Presentation Outline

1. Rock Anchors
   - National Research Project (1962-2004 Projects)
     - Compilation of Technical Papers (over 230)
     - Creation of project database (over 400)
   - Update (2005-2012 Projects)
     - Technical Papers (55 more)
     - Case Histories (72 more)
   - Current CEATI Project (Headed by P.C. Rizzo and Associates)
     - “Study and evaluate the condition of grouted anchors through literature review and forensic study”
Presentation Outline (continued)

2. Concrete Cutoffs
   - 2006-2013 Update (Post-Katrina)

3. New Data Source
   - “Specialty Construction Techniques for Dams and Levees”
     Published October, 2012

4. Summary of Research Needs
   - Anchors
   - Cutoffs

NOTE: By concrete cutoffs, we refer to diaphragm walls/slurry walls (Category 1 Walls). This therefore excludes from discussion seepage cutoffs built by the Deep Mixing Method Technologies (Vertical Axis, TRD or CSM) or by drilling and grouting. Both have widespread application and are equally in need of fundamental research into certain aspects.
1. Rock Anchors
National Research Project (1964-2004)
Task 1: Analysis of Successive PTI Recommendations

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<td>Post-Tensioning Materials and Equipment Specialists</td>
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<td>12</td>
<td>8</td>
<td>9</td>
<td>11</td>
<td>12</td>
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*Including the same Chairman (Heinz Nierlich of DSI).
†Chairman from VSL (David Swanson).

Composition of the Drafting Committees

Size (in Pages) of Major Subject Chapters

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<td>6 ½</td>
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<td>15</td>
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<td>Stressing and Testing</td>
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<td>8</td>
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<td>18</td>
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<td>0</td>
<td>Very minor reference.</td>
<td>Frequent references but no separate section.</td>
<td>10 Separate section.</td>
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<td>TOTAL PAGES*</td>
<td>32</td>
<td>57</td>
<td>41</td>
<td>70</td>
<td>98</td>
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*Total is not the sum of the individual subjects tabulated since peripheral subjects like Scope, and Definitions are not included in this review.
Main Conclusions from Task 1

- North American practice has evolved substantially over the past forty years through emphasis on technology and refinements in construction techniques.
- Through five successive editions, the “Recommendations” have evolved from Applications Oriented to State of Practice.
- Particular progress has been made in the areas of corrosion protection, quality control, and stressing/testing procedures. Design approaches remain “traditional.”
- Developments in construction equipment and techniques have raised quality and productivity.

Task 2: The Bibliography

- Hard copy and electronic versions of each published paper were collected.
- A total of 235 papers were found relating to over 200 dams.
- Data used to populate project database.
Task 3: The Database of Projects

1. Dam Construction Statistics

Histogram of US Dam Construction (1600-2004)

Notes:
1. Source of Data: National Inventory of Dams, USADE, 97777 Dam Total
2. Does not include 8500 dams where the year of construction completion is not reported or invalid
3. Total number of dams; just including 8500 with year of completion valid.
Numbers of dams anchored/numbers of masonry and concrete dams, per state

Notes:
1) Source of data – National Inventory of Dams USACE
2) Statistics may be skewed based on how states classify their dams.
Update (2005-2012 Projects)

- 55 Additional technical papers (big boost from 2007 Institution of Civil Engineers Conference, London). Average is around 5 per year.
- 72 new case histories with 60% in U.S. 12 Projects featured anchoring for the second or third time.
Current CEATI Project
("Grouted Post-Tensioned Rock Anchor Assessment")

- Technical Proposal September 24, 2012
  - Main objective “to provide additional information regarding the question of the reliability of grout protected anchors.”
  - Provide real data through removal of anchors at decommissioned dams or anchors which have become redundant.
  - Related studies:
    - Elwha Dam, WA
    - Condit Dam, WA
- Contract November 12, 2012

2. Concrete Cutoffs (1975-2005)
- Construction Principles
  - Panels (Clamshells or Hydromill)
Conventional Secant Pile Method
# 2. Concrete Cutoffs (1975-2005)

<table>
<thead>
<tr>
<th>Date/Project Name</th>
<th>Contractor</th>
<th>Type of Wall</th>
<th>Composed of Wall</th>
<th>Ground Conditions</th>
<th>Purpose of Wall</th>
<th>Scope of Project</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wolf Creek, KY</td>
<td>ICOS</td>
<td>Concrete</td>
<td>Concrete</td>
<td>Dams, Fills, and Alluvial fans</td>
<td>To provide a residual cutoff wall to stop flow through the karst.</td>
<td>30 ft, M: 20 ft, 4,000 ft</td>
<td>ICOS (1988)</td>
</tr>
<tr>
<td>2. W.F. George, AL</td>
<td>Selotanex (Phase 1)</td>
<td>Concrete</td>
<td>Concrete</td>
<td>Runoff, seepage fill with very high water tables</td>
<td>To provide a cutoff wall with a high flow capacity</td>
<td>120,000 ft, Phase 1, 150,000 ft, Phase 2, 300,000 ft, Phase 3</td>
<td>Selotanex (1982)</td>
</tr>
<tr>
<td>3. Aberdeen, SD</td>
<td>Selotanex</td>
<td>Concrete</td>
<td>Concrete</td>
<td>Composed of Clay, sand, silt, and gravel</td>
<td>To provide a cutoff wall with a high flow capacity</td>
<td>65,000 ft, Phase 1, 45,000 ft, Phase 2, 60,000 ft, Phase 3</td>
<td>Selotanex (1984)</td>
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<tr>
<td>4. St. Stephens, SC</td>
<td>Selotanex</td>
<td>Concrete</td>
<td>Concrete</td>
<td>Composed of Clay, sand, silt, and gravel</td>
<td>To provide a cutoff wall with a high flow capacity</td>
<td>45,000 ft, Phase 1, 60,000 ft, Phase 2, 65,000 ft, Phase 3</td>
<td>Selotanex (1985)</td>
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* Selotanex have operated in the U.S. under different business identities over the years. *Selotanex* is used herein as the general term.

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### Project Listing Showing Chronology

**Type of Cut-Off and Specialty Contractor (to 2005)**

![Diagram showing project listing chronology]

- Wolf Creek, KY
- W.F. George, AL
- Aberdeen, SD
- St. Stephens, SC
- W.F. George, AL, Phase 3
- Watertown, NY

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**CEATI International**

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Category 1 Concrete Cut-Offs for Existing Embankment Dams

<table>
<thead>
<tr>
<th>TYPE OF CONSTRUCTION</th>
<th>NUMBER OF PROJECTS</th>
<th>SQUARE FOOTAGE</th>
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<tr>
<td></td>
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<td>SMALLEST</td>
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<td>Mainly Clamshell</td>
<td>7</td>
<td>51,000</td>
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<td>Mainly Hydromill</td>
<td>9</td>
<td>104,600</td>
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<td>Mainly Secant Piles</td>
<td>4</td>
<td>12,000</td>
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<tr>
<td>Total</td>
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Note:
1. This is the cumulative result of 32 years of activity to 2005. During the next 5 years, USACE planned to conduct a similar dollar value again, on 4 dams.

2006-2013 Update

<table>
<thead>
<tr>
<th>DAM</th>
<th>STATE</th>
<th>SCOPE</th>
<th>STATUS OF PROJECT AS OF FALL 2012</th>
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<tbody>
<tr>
<td>Wolf Creek</td>
<td>KY</td>
<td>Approximately $400M Category 1 cutoff to 275' depth.</td>
<td>90% complete.</td>
</tr>
<tr>
<td>Clearwater</td>
<td>MO</td>
<td>Approximately $100M Category 1 cutoff to 150' depth.</td>
<td>Complete.</td>
</tr>
<tr>
<td>Center Hill</td>
<td>TN</td>
<td>Approximately $100M Category 1 cutoff to 300' depth.</td>
<td>10% complete.</td>
</tr>
<tr>
<td>Herbert Hoover Dike</td>
<td>FL</td>
<td>About 22 miles of Category 1 and 2 cutoff to 90' depth.</td>
<td>Complete.</td>
</tr>
</tbody>
</table>

In addition, major cutoff walls are in design stage for other USACE DSAC 1 and 2 dams including East Branch, Bolivar, Mohawk and Addicks & Barker Dams.
3. New Data Source

Chapters on:
- Drilling and Grouting Cutoffs
- Category 1 Cutoffs (Concrete)
- Category 2 Cutoffs (DMM)
- Composite Walls
- Anchors
- Instrumentation

4. Summary of Research Needs

Anchors
Design methodology has not changed in over 51 years, but provides conservative and serviceable results. The main issue is the reliability of anchors installed before the requirements to have Class 1 Protection.

Note: From 1996 onwards, the term “Class I Protection” superseded the old “Double Corrosion Protection.”
Therefore the strategies are:

1. **Exhume and examine existing “aging” anchors** (as per the current CEATI Program), but extended to involve USACE and others.

2. **Conduct a Portfolio Risk Screening Assessment** (similar to USACE in 2006-2007) on all structures anchored before 1996. The goal would be to identify those projects at highest risk due to potential defects/weaknesses in design and/or construction (especially with respect to corrosion protection).

**Notes:**
(1) The database already exists for North America.
(2) The problem also exists in other countries, e.g., Australia.

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**Concrete Cutoff Walls**

There is a small but technologically advanced pool of specialty contractors who conduct the work using a wide range of technologies (grabs, hydromills, secant piles). Technical papers (and “post action” reports) are typically written by these contractors soon after the project has been built. However, very few papers are written about the performance and efficiency of these walls over time.

Thus, the first need is to contact owners/operators and evaluate all relevant piezometric and seepage readings to quantify the efficiency of these walls. Encourage owners/operators to write “follow-up” papers for the benefit of the engineering community.
The second major research effort is more fundamental. Dams founded on erodible/soluble foundations (including those on karst) have a finite (and often very short) window of safe performance, often less than 30 years. Examples of near failure should be very closely studied to help understand and quantify the effect of the various drivers (e.g., geological conditions, hydraulic head, fluctuations, etc.). This analysis would then be invaluable in predicting when other dams would have similar “near death” events.

Summary of Major Research Needs

**Anchors**
- Exhume and study (as per current CEATI/PCR study)
- Conduct Portfolio Risk Screening Assessment

**Cutoffs**
- Evaluate performance of existing cutoffs and encourage publications
- Research “drivers” for failure and so construct a predictive model for dams on soluble foundations.