WOLF CREEK DAM - Overview and Update of Rehabilitation Efforts

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USACE Nashville District
Wolf Creek Dam History
- Dam Construction 1941-1951
- Seepage Problems 1967-68
- Remediation and Instrumentation 1968-1979
- Seepage Problems Resurface in 2000
- Additional Drilling and Study Using Rotosonic Drilling Methods 2002-2003
- 2005 Major Rehabilitation Report

The Seepage Analysis and 3-D Modeling
- Construction Foundation Treatment
- Seven Tasks Published in a Comprehensive Report (2004)
- MVS/EVS Software Used to Construct Twelve Data Layers
- Individual Layers Were Used to Compare And Contrast Data

Recent Activities
- Risk Reduction
- New Barrier Construction
Wolf Creek Dam Location

Wolf Creek Dam
Jamestown, Kentucky
• Designed in mid to late 1930’s
• Construction began with grading activities in 1941
• Construction was interrupted from 1943 to 1946 due to WWII with the total completion of the dam in late 1951
• The reservoir was impounded in late December 1950
• By early April 1951, water was flowing over the uncompleted spillway, impounding over 4 million acre-feet of water in just over 90 days
Wolf Creek Dam
Project Features

• Largest Reservoir in the Eastern U.S.

• 6 million Ac-Ft. of Pool Storage

• Concrete 1,796’ long and 258’ above the founding level

• Earth Emb. 3,940’ long and 215’ high

• Hydro Power

• US F&W Fish Hatchery

• Straightest Section of Highway 127 for 2 counties
Post Dam
Construction History

• Late 1967- early ‘68 Muddy flows appeared in tailrace; two sinkholes developed in d/s toe at the switchyard and wraparound area;

• ‘68-’72 An emergency exploration, instrumentation and grouting program instituted

• ‘70-’75 Pre-wall installation exploration and grouting program was completed along the proposed alignment of the cutoff wall

• ’75-’79 Diaphragm walls were constructed along the axis of the dam and around the switch yard extending only two-thirds of the length of the embankment
2000 Elevated piezometric readings were recorded with expanded wet areas below the dam. A review of seepage issues below the dam was begun.

2002-2003 Embankment investigation was begun using “Rotosonic” drilling techniques in order to minimize the embankment disturbance.

2005 Major Rehabilitation Report

2006-07 Repair Solution Defined

2008 Rehabilitation Bid and Awarded
• Wet areas that had disappeared have redeveloped

• Significant reductions in PZ water levels were anticipated. However, only slight reductions occurred with 2 PZ’s in the wraparound area actually rising 13 feet since 1984

• Settlement monuments indicated subsidence of the embankment crest in the wraparound area of 0.15 feet from 1981 to ‘97 with an additional 0.15 feet from ‘97 to 2004
Subsidence At Monolith 37 And The Embankment

Asphalt Patch On Roadway And Swag in Guard Rail Due To Settlement
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  • 2005 Major Rehabilitation Report

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  • Seven Tasks Published in a Comprehensive Report (2004)
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• Recent Activities
  • Risk Reduction
  • New Barrier Construction
• A single line grout curtain was installed in the core trench on 10 ft centers with some holes split on 5 ft centers, based on grout takes.

• Most of the in situ alluvial material was left in place beneath the embankment.

• The Core Trench was adjusted upstream to follow an existing solution features along the upstream toe of the embankment.
Embankment Section
STA. 44+50L

Flow

Drainage Blanket

C.L. Roadway & Embankment Sta. 0+16B

End of Drainage Blanket

Foundation of Toe Drain

Axis of Dam

Core trench

Bedrock

Emb

Qal

EL. 660

EL. 690

EL. 730

EL. 763

EL. 773

EL. 640

EL. 665

EL. 690

EL. 730

EL. 763

EL. 773

EL. 665

EL. 640
Embankment Plan

Sinkhole No. 1
13 March 1968
Sta. 32+16L, 4+13B
13' Dia. & 10' Deep

Sinkhole No. 2
22 April 1968
Sta. 32+58L, 4+13B
6' Dia. & 6' Deep

Muddy Water

Cut Off Trench in and along an upstream solution feature

Downward Slope of Cut Off Trench

Toe of Random Fill

Wet Area No. 1
Sinkhole 3' Dia.
15 August 1967
Sta. 56+75L, 4+36B

Wet Area No. 2

Wet Area No. 3

Wet Area No. 6

Wet Area No. 4
Foundation Treatment

Solution Features
Foundation Treatment

Solution Features

Cave
Examples of the numerous solution features in and around Monolith 37
Foundation Treatment

Cave backfill by dozer

Handwork to fill-in overhangs

Cutoff Trench Bedrock Weaknesses and Repairs
• Utilized Rotosonic Drilling techniques to minimize embankment disturbance

• Included Twelve Borings, Six of which encountered soft zones within the embankment at or near top of rock

• The borings were located within the embankment adjacent to the concrete monolith, approximately 4 feet d/s of the existing diaphragm wall; 100 feet into the “wraparound” section d/s of Monolith 37; in the area of the grout curtain; and within the solution features passing beneath the embankment and Monolith 37
Seven Tasks As Part Of The Comprehensive Report

- **Task 1 - Drilling and Piezometer Installations**
  - Install two pairs of PZ’s
- **Task 2 - Temperature Survey**
  - Measure 110 currently active PZ’s
- **Task 3 - Evaluation of Piezometric Data**
  - Compare and contrast 20 years of data for trends
- **Task 4 - Evaluation of Grouting Records**
  - Evaluate existing Diaphragm wall installation for weaknesses
- **Task 5 - Evaluation of Possible Correlations Between The Data**
  - Compare data from tasks 3 & 4 with known geology to identify correlations with PZ levels, wall construction anomalies, grout takes, drill water loss and/or mapped bedrock weaknesses.
- **Task 6 - 3-D Seepage Analysis**
  - 3-D steady state seepage analysis using FEFLOW (Finite Element subsurface FLOW system)
- **Task 7 - Stability Analysis**
  - 2-D model developed using Geo-Slope’s GeoStudio 2004, SLOPE/W
Prior to 1968, NO piezometers were installed to monitor embankment or foundation performance!!
Piezometer Data Review

• Data from a total of 195 piezometers were cleaned and reviewed
  • 104 used in plotting
  • All Piezometers located at soil/bedrock interface

• 20-yr data record for piezometers 35’ D/S of Centerline

• Plotted with actual 20-yr pool elev. Record (1984-2004)

• Rising water levels within the embankment with highest levels were nearest Monolith 37
• 20-yr data record normalized based on constant pool elev. 712±1’ ft, MSL

• Plotted with 1-yr and 3-yr running average pool elev. over 20 years (1984-2004)

• History suggests the higher piezometer readings of last 3-5 years are independent of pool elevations
Aerial Photo With High PZ Pressure Zones

Areas of High PZ Pressures
Emergency Grouting '68-'75

Primary Focus of Grouting Program
300,000 cu ft Of Grout Placed
Diaphragm Walls – Project Features

- Diaphragm Wall
- Concrete Dam
- Earth Emb
- Switchyard
Profile along Diaphragm Wall

Monolith 37

- End wall Sta. 57+50
- Top of Dam EL.773
- Top of Rock
- Top of Alluvium
- Soft Zone

Elevation

55+00  50+00  45+00  40+00  35+00
Evaluation of Grouting Results

Statistics:

- 1941-43 – 600 holes for core trench
- 1968-69 – 594 emergency holes in “wraparound” area and switchyard
- 1973-75 – 875 holes for Diaphragm Wall
- Volume of grout 3x theoretical volume of drilled holes
- Excess of 2,074 CY of grout in ±153 holes
Evaluation of Secondary Diaphragm Wall Elements:

- 498 total elements installed
- 43 cored; 22 extended into bedrock
- 36 (84%) showed honeycomb and/or aggregate segregation
- 13 (30%) showed poor contact with bedrock
- Extending statistics to all secondary elements:
  - 417 have honeycomb or aggregate segregation
  - 151 do not have intimate contact with bedrock
- Seepage through Diaphragm Wall??
3D Seepage Analysis

- FEFLOW 3D Finite Element subsurface FLOW system
- 150,000 nodes
- Results included ±90,000 saturated nodes
Wet Areas
• **Data was derived from following sources:**
  - Grout Curtains – Emergency and Diaphragm Walls from Sta. 35+11 to 56+50
  - USACE provided data from piezometers, control points and borings
  - Phase III Grouting Logs – Sta. 56+53 to 74+00
  - Core Trench Grouting
  - Core Trench profiles
  - Geologic maps where other nearby site specific data was unavailable

• **Known Bedrock Weaknesses:**
  - Based on design and construction records
  - Emergency and permanent repairs completed in 1970’s
  - Major Weaknesses Include:
    - Concrete and Earthen dam contact near Sta. 35+00
    - Deeply weathered joint U/S of dam (became the cutoff trench)
    - Over 20 locations/voids below bedrock surface that received > 1,000 CF of grout to repair
MVS/EVS – Software Used to Construct Information “Layers”

- **MVS/EVS** (*Mining Visualization System/Environmental Visualization System)*

- From CTech Development Corporation (Kaneohe, Hawaii)

- Existing data in addition to new data constructed into twelve layers:
• 3-D Model of the Wolf Creek Seepage Study was developed from a variety of data sources:
  • The surface topography was constructed from digital files containing mass point elevations and break lines.
  • Rhinoceros software was used to convert 2-D and 3-D drawings into a 3-D SOLID models.
  • Text files with horizontal position and depth data for rock contacts and cavity locations were converted into EVS importable file formats.
Base Map With Diaphragm Wall
Diaphragm Wall And Grout Curtain
Diaphragm Wall, Grout Curtain, And Wet Areas
Diaphragm Wall And Top of Rock
Base Map With Colorized Elevations
Diaphragm Wall, Grout Curtain, Wet Areas, And Piezometers
EVS Core Trench With Diaphragm Wall and Down Stream Slope
EVS With The Ground
Water Temperature
Survey
EVS With Karst, Grout Curtain, Diaphragm Wall, And Piezometers
EVS With Top of Rock, Grout Curtain, and Diaphragm Walls
EVS Top of Rock With Diaphragm Wall and Concrete Monolith
EVS Bottom of Dam With Top of Rock, Diaphragm Wall, And Grout Curtain
EVS – Putting it all Together Visually

- Visualize some or all of the data spatially
- Manage and manipulate large quantities of data
- Confirm what was suspected but was “buried in the details”
  - Karst joints and weathered zones in the “wraparound” section and switchyard appear to be contributing to continued seepage and at times have been potentially near catastrophic (1968)
  - Elevated piezometric readings near the concrete soil discontinuity match well with cut-off trench orientation and potential leakage through/under/around Diaphragm Wall
- The graphical and visual data presentation is very convincing with the ability to manipulate individual layers in order to compare and contrast the data
The Corps of Engineers, Nashville District completed a Major Rehabilitation Report to evaluate alternatives to improve the long-term reliability of the Wolf Creek Dam. That report outlined the need for a new cutoff wall. Those conclusions were supported by Headquarters, and funding was approved. The initial phase of construction was advertised in March 2006.
In September of 2006, two initial projects were awarded to facilitate the construction of the new wall. One was for $7.9M (awarded to VCI-Doyon JV, Knoxville, TN) to relocate Holcomb's Landing to allow space for a contractor staging area for future construction efforts.

The other $52 million contract was to Advanced Construction Techniques LTD, Toronto, Canada (ACT) to perform grouting required to facilitate the barrier wall construction.
The Corps conducted a formal risk-based assessment during the winter of 2006, which considered the impacts of additional risk reduction measures, including further lowering of lake levels, to reduce risk to people and property.

An emergency decision was made January 2007 to maintain the reservoir pool at 680-foot elevation until closure of the initial grout line (as of January 2009, the target elevation for the pool was still elevation 680).
Grouting Operations
Gallery Grouting
In July 2008, a $341M contract for a 4200LF barrier wall was awarded to Treviicos-Soletanche JV.

The contractor for the barrier wall mobilized in October 2008, with a contract performance period of four years. The concrete barrier wall is the primary element of the Wolf Creek Dam Seepage Rehabilitation Project. The wall will be a combination of secant piles and rectangular panels installed through the earthen embankment to a depth of about 275 feet. The wall will extend eastward along the upstream embankment from the concrete section to the right abutment, a length of about 4,200 feet.
QUESTIONS?
CREDITS:

AMEC Wolf Creek Dam Project Team, composed of:

Jim Richardson, Dan Hurst, Bill Spencer, Doug Tate, Dave Sawitzki, Shea Carr, Joe Robins, David Greene, and Sean Birch.
Animation Of Structural Units With Ground Surface

Animations\wolfcreek_ground.avi
Animation Of Structural Units

Animations\wolfcreek.avi
10 Year Animation Of Piezometers

Animations\wolfcreek_pz2.avi
2004 Temperature Survey

AMC Temperature Survey 2004

Icons for cool spots and temperatures less than 59°F are enlarged.

Legend:
- Diaphragm Wall
- Switchyard
- Road
- SY Diaphragm Wall
- Monolith
Temperature measurements were conducted in 110 Piezometers in addition to reviewing pre-diaphragm wall construction data.

- The study focused on approx 2,800 LF of earthen emb. plus 10 monoliths
- 148’ U/S to 1,080’ D/S

Results:
- Temperatures Ranged from 55.9°F to 73.8°F (Average 60.8°F)
- 6 cool spots were identified
- Matched well with the 1968 data although temp ranges were smaller
  - Temperature Differential 1968 12° cooler (Spring sampling)
  - Temperature Differential 2004 4° cooler (Fall sampling)
- Source of cool water exists near Sta 35+60; 235’ D/S
- Seepage beneath Monoliths 36 & 37 CONTINUES