CANTON DAM
SPILLWAY STABILITY

Is a Test Anchor Program Necessary?

US Army Corps
of Engineers

One Corps Serving The Army and the Nation
CANTON DAM
SPILLWAY STABILITY

- Background and History
- Determining Anchor Capacity
- Investigation and Test Anchor Program
- Summary
Background and History
CANTON LAKE
LOCATION

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CANTON DAM

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CANTON DAM

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CANTON DAM
PROJECT DESCRIPTION

- Rolled Earthfill Embankment with a Length of 15,140 ft. and max. height of 73 ft.
- Gate Controlled Concrete Chute Spillway with 16 - 40 ft. wide by 25 ft. high Tainter Gates with a Total Capacity of 274,000 cfs.
- Outlet Works Consists of 3 - 7 ft. wide by 12 ft. high sluice gates.
- Downstream Channel Capacity is Approx. 1000 cfs.
CANTON DAM

PERTINANT DATA

- Top of Dam: 1648.0
- Top of Flood Control Pool and Top of Spillway Gates: 1638.0
- Top of Conservation Pool: 1615.4
- Pool Restriction: 1626.0
CANTON DAM
DAM SAFETY ISSUES

- HYDROLOGIC DEFICIENCY
- SEISMIC DEFICIENCY
- SEEPAGE DEFICIENCY
- SPILLWAY STABILITY
FOUNDATION MATERIALS

– PERMIAN RED BEDS
  • RUSH SPRINGS SANDSTONE
  • DOG CREEK SHALE
    – COMPACTION SHALE
    – POORLY INDURATED
    – GYPSUM LAYERS
    – SOFT LAYERS
  • BLAINE FORMATION
    – COMPACTION SHALE
    – 2 MASSIVE GYPSUM/ANHYDRITE LAYERS
DOG CREEK SHALE
STRENGTH CHARACTERISTICS

• OVERCONSOLIDATED
• DILATES WHEN SHEARED (AT LOWER CONFINING PRESSURE)
• LOWEST STRENGTHS 20-30 FEET, OR 1570-1580 ELEVATION, AND BELOW 50 FEET
• HIGHEST STRENGTHS BETWEEN 30 AND 40 FEET
DATA FROM ALL SHEAR TESTS

DEPTH, FT

SHEAR STRENGTH, TSF
TECHNICAL CONCERNS

• WEAK LAYERS IN FOUNDATION
  – GYPSUM SEAMS
  – OTHER SOFT SEAMS

• DESIGN SHEAR STRENGTH
  – USE OF COHESION

• DRAINAGE
  – 50 PERCENT EFFECTIVE
  – 0 PERCENT EFFECTIVE
## Listing of Safety Factors

<table>
<thead>
<tr>
<th>Year</th>
<th>C</th>
<th>PHI</th>
<th>Uplift</th>
<th>FS</th>
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<tbody>
<tr>
<td>1944</td>
<td>880</td>
<td>31</td>
<td>2.38</td>
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</tr>
<tr>
<td>1946</td>
<td>0</td>
<td>31</td>
<td>1.40</td>
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<tr>
<td>1973</td>
<td>600</td>
<td>30</td>
<td>1.39</td>
<td></td>
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<tr>
<td>1979</td>
<td>1200</td>
<td>50</td>
<td>2.16</td>
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<tr>
<td>1983</td>
<td>0</td>
<td>39.3</td>
<td>100%</td>
<td>0.88</td>
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<tr>
<td>1983</td>
<td>0</td>
<td>39.3</td>
<td>50%</td>
<td>1.2</td>
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<tr>
<td>1997</td>
<td>0</td>
<td>33</td>
<td>100%</td>
<td>0.7</td>
</tr>
<tr>
<td>1999</td>
<td>0</td>
<td>25</td>
<td>100%</td>
<td>0.55</td>
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<tr>
<td>1999</td>
<td>0</td>
<td>25</td>
<td>50%</td>
<td>0.88</td>
</tr>
<tr>
<td>2004</td>
<td>0</td>
<td>25</td>
<td>100%</td>
<td>0.50</td>
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</tbody>
</table>
CANTON DAM
SPILLWAY STABILITY

Spillway Cross Section
Showing Failure Plane
and Typical Post-Tensioned Anchor Layout
Determining Anchor Capacity
AN CHOR DES IGN LOAD FORMULA

\[ P = \tau_w * L_b * \pi * d \]

- \( P \) = design load for the anchor
- \( \tau_w \) = working bond stress along the interface between rock and grout
- \( \tau_w = 50\% \text{ of the ultimate bond stress} \)
- \( L_b \) = bond zone length
- \( d \) = diameter of drill hole
# RECOMMENDED BOND STRESS VALUES FROM PTI

<table>
<thead>
<tr>
<th>ROCK</th>
<th>AVERAGE ULTIMATE BOND STRESS-ROCK/GROUT (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite and Basalt</td>
<td>250 – 450</td>
</tr>
<tr>
<td>Dolomitic Limestone</td>
<td>200 – 300</td>
</tr>
<tr>
<td>Soft Limestone</td>
<td>150 – 200</td>
</tr>
<tr>
<td>Slates &amp; Hard Shales</td>
<td>120 – 200</td>
</tr>
<tr>
<td>Soft Shales</td>
<td>30 – 120</td>
</tr>
<tr>
<td>Sandstones</td>
<td>120 – 250</td>
</tr>
<tr>
<td>Weathered Sandstones</td>
<td>100 – 120</td>
</tr>
<tr>
<td>Chalk</td>
<td>30 – 155</td>
</tr>
<tr>
<td>Weathered Marl</td>
<td>25 – 35</td>
</tr>
<tr>
<td>Concrete</td>
<td>200 – 400</td>
</tr>
</tbody>
</table>

Table 6.1, Recommendations for Prestressed Rock and Soil Anchors, PTI, 1996
TEST ANCHOR PROGRAM
PHASE I CORE STRENGTHS

Minimum = 120 psi
One Third = 330 psi
Median = 420 psi
Average = 456 psi
Maximum = 1,040 psi
TEST ANCHOR PROGRAM
PHASE II CORE STRENGTHS

Minimum = 50 psi       Maximum = 860 psi
One Third = 300 psi     Average = 460 psi
Median = 440 psi
TEST ANCHOR PROGRAM
PHASE I & II SUMMARY

- Ultimate Bond Stress = 10% of the Unconfined Compressive Strength of the Rock
- Minimum Value = 5 to 12 psi
- One Third Value = 30 to 33 psi
- Median Value = 42 to 44 psi
- Average Value = 46 psi
- Maximum Value = 86 to 104 psi
## TEST ANCHOR PROGRAM
### LAB BOND TESTS

<table>
<thead>
<tr>
<th>Boring</th>
<th>Maximum Bond Stress (psi)</th>
<th>Boring</th>
<th>Maximum Bond Stress (psi)</th>
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<tbody>
<tr>
<td>BL-1</td>
<td>102</td>
<td>BR-4</td>
<td>104</td>
</tr>
<tr>
<td>BL-1</td>
<td>57</td>
<td>BR-4</td>
<td>233</td>
</tr>
<tr>
<td>BL-2</td>
<td>81</td>
<td>BR-5</td>
<td>176</td>
</tr>
<tr>
<td>BL-2</td>
<td>84</td>
<td>BR-5</td>
<td>62</td>
</tr>
<tr>
<td>BL-2</td>
<td>141</td>
<td>BR-6</td>
<td>154</td>
</tr>
<tr>
<td>BL-3</td>
<td>98</td>
<td>BR-6</td>
<td>65</td>
</tr>
<tr>
<td>BL-3</td>
<td>76</td>
<td>BR-6</td>
<td>300</td>
</tr>
</tbody>
</table>

Minimum = 57 psi  
One Third = 80 psi  
Median = 100 psi  
Maximum = 300 psi  
Average = 109 psi
## TEST ANCHOR PROGRAM

### PHASE I PULLOUT TESTS

<table>
<thead>
<tr>
<th>Boring</th>
<th>Bond Zone Length (ft)</th>
<th>No. of Strands</th>
<th>Percent of Design Load (%)</th>
<th>Bond Stress (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1LA</td>
<td>15</td>
<td>7</td>
<td>118</td>
<td>63</td>
</tr>
<tr>
<td>A-1RA</td>
<td>15</td>
<td>7</td>
<td>165</td>
<td>97</td>
</tr>
<tr>
<td>A-3L</td>
<td>15</td>
<td>7</td>
<td>160</td>
<td>94</td>
</tr>
<tr>
<td>A-3R</td>
<td>15</td>
<td>7</td>
<td>155</td>
<td>91</td>
</tr>
<tr>
<td>A-2L</td>
<td>15</td>
<td>16</td>
<td>188</td>
<td>221</td>
</tr>
<tr>
<td>A-2R</td>
<td>15</td>
<td>16</td>
<td>190</td>
<td>224</td>
</tr>
<tr>
<td>A-5L</td>
<td>15</td>
<td>16</td>
<td>188</td>
<td>221</td>
</tr>
<tr>
<td>A-5R</td>
<td>15</td>
<td>16</td>
<td>190</td>
<td>224</td>
</tr>
<tr>
<td>A-4L</td>
<td>40</td>
<td>16</td>
<td>133</td>
<td>83</td>
</tr>
<tr>
<td>A-4R</td>
<td>40</td>
<td>16</td>
<td>133</td>
<td>83</td>
</tr>
</tbody>
</table>

No anchors failed during pullout tests
CANTON DAM
SPILLWAY STABILITY

- Investigation and Test Anchor Program
INVESTIGATION AND TEST PROGRAM

• Two phase test program required due to lack of funding
  • Phase I – abutment drilling
    – 6 core holes
    – 8 anchor pullout tests
    – 2 anchor creep tests
  • Phase II – spillway drilling
    – 4 core holes
    – 2 full scale anchor tests
• Awarded task orders for investigations and test anchors to MACTEC (Prime) and Hayward Baker (Sub)
TEST ANCHOR PROGRAM
PHASE I

- 3 core holes on each side of the spillway
  - 2 to 140 feet
  - 1 to 180 feet (top of gypsum)
- 2 test anchors on each side of spillway
  - 105 and 140 feet deep
  - 6 inch diameter hole
  - 7 strand tendon instrumentation
  - 15 foot bond zone
  - Perform pullout test to failure
    - Could not fail anchors
TEST ANCHOR PROGRAM
PHASE I - INVESTIGATION

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TEST ANCHOR PROGRAM
PHASE I - INVESTIGATION

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TEST ANCHOR PROGRAM
PHASE I - INVESTIGATION

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TEST ANCHOR PROGRAM
PHASE I - INVESTIGATION

FINDINGS

• Original boring logs indicated caved material
• Caved material turned out to be the result of dissolution and collapse
• Noticeable increase in core recovery, RQD, and strength of core below 90 feet
• Rock dips slightly to the southwest
TEST ANCHOR PROGRAM
PHASE I

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TEST ANCHOR PROGRAM
PHASE I

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TEST ANCHOR PROGRAM
PHASE I

Load vs. Movement Graph

Minimum  Theoretical  Maximum  Actual
TEST ANCHOR PROGRAM
PHASE I REVISED

• 2 test anchors on each side of spillway
  – 105 feet deep (one grouted and one not grouted)
  – 6 inch diameter hole
  – 16 strand tendon
  – 15 foot bond zone
  – Perform pullout test to failure

• 2 test anchor on each side of spillway
  – 105 feet deep
  – 6 inch diameter hole
  – 16 strand tendon with instrumentation
  – 40 foot bond zone
  – Conduct performance test and creep test
TEST ANCHOR PROGRAM
PHASE I REVISED
TEST ANCHOR PROGRAM
PHASE I REVISED

Load vs. Movement Graph

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TEST ANCHOR PROGRAM
PHASE I REVISED

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TEST ANCHOR PROGRAM
PHASE I REVISED

ANTON DAM TEST PROGRAM - TENSION MEASURING GAUGE

BOND ZONE - 40 FT

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## Canton Dam, A4 Left Load Test - Load Per Depth in Bond Zone

<table>
<thead>
<tr>
<th>Tensmeg Strain Gage ID and Depth from Top of Bond Zone</th>
<th>Load Interval % and kips</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM-1 (0.06)</td>
<td>1.33750</td>
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<tr>
<td>TM-2 (3.6)</td>
<td>1.564</td>
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<tr>
<td>TM-3 (9.2)</td>
<td>0.5282</td>
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<tr>
<td>TM-4 (6.4)</td>
<td>0.1564</td>
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<tr>
<td>TM-5 (12.0)</td>
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</tr>
<tr>
<td>TM-6 (14.8)</td>
<td></td>
</tr>
<tr>
<td>TM-7 (17.6)</td>
<td></td>
</tr>
<tr>
<td>TM-8 (20.4)</td>
<td></td>
</tr>
<tr>
<td>TM-9 (23.2)</td>
<td></td>
</tr>
<tr>
<td>TM-10 (26.0)</td>
<td></td>
</tr>
<tr>
<td>TM-11 (28.8)</td>
<td></td>
</tr>
<tr>
<td>TM-12 (31.6)</td>
<td></td>
</tr>
<tr>
<td>TM-13 (34.4)</td>
<td></td>
</tr>
<tr>
<td>TM-14 (37.2)</td>
<td></td>
</tr>
<tr>
<td>TM-15 (40.0)</td>
<td></td>
</tr>
</tbody>
</table>

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TEST ANCHOR PROGRAM
PHASE I REVISED

Creep Movement Plot

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TEST ANCHOR PROGRAM

PHASE II

• Core 4 investigation holes in spillway to an elevation of 1460
  – Collect and test samples for strength and consolidation
• 2 production anchors at gate 16 in existing spillway
  – One 32 strand anchor drilled at 18.4° to elevation 1470
  – One 28 strand anchor drilled at 30.0° to elevation 1470
  – 12 inch diameter hole
  – 40 foot bond zone
  – Conduct performance test and creep test
ANCHOR INSTALLATION
PHASE II
ANCHOR INSTALLATION
PHASE II

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ANCHOR INSTALLATION
PHASE II
ANCHOR INSTALLATION
PHASE II FINDINGS

• Weir access is difficult
  – Slick surface
  – Tight workspace
  – Load limit on spillway bridge

• Continuous flow of cuttings is required
  – Falling cuttings blocked hole and drill tools

• Hole will cave in 12 to 24 hours
  – Duplex type casing would be ideal but none exists for this size of hole

• Control elongation of corrugated pipe

• Drill one hole and install corrugated pipe in that hole before starting another one

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ANCHOR INSTALLATION

PHASE II FINDINGS

- Stage grout to avoid buckling corrugated pipe
- Measure top of grout accurately to avoid clogging of other grout tubes
- Consider single stage vs. two stage grouting
- Label grout and flush tube adequately
ANCHOR DESIGN
CANTON DAM
SPILLWAY STABILITY

• Summary
TEST ANCHOR PROGRAM SUMMARY

• Ultimate Bond Stress Values
  – From PTI Table = 30 to 120 psi
  – From Unconfined Compressive Strength Tests = 30 to 45 psi
  – From Lab Bond Tests = 80 to 110 psi
  – From Pullout Tests = 100 to 220 psi
    • No anchors failed during pullout test
  – Full scale anchor tests loaded to 133% of design load = 83 psi working bond stress
TEST ANCHOR PROGRAM SUMMARY

- Total force required for weir section = 1,550 kips
  - 12 anchors would be required for an ultimate bond stress of 30 psi
  - 2 anchors are required for an ultimate bond stress of 120 psi

- Total force required for pier section = 1,830 kips
  - 14 anchors would be required for an ultimate bond stress of 30 psi
  - 2 anchors are required for an ultimate bond stress of 120 psi
• Phase I
  – Cost approximately $700,000
  – Reduced the number of anchors from over 400 to 112
  – Cost savings of over $6,000,000

• Phase II
  – Cost approximately $800,000
  – Reduced the number of anchors from over 112 to 64
  – Cost savings of over $2,000,000

• Total cost of $1,500,000
• Total savings over $8,000,000
• Return on the investment of more than 5 to 1
SPILLWAY STABILITY
CANTON LAKE

Is a Test Anchor Program Necessary?

It certainly was for us

Some considerations if you are thinking about a test program
- Consider the total load required per monolith
- Consider the type of rock
- Consider the configuration of the structure
SPILLWAY STABILITY
CANTON LAKE

Tulsa District

Dam Safety Assurance Project
Is a Test Anchor Program Necessary?

US Army Corps of Engineers

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