<tr>
<td>II</td>
<td>GROUT PROTECTED TENDON</td>
</tr>
</tbody>
</table>

## PTI Class I Bond Zone

![PTI Class I Bond Zone Diagram](image-url)
Anchor Inspections

4.0 Evolution of Stressing and Testing

1974:
- Progressive simple loading to 115% Design Working Load (to maximum 80% GUTS)
- Alignment Load of 10% Test Load
- No cycling
- Very little data recording required or analysis described (Read extension only at Test Load)
- Lock off at 50 to 70% GUTS
- Lift off test
- No creep test
Stressing and Testing

2004:
- Proof and Performance Tests
- Analysis of elastic movement data
- Creep testing: short and extended
- Lift off testing
- Lock off $\geq 60\%$ GUTS
- Special provisions for epoxy coated strand
- Clear acceptance criteria and “rework” guidance

Overview

- National Research Program has been invaluable in clarifying the evolution of the anchor industry, especially with respect to corrosion protection.
- The PTI Recommendations (2004) is the referenceable document.
- Anchors without Class I Corrosion protection cannot be regarded as Permanent. Thus, many dams anchored before 1996 may not have fully functional post-tensioning systems.
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