Epoxy Protected Strand

A Historical Review of its Use for Prestressed Rock Anchors Part II

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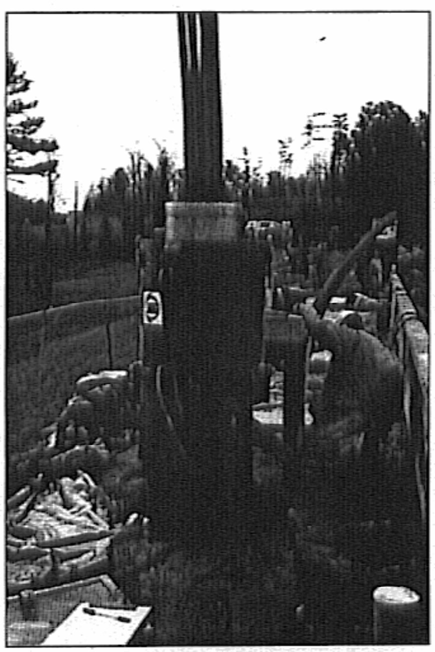
It is hoped that this article will stimulate critical debate and attract more data. It is not the intention of this article to either promote or discourage the use of epoxy protected strand, but to review the issues surrounding its use, especially in high capacity tendons for dam rehabilitation.

History and Usage

Based on a survey of suppliers, owners, consultants, and contractors, supplemented by published data and the proceedings of successive Task Force meetings, the authors have generated the data shown in Table 2 and Figure 1 (see November issue). During the period from first usage in 1985 to early 2002 there would appear to have been 47 projects (some being consecutive, but separate contracts on the same structure), of which 33 were related to dam or hydro schemes. During the period from 1990 to 2001, it is estimated that between 100 and 120 dams and hydro facilities were repaired by prestressed rock anchors in North America, at a total price of $200 to 300 million. Therefore it would seem that, overall, around 30% of the projects involved epoxy protected strand with an estimated 25% of each project's price being linked directly to the provision of the tendon and its hardware (i.e., $15 to 23 million). Figure 1 does illustrate, however, a smaller but relatively constant use of epoxy coated strand, following its peak of 9 projects in 1999.



Anchor undergoes rigorous testing.

In contrast, Kido (2002) notes that in Japan, Sumitomo Electric Industries Co., Ltd. started using epoxy protected strand ("Flotech") in 1991, the main applications being for ground anchors and post tensioned bridges. Statistics through 2000 on over 700 projects are summarized in Table 3.

Forty-three of these projects involved dam stabilization. At an average of 20 m per strand, one may assume that a total of around 30,000 strands have been installed, stressed, and locked off. There are no reports of problems in the short or long term. A few projects (for bridges) have been undertaken in Korea and the Philippines. No other foreign applications have been recorded to date.

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Review of Published Data

Since 1991, there have been numerous publications on aspects of the use of epoxy protected strand, mainly in the form of project case histories. Key points from these papers are summarized in Appendix 1. These papers in fact provide details on 24 projects excluding only one – the cable stay construction of the Alton Clark Bridge, Illinois – not included in Appendix 1 as it was not a geotechnical application. A close examination of the case history data reveals a very interesting pattern (Table 4), in that of the 24 projects that were detailed in any way:

- Seven reported strand slips through the wedges on a limited number of early tendons.
- One other reported "excessive

(continued on page 25)

Table 3. Data on Japanese usage of epoxy protected strand in ground anchors.

YEAR	NUMBER OF PROJECTS
1991	1
1992	3
1993	1
1994	0
1995	6
1996	17
1997	47
1998	89
1999	266
2000	303
Total	703 projects for a total of 606,000 lin. m.

Note: "Super Flotech" introduced in 1999 and now dominates usage.

creep" (which could, however, have been due to the inherent properties of the material or inaccuracies in load measuring). Slippage of one or more strands after Lock Off is considered most unlikely to have occurred without being noticed.

- At least three took careful preemptive steps (or special monitoring) to successfully avoid short and long term problems.
- Two referred to "previous problems" having been reported on other projects.
- In addition, the authors are aware that examples of strand slippage at Lock Off were noted (but not published) on a few strands at Stewart Mountain, Tolt River, High Rock and Rocky Creek Dams: all were simply remediated by thorough cleaning of the wedges and their seats.

The following conclusions may be drawn:

1. "Excessive" short term creep, relative to contemporary *PTI Recommendations* (1986) for bare strand, was first recognized in 1991, but was rationalized after laboratory testing, first described in 1994 (Bonomo).
2. Projects undertaken with strand manufactured in 1999 and/or 2000 seem to have had most slippages, following initial problems in the early 1990s, possibly due to stressing techniques.
3. Regarding those projects where strand slippages were recorded, these were typically only found during the "learning curve," i.e., on the first few anchors stressed. For example, wedges contained grout, rust, or other debris, and the importance of accurate alignment was not fully appreciated. Problems were most prevalent where the work was conducted by contractors using the material for the first time. Modifications to construction/stressing techniques, allied to intensive monitoring were successfully implemented, although at Wirtz Dam the problems were more pervasive and took longer to resolve.
4. It is conceivable that site personnel – "in the heat of battle" – may have not noticed individual strand slippages after lock-off in other multistrand tendons. Such unrecorded slippages would account for the "excessive creep" observations noted by certain authors. However, it must be noted that losses of the order of 2 to 3% may in fact result from the natural relaxation losses, and that the dramatic nature of individual strand slippages make such events difficult to ignore.
5. It must be realized that the actual number of strands recorded as having slipped through the permanent wedges is a very small percentage of the total number of strands installed (perhaps about 0.1 to 0.2%). However, the technical, financial, and contractual impacts arising from the resultant project delays, and the general level of suspicion regarding the installed anchors, are disproportionally high.
6. In virtually every case, the failures have been ascribed to inefficient seating of certain designs of wedges, i.e., their inability to quickly and uniformly bite through the epoxy and firmly engage the underlying steel. A detailed review of the literature dealing with the projects, and the forensic testing conducted in association, leads to defining certain broad groups of causes. It would seem that on any given project, failure is a combination of some or all of these individual factors, in proportions which cannot always be determined. Critical variations in aspects of material quality and construction processes can create a marginal environment on any given project wherein even small or otherwise unimportant details can prove sufficient to catalyze a slippage. In other words, the material and its associated lock off hardware are not as forgiving as bare strand to site practices and so special steps and care must be taken to assure reliable performance. Broadly speaking, the causes of problems may be summarized as follows:

a) The nature of the product itself – being epoxy coated and filled, there will always be a tendency for higher short-term load loss to occur due to the plastic properties of the coating, even under the best of circumstances (as acknowledged by PTI, 1996). This can be accommodated by revising short term creep acceptance criteria. Also the higher creep losses require their own acceptance criteria, and can actually be beneficial for the long term performance of the anchor. The initially reported creep losses will reduce the later occurring relaxation losses proportionally, allowing a higher design load, closer to the one for bare strand.

b) Manufacturing variations in the product – variations in epoxy thick-

(continued on page 26)

Table 4. Summary of published case history performance characteristics

PROJECT	YEAR	REPORTED PROBLEMS	COMMENTS
Stewart Mountain Dam	1991	No	Acceptable long term performance confirmed by monitoring
Mathis Dam	1991	Yes	"Excessive creep" reported
Martin Dam	1992	No	Special testing used to ensure acceptability
Byllesby Dam	1992	Yes	30% slippage on first three anchors due to misalignment and cleanliness issues.
Occoquan Dam	1992	Yes	Strand slippages on early anchors due to grout in wedges; excessive creep.
Saluda Dam	1995	No	–
Railroad Canyon Dam	1996	No	Special wedges used.
Alton Clark Bridge	1995	Yes	Early strand slippages, plus corrosion under epoxy (Flo-Bond).
Pardee Dam	1997	No	"Previous problems" referred to.
Minidoka Dam	1997	No	"Previous problems" referred to in paper relating to other projects.
Tolt River Dam	1998	No	"Minor flaking" above wedges; 2 strands slipped.
Lake Quinesec Dam	1998	No	–
Big Creek Bridge Piers 1 and 3	1998	No	–
Santeetlah Dam	1998	Yes	One strand on a vertical anchor slipped.
High Rock Dam	1999	No	–
Ribbon Bridges	1999	No	–
Bixby Dam	1999	No	–
Fern Canyon	1999	Yes	Strand slippages.
Wirtz Dam	1999	Yes	Strand slippages.
Lookout Shoals Dam	1999	Yes	Strand slippages, and corrosion concerns.
Pacoima Dam	1999	?	?
Cowan's Ford Dam	2000	Yes	Strand slippages.
Big Creek Bridge Pier 2	2000	No	–
Carquenez Bridge	2000	No	–

ness, homogeneity ("foaming" has been discovered on one company's product from 1999 and 2000), adhesion to the steel, and adhesion of grit to epoxy, will each affect lock-off effectiveness. Also flaws in the epoxy coating (apparently also related to foaming) can create gaps in the corrosion protection which will permit the steel to corrode and thus further impact epoxy adhesion. Repair of such defects can be done on site but is tedious and costly, and is impractical if steel corrosion has already begun. (Corrosion will further reduce the epoxy-steel adhesion.)

c) Tendon and anchor geometry – uneven seating of the individual wedge parts may occur due to "differential" friction during multistrand loading. This is exacerbated in inclined tendons where strands have not been completely straightened prior to grouting, in tendons which have been poorly sorted (with spacers/centralizers) in their free lengths, and in anchors where primary grouting has been conducted to within 10 feet of the top anchorage plate prior to stressing. Primary grouting should not be conducted within 35 feet of the head. As for bare strand tendons, strands should be loaded individually to Alignment Load to ensure even loading during subsequent multijack stressing.

d) Contamination of wedges and wedge holes – corrosion and dirt can build up on these vital components in the period between tendon installation and stressing. This is particularly significant in humid, dam environments, and is worsened by situations where inclined spillway anchors are inundated after installation. Such critical interfaces must be cleaned and lubricated prior to stressing. The strand should also be cleaned as far as practical. Also grit from the coating can clog wedge teeth if left in place during Performance Testing, further acting to prevent the essential "bite through" occurring into the steel. Preferably, final wedges should be placed only before the lock off process, or allowed to float freely above the wedge plate during the loading cycles. (There are significant advantages in having the anchor head assemblies fitted to the tendon prior to shipment to site.)

e) Misalignment – it is essential that all the stressing components, from tendon to jack gripper wedges are collinear, so eliminating the possibility of lateral loads preventing uniform and quick wedge seating.

f) Inappropriate anchor components – it is expressly recommended not to strip the epoxy in the stressing tails to allow the use of "conventional" bare strand wedges in the top anchorage. Special wedges designed to reliably bite through the coating and into the steel strand, and special wedge plates – all free of dirt and dust, and well lubricated – must be used.

Duties and Responsibilities of the Respective Parties

The authors believe that the responsibility for the past problems that industry has encountered should be shared by all parties – if not necessarily equally. Epoxy protected strand has been produced which has not always satisfied the challenges of field conditions and construction practices. Owners have perhaps been over eager to accept the financial benefits the product can afford, but have undervalued the concomitant risks. Designers have not always been systematically informed about load loss issues and so have not always specified realistic acceptance criteria. Post tensioning companies that assemble tendons have occupied a pivotal position (technically, financially, and contrac-

(continued on page 28)

tually) between manufacturer and contractor, but until recently, the majority has not consistently exerted the industry leadership their knowledge and experience would arguably merit. Contractors who have not taken the necessary steps in their construction techniques to accommodate the special aspects of epoxy protected strand have simply attempted to blame the other parties for problems subsequently found in the field. Codes, standards, and recommendations have not comprehensively protected the goals of all parties. Nevertheless, it is equally clear that the current reassessment of the issues has forged a new awareness in the industry, which, if appropriately exploited, can lead to mutual benefit.

Anchor Industry in General

1. Be aware of the types of problems which have occurred when using the material and have cognizance of remedial measures, options, or alternatives available. Also realize that different post tensioning systems exist and may provide different levels of performance.
2. Take a systematic and pragmatic view of the risk/benefit issues involved in the selection of the corrosion protection system, for each project.
3. Share fully and honestly all relevant experiences (good and bad) in an appropriate forum (e.g., ADSC Epoxy Coated Strand Task Force).
4. Promote and support the highest practical quality of manufacture and application via appropriate testing, and through revision and subsequent conformance with relevant recommendations and standards (e.g., ASTM A882, PTI, 1996). In this regard, it must be realized that a materials standard such as ASTM A882 will not cover handling and construction-related practicalities. The new supplement to the *PTI Recommendations* will address such issues.

Strand Manufacturer

1. Provide a consistent and reliable product conforming to all relevant codes, standards, and recommendations.
2. Knowing fully the "end use" of the product in such cases, provide all technical support to its clients in the development of appropriate tests and QA/QC methods (e.g., an adhesion test).
3. Immediately notify customers of any significant changes in the materials or details of manufacture which may potentially influence the product's ability to consistently satisfy project requirements.

Project Owner

1. Even as a "non-specialist" relying on the advice of others, become in advance, cognizant of the state of industry thinking.
2. Ensure that the highest standards of site inspection are provided, and that the supervisory personnel involved have clear mandates as to their limits of authority regarding issues in non-conformance to the specification.
3. Provide an unbiased forum to help resolve any issues which may arise, and be prepared to provide sponsorship of any forensic efforts which may be required. (In this regard, the attitude of the Lower Colorado River Authority during and after the problems at its Wirtz Dam, has set the industry standard.)

Anchor Designers and Specifiers

1. Where allowed by the Owner, offer Bidders the option of epoxy protected strand, or corrugated sheathed tendons – price and performance to decide.
2. Specify two-stage grouting. The second stage shall have a minimum length of 35 feet.
3. Specify special standards of care during tendon assembly, transportation, installation, grouting, and stressing especially for inclined anchors. In particular, the absolute cleanliness of the wedges and their anchor head pockets must be specified (especially for inclined anchors subjected to running water prior to stressing) together with appropriate use of spacer/centralizer units in the free length also.
4. Clarify precisely the liability of each party involved on the project, relative to the use of the product.
5. When assessing short and long term performance acceptance levels, be cognizant of the higher creep and relaxation losses inherent to epoxy protected strand. Specify short and long term load monitoring in excess of the minimum recommended by PTI. (This may require sheathing on the free length strand.)
6. Ensure that close and empowered independent site inspection is provided.
7. Specify exactly what will be expected of the contractor in event of "incidents."

Post Tensioning Companies That Also Assemble Tendons

1. For every delivery of strand, secure confirmation from the supplier that the product is in conformance with all relevant and contemporary codes, standards, recommendations, and specifications.
2. Obtain from the manufacturer any and all special test data (e.g., pullout tests, creep tests) which are required by the specification and/or the contractor, on a project-specific basis.
3. Exercise special care in the assembly, and transportation of the assembled tendons to avoid significant damage to the coating.

(continued on page 31)

Attention to fabricating details are essential for product dependability.

4. Provide only anchorage hardware which is fully appropriate to the material and the project conditions.
5. Provide only anchorage hardware which is fully appropriate for the stressing systems and methodologies.
6. Observe the provisions of all relevant codes, standards, recommendations, and specifications.
7. Communicate with contractor regarding the special issues governing the use of epoxy protected strand.

Anchor Contractor

1. Obtain all relevant certification and test data from tendon assembler, as required by the specifications and by the specific project requirements.
2. Be aware of all the potential causes of problems, and develop site practices to preempt them (from receipt of tendon to final anchor acceptance).
3. Observe the provisions of all relevant codes, standards, recommendations.
4. Observe the requirements of the specifications, as a minimum acceptable standard.
5. Provide only knowledgeable and experienced stressing personnel who have executed such work previously. (If not available, ensure that appropriate training or resources are obtained via the post tensioning companies)
6. Maintain full, frank, and informed technical dialogue with all parties at every phase of the project (from preconstruction submittals to final anchor report).
7. Inspect all tendons upon delivery to site and prior to and during installation so that any problems can be immediately referred to the tendon supplier.

Final Remarks

This article is written with the benefit of long hindsight, and so illustrates certain shortcomings in the way we in the anchor community have collectively addressed certain issues. While there is no systematic reason to doubt the ability of the anchors installed to date to satisfy the owners' goals – there is an almost overwhelming degree of redundancy in certain aspects of dam anchor systems – there is a clear need to improve current practice to eliminate the costly and controversial problems which have affected the construction phase of several projects to date.

Awareness of problems is the first major step in solving them, and in this regard, the activities of the Task Force of ADSC, have provided vital industry leadership. In addition to facilitating papers such as this, the Task Force is exerting an active and consistent influence on the *PTI Recommendations*, via the upcoming supplement, and upon the current version of the ASTM standard (ASTM A882/A882-96). As an example, the following items are understood to be approved for future incorporation (inter al.) in the revision of the ASTM standard:

1. Only epoxy coated and filled strand is recommended for use in anchors.
2. "Disbonding" is a term introduced to describe loss of adhesion between epoxy and steel.
3. Manufacturer to provide creep data on strand (at 80% GUTS) over periods of 10 minutes, 1 and 3 hours, in combination with relaxation test data.
4. A change in the permissible range of epoxy thicknesses from 25-45 mils to 15-45 mils has been approved. The thinner coating has been proven to afford adequate corrosion protection, seems to have a better and more consistent adhesion to the strand, and is more easily gripped by the wedges.

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Furthermore, the Task Force feels that more rigorous tests are needed to verify the adhesion of the epoxy to the steel and are investigating appropriate methodologies.

Readers of this article are strongly encouraged to provide critical comment and factual input so that a full and accurate document will ultimately be produced. Such a document will hopefully be beneficial to the interests of all parties in the dam anchor industry.

For a copy of the November issue of **Foundation Drilling** *magazine, contact Teri Dres at the ADSC office, 214-343-2091.*■