Instrumentation During Grouting and Cutoff Wall Construction

Scottie L. Barrentine, PE

AEG – Specialty Geotechnical Workshop for Dam & Levee Investigations & Modifications

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Welcome to Boone Dam
LOCATION OF BOONE DAM

• Owned and operated by the Tennessee Valley Authority.
• Located on the South Holston River in Northeast Tennessee.
• Used for hydroelectric generation, flood control and recreation.
• Constructed between 1950 and 1952.
• Concrete gravity dam across the South Holston River channel with an earth embankment dam.
• Approximately 900’ embankment dam.
SURFACE FEATURES AT BOONE DAM

RIGHT DESCENDING BANK

FORMER PUBLIC BEACH

SHEAR ZONE

EMBANKMENT DAM

CONTROL BUILDING

SWITCHYARD

DOWNSTREAM FILL

CONCRETE DAM

PREVAILING GEOLOGIC STRIKE

TAILRACE

SPURGEON KNOB

7 AUGUST 2015 / c. 10:00

NORTH

LEFT DESCENDING BANK

“RIGHT RIM” (TOPOGRAPHICALLY HIGHER)
Cutoff trench excavated into the epikarst was backfilled with compacted clay.
CONSTRUCTION OF CUTOFF TRENCH, ~1951

NATURAL G.S.
FOUNDATION SOIL
“EPIKARST”
NATURAL G.S.
OBSERVATIONS IN OCTOBER 2014

SINKHOLE IN PARKING LOT OF CONTROL BUILDING

MUDDY DISCHARGE INTO TAILRACE

20 OCT 2014 / 08:13

30 OCT 2014 / 18:42
GEOLOGY AT BOONE DAM (STRATIGRAPHY)

- Conococheague Formation
- Cambrian-Ordovician Carbonate Sequence, ~500 Mya
- Nolichucky Formation
- Embankment
- Downstream Fill
- Concrete Dam
- Turbid Discharge
- Sinkhole
- Jointing at Anticline
- Shear Zone

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Advanced Instrumentation Systems for Investigation and Construction
INSTRUMENTATION FOR EXPLORATION

• Within a karst system significant number of instruments may be required to understand the flow patterns

• Design instrumentation to understand vertical and horizontal flow directions

• Design instrumentation for dye tracing

• Guide where to place the next instruments based on analysis of previous instruments

• High frequency reading intervals required to understand relationship to environmental factors
• Soil and Bedrock Coring
  • (~ 26 borings)
• Televiewer / Borehole Camera surveys
• Instrumentation
  • Mix of Nested PZs and Open Standpipes
• Dye Testing
• Soil and Bedrock Coring
  • (~ 48 borings)
• Televiwer / Borehole Camera surveys
• Instrumentation
  • Mix of Nested PZs and Open Standpipes
MAPPING KARST - 2017

- Soil and Bedrock Coring
  - (>96 borings)
- Televviewer / Borehole Camera surveys
- Instrumentation
  - (>200 piezometers)

Good luck modeling karst, the best you can do is hope to map it !!
Key Observations:
1. Predominant flows in epikarst with contribution from the higher elevations of the right rim;
2. Concentrated flow occurs through the alluvial trough and within solution features along bedding;
3. The original cutoff was not effective at cutting off flows from the reservoir;
4. The “shear zone” is performing as an aquitard;

Hydrogeologic Model Prior to DGP: 1952 - 2015
Instrumentation Planning for Construction
Considerations for System Development

• What is the risk to the dam?

• Who is going to own and operate the system?

• What is the risk to construction process?
Instrumentation and Monitoring Plan is a MUST!!!

Contents should include:

- Organization of the monitoring Team
- PFM’s being monitored
- System Design and Operations
  - Operation
  - Redundancies
  - Actions for Damage
  - Replacement
  - Outages
Instrumentation and Monitoring Plan is a MUST!!!

Contents should include:

- Network Design Diagrams
- Instrumentation Installation Records and Data
- Instrumentation Tables with Constants
Instrumentation and Monitoring Plan is a MUST!!

Contents should include:

- Monitoring, Alerts, and Responses
  - Alert Levels
  - Actions
  - Construction restart
- Reporting
  - Routine Reporting
  - Incident Reporting
INSTRUMENTATION PLANNING FOR CONSTRUCTION

What Needs to Be Monitored?

- Deformation
  - Automated Total Station
  - Inclinometers
  - Shape Array Accelerometers
- Groundwater
  - Open standpipe
- Porewater Pressures
  - Grouted-in-Piezometers
- Toe Drain Flows
  - Automated Flumes
INSTRUMENTATION PLANNING FOR CONSTRUCTION

Deformation Monitoring – Three ATS Systems
Deformation Monitoring – Inclinometers
Groundwater and Porewater

- Split the Piezometer network into Construction Monitoring and Hydrogeological Monitoring
How do you gather, control, and make useful information out of so much data?

• Hardware Design
• Network Design
• Reporting Design
In All Things Remember the 3 R’s (Robust, Redundant, Reliable)

- Robust and Reliable
  - How long will your equipment be exposed?
  - Think about the improbable.
Hardware Considerations

- Redundant Power Supplies (Solar and AC)
- Quality boxes and ventilation
- Conduit Drainage and vents
- Quality gear
- Spare Parts onsite
In All Things Remember the 3 R’s (Robust, Redundant, Reliable)

- Can you access engineering units onsite in the event of a blackout?
- Are you vulnerable to Cyber events?
- How does the data get to the web?
Network Design Considerations

• Redundant Network Communications (Fiber, Cellular, & Laptops)
• Programming Dataloggers to Calculate Engineering Units
• Send Both Raw and Calculated Data to Servers
• Consider Separate Servers for Backup
• Cyber-Security
In All Things Remember the 3 R’s (Robust, Redundant, Reliable)

- Active and Passive Reporting
- How fast does your reporting tools work?
- Are they redundant?
- How are alerts sent?
- Is it compatible with Information Management Systems?
Reporting Design

• Boone utilized two separate software programs for construction monitoring
  - One for onsite fast paced monitoring with highly configurable dashboards. This system received engineering units from the dataloggers.
  - The other system received raw data and calculated as a separate check. This system sent daily emails for weekly, monthly, and long term plots.
REPORTING DESIGN CONSIDERATIONS

Reporting Design

• Onsite personnel was responsible for monitoring the system for alerts with the first system
• The second system would send email alerts and test alerts for threshold and action exceedances.
• These systems would communicate with an IMS/GIS system to bring in a complete picture.
In All Things Remember the 3 R’s
(Robust, Redundant, Reliable)

Why?
Why Have the Advanced System?

• FIRST - Dam Safety

• Engineering during Construction
  - Instrumentation verifies design assumptions
  - Instrumentation informs staged construction
  - Grouting control
  - Dam responses

• AND………
Dam Response to Construction Activities
Utilizing Instrumentation to Control Grouting Construction
Exploratory Drilling and Grouting

- 539 LMG holes Drilled & Grouted
- 276 HMG Holes Drilled & Grouted

Total Drilling Footage

21.0 Miles

Total Grout Placed

233 Avg. concrete truck loads
Controlling Grouting With Instrumentation

Grouting was stopped due to a piezometer response in the embankment.

Note: Pressure drop prior to flow spike

Fracturing Signature in CTR1214

Open and Clay filled voids adjacent to known foundation soils (alluvial trough)

Bottom of MPSP
Piezometric Responses to Drilling and Grouting

Start/End DS BRG CTR1214
Gauge Pressure: 60 psi
Effect. Pressure: 92 psi
Stage Volume: 451 gallons

Start/End DS BRG CTR1214
Gauge Pressure: 40 psi
Effect. Pressure: 80 psi
Stage Volume: 265 gallons*
*Stopped due to PZ Reaction

Note reverse in trend (i.e. larger response in embankment vs. rock)

Embankment PZ Response

Slightly higher pore pressure response in embankment after downstage grout
Controlling Grouting by Instrumentation

Deformations measured by the ATS system
Evaluation of Deformation

Primary holes are grouted on C-Line.
Secondary and Tertiary Holes begin.
Quaternary Holes begin.
Total Grout Injected.
Work Stopped.
Movement linked to known grouting events.
Threshold.

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Grout Observations from Sonic Drilling

HMG Observation
Response to Berm Construction
Berm Construction
PATTERNS OF U/S SURVEY PRISM DISPLACEMENTS

VERTICAL DISPLACEMENT

TRANSVERSE DISPLACEMENT
PATTERNS OF INCLINOMETER DISPLACEMENTS

- 1.0 INCH
- 0.3 INCH
- 0.3 INCH

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Overall Performance Monitoring
DAM SAFETY PERFORMANCE - DEFORMATIONS

Observations:
- Largest movement observed during berm construction
- Patterns of deformation appear similar in upstream and downstream directions

Movements during Grouting Programs
Consolidation settlement from berm construction
Prism struck by falling rock
Observations:
• Largest movement observed during berms construction
Observations:

- Grouting program was effective at reducing pore pressures downstream of treatment
- Further “sealing” of the epikarst is being observed during COW Element Construction

Downward trend starting Late 2019
Conclusions
Instrumentation for Dam Remediation Projects

- Automated systems are very valuable in remediation projects
  - Dam Safety
  - Allows for time stamped data to traceable events
  - Reduces potential for delays
  - Provides understanding of dam behavior
  - Verifies design assumptions and informs stage construction
  - Reduces construction risk
Instrumentation for Dam Remediation Projects

• Systems may need to be larger or smaller based on geology, construction techniques, design verification, and PFM’s
• Utilize design of instrumentation system to verify your data (differing types of data)
• Design the instrumentation system with the 3 R’s in mind
• Make the instrumentation accessible and compatible with Information management systems
• Understand the soil mechanics of the instrumentation
CLOSURE


SAFETY OF WORKERS ON SITE AND THE DOWNSTREAM PUBLIC ARE OF PARAMOUNT IMPORTANCE DURING COMPLETION OF THE PROJECT. TO MINIMIZE RISK TO DOWNSTREAM PUBLIC, TVA HAS LOWERED THE RESERVOIR DURING THE CONSTRUCTION PERIOD.

THE PROJECT IS ON TARGET TO BE COMPLETED ALONG THE 5- TO 7-YEAR TIMELINE COMMUNICATED BY CEO BILL JOHNSON DURING A PUBLIC MEETING WITH STAKEHOLDERS HELD IN THE SUMMER OF 2015. THE RESERVOIR IS CURRENTLY ON SCHEDULE TO RETURN TO NORMAL OPERATIONS BY AUGUST 2022.

THIS PRESENTATION ONLY TAKES VIEWERS THROUGH THE PRESENT DAY, SUCH THAT THE “CONCLUSION” OF THE PROJECT (i.e., THE IMPLEMENTATION OF THE REMEDIATION) HAS YET TO BE FULLY REALIZED. STAY TUNED FOR FUTURE UPDATES!

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Boone website:  
https://www.tva.com/Newsroom/Boone-Dam-Project

Boone Community Relations Office:  
320 Boone Dam Road / Kingsport, TN 37663

Boone public e-mail program:  
boonelake@tva.gov