ROCK ANCHORS AND CONCRETE CUTOFFS
A Historical Review
and Future Research Needs Assessment

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Presentation Outline

1. Rock Anchors
   - National Research Project (1962-2004 Projects)
     - Analysis of Successive PTI Recommendations (1974, 1980, 1986, 1996, 2004)
     - 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"

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Presentation Outline (continued)

2. Concrete Cutoffs
   - Original study (2006): 20 Case Histories 1975-2005
   - 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

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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.

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1. Rock Anchors

National Research Project (1964-2004)

Task 1: Analysis of Successive PTI Recommendations

Aspect	1974	1980	1986	1996	2004
Post-Tensioning Materials and Equipment Specialists	6†	4*	4*	2*	3*
Anchor Contractors	2	2	3	3	3
Consultants	2	None	1	2	2
Owners	1	2	1	3	3
Sponsor Organizations	1	None	None	1	1
TOTAL	12	8	9	11	12

*Including the same Chairman (Heinz Nierlich of DSI).
†Chairman from VSL (David Swanson).

Composition of the Drafting Committees

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Size (in Pages) of Major Subject Chapters

Subjects	1974	1980	1986	1996	2004
Anchor Materials	1	2	2	8	10
Site Investigation	0	1	1	1	2
Design	2	6 ½	6 ½	12 Plus an appendix on grout/strand bond testing	14
Corrosion Protection	1	4	5	10	14
Construction	7	9	9	10	15
Stressing and Testing	1	6	8	17	18
Bibliography/References	0	1	1	1 ½	4
Applications	16	18	0	0	0
Recordkeeping/Submittals	0	1	1	1 ½	1 ½
Procurement/Specifications	0	1	1 ½	2	2
Epoxy-Coated Strand	0	0	Very minor reference.	Frequent references but no separate section.	10 Separate section.
TOTAL PAGES*	**32**	**57**	**41**	**70**	**98**

* Total is not the sum of the individual subjects tabulated since peripheral subjects like Scope, and Definitions are not included in this review.

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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.

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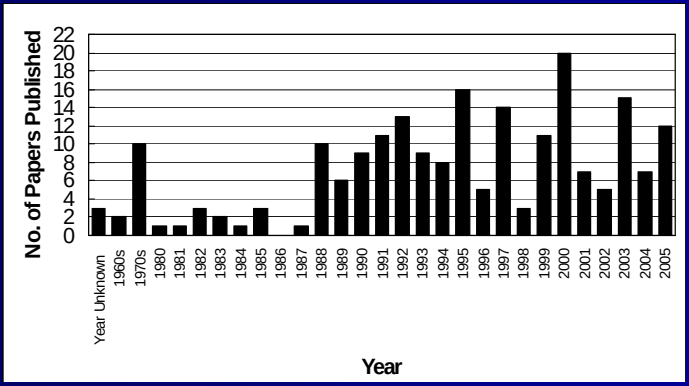
Task 2: The Bibliography

- 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.



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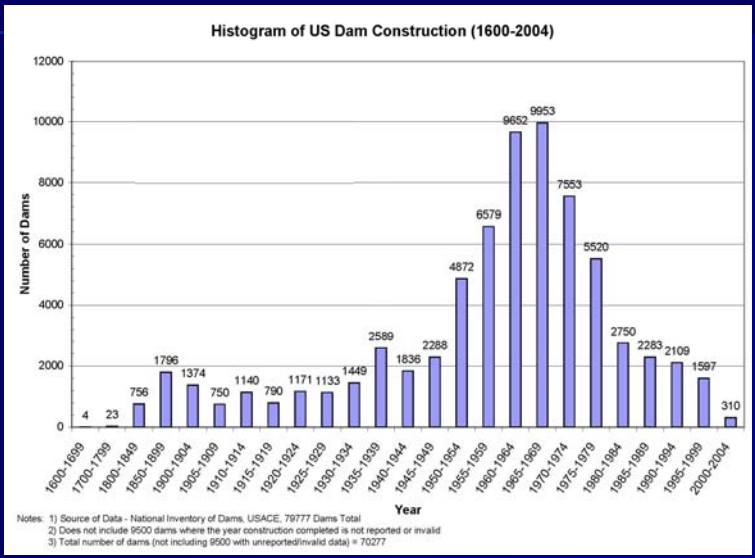
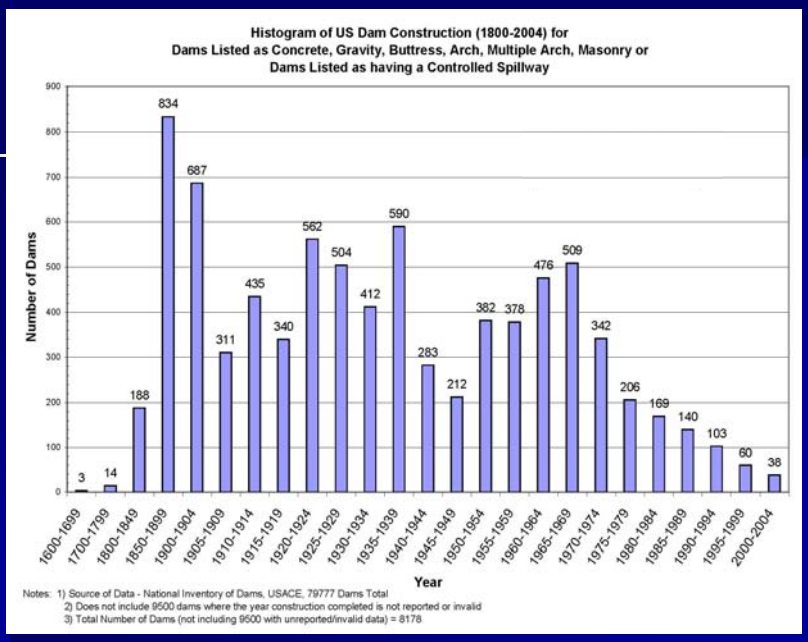
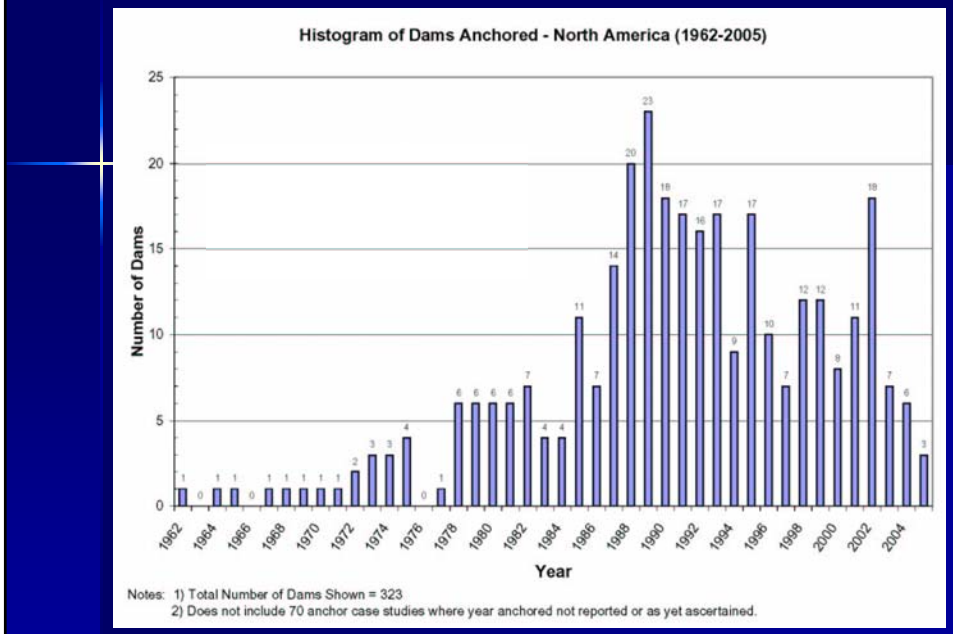
Task 3: The Database of Projects

1. Dam Construction Statistics







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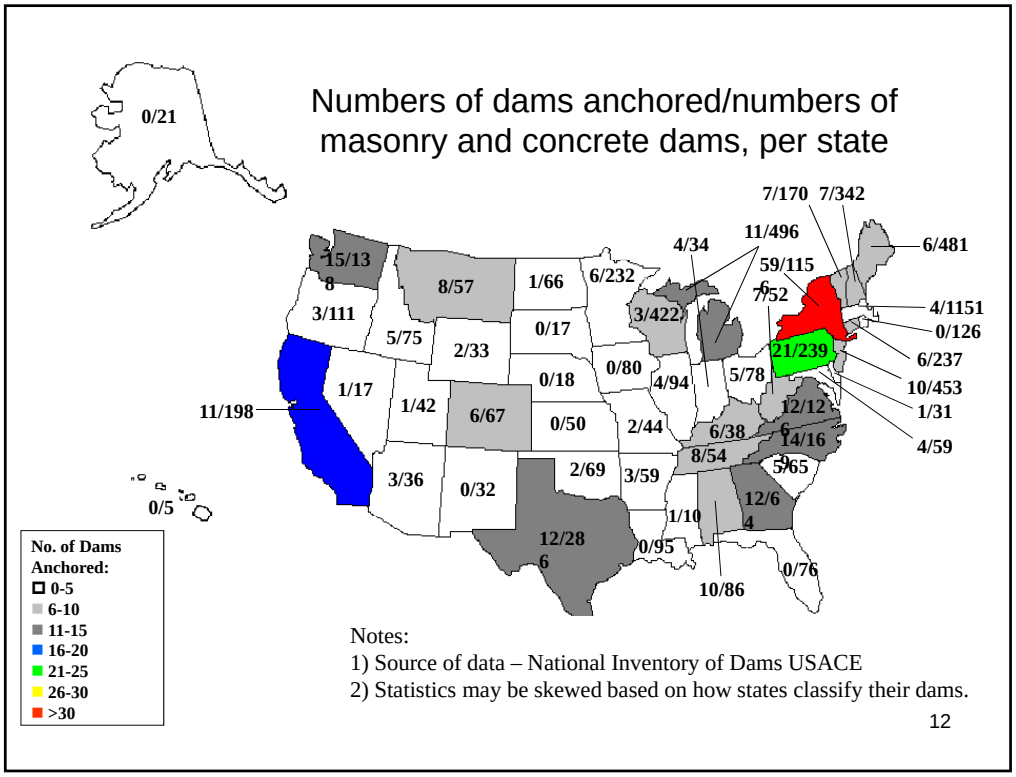

Notes:
1) Source of data – National Inventory of Dams USACE
2) Statistics may be skewed based on how states classify their dams.

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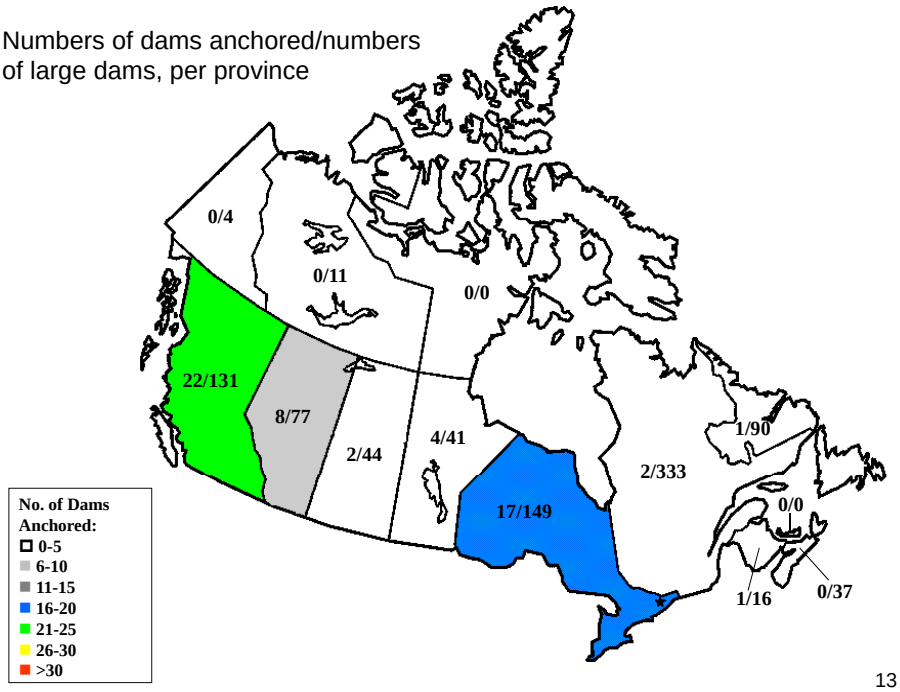
Numbers of dams anchored/numbers of large dams, per province



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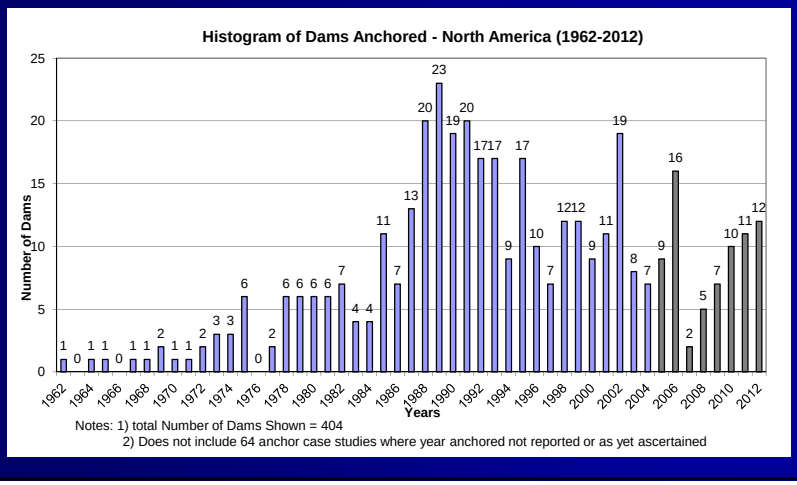
Update (2005-2012 Projects)

- 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.



Notes: 1) total Number of Dams Shown = 404
2) Does not include 64 anchor case studies where year anchored not reported or as yet ascertained

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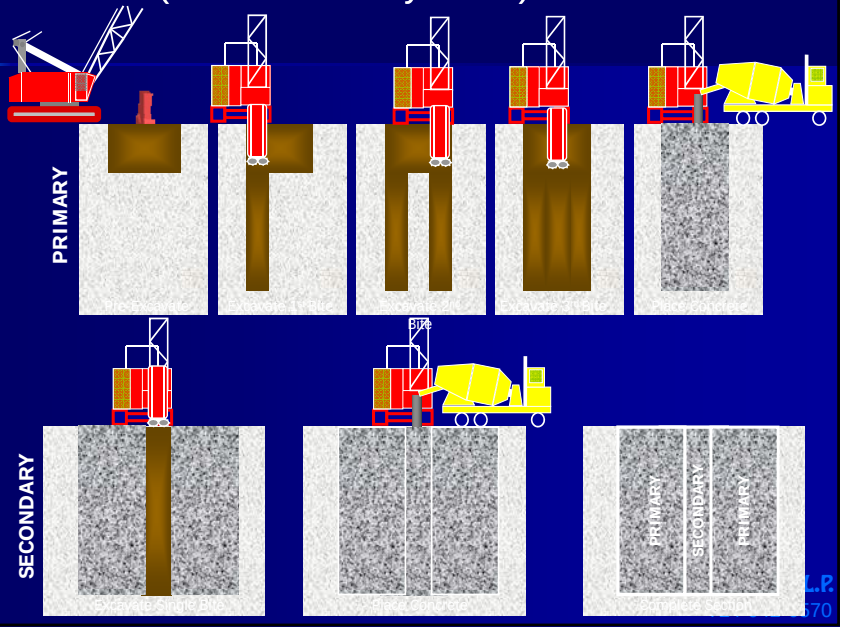
Current CEATI Project

("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)



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Conventional Secant Pile Method

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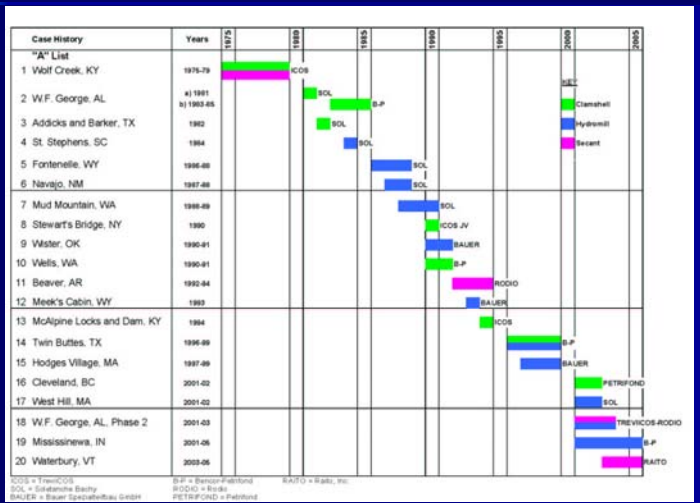
2. Concrete Cutoffs (1975-2005)

Dam Name and Year of Remediation	Contractor	Type of Wall	Composition of Wall	Ground Conditions	Purpose of Wall	Scope of Project: Area	Scope of Project: Min. Width	Scope of Project: Depth	Scope of Project: Length	References
1. WOLF CREEK, KY. 1975-1979	ICOS	24-inch diameter Primary Piles, joined by 24-inch wide clamshell panels. Two phases of work.	Concrete.	Dam FILL, and ALLUVIUM over argillaceous and karstic LIMESTONE with cavities, often clay-filled.	To provide a "Positive concrete cut-off" through dam and into bedrock to stop seepage, progressively developing in the karst.	270,000 sf (Phase 1) plus 261,000 sf (Phase 2)	24 in	Max. 280 ft	2,000 ft plus 1,250 ft	• ICOS brochures (undated) • Felzer (1988)
2. W.F. GEORGE, AL 1981 1983-1985	Soletanche (Phase 1) Bencor-Petrifond (Phase 2)	26-inch thick panels using cable and kelly-mounted clamshell 24-inch panels 15-27 ft long	Plastic concrete 3,000 psi Concrete	Random, impervious FILL with silty core over 25-30 ft ALLUVIUM over chalky LIMESTONE	To provide a "positive concrete cut-off" through the dam and alluvials.	130,000 sf (Phase 1) plus 951,000 sf (Phase 2)	26 in 24 in	Max 138 ft 110-190 ft	Approx. 1,000 ft 8,000 ft	• Soletanche Brochure (undated) • Bencor Brochure (undated)
3. ADDICKS AND BARKER, TX. Completed in 1982 (Phase 1 took 5 months)	Soletanche*	36-inch thick panel wall with clamshell excavation using Kelly.	Soil-Bentonite.	Dam FILL over CLAY.	To prevent seepage and piping through core.	450,000 sf (Phase 1) plus 730,000 sf (Phase 2)	36 in	Max 66 ft typically 35 to 52 ft	8,330 ft plus 12,900 ft	• Soletanche website.
4. ST. STEPHENS, SC. 1984	Soletanche	24-inch-thick concrete panel wall, installed by Hydromill. Plus upstream joint protection by soil-bentonite panels.	Concrete and soil-bentonite.	Dam FILL, over sandy marly SHALE.	To provide a cut-off through dam.	78,600 sf (concrete) plus 28,000 sf (soil-bentonite)	24 in	Max. 120 ft including 3 ft into shale	695 ft	• USACE Report (1984) • Soletanche (various) • Parkinson (1986) • Bruce et al. (1989)

* Soletanche have operated in the U.S. under different business identities over the years. "Soletanche" is used herein as the general term.

Project Listing Showing Chronology Type of Cut-Off and Specialty Contractor (to 2005)



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Category 1 Concrete Cut-Offs for Existing Embankment Dams

Type of Construction	Number of Projects	Square Footage		
		Smallest	Largest	Total
Mainly Clamshell	7	51,000	1,400,000	3,986,320
Mainly Hydromill	9	104,600	850,000	2,389,415
Mainly Secant Piles	4	12,000	531,000	1,050,700
Total	**20**			**7,426,435**

Note:

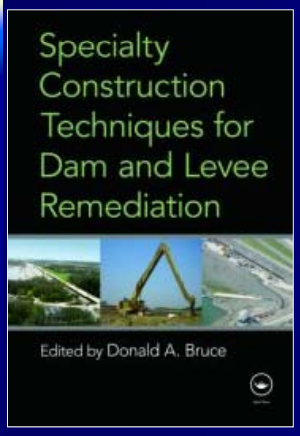
1. This is the cumulative result of 32 years of activity to 2005. During the next 5 years, USACE planned to conduct a similar dollar value again, on 4 dams.

2006-2013 Update

Dam	State	Scope	Status of Project as of Fall 2012
Wolf Creek	KY	Approximately $400M Category 1 cutoff to 275′ depth.	90% complete.
Clearwater	MO	Approximately $100M Category 1 cutoff to 150′ depth.	Complete.
Center Hill	TN	Approximately $110M Category 1 cutoff to 300′ depth.	10% complete.
Herbert Hoover Dike	FL	About 22 miles of Category 1 and 2 cutoff to 90′ depth.	Complete.

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

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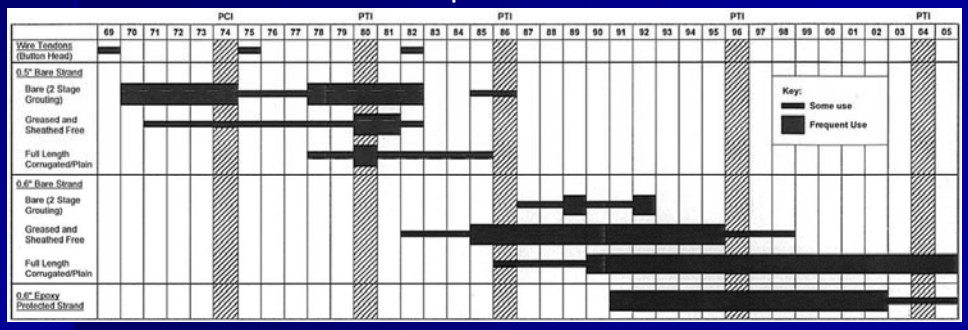
4. Summary of Research Needs

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.



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

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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.

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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.

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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.

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