Scenic Lake Dam Rehabilitation & Improvements Project – Liquefaction Analysis and Deep Mixing Method (DMM) Construction

John James Audubon State Park, Henderson, KY

Kentucky Association of Mitigation Managers, 2018 Conference
Lake Barkley State Resort Park, Cadiz
September 19, 2018
## Project Team

<table>
<thead>
<tr>
<th>Kentucky Division of Water – Dam Safety</th>
<th>AECOM</th>
<th>Raito, Inc.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Carey Johnson</strong> - FEMA CTP Program Manager</td>
<td><strong>Kristen Crumpton</strong> – Louisville, Kentucky Water Business Unit Lead</td>
<td>Chris McGhee – VP of Corporate Operations</td>
</tr>
<tr>
<td><strong>Jory Becker</strong> - Water Infrastructure Branch Manager</td>
<td><strong>Sean Craig</strong> – Louisville, Project Manager</td>
<td>Doug Barber – Project Manager</td>
</tr>
<tr>
<td><strong>Glen Alexander</strong> - Environmental Engineer Supervisor</td>
<td><strong>Mark Jones</strong> – Louisville, Geotechnical Engineer III</td>
<td>Ron Diaz – Senior Superintendent</td>
</tr>
<tr>
<td><strong>Marilyn Thomas</strong> - Environmental Engineer II</td>
<td><strong>Aaron Wagner</strong> – Louisville, Engineer in Training</td>
<td></td>
</tr>
<tr>
<td><strong>Gary Wells</strong> - Environmental Engineer II</td>
<td><strong>Bethany Shain</strong> – Louisville, Project Manager</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Davis Murphy</strong> – Louisville, Project Manager and Water Resources Engineer</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Vik Gautam</strong> – Cleveland, Senior Geotechnical Engineer</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Mike Zusi</strong> – Denver, Senior Professional Engineer</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Adam Lowell</strong> – Denver, Structural Engineer IV</td>
<td></td>
</tr>
</tbody>
</table>
Presenters

Marilyn Thomas
- Kentucky Division of Water (KDOW), Dam Safety and Floodplain Compliance
- Client and Regulatory Agency

Sean Craig
- AECOM
- Engineering Consultant and Construction Observation

Doug Barber
- Raito, Inc.
- Construction Contractor
Department for Environmental Protection - Kentucky Division of Water (KDOW), Energy and Environment Cabinet (EEC) - Dam Safety
What is a dam?

- KRS Chapter 151 defines a dam as:
  - Any structure that is, or will be, **25 feet in height**, measured from the downstream toe to the crest of the dam, OR
  - has, or will have, a maximum **impounding capacity of 50 acre-feet** or more at the crest of the dam.
Kentucky Division of Water, Dam Safety

– KRS Chapter 151
  • Authorizes the Energy and Environment Cabinet to:
    o **Regulate** the construction and operation of dams and hazardous impoundments.
    o **Inspect** dams and hazardous impoundments.
    o Require **remedial actions** to protect public health, safety & welfare.

– 401 KAR 4:030
  • Outlines **design requirements** for dams and hazardous impoundments.
## Dam Classifications

<table>
<thead>
<tr>
<th>Hazard Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Hazard (C)</strong></td>
<td>Structures located such that <em>failure may cause loss of life</em> or <em>serious damage</em> to houses, industrial or commercial buildings, important public utilities, main highways or major railroads.</td>
</tr>
<tr>
<td><strong>Moderate Hazard (B)</strong></td>
<td>Structures located such that <em>failure may cause significant damage</em> to property and project operation, but loss of human life is not envisioned.</td>
</tr>
<tr>
<td><strong>Low Hazard (A)</strong></td>
<td>Structures located such that <em>failure would cause loss of the structure</em> itself but little or no additional damage to other property.</td>
</tr>
</tbody>
</table>
Inspection of Dams in Kentucky

– High and moderate hazard dams are currently inspected every two years.

– Low hazard dams are currently inspected every five years.

– A condition assessment is performed during each inspection.
State-Owned Dam Repair Program

– KDOW manages the State-Owned Dam Repair (SODR) program
  • Oversees engineering analyses, design, and construction for repair and rehabilitation of state-owned dams
  • Ensures that the Commonwealth’s dams are constructed to regulatory requirements
  • 5 active projects
    o Bullock Pen Lake Dam (High hazard)
    o Scenic Lake Dam (High hazard)
    o Beech Creek Dam (High hazard)
    o Willisburg Lake Dam (High hazard)
    o Spurlington Lake Dam (High hazard mitigated to low hazard)
State-Owned Dam Repair Program

– SODR has acquired at-risk properties
  • Collaborated with local communities to restrict development downstream of dams.
  • Saved millions of dollars that otherwise would have been spent on upgrading dam structures because of the change in hazard class resulting from downstream development.

– The savings realized by mitigating downstream risks are directed to other high priority SODR projects that require significant construction.
State-Owned Dams

Map prepared by KDOW GIS & Data Analysis Section
September 2015

This work represents only generalized locations of features, objects or boundaries and should not be relied upon as being legally authoritative for the precise location of any feature, object, or boundary.

73 State-Owned Dams
Lessons Learned

– Communication is key
  • DOW (user agency), KY Finance Cabinet (contract administrator), Design Consultant, Contractor, other applicable agencies (e.g. USACE, SHPO, dam owners, etc.

– Regulatory actions generally involve considerable time and unknown consequences may arise
  • Permitting and property acquisition have proven to be most difficult for KDOW in SODR projects
Lessons Learned

– Employ a team approach - don’t rely on a single person to manage projects

– Be conservative when creating estimates
  • Many dams built decades ago
  • Don’t know what’s in the ground until you dig

– An active management approach is required
  • Frequent site visits
  • Construction contractor must be qualified and sufficient oversight provided

– Design engineer and testing labs must be qualified and kept on track
  • Adherence to specification eliminates the need for costly reworks
Scenic Lake Dam, Rehabilitation & Improvements - Project Background
Audubon Memorial State Park in Henderson County, KY.

The dam was built in 1930 by the Works Progress Administration (WPA) and Civilian Conservation Corps. (CCC)

A portion of the embankment was reconstructed in 1953 in order to repair damage caused by burrowing muskrats.
Dam Structure

- Embankment type structure.
- 30 feet in height and 330 feet long.
- The total impounded volume is 348 acre-feet at the crest of dam.
  - Elevation of 430.4 feet (NAVD88).
- The dam does not have an emergency spillway.
Design Scope

Phase I - Liquefaction Susceptibility and Mitigation

- Deep Mixing Method (DMM)

Future Phase II

- Spillway and Buttress
- Widen Crest & Stabilize
- Constructing a Spillway
- Converting the existing spillway to a Low-Level Outlet
- Address Seepage Concerns
Project Background – Geotechnical Report

Original field exploration conducted (non URS/AECOM firm) August-September 2013.

Geotechnical Report submitted in March 2014.

Gaps needed to be addressed in analyses.
- Thick deposits of soft and saturated silts
- No discussion of liquefaction potential
- Western KY known to be an area of historically high seismicity

(non URS/AECOM firm)
Rehabilitation & Improvements Project – Design Scope

Phase I – Liquefaction Susceptibility and Mitigation
- Deep Mixing Method (DMM)

Future Phase II – Spillway and Buttress
- Widen Crest & Stabilize
- Constructing Spillway
- Converting the existing spillway to a Low-Level Outlet
- Address Seepage Concerns
Liquefaction Susceptibility Analysis, Mitigation by Deep Mixing Method (DMM)
AECOM began reviewing Scenic Lake Dam historic Geotechnical Data in Summer of 2016:

– Silt deposits appeared highly susceptible to classical liquefaction (non-plastic and saturated)

– Western Kentucky known for historical seismicity (New Madrid Earthquakes of 1811-1812)

– Liquefaction susceptibility had not been previously assessed

– AECOM had recent experience at a nearby site with similar liquefaction-prone soil conditions in late 2015
  • Engineering analyses and laboratory testing concluded liquefaction could occur and remediation was recommended
National and Regional Seismic Hazards
Regional Seismic Hazards: Wabash Valley Seismic Zone

Notable recent Wabash Events:

April 18, 2008: $M = 5.4$

June 18, 2002: $M = 4.6$

Scenic Lake Dam
Seismic Hazard of Key Concern: Liquefaction

Soil liquefaction

Liquefaction is a phenomenon in which water-saturated sandy layers of earth act like liquids due to the pressure created by earthquakes.

- Ground surface
- Sediment layer
- Water-saturated granular layer

Normal pressure
Soft sands can maintain strength or hardness because of friction from the grains touching, even though they are saturated with water.

Intense pressure
Force from an earthquake causes the water to increase in pressure. With enough pressure, the water will break the friction in the grains and fill the spaces, causing liquefaction.

Lateral movement can create uneven ground, damaging structures

Movement
Sand layers can slide, causing rips in the ground surface or uneven settling of building foundations. The sand can even push up through the ground.

Source: California Watch research

BRIAN CRAGIN / CALIFORNIA WATCH
Severe Damage Potential to Structures at Surface

Lower San Fernando Dam, 1971. Liquefaction of hydraulic fill.
Additional Field Investigation and Site-Specific Liquefaction Evaluation Plan, Fall 2016:

1. Mobilize Cone Penetration Testing (CPT) rig
   - Essentially continuous data on soil strength correlations (every 5 cm)
   - Obtain seismic shear wave velocity of materials

2. Run Deterministic Seismic Hazard Analysis (DSHA)
   - Determine rock accelerations for Maximum Credible Earthquake (MCE) M=6.8

3. Run QUAD4M analysis
   - Utilizes Shear Wave Velocity data from CPT
   - Determine seismic stresses (CSR values) for actual cross section and material geometry

4. Revise Liquefaction Analysis with high quality site-specific data
   - Accurately determine susceptibility to liquefaction
   - Determine residual or “liquefied” strengths of soils

5. Run post-liquefaction stability analyses based on previous models
DMM Configuration for Scenic Lake Dam

Camp Grounds

Lake

Dam Crest
Deep Mixing Method (DMM) Installation
Completed Soil-Cement Columns (Unmixed soil removed between panels)
DMM Benefits

- All DMM elements underground
- Little to no concern of vibration/noise compared to other methods
- Phase I soil-cement panels will be fully concealed underneath Phase II improvements (buttress and spillway)

- Proven and established methodology for liquefaction mitigation
- Reduced volume of spoils compared to other in-situ methods (e.g. slurry walls)
- Spoils can be used as fill materials later in project
Deep Mixing Method (DMM) Construction
DMM Layout: Original Design vs. Alternate
Original Design Concept
Original Design Concept (cont.)

- 6ft Diameter Columns
- 5ft Center Spacing
- 12ft +/- Wall Spacing
- Single Column Installation
- 390 psi UC Strength
Raito’s Alternate Design
Raito’s Alternate Design (cont.)

– 3ft Diameter Columns
– 2ft Center Spacing
– 6.5ft Wall Spacing
– Multiple Column Installation
– 300 psi UC Strength
Benefits of Multi-Axis Installation

– Overlapping, counter-rotating mixing blades provide superior mixing quality and distribution of grout
Benefits of Multi-Axis Installation (cont.)

– Dedicated grout pump for each auger
Raito’s DMM Equipment

- 180 ton Base Rig
- 6 auger motor
- 65ft maximum drilling depth
- 16 trucks to transport (including Batch Plant & parts, etc.)
Raito’s DMM Equipment

– Two 55 ton cement silos
– 1,800 liter batching
– Powered entirely by generator
Quality Control System

– Grout volume, RPM, Verticality, Speed, and Depth continuously monitored, controlled, and recorded to ensure targets are met.
Coring Equipment

– 2.5 inch or 3.5 inch recovery
– Low pressure, designed specifically for soil-cement
Finished Product!!! (2.5 inch)
Finished Product!!! (3.5 inch)
What Makes Scenic Lake Unique for Raito?
Short Duration

Mob & Demob combined likely longer than DMM installation
Short Duration (cont.)

– Original Design Concept had 160 of strokes
– Alternate Design reduced this to 136
– 16 Production days, average of 550 yd$^3$ per day
Big Toys in a Small Sandbox
Big Toys in a Small Sandbox (cont.)
Big Toys in a Small Sandbox (cont.)
Big Toys / Scale of Project
Question & Discussions

**Marilyn Thomas – KDOW, Dam Safety and Floodplain Compliance**
- 300 Sower Boulevard, Frankfort, KY 40601
- (502) 564-3410

**Sean Craig - AECOM**
- 500 W. Jefferson St., Suite 1600, Louisville, KY 40202
- (502) 569-2301

**Doug Barber – Raito, Inc.**
- 23595 Cabot Blvd # 106, Hayward, CA 94545
- (510) 259-9900