

# **Rock Anchors for Dams: The Preliminary Results of the National Research Project**

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## **Abstract**

Rock anchors have been used to stabilize dams and appurtenant structures in North America for over three decades. During this period several hundred projects have been conducted with an estimated total cumulative value of around 1 billion dollars. The new National Research Program has been funded by private industry and trade/professional associations. Prime goals are to a) produce a definitive and detailed list of all the North American dam anchor projects, b) analyze special test programs, and c) trace the evolution of practice via an analysis of codes and specifications,

This paper presents the preliminary results of this study, which is set to conclude in December, 2005.

## **1. Background to the Study**

The history of the use of prestressed rock anchors to stabilize concrete dams and their appurtenances extends to the early 1970s in North America. Extending recent studies dealing only with epoxy-coated strand tendons (Bruce, 2003), it is possible to estimate that in that period literally hundreds of projects have been undertaken with their combined costs in the region of 1 billion dollars.

Over the last few years, the authors have tried to secure funding for a National Research Project dealing with the use of rock anchors for dams. By early this current year, sufficient funding had been put in place to allow Phase 1 of the effort to commence. This funding was provided by Japanese-owned steel strand manufacturers (Sumitomo (SEI) Steel Wire Corp. and Sumiden Wire Products Corporation); Boart Longyear, an international drilling company; and the Industry Advancement Fund of ADSC: The International Association of Foundation Drilling. In addition, the authors' companies each pledged the services of their respective staffs, without charge, to the project. Dam-related bodies in North America, including ASDSO, CDA, USSD and certain government agencies have expressed interest in and support for the project.

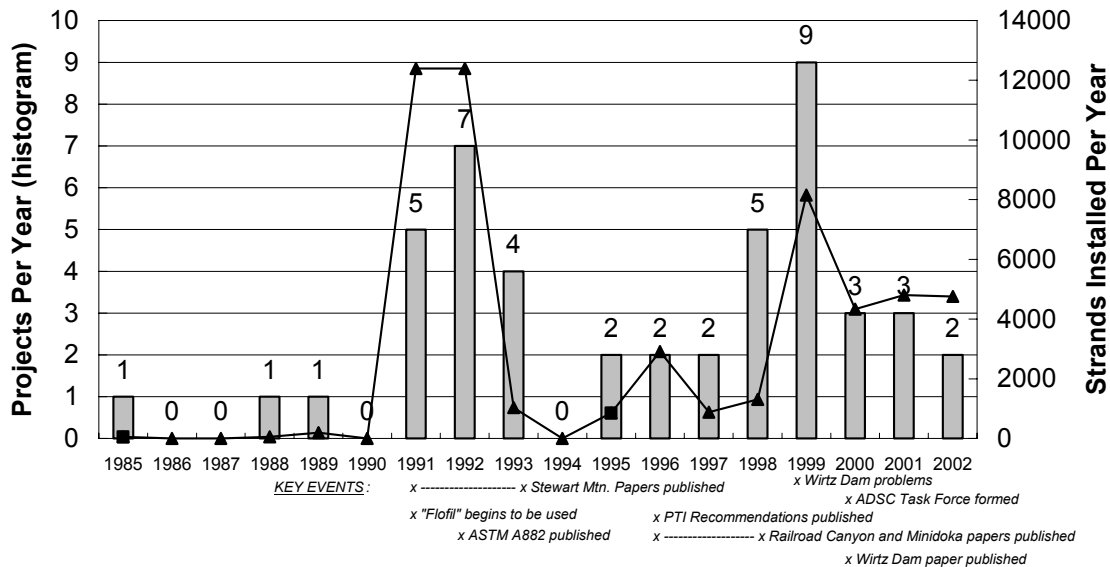
The concept of conducting such a study arose out of the impact that the above-referenced study on epoxy-coated strand tendons has had on the use of that material in anchors. Although such strand had been used in major dam anchor projects since 1991 (Bruce and Bianchi, 1992), growing concerns in the industry regarding certain behavioral characteristics of epoxy-coated strand led to a crisis of confidence in its use, and to potential users refusing to specify it. Hence, by 2000, use was declining, and the efficacy of rock anchors as a reliable and cost-effective dam remediation tool was being challenged. The Epoxy-Coated Strand Task Force established by ADSC conducted a detailed investigation of all epoxy-coated strand projects for dams which had been conducted to that time. This study was able to rationalize the technical causes for concern, and these conclusions heavily influenced the complete rewriting of sections of the Post Tensioning Institute's Recommendations for Rock and Soil Anchors (2004).

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In addition, however, the study was able to generate statistics of usage (e.g., [Figure 1](#)) which proved to be of interest and value to industry: potential users could gain comfort that so many projects had been successfully completed, while specialty contractors at last had some firm basis upon which to base strategic planning projections.



**KEY TO GRAPH:**

- Histograms show number of projects per year
- Strands installed per year:
  - Approximated and/or estimated quantities
  - ▲ Quantities determined more closely

[Figure 1](#). Epoxy protected strand usage for prestressed anchor applications, United States.

During the Task Force’s researches, it appeared that the epoxy-coated strand market accounted for perhaps about one-third of the total dam anchor market in the 10 years or so encompassed by its study. Simple projections therefore led to estimates of the total numbers of structures which had been remediated in this way since the early 1970s.

The authors therefore felt that a new study, covering all types of dam anchors, would be of considerable value and interest to the dam community in North America, as well as providing a unique industry survey of international standing and benefit. Such a study involves collecting information from contractors, suppliers, consultants and owners. Investigations of this nature typically provide unexpected “gems” in the form of reports of special test programs and long-term monitoring projects, the results of which have never been published, either through reasons of security or simply an unawareness of their significance to the industry at large. Furthermore, it may be expected that the research would uncover the original project plans and specifications, which clearly illustrate the evolution of practice over the years. In this regard, the authors have obtained copies of anchor “recommendations” dating from September, 1974 (Prestressed Concrete Institute), through the four editions of the Post Tensioning Institute’s Recommendations, concluding in 2004.

With the funding currently available, it is expected that (i) a complete project database can be compiled, and (ii) a plethora of original reports on test programs and plans and specifications can be collected. However, a comparative analysis of the various successive sets of Recommendations, and a detailed review of the test programs, plans

and specifications will constitute the goals of a second phase of the program which will require additional funds.

## 2. Scope of the Study

At the USSD Conference in Atlanta, GA in May, 1999, a session was held dealing with the various dam safety programs in place nationwide. The following provides statistics to illustrate the scope of the current research effort. Presentations were made by senior representatives of each body.

- TVA. Responsible for 54 dams and 14 locks, built from 1910 to 1975. No major modifications have been found necessary on 31 dams.
- USACE. Of the 100,781 dams inventoried by USCOLD in 1997, 1,586 were over 30 m high, and 6,389 were over 15 m. The Corps operates 570 structures of which 37 are concrete dams and 38 are combinations. This figure excludes 218 Army, 16 Navy and 25 Air Force dams, and 133 others turned over to other parties.

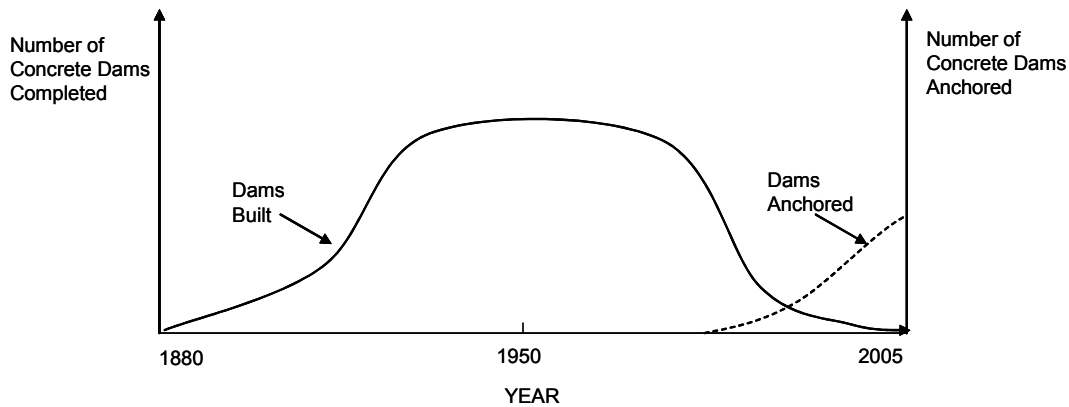
Of the Corps dams, 84% were completed from 1930 to 1980, and 60% from 1950 to 1980. In 1998, 167 dams were over 50 years old, and 32 were over 75 years old. The average age then was 43 years. A new inventory was planned in 2000.

- FERC. Regulates 2,524 dams, of which:
  - 60% were over 70 years old
  - 34% were over 100 years old
  - 702 were classified as High Hazard
  - 273 were classified as Significant Hazard

In 1999, 162 new modifications totalling 1.11 billion dollars were underway. Each year there were estimated to be 2,800 inspections and 100 ongoing modifications.

- Bureau of Reclamation. Owns 362 High and Significant Hazard dams out of the total of 457 dams and dykes. Average age (again in 1999) was 54 years. About two-thirds of the structures are now operated and monitored by local authorities.

These statistics are both very revealing, but also very challenging from the researchers' viewpoint. Assuming that there are, in fact, around 100,000 dams in the U.S., then the combined number about which good data should readily exist and are easily analyzed (i.e., from TVA, USACE, FERC, and Reclamation) is barely 4% of the total. Furthermore, initial studies of these lists and databases reveal obvious errors in the classification of certain dams well known to the authors. Thus the goal of trying to identify the total number of concrete structures which exist and which could potentially be anchored is proving very difficult to reach. However, these preliminary data do confirm the overall picture of our major dams having an average age in excess of 50 years. With this increasing dam age, and the natural tendency for safety evaluation criteria to become more rigorous, it can reasonably be expected that the need to provide anchors to remedy overturning, sliding, raising, seismic effects, spillways and abutment stabilization will continue to exist. Firm data, however, are necessary to allow project data and dam construction data to be quantitatively compared in the fashion of Figure 2, and every practical step will be taken to finally collect the data.



**Figure 2.** Concept of graphically comparing frequency of concrete dam construction and frequency of dam anchoring projects. The “shape” of the respective curves should permit a logical basis for predicting the likely number of future anchor projects.

### 3. Sources of Data

Data are to be compiled by a number of parallel tasks:

- Direct contact with industry sources, in a sequence designed to progress from the general to the particular, viz, first tendon suppliers, then specialty contractors, owners and consultants, and finally “industry at large.”
- Literature search of published papers.
- General requests for data at conferences dealing with dams, and in related magazines ([Appendix 1](#)).

### 4. Database Structure

A web-based database, accessible to all the research team members, is being developed. Each case history is to be numbered, and separate electronic/paper files are to be created containing the data from each project. Each file will contain data in the following major groups:

1. General information: Details of dam (i.e., location, type, geometry, reason for anchoring) and anchor program (e.g., date, contractor, procurement method, layout). Summary of geology.
2. Anchor details: Number, length, capacities, diameter, protection details, construction data.
3. Additional information available: e.g., plans and specifications, details of special preproduction testing or long-term monitoring programs.

### 5. Preliminary Results

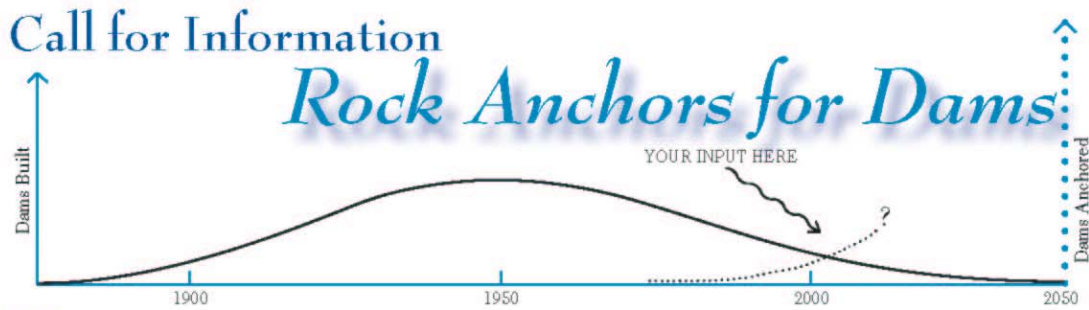
The “first cut” of information so far obtained from the tendon suppliers and contractors indicates we have found about 190 case histories, dating back to 1972. Understandably, it appears that most is known of the more recent projects which

tend to have been better documented (for corporate marketing efforts), and for which construction records are still physically available. Particularly encouraging has been the willingness of all the parties listed in Section 3 above to make data available, while the response to the appeals for information circulated in conferences and in publications has just begun to bear fruit. Phase 1 of the project is projected to be completed in December 2005. It is intended that much of the “field work” will be conducted prior to mid-September 2005, ensuring that a report of the draft findings can be presented verbally in this conference.

### **References**

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2. Bruce, D.A. and R.H. Bianchi. (1992). “The Use of Post-Tensioned Tendons on Stewart Mountain Dam, Arizona: A Case Study Involving Precision Drilling.” Proc. 2nd Interagency Symposium on Stabilization of Soils and Other Materials, Metairie, LA, November 2-5, pp. 5.39-5.54.
3. Prestressed Concrete Institute (PCI). (1974). “Tentative Recommendations for Rock Anchors.
4. Post Tensioning Institute (PTI). “Recommendations for prestressed rock and soil anchors.” First edition–1980; Second edition–1986; Third edition–1996; Fourth edition–2004; Phoenix, Arizona.

## Appendix 1



Post-tensioned rock anchors have been used in North America dam projects for about 30 years. In the last decade alone, the estimated value of anchoring work for dams is around \$500 million. As the ages of our dams increase, and advances and reassessments continue in dam safety analyses, the number of dam rehabilitations continues to grow. Despite proven successful case histories, reservations remain in certain quarters about the acceptability of rock anchors as a long-term engineering tool. Most concerns seem to revolve around their long term performance characteristics,

usually related to the corrosion susceptibility of the steel of the tendon.

The actual practices and procedures used for the design, construction, testing, and monitoring of anchors have varied from agency to agency and district to district over the years. While many published case histories exist, a wealth of unpublished data resides in the archives of owners, engineers, regulators, contractors, and suppliers. This project begins with a national survey of practice to collect data on every dam anchoring project conducted in North America.

Please join this effort. Help us collect the information requested by providing case study information.

### Research Outline.

Phase I (January through December 2005):

Collect data and compile initial database. Analyze type, age, and nature of existing concrete dams. Compare anchor statistics with dam statistics.

Phase 2 (January 2006 to December 2007):

Compile final database and analyze "special information" sources in detail. Historical evolution of Specifications. Preparation of Design and Construction Manuals. Organization of Short Courses/Workshops.

### Benefits of this Project.

- Increased confidence in the design, specification, construction and long-term performance of anchors in dams.
- Continued growth in the number of projects undertaken.
- Compilation of historical statistics and on the concrete dams themselves will permit industry to judge quantitatively the likely "shape" of the market in years to come.
- Archiving of institutional memory now diminishing at an accelerating rate due to retirement and corporate restructuring.
- Reference source for owners considering major anchor projects.
- International promotion of North American engineering skills over a thirty-year period.

### Requested Information.

Technical papers or other case history information detailing dam anchor projects in the U.S.

- Classification data on dam
- Classification data on the anchors (scope)
- Details on number of anchors, loads, lengths, etc.
- Details on corrosion protection
- Details on long-term observation, special tests, problems, etc.

The project is sponsored by:

Association of Drilled Shaft Contractors (ADSC)  
Freese and Nichols, Inc.  
Sumitomo (SEI) Steel Wire Corp.

Boart Longyear  
Geosystems, L.P.  
Sumiden

The project is supported by:

Association of State Dam Safety Officials (ASDSO)  
Deep Foundation Institute (DFI)  
U.S. Army Corps of Engineers (USACE)

Post-Tensioning Institute (PTI)  
U.S. Society on Dams (USSD)  
U.S. Bureau of Reclamation (USBR)

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