

What's Wrong with this Picture?





1. The Background to the National Research Program

The main project tasks were to:

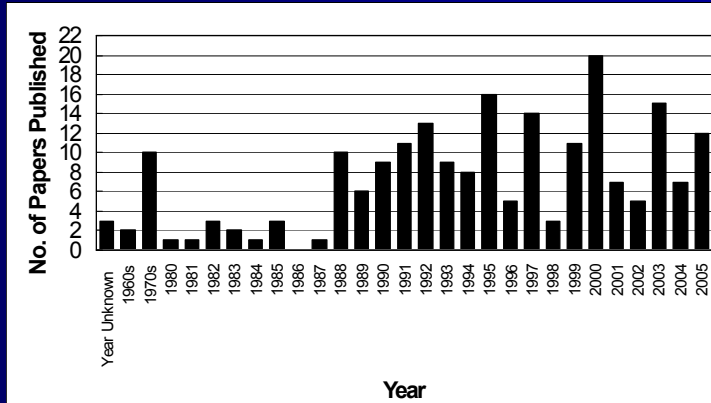
1. Collect and analyze all successive editions of PTI "Recommendations" (1974, 1980, 1986, 1996, 2004).
2. Research and compile all technical papers written about North American dam anchoring projects. (over 230).
3. Collect hard copies of information, and create database of all dam anchoring projects in North America (over 400).



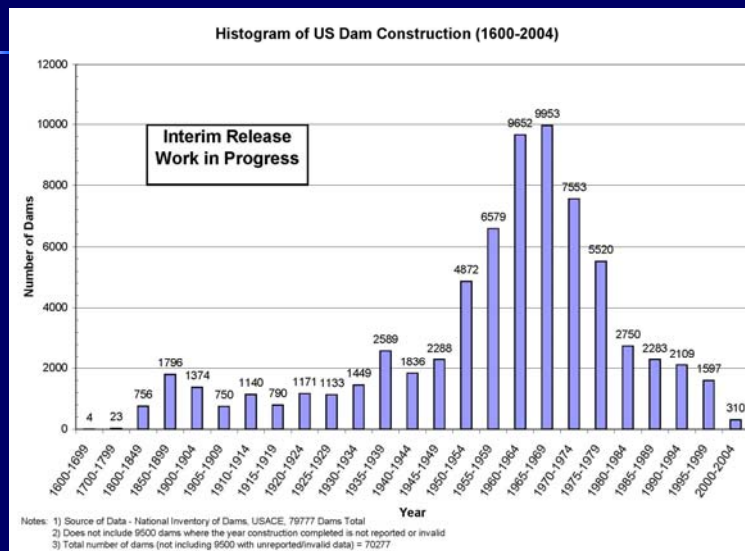
2. The Bibliography

Collection and Analysis of Published Technical Papers

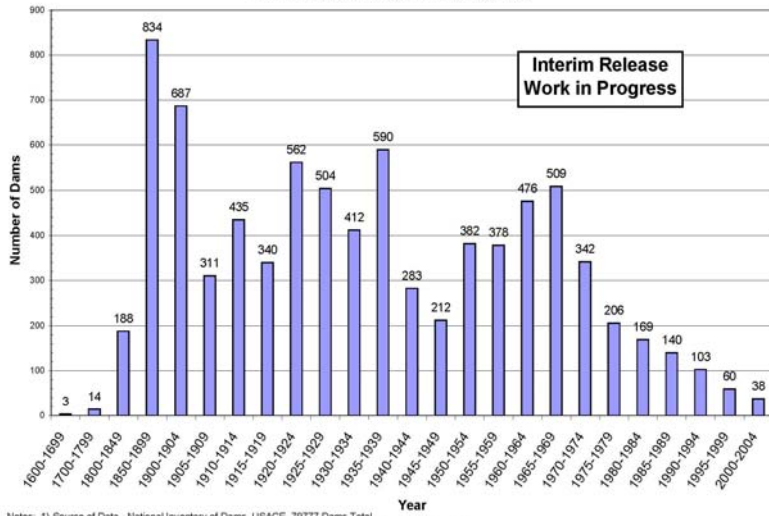
- Hard copy and electronic versions of each published paper have been collected.
- A total of 235 papers have so far been found relating to over 200 dams.
- Data used to populate database.



3. The Database of Projects



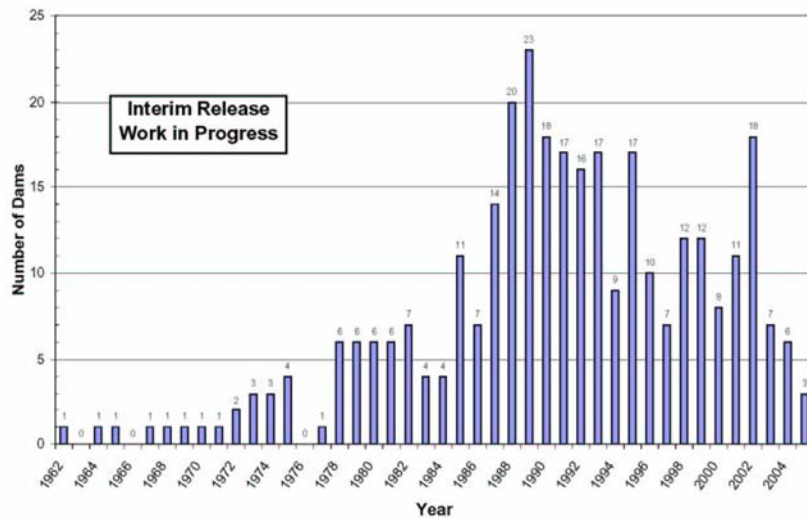
Histogram of US Dam Construction (1800-2004) for Dams Listed as Concrete, Gravity, Buttress, Arch, Multiple Arch, Masonry or Dams Listed as having a Controlled Spillway



Notes: 1) Source of Data - National Inventory of Dams, USACE, 79777 Dams Total
 2) Does not include 9500 dams where the year construction completed is not reported or invalid
 3) Total Number of Dams (not including 9500 with unreported/invalid data) = 8178

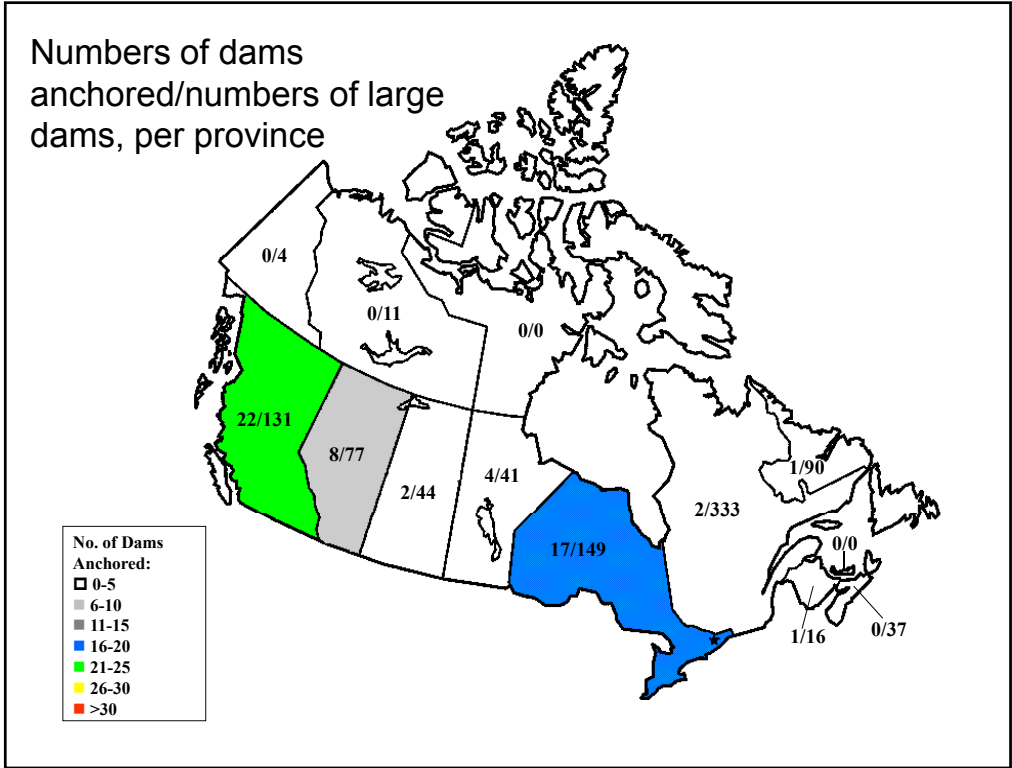
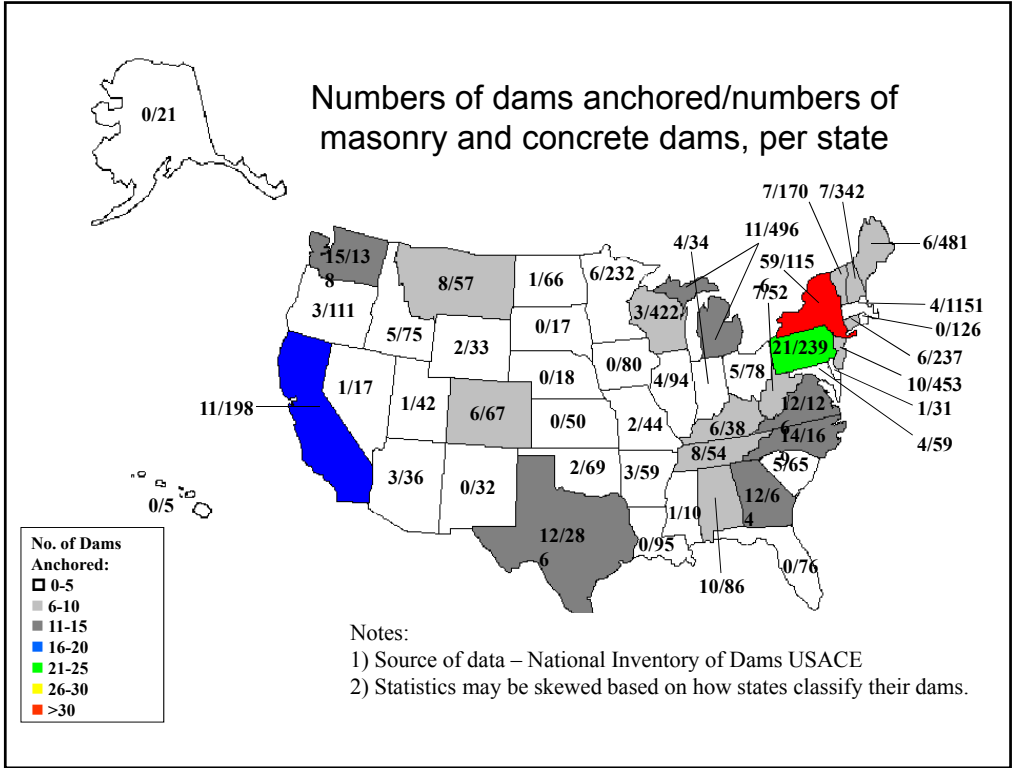


Histogram of Dams Anchored - North America (1962-2005)



Notes: 1) Total Number of Dams Shown = 323
 2) Does not include 70 anchor case studies where year anchored not reported or as yet ascertained.





2. Geotechnical Design

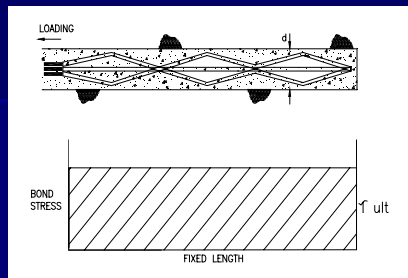
Traditional Approach:

- Uniform bond distribution
- $\tau_w = 100$ to 130 psi
- "Volume of rock cone" theory for overall stability



GEOSYSTEMS, L.P.

ASSUMPTION



Stress distribution of a simple design approach

$$\text{Ultimate load} = \pi \times d \times L \times \tau_{ult}$$

This means load \propto fixed length

This is not a true statement.



However, it is a conservative approach, and is most unlikely to change.

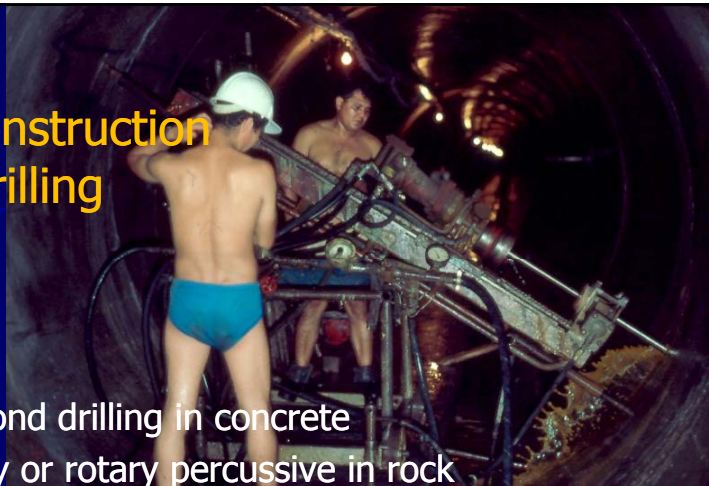


3. Construction

3.1 Drilling

Then:

- Diamond drilling in concrete
- Rotary or rotary percussive in rock
- Deviation monitoring (< 1 in 100)
- Pressure grouting
- Maintain full logs



3.1 Drilling

Now:

- Diamond drilling only for reinforced concrete or very weak structures
- Use down-the-hole hammer
 - Deviation control
 - Speed
 - Vibrations/pneumatic fracture
- MWD



3.2 Water Pressure Testing

Then:

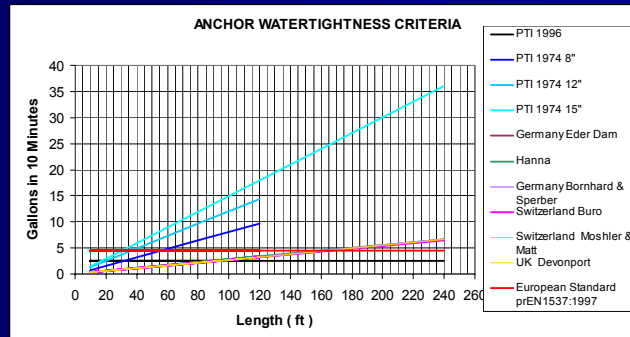
- Full length
- 0.5 gpm at 60 psi
(more typical
0.001 gal/inch
diameter/ft/min
at 5 psi)
- Very conservative
criterion



3.2 Water Pressure Testing

Now:

- Knowledge of fissure control on permeability
- 2.5 gal at 5 psi excess
- Testing of corrugated protection also



3.3 Grouting



Then:

- Proprietary non-shrink grout for first stage
- Water:cement ratio ≤ 0.45
- Pre-construction testing
- High speed, high shear mixer
- Tremie grout



1960s – 1970s Bare Strand/Wire Throughout



- Tendon proposed/selected by Contractor/PT Supplier (wire, strand, bar).
- Grout conceived to be the only protection: 2 stages essential.
- Fully bonded, and so no long-term load monitoring capability.



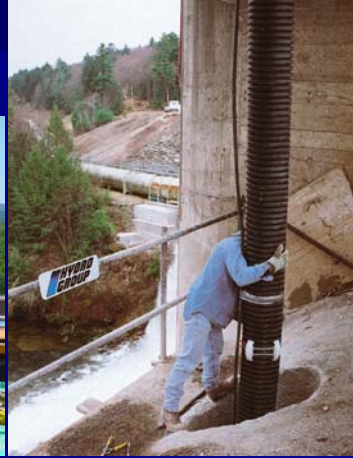
1970s – 1980s

Greased and sheathed
free lengths, bare
strand on bond length.



1980s Onwards

Corrugated Sheathing on Bond Length (1980s) Extending to Full Length Protection by 1990s



Greased and sheathed protection on individual strands, permitting single stage grouting.



1990s Onwards

Epoxy-coated and filled strand with or without grease sheathed free length. Typically require special handling and installation methods.

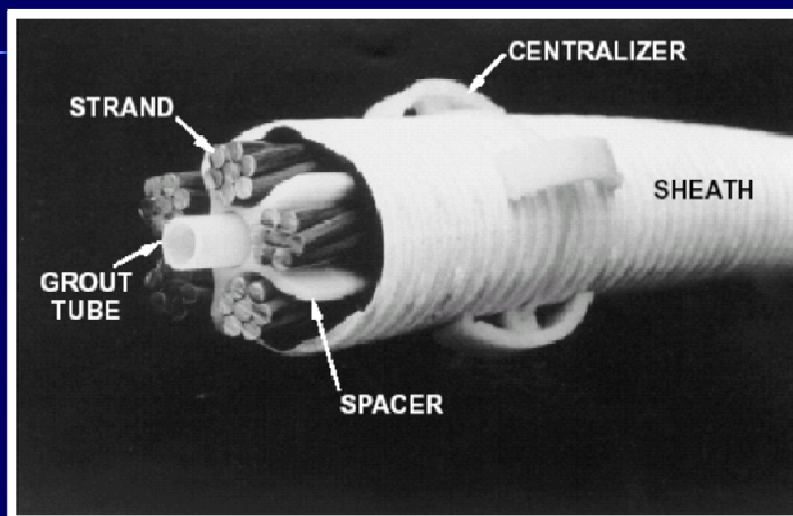


Corrosion Protection Requirements

CLASS	PROTECTION REQUIREMENTS		
	ANCHORAGE	UNBONDED LENGTH	TENDON BOND LENGTH
I ENCAPSULATED TENDON	<ol style="list-style-type: none"> 1. TRUMPET 2. COVER IF EXPOSED 	<ol style="list-style-type: none"> 1. GREASE-FILLED SHEATH, OR 2. GROUT-FILLED SHEATH, OR 3. EPOXY FOR FULLY BONDED ANCHORS 	<ol style="list-style-type: none"> 1. GROUT-FILLED ENCAPSULATION, OR 2. EPOXY
II GROUT PROTECTED TENDON	<ol style="list-style-type: none"> 1. TRUMPET 2. COVER IF EXPOSED 	<ol style="list-style-type: none"> 1. GREASE-FILLED SHEATH, OR 2. HEAT SHRINK SLEEVE 	GROUT



PTI Class I Bond Zone



Anchor Inspections



4.0 Evolution of Stressing and Testing

1974:

- Progressive simple loading to 115% Design Working Load (to maximum 80% GUTS)
- Alignment Load of 10% Test Load
- No cycling
- Very little data recording required or analysis described (Read extension only at Test Load)
- Lock off at 50 to 70% GUTS
- Lift off test
- No creep test



Stressing and Testing

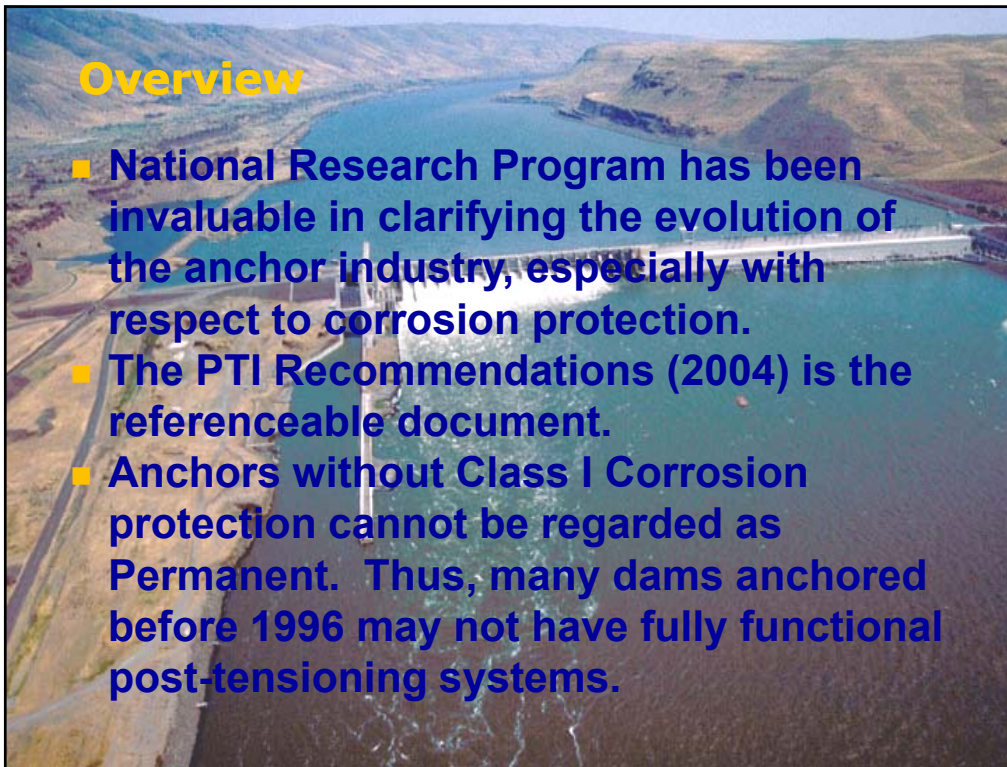
2004:

- Proof and Performance Tests
- Analysis of elastic movement data
- Creep testing: short and extended
- Lift off testing
- Lock off $\geq 60\%$ GUTS
- Special provisions for epoxy coated strand
- Clear acceptance criteria and “rework” guidance



Overview

- National Research Program has been invaluable in clarifying the evolution of the anchor industry, especially with respect to corrosion protection.
- The PTI Recommendations (2004) is the referenceable document.
- Anchors without Class I Corrosion protection cannot be regarded as Permanent. Thus, many dams anchored before 1996 may not have fully functional post-tensioning systems.



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