Dispersive Wave (DW) Testing of Trunnion Rods
Trunnion Rods

- Mandated Design by USACE HQ. (1960s)
- COE Standard (EM 1110-2-2702)
- Adopted by other Government Agencies and Industry
- Offered Advantages over Steel Beam/Girder Designs
- Limited Suppliers
- Difficult for Inspection / Repair
 Pretensioned trunnion anchorage
Designed by ACOE
Put into service from early 1960s onward
### Rod Inventory - How many known failures??

<table>
<thead>
<tr>
<th>Location</th>
<th>Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenup</td>
<td>4 tension loss, 2 broken</td>
</tr>
<tr>
<td>Meldhal</td>
<td>7 tension loss</td>
</tr>
<tr>
<td>Belleville</td>
<td>None reported</td>
</tr>
<tr>
<td>Racine</td>
<td>1 tension loss (not re-tensioned)</td>
</tr>
<tr>
<td>Willow Island</td>
<td>1 loss (not re-tensioned), 8 broken</td>
</tr>
<tr>
<td>Winfield</td>
<td>6 broken</td>
</tr>
<tr>
<td>Markland</td>
<td>2 tension loss, 2 broken</td>
</tr>
<tr>
<td>McAlpine</td>
<td>None reported</td>
</tr>
<tr>
<td>Cannelton</td>
<td>61 tension loss, 2 broken</td>
</tr>
<tr>
<td>Newburgh</td>
<td>3 tension loss, 2 broken</td>
</tr>
<tr>
<td>J T Myers</td>
<td>37 tension loss, 8 broken</td>
</tr>
<tr>
<td>Smithland</td>
<td>3 tension loss, 2 broken</td>
</tr>
<tr>
<td>West Point</td>
<td>5 broken</td>
</tr>
<tr>
<td>R. F. Henry</td>
<td>6 broken</td>
</tr>
</tbody>
</table>
Safety

• Examples of Rod Failures

WEST POINT PROJECT

Pier #10 Trunnion Anchor Boxes West (10W) and East (10E)
March 6, 2008
Dam Anchor Rod Testing

Safety

• Although every project should be approached with care and consideration for safety, the nature and environment of dam inspections creates a much lower margin for error than typical job sites.
  – Slips, trips, and falls: We use fall arrest systems similar to those used in tower climbing, but given the proximity to water, the other threat lies in falling into that water.
  – Heavy equipment: Most inspections involve the use of heavy equipment in confined spaces as well as the presence of ongoing construction (i.e. usually inspections are completed in tandem with repairs)
  – Rod failure: The anchor rods supporting the dam are under thousands of pounds of tension, and while we do our best to mitigate risk associated with man-made rod failure, **RODS CAN FAIL SPONTANEOUSLY AT ANY TIME WITHOUT WARNING.**
    • **AVOID STANDING IN FRONT OF RODS AS MUCH AS POSSIBLE.**
Dam Anchor Rod Testing

General Concept
Dam Anchor Rod Testing

General Concept

**ANCHOR ROD ASSEMBLY**

- TRUNNION GIRDER BASE PLATE
- GRIP NUT
- DEAD END ANCHOR
- NUT
- TAIL
- FREE LENGTH

**GRIP NUT ASSEMBLY**

- GRIP NUT
- BAR
- GROUT HOLE
- DRY PLACED PLATE
- FLEXIBLE TUBING

Howlett Grip Nut

**WEST POINT PROJECT**

Tainter Gate Trunnions
(6 Gates – 5 Shared Piers with 2 End Blocks)
Constructed 1989
376 trunnion anchor rods

**West Point Dam**

- Trunnion Rods with Cover Removed
  Note two rods missing.
- Rods 1-1/4” diameter
- UTS is 145 ksi
- Post-tensioned to 115.7k
Dispersive Wave Testing of Trunnion Rods

- Magnet-mounted accelerometer on rod tip.
- Strike lightly with impact device.
- Measure vibration response.
- Calculate modal frequency – directly correlated to rod tension.
- Feasibility proven through prototype testing, plus two dams (RF Henry and West Point).
Dam Anchor Rod Testing

Overview

LO Testing – Equipment
Dam Anchor Rod Testing

Liftoff Testing

- Load (kips)
- Displacement (1/1000 inch)

100 kips
Prototype Testing at FDH Lab

205 data points.
67% DWT within 8 kips of Liftoff

8 kip error bar
(±8% at 100 kips)
R. F. Henry Dam – Results

- 66 data points
- All DWT within 8 kips of Liftoff

Graph showing:
- DWT Tension (kips) on the y-axis
- Liftoff Test Tension (kips) on the x-axis

- 8 kip error bar
  - ±8% at 100 kips

Image of a construction site with scaffolding.
Greenup Dam – DWT & Lift-off Results

Empirical Model Performance

- Mode with Lift-off and JW Data
- 1%
- 25%
- 98%

Regression Statistics
- Multiple R: 0.901
- R-squared: 0.804
- Adj. R-squared: 0.770
- Standard Error: 1.03 kips

Equation: $P = 3235.3^2 + 1626.6^2 - 3243.6^2 + 1748.2^2 - 1622.7^2 - 1287.8^2$
Greenup Dam – Test Program

- Two piers (Piers 2 & 3), 206 rods total
- Dispersive Wave (DW) data collected on all rods – 12 sets of data/rod
- 3 impact devices – varying excitation frequency
- 4 tests per device
- Acceleration recorded at rod end
- Cantilever length measured
- Twenty (20) liftoff tests
  - Pier 2: Ten (10) selected by USACE
  - Pier 3: Ten (10) randomly selected by FDH
- Maximum load = 110 kips

206 rods tested
Greenup Dam – Lift-off Testing

- Equipment enabled precise control of test, while maximizing safety
- Hand-operated hydraulic pump
- Electronic load cell and displacement transducer
- All personnel off of lower platform during test
- Maximum load allowed = 110 kips
- Twenty tests
  - 16 achieved liftoff
  - 4 reached max load before liftoff
- Rods re-tensioned to increase load by up to 5%, with max load = 100 kips

- Chair, Jack, load cell and locking ring attached to rod
VALIDATION PROGRAM

1. At direction of USACE HQ – FDH partnered with USACE ERDC (Vicksburg)
2. Select 4-8 dams for validation of FDH DWT method:
   A. Perform DW Test on all rods in each dam
   B. Perform confirming liftoff test in 10% of rods
3. Perform additional “blind” testing at ERDC facility in Vicksburg
4. Future dams can then be tested without confirming liftoff test
5. First two dams (JT Myers and Markland) to be tested in summer 2014
6. Additional dams needed to complete validation study.
Cost Savings Using DWT Method

For dam with 1,400 rods:
- Lift-off testing = $2,8 million
- DWT + 10% lift-off = $350,000  \( \Rightarrow 87.5\% \text{ savings} \)
- DWT Only (no lift-off) = $280,000  \( \Rightarrow 90\% \text{ savings} \)

New Hogan = 90 rods at $655/rod tested in 2013
Greenup = 208 rods at $326/rod tested in 2012
JT Myers = 1,000+ rods at $250/rod – TBD 2014
FDH goes the extra mile for its clients!