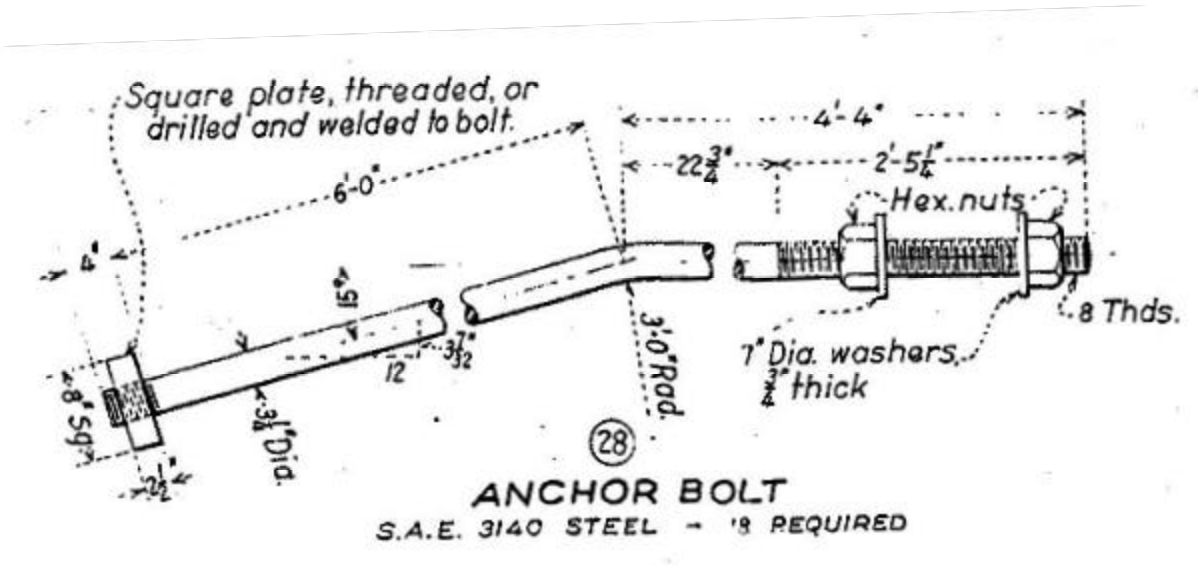
RECLAMATION
Managing Water in the West

MERL-04-12

Developing NDT Methods to Evaluate Large Anchor Bolts



U. S. Department of Interior
Bureau of Reclamation
Materials Engineering and Research Laboratory
Denver, Colorado

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Introduction

Established in 1902, the Bureau of Reclamation (Reclamation) is best known for the dams, power plants, and canals it constructed in 17 Western states. These water projects led to homesteading and promoted the economic development of the West. Reclamation has constructed more than 600 dams and reservoirs, including Hoover Dam on the Colorado River and Grand Coulee on the Columbia River.

Reclamation has built a number of dams that use large anchor bolts to support large spillway gates. These bolts measure up to three inches in diameter and are over 10 feet long. Many of them were installed more than 50 years ago. Having been in place for half a century or longer, it is imperative to find a non-destructive method to determine the load-carrying capacity of these bolts. No methods currently have been identified.

Large anchor bolts are used on a wide variety of infrastructures including dams, highway structures, electrical towers, large tanks, nuclear power plants, foundations, and mining.

The absence of having a method to determine the load-carrying capacity of large anchor bolts has lead to the use of unsupported conjectures about the load carrying capacity of these bolts. This can result in the replacement of bolts that are satisfactory and, worse, leave untouched bolts that are prepared to fail.

Addressing the Problem

To address this dilemma, Reclamation formed a research consortium under the auspices of the American Concrete Institute's Strategic Development Council, to investigate nondestructive testing (NDT) methods for determining the in-place load-carrying capacity of large anchor bolts cast in concrete. This consortium consists of partners interested in evaluating various NDT methods for solving this serious and imminent problem. Each partner provides its own funding to support the consortium. For a list of the members of the consortium, please refer to Appendix B.

The goal of the consortium is to find a nondestructive testing procedure that can determine the load-carrying capacity of large anchor bolts. This procedure should be able to accomplish this while only accessing one end of the bolt, and should be capable of measuring a 10 percent loss in cross-sectional area within the bolt. Any damage to the bolt is expected be caused by corrosion.

Current evaluation methods consist of "lift-off" tests, where a jack is used to pull the end of the bolt and measure the amount of movement. This is a destructive test, inducing loss of bond between the bolt and the surrounding concrete.

The NDT of Large Anchor Bolts Research Consortium believes that the best method for solving this problem is for the members of the industry to work together to find a solution to this problem. It is unlikely that any single organization has the resources or funding to develop a suitable NDT procedure on its own. It is proposed that the interested parties work together, each organization taking a bite of the apple, working with the consortia to ensure that we are not duplicating efforts.

Currently, the Consortium is reviewing testing procedures proposed by:

- Pacific Northwest National Laboratories
- Southwest Research Institute

Both of these procedures are still under development. They are not ready to deploy for field trials, let alone ready for commercialization and acceptance by the structural-engineering industry.

The Consortium will promote research in this area by uniting industry partners that are willing to fund work with experienced researchers capable of advancing the state of the art. We believe that it will be possible to combine funding from various sources. The Consortium will continue its efforts in bringing attention to this problem so that all interested participants are working together.

In addition, the Research Consortia will be forming a Second Party Evaluation Program that will provide researchers and funding agencies with an objective evaluation of NDT methods for large anchor bolts.

The first step of this program will be to determine the most likely failure modes based on historical evidence and structural analysis. This will included: materials used, date installed, installation methods, protection methods and any problems noticed so far. Cause of damage should go beyond corrosion and include other factors like fatigue loading. Using this information, we will design and build a testing program that will provide researchers with problems similar to those found in the field, and provide enough information that probability of detection curves can be developed.

Related Incidents

Large anchor bolts are used on a wide variety of infrastructures including dams, highway structures, electrical towers, large tanks, nuclear power plants, foundations and in mining.

On highway projects, large anchor bolts are used to support steel beams, girders, trusses, and large road signs. These anchor bolts primarily provide support for wind loads. A significant issue is failure due to fatigue loading, (Texas DOT Bridge Design Manual, December 2001). Fatigue strength is significantly lower than manufacture-specified strength. In response to this problem, Florida DOT requires six to eight bolts to provide redundancy in case one of the bolts fails.

Large anchor bolts are also used to hold down power transmission towers and in radio tower reaction blocks. Two failures of note are a radio tower in Cedar Rapids (http://www.wje.com/projects_8.html) and a parachute tower in Oklahoma, (http://www.stormtrack.org/library/damage/utlizat.htm).

The nuclear power industry uses large anchor bolts in a number of ways. With their higher quality control inspections, they have found anchor bolt problems including anodic corrosion occurring between zinc and steel in presence of water, known as hydrogen embrittlement (http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0933/sec3/029r2.html). They also found anchor bolts that had a significantly lower tensile strength than was specified by the manufacture (http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1986/in86094.html).

Large anchor bolts used in mining and foundations are also known as rock anchors. Part of the anchor is bonded to rock or concrete by cement grout, or resin, or is fixed by a mechanical anchor. The upper portion of the bolt is left un-grouted until after the bolt is loaded. Then it is encased in grout to provide protection against corrosion. Rock bolts are used in retaining walls, tunnels, mines, slope stabilization, and rock fall protection.

Most of the recorded failures for foundation anchor bolts have occurred in mining applications, primarily because failures in other locations are not visible. (http://www.cdc.gov/niosh/mining/pubs/pdfs/2001a-138.pdf)

Conclusions

1. The possible failure of large anchor bolts is a problem that affects a number of very different infrastructures, including dams, large tanks, tall towers, nuclear power plants, foundations, and mines.

2. Current evaluation methods are not capable of accurately determining the load carrying capacity of these large anchor bolts.

3. It is unlikely that any single organization has the resources or funding to develop a suitable NDT procedure on its own.

4. It is proposed that interested parties work together, with each organization "taking a bite of the apple," working with the consortia to ensure that we are not duplicating efforts

5. The research consortia will continue its efforts to promote research to solve this problem, and will provide a second-party evaluation program to evaluate proposed nondestructive methods.

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Appendix A: Figures

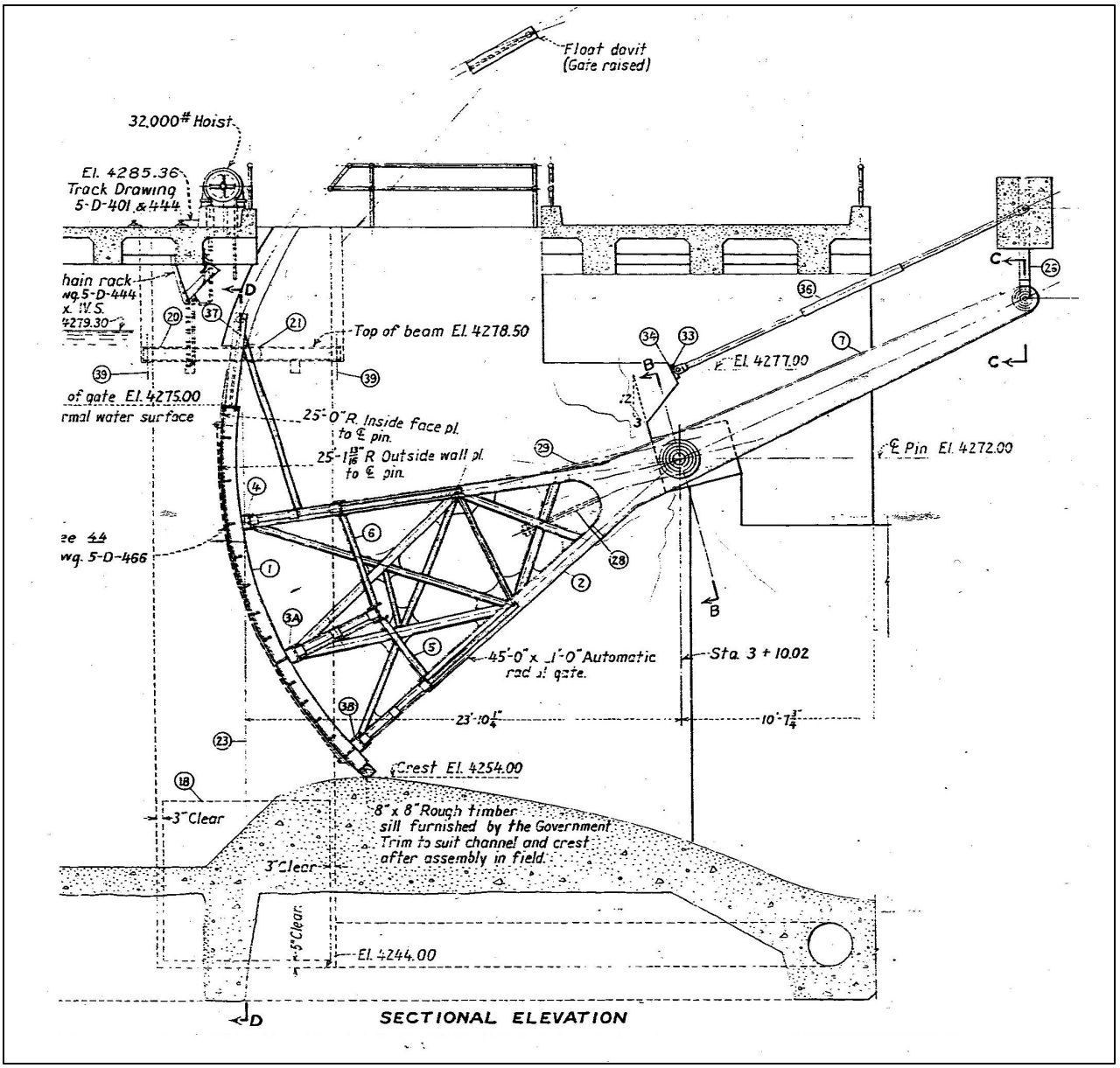

Figure 1. Many of Reclamation's dams have radial gates that control the flow of the water through the spillway. The gate rotates around the hinge pin, shown as the "bull's eye" in the center of the figure.

Figure 2. Photograph of a radial gate taken from the downstream face. The radial gate rotates on two arms. Each arm rotates around a hinge pin. The white arrow points to one of the hinge pins.

Figure 3. This photograph shows the top of one anchor bolt, just behind the hinge pin.

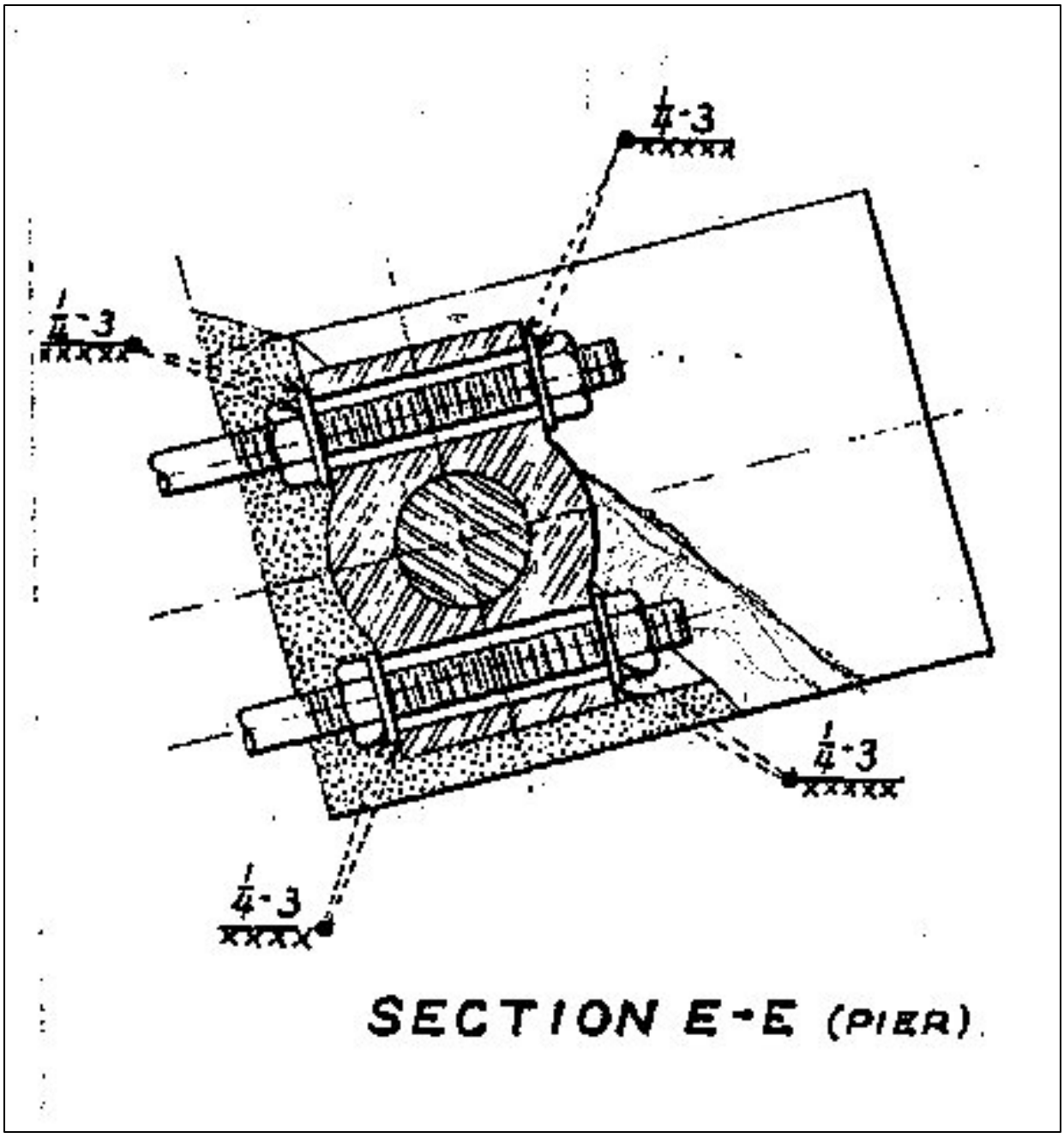

Figure 4. This cross-section drawing shows how the hinge pin bearing is anchored into the pier wall. Only one of the six anchor bolts is exposed, the others are completely buried in the concrete.

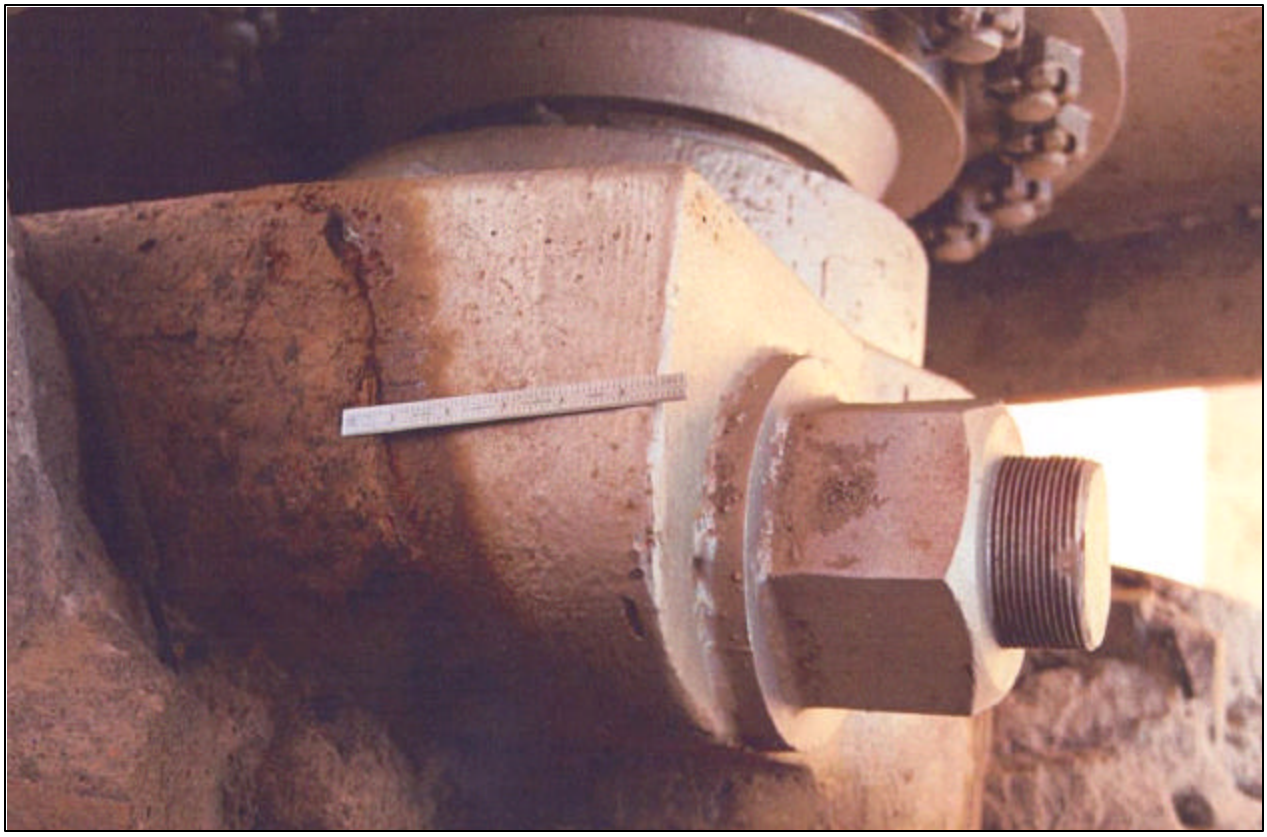

Figure 5. This photograph shows the end of the hinge pin bearing. Only one of the six anchor bolts is exposed

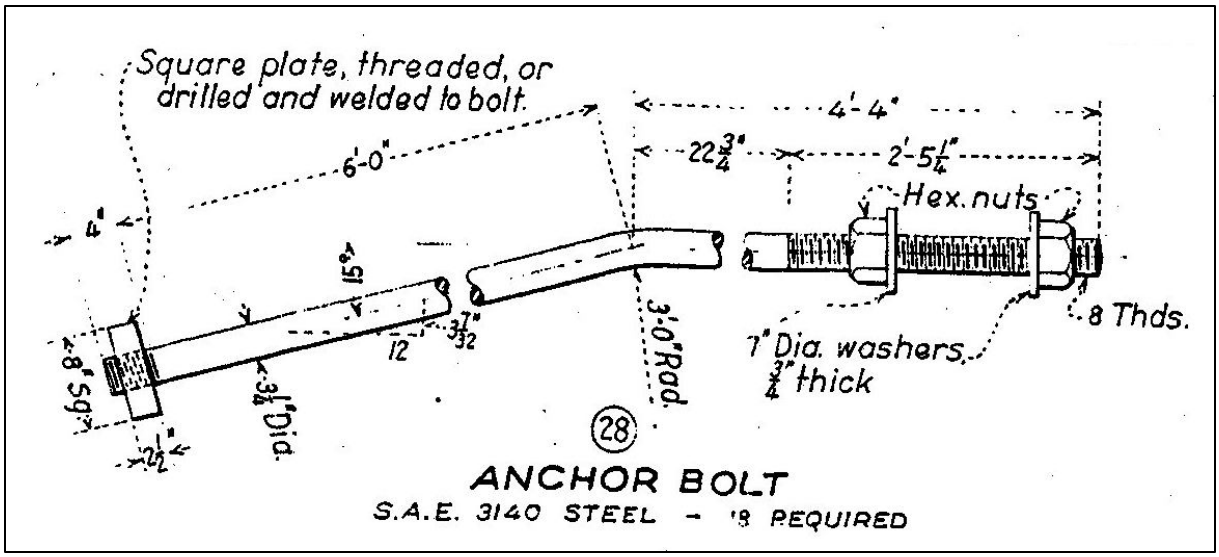

Figure 6. This drawing shows typical anchor bolt detail. The anchor bolt is over 10 feet long and 3.25 inches in diameter. Some bolts are straight.

Appendix B: Consortium Members

The following list provides the names for members of the Consortium on Nondestructive Testing of Large Anchor Bolts.

Member	Position
Bill Kepler	U.S. Bureau of Reclamation
Robert D. Finfrock	Finfrock Design
Jim Olshefsky	ASTM International
Tony Fiorato	Construction Technology Labs
Narendra Gosain	Walter P. Moore Structural Diagnostics
Jorge I. Calvo	Ulma Form Works, Inc.
Vilem Petr	Colorado School of Mines
Tony Murray	Restruction Corp.
Bernie Hertlein	STS Consultants
Yazmin Seda-Sanabria	U.S. Army
Enrique Matheu	U.S. Army
Adrian Ciolko	Construction Technology Labs
Allen Davis	Construction Technology Labs
Richard Klingner	University of Texas
Wayne Holliday	American Society for Nondestructive Testing
Henrique Reis	University of Illinois - Champaign-Urbana
Doron Kishoni	Business Solutions- USA
Robert E. Green, Jr.	Johns Hopkins University
William Dover	TSC Inspection Systems
Herman Graves	NRC
Stephen Meier	Tank Industry Consultants, Inc.
Keven Heinert	Williams Forms
Leonard J. Bond, Ph.D	Pacific Northwest National Laboratory
Steve Ziola	Digital Wave
Bob Mast	Berger / Abam Engineers