



ENGINEERING INNOVATION

FEBRUARY 29, 2012 / Presented by: Darrin Holt/Mark Cesare

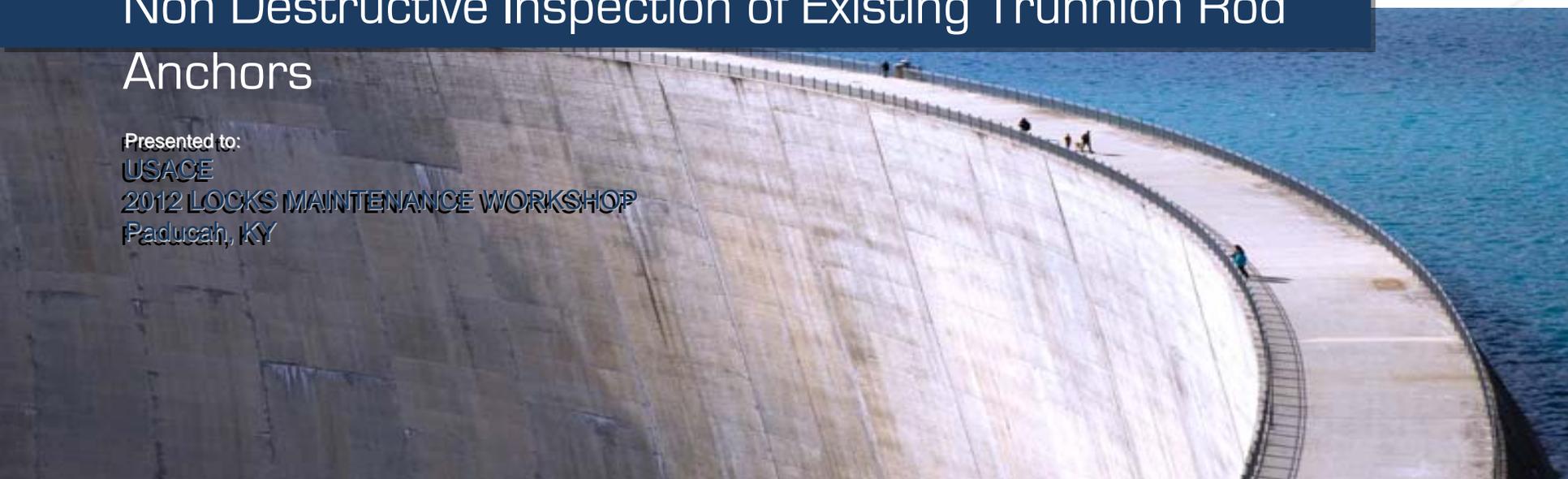
Non Destructive Inspection of Existing Trunnion Rod Anchors

Presented to:

USACE

2012 LOCKS MAINTENANCE WORKSHOP

Paducah, KY



Outline

- Trunnion Rods
- Dam Inventory
- Prototype Testing
- West Point Dam
- R. F. Henry Dam
- Greenup Dam



Trunnion Rods – The Design

- Mandated Design by USACE HQ. (1960s)
- COE Standard (EM 1110-2-2702)
- Adopted by other Government Agencies and Industry
- Limited Suppliers
- Difficult for Inspection / Repair

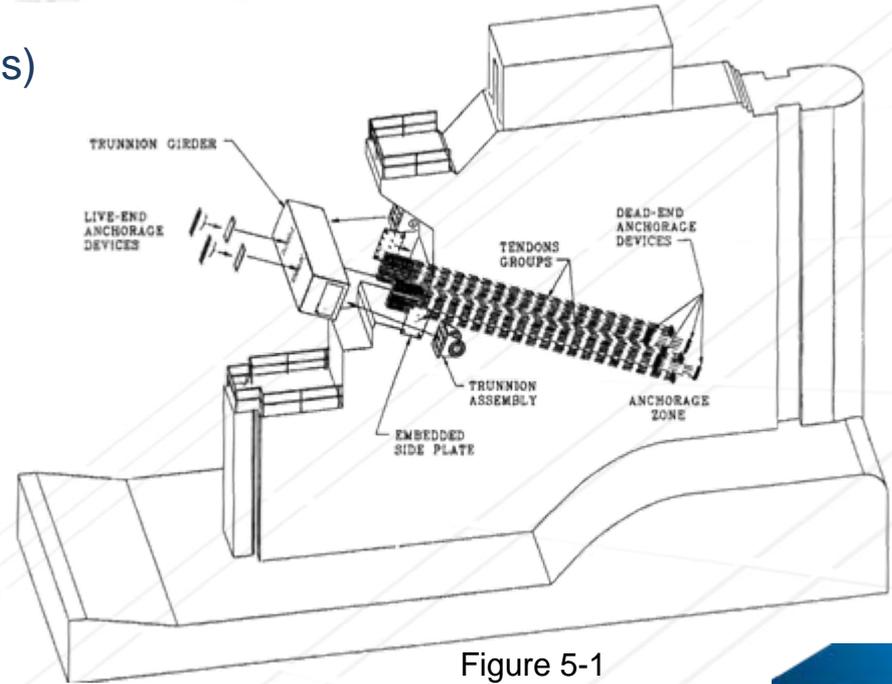


Figure 5-1
EM1110-2-2702

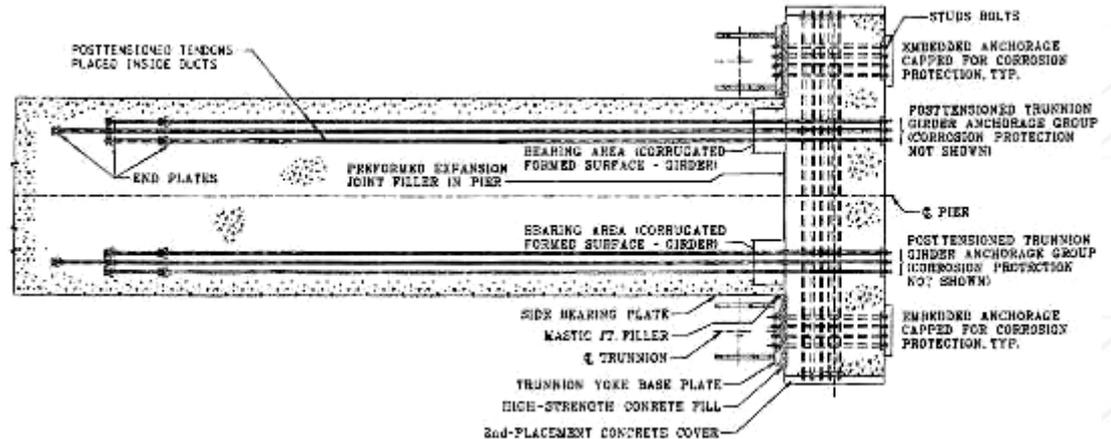
Trunnion Rods – Historical Construction

- Rods stockpiled on site
- Rod groups assembled on site
- Lifted to dam
- Concrete poured around them
- Post tensioned



Trunnion Rods

- Live End
 - Sometimes Exposed
 - Cut to different lengths
 - Protected with Cover Box
- Dead End
 - Most buried in dam
 - Staggered Lengths



How many rods are out there??

<i>District</i>	<i>Location</i>	<i>Number of Rods</i>
Huntington	Greenup	988
	Meldhal	1196
	Belleville	884
	Racine	520
	Willow Island	432
	Winfield	90
Louisville	Markland	1400
	McAlpine	204
	Cannelton	1300
	Newburgh	912
	J T Myers	1008
	Smithland	1380
Mobile	West Point	376
	R. F. Henry	476
Total		11166

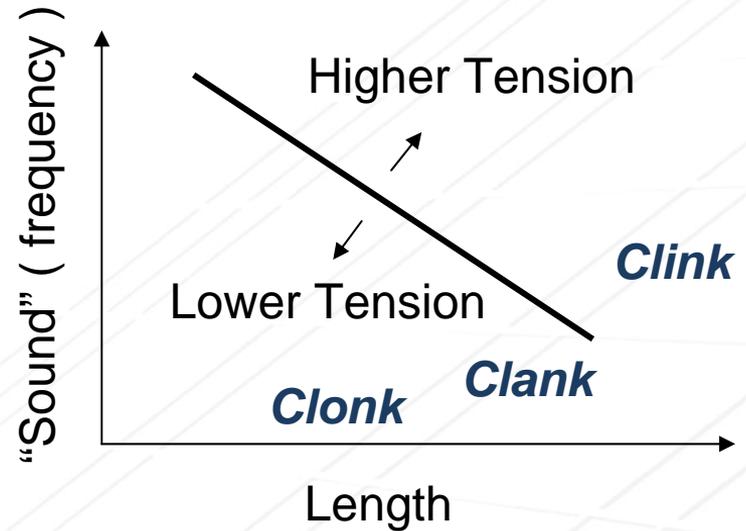
How many known failures??

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



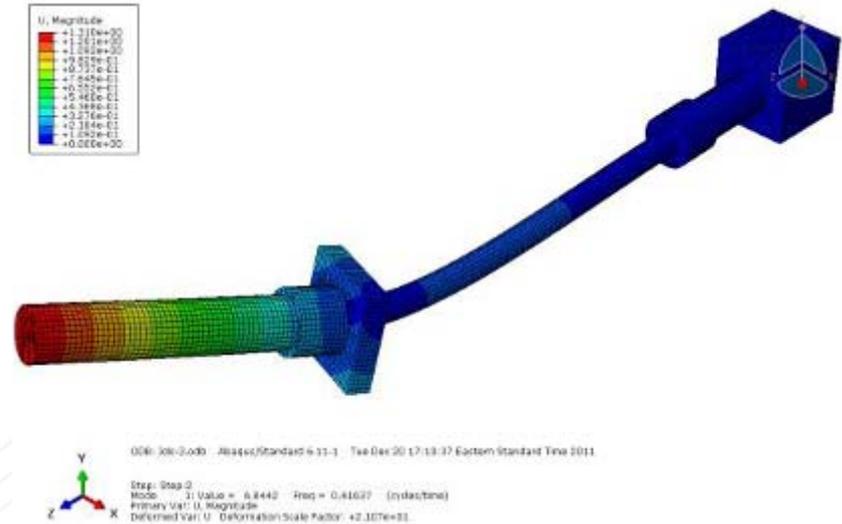
High Tech “Tap” Tests

- **Clonk** – a low, dull sound of impact, as of a heavy object striking against another.
- **Clank** – a sharp, hard sound like that produced by two pieces of metal striking, one against the other.
- **Clink** – a light, sharp, ringing sound.

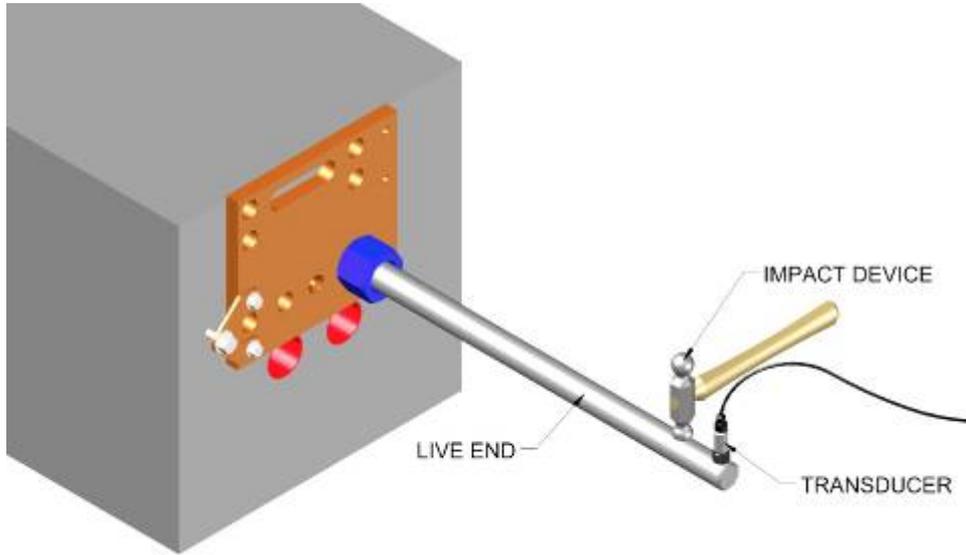


Addressing the Problem

- Full 3D Finite Element Model of Rod, Grip Nut, End Plates and surrounding concrete (not shown)
- May reduce need for many Lift-off tests
- **Prototype (Model) testing**



A Nondestructive Testing Scheme



Dispersive Wave Propagation Technology



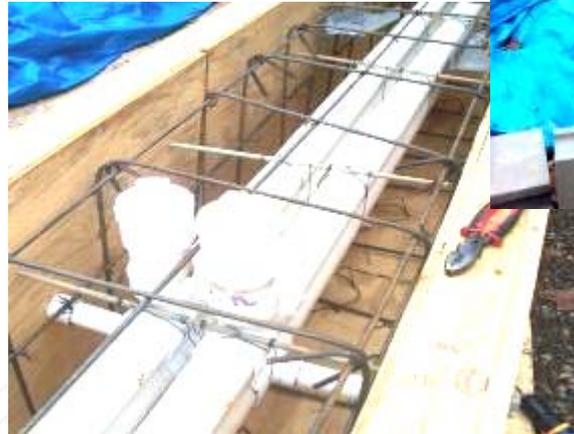
The Beginning - Full-Scale Model / Tests

- FDH constructed a full scale prototype of a Trunnion Rod assembly
 - Reinforced concrete
 - PVC pipe for rods
 - Access to tensioned part of rods for detailed instrumentation



Prototype Testing

- Allowed validation and calibration of NDT Method
- Data collected at different live-end lengths and different tensions
- Capacity for 4 rods at $>100K$ each

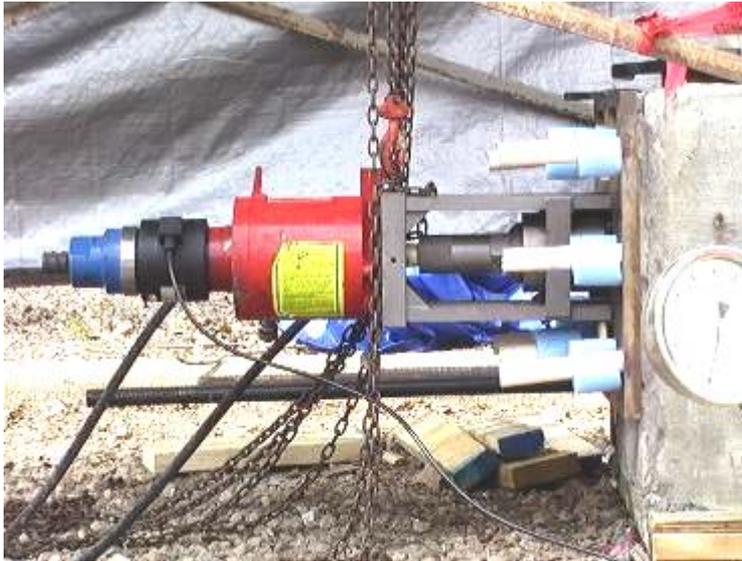


Prototype Tests – Simulating Actual Dams

- Allows similar and salvaged rods to be tested
- Mock rods and grip nuts simulated working conditions at West Point and R. F. Henry Dams
- Could be Used for Simulating other Dams



Prototype Tests – Lift-off Tests



Accessibility Issues – Those Cover Boxes!

- Testing Rods with Cover Boxes in place
- Built Cover Box Model
 - Design special impact tools
 - Remote camera techniques for measuring rods
 - Practice data collection



Testing with Boxes in-Place

- Specialized equipment developed
- Difficult at times, but do-able
- Saves \$\$ by eliminating cover box removal



West Point Dam, GA – Actual Testing

- 30 rods per group
- 2 groups per Tainter Gate
- 6 Gates / 2 end groups
- 376 rods total
- 1 ¼" Diameter
- 145,000 lb tensile capacity
- Anchor plate at far end
- Rods are in tubes and not grouted



West Point Dam – Rod Failures

- In 2008
 - 5 Failures total
 - 3 on one pier
- Failed rods removed
 - Measured to find failure location
 - Sent for metallurgical testing



West Point Dam – First Round of Tests

- Boxes removed in one location initially
 - Selected rods tested w/ lift-off as well
 - Lift tested rods NDT tested before and after Lift-Off tests
 - Lift-off done by DSI
 - Dispersive Wave Test Data calibrated with lift-off results

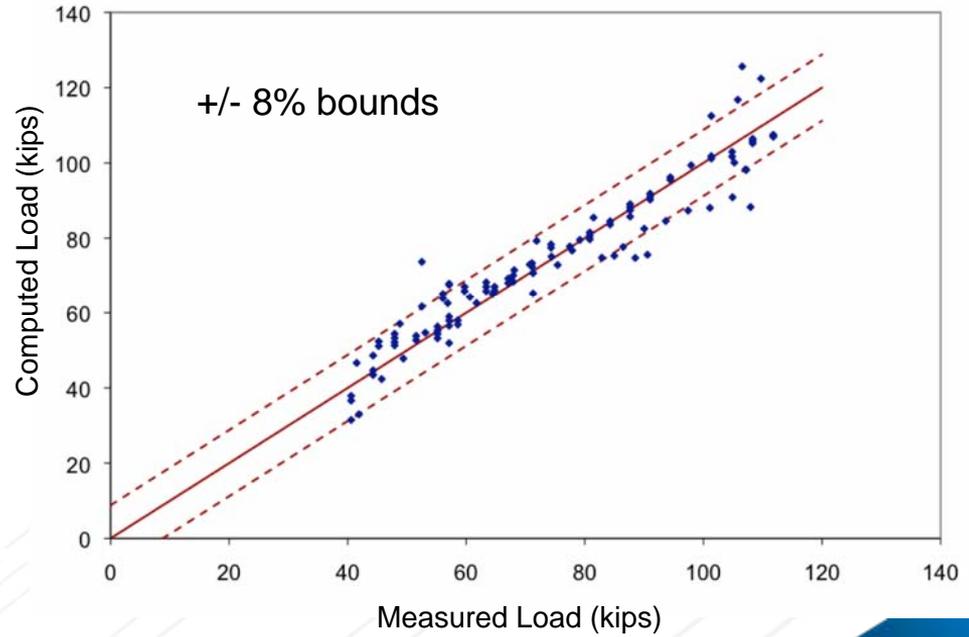
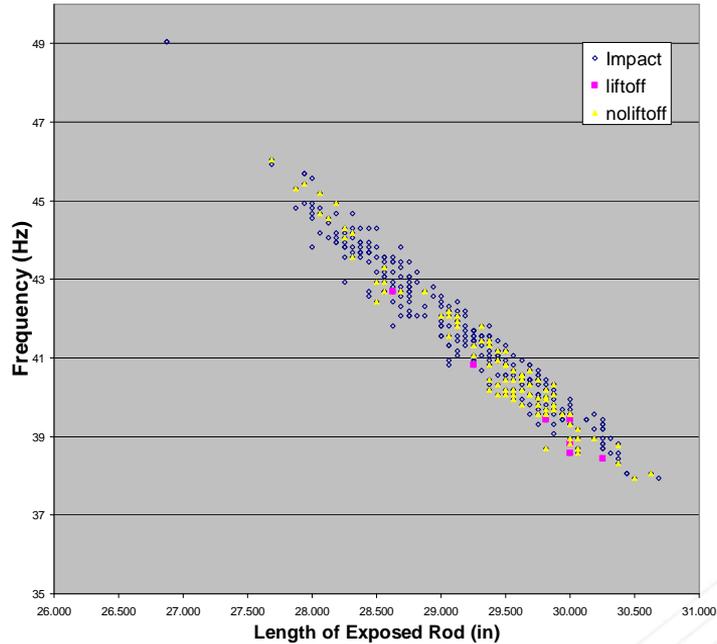


West Point Dam – Second Round of Tests

- Data collected on all remaining rods
- Transducers lowered into box and attached to rods
- Rods hit with hammer (rod with foot welded on)
- 5 days to test 371 rods



West Point Dam – Dispersive Wave Results



West Point Dam – The End

- Scaffolding removed
- Cover Boxes returned



R. F. Henry Dam

- 21 rods per group
- 2 groups per Tainter Gate
- 11 Gates
- 2 end groups of 7 rods
- 476 rods total
- 1 ¼" Diameter
- 145,000 lb tensile capacity
- Anchor plate at far end
- Rods are in tubes and not grouted
- Rods from same manufacturer and lot as West Point



R. F. Henry Dam – Rod Failures

- 4 broken rods found
- Rod removed & sent for testing. Cracks found in material.
- 3 of the failures at threads near Dead End
- 1 rod broke between inspections (a 3 month interval)



R. F. Henry Dam – Slipped Grip Nut

- 2 Rods found to have slipped Grip Nuts
- Provided good data point for un-tensioned rods
- Rods re-tensioned as part of testing operation



R. F. Henry Dam – NDT Testing

- Scaffolding built on all Piers
- Cover boxes removed
- NDT testing done thru the access holes in boxes
- Pre and post NDT test data collected on lifted rods
- 5 days to test 476 rods

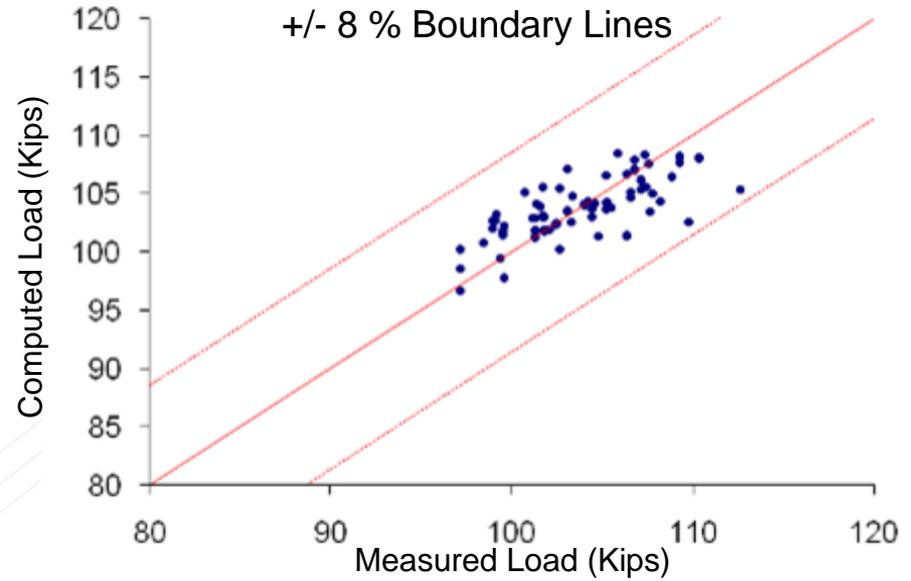
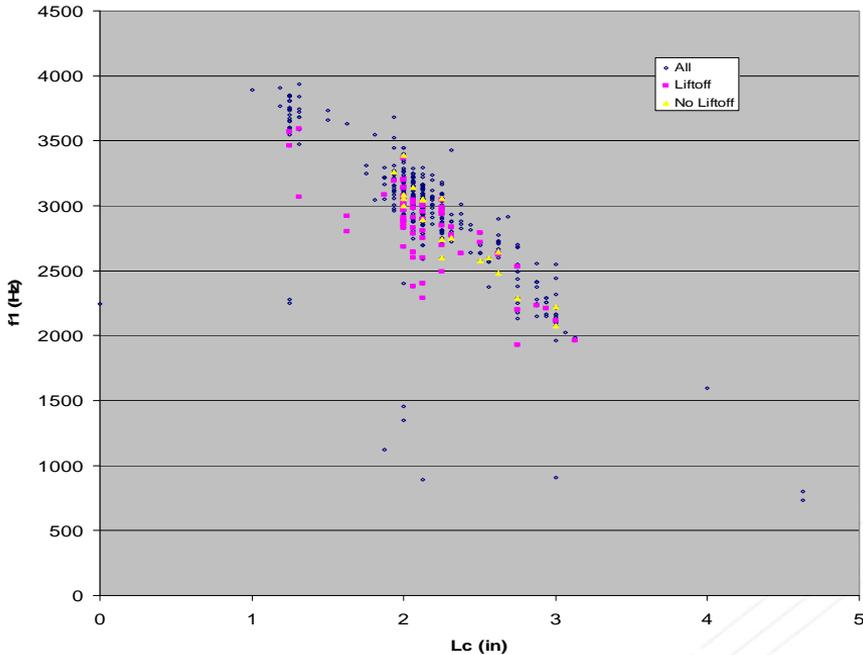


R. F. Henry Dam – Lift-off Testing

- 108 Rods Lifts Attempted
 - 73 lifted
 - 33 did not lift at maximum load
 - 2 were not loaded
- 5 Tested below 100K
 - 3 shimmed to about 106K
 - 2 reseated grip nut at 106K



R. F. Henry Dam – Dispersive Wave Results



R. F. Henry Dam – The End

- Cover Boxes replaced
- Scaffolding removed



Greenup Dam

- 52 rods per group
- 2 groups per Tainter Gate
- 1 1/8" Diameter
- 145,000 lb tensile capacity
- Anchor plate at far end
- Rods are in tubes and not grouted



Greenup Dam – Design Details

- Trunnion Girder is steel
- Much heavier face plate
- Gripping inserts fit within tapered holes in plate



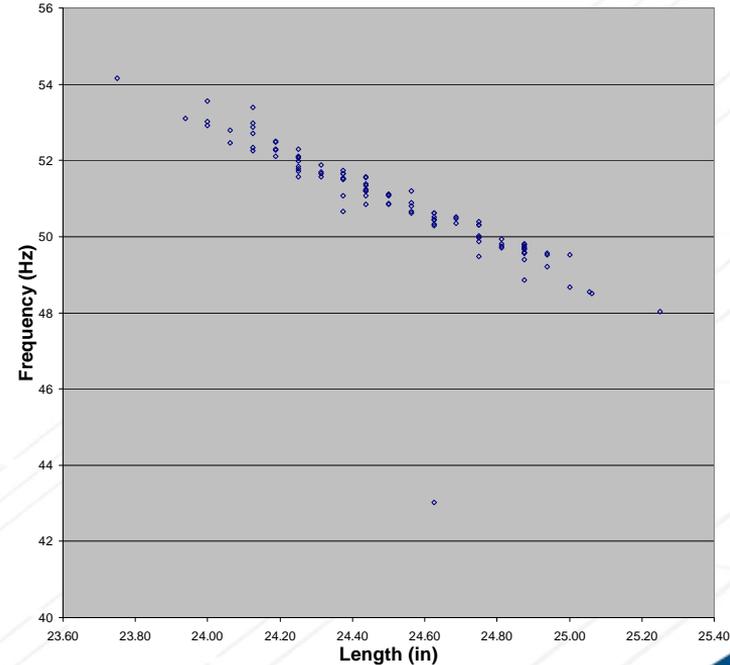
Greenup Dam – NDT testing

- Only one pier tested to date
- Working with boxes removed (Easier to acquire rod dimensions)



Greenup Dam – Vibration test results

- Broken rod clearly found
- Less scatter than other tests
- Lift-off tests planned but not done yet
- Estimate of tension made by assuming that points near top of this cloud of data are near original lock-off loads





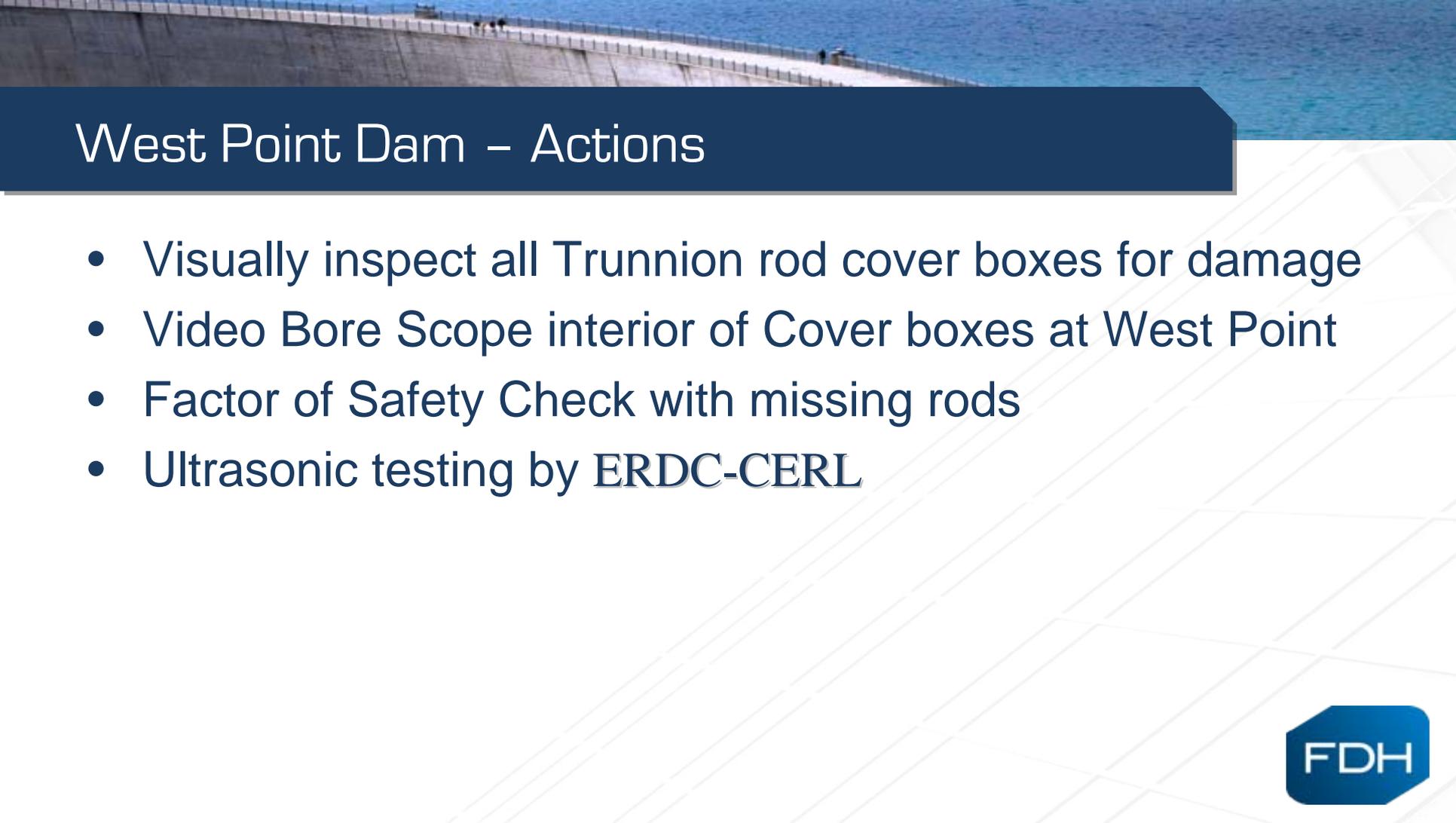
Summary – NDT Testing Technology

- Safe method of testing; for rods & personnel
- Ability to model/simulate near-actual conditions
- Has demonstrated to be a possible alternative to Lift-Off testing of all rods in a dam.
- Economical. ~ 10 days to test 852 rods

Thank You







West Point Dam – Actions

- Visually inspect all Trunnion rod cover boxes for damage
- Video Bore Scope interior of Cover boxes at West Point
- Factor of Safety Check with missing rods
- Ultrasonic testing by ERDC-CERL

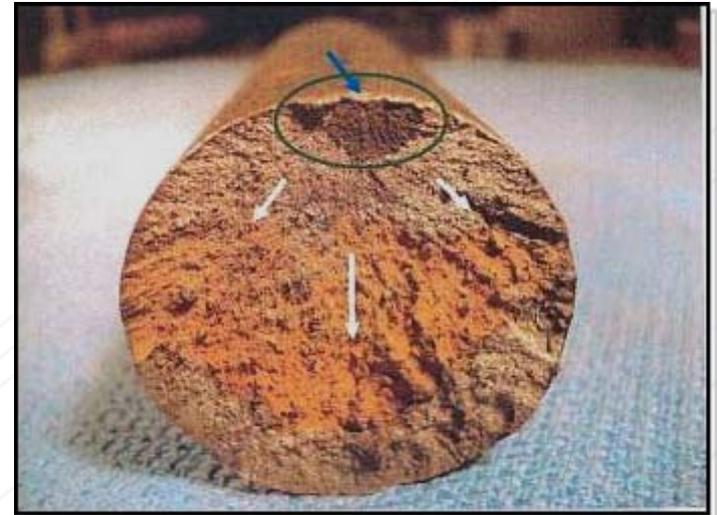
Mockup Tests -

- Dimensions 2 ft x 2 ft x 40 ft
- Capacity for 4 rods at 100K each



West Point Dam – Rod Failures

- Failures closer to far end but NOT at threads
- Failure Surfaces
 - All showed initial flaw
 - Brittle failure
- Composition within spec



West Point Dam – Cover Boxes

- Cover Boxes were
 - Repaired
 - Cutout for access hatch
 - Painted
 - Numbered
 - Replaced on the dam



West Point Dam – Measuring Rods

- Accurate measurement of Rods needed
- USB camera and ruler mounted on poles
- Camera read from laptop computer
- Snap shot taken of measurement



West Point Dam – Proof-of-Concept Tests

- Block E at West Point Dam
 - Easy access
 - 37 Rods tested
- Accelerometers attached to rods
- Rods hit with hammer
- Vibration recorded by Data Acquisition System and laptop
- Time histories sent to office to data processing



Versatility of the Prototype

- Custom face plates manufactured for West Point and R. F. Henry configuration
- Salvaged West Point rod material threaded and coupled to modern rod
 - Liftoff test have load/displacement of full length rods
 - Testing gripping device on real rod
 - Test ability to reseal grip nut
- Could be Used for Simulating other Dams



R. F. Henry Dam – Rods with Cover boxes in place

- Much shorter tails left on rods
- As a result the cover boxes very narrow
- NDT testing done thru the access holes in boxes

