Epoxy Protected Strand

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

Collated by Dr. D.A. Bruce based on input from the ADSC Epoxy Coated Strand Task Force

*This is Part I of a two-part article that highlights the past, current, and the anticipated future use of epoxy coated strand for prestressed rock anchors. Part I provides a history of the use of the material for anchor projects in the United States. Part II will report on the activities and findings of the ADSC's Epoxy Coated Strand Task Force. It will appear in the December/January 2002-03 issue of **Foundation Drilling** magazine. (Editor)*

Introduction

Fusion bonded epoxy protected strand has been used in post tensioning applications in North America since 1983, with the first ground anchor project undertaken in 1985. The product has been used in dam anchor tendons since 1991. A recent and significant problem at Wirtz Dam, Texas has focused industry attention on vital issues relating to the production, testing, specification, installation, and stressing of the material. It is clear that this problem has raised questions in the industry regarding the use of the product, but the authors believe that through the development and application of appropriate codes, standards, recommendations, and specifications, the inherent advantages of the material can again be routinely exploited in sensible fashion for mutual benefit. The article provides a historical and technical overview of the use of epoxy protected tendons, primarily in dam rehabilitation.

Background

The process of applying fusion bonded epoxy coating to 0.6-inch diameter, 7-wire prestressing strand appears to have been developed commercially in 1981, following earlier experiences with epoxy coated reinforcing bar. According to Bonomo (1994), the product was first commercially used in 1983 to post tension a precast concrete floating dock in Portsmouth, Virginia. Until 1985, epoxy protected strand was used only in structural/building related projects. Early examples of its use include the Bayview cable stay bridge in Quincy, Illinois (1984) and post tensioned pier caps on I-495 in Rochester, New York (1988).

Although ground anchor practice in the United States has enjoyed a long, successful and internationally acclaimed reputation (Bruce, 1997) one area in which it differed from European concepts was in its somewhat more relaxed approach to corrosion protection. For example, what British practice (BS8081, 1989) regarded as single corrosion protection (i.e., the use of a protective corrugated sheath, grouted in situ) U.S. specialists typically referred to as double corrosion protection. The difference lay in the interpretation of the reliability of the grout in the bond zone as an acceptable layer of corrosion protection. Thus while the British tended not to count the grout as a reliable and permissible layer of corrosion protection since it could crack during stressing due to its strain differential with the far more elastic steel it encased, others disagreed. It was argued that any stress fractures would be of very small aperture, and that the highly alkaline environment of the grout would prevent acid corrosion of the steel – should it actually be exposed to direct contact with continually aggressive groundwater in any case. No case has been reported, nevertheless, of failure resulting from bond length corrosion in a properly grouted anchor.

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Around the same period in the late 1980s, U.S. contractors installing permanent multistrand ground anchors began to realize that the use of a corrugated plastic duct as corrosion protection over the bond length required special attention to construction detail during the grouting operation (e.g., tremie tubes inside and outside the sheath, grouted in careful sequence to avoid structural

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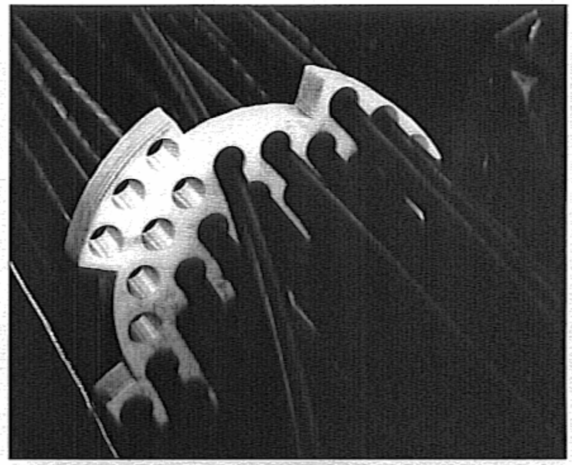
distress to the sheath due to differential fluid grout pressures); as well as demanding larger diameter drill holes to accommodate the tendon, the corrugated sheath, and the multiple tremie tubes with appropriate thicknesses of grout cover.

It was logical, therefore, that epoxy protected strand should become considered for strand tendons: it removed the necessity for a separate tendon protective encapsulating sheath, allowed hole diameters to be minimized, and simplified the grouting operation. Such construction efficiencies would have the potential to offset the far higher material costs of such strand. Its first use in an anchoring application was to stabilize the foundation of a private residence in Malibu, California, in 1985, while the first *major* anchoring project was a permanent tieback wall at the Los Angeles City Library in 1989. This followed a smaller similar project in Phoenix, Arizona, in 1988. However, little interest seems to have been generated within the ground anchor community during this period, and high capacity permanent anchors for high dams continued to be installed using only grout as the definitive (and sole) barrier to corrosion of the tendon in the bond length (e.g., Bruce, 1989).



Coated strand running through guide.

In contrast, the Bureau of Reclamation specified in 1990 (following 3 years of market research) the use of epoxy coated strand for the seismic rehabilitation of Stewart Mountain Dam, Arizona, incorporating long, high capacity tendons (Bruce et al., 1992). Here, the Bureau was concerned about the impact that such high, concentrated, compressive prestress loads could have on their tall, thin arch dam. They therefore mandated that the tendons should be installed, primary grouted, stressed, and then monitored (together with the structure) over a period of 90

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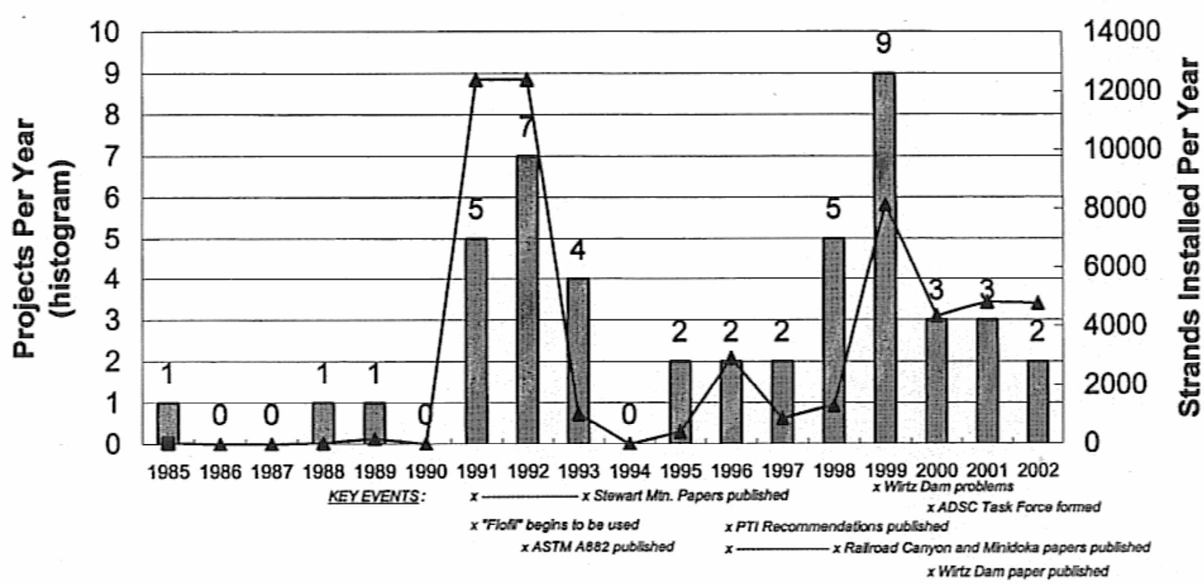

KEY TO GRAPH:

- 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.

days to assure acceptable performance of both anchors and structure. Given successful performance of dam (and anchors) under this new loading condition, the tendons would then have their free lengths grouted in a secondary operation. However, the structural engineers required, for seismic considerations, that the tendons be fully bonded by grout to the dam *in the free length also*: this meant that the tendon in the free length could *not* be protected conventionally over the 90-day observation period (i.e., by extruded or greased and sheathed, plastic coating) during which time there was considerable concern about the corrosive effect of the ambient conditions on the exposed, unsheathed tendon free length. The Bureau therefore specified epoxy coated strand ("Flo-Bond," from Florida Wire and Cable*) as the tendon material. The project was conducted expeditiously, and the case history was widely promoted by dam owner, anchor contractor, tendon supplier, and strand manufacturer alike. Industry was keen to emulate and take advantage of this success and many projects followed (Figure 1). By the end of 1991, "Flo-Bond" was replaced as the material of tendon choice by "Flo-Bond-Flo-Fill," a product wherein epoxy was also introduced around the central wire of each strand, to guard against the possibility of water "wicking" up the otherwise unfilled interstices surrounding the central wire.

In 1992, ASTM A882/A882M-92 "*Standard Specification for Epoxy Coated Seven Wire Prestressing Steel Strand*" was published, followed by a PTI publication, "*Guidelines for the Use of Epoxy Coated Strand.*" In a significant paper that did not receive commensurate attention, Bonomo (1994) further promoted the use of the material while strongly advising against stripping the epoxy coating off the strand in the stressing tails, a practice which was becoming common, especially on the earlier projects, mainly east of the Mississippi. He provided specific guidance on certain "unique properties" of the epoxy protected material:

A further goal of the ADSC Task Force has been to collect published and unpublished data regarding the historical size and value of the epoxy coated anchor tendon market over the years.

- **Relaxation:** Losses are higher than for bare strand. In a 1000-hour test at 70% GUTS, the loss in bare strand (low relaxation) was 1.5% compared to 4% in "Flo-Bond" and 5.2% in "Flo-Bond-Flo-Fill." Further, ASTM A882 specifies a maximum relaxation loss for epoxy filled strand of 6.5% over a 1000-hour period when held at 70% GUTS, while the corresponding value for bare strand is 2.5% (ASTM A416).
- Creep: For a short period of time during the load hold test, both types of epoxy strand "undergo creep at a rate appreciably greater than that experienced by uncoated strand." He did conclude, however, that the long term performance of the material "is not impaired by the initial creep, which can be allowed for in the design of the anchor." The initial creep that occurs during the load hold test will reduce subsequent relaxation losses.
- **Wedge Seating Loss:** At 3/4 inch, this loss is significantly higher than that of bare strand (3/8 to 1/2 inch) at 80% GUTS. Emphasis was placed on the merits of correct wedge design to assure proper seating performance at Lock Off.
- **Construction Issues:** Special care during handling, and installation was recommended, together with (routine) cleanliness of the anchorage hardware, and correct tendon/jack alignment (especially for inclined anchors).

During the period 1993 to 1995, the Rock and Soil Anchor Committee of the Post Tensioning Institute, under the chairmanship of **Heinz Nierlich**, drafted completely revised *Recommendations* later published in 1996. These *Recommendations* included a new and enhanced approach to corrosion protection (Nierlich and Bruce, 1997). In particular, the terms "Double" and "Single" Corrosion Protection were dispensed with, in favor of the less judgmental terms "Class I and II" levels of corrosion protection, as

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Table 1. Corrosion Protection Requirements as Recommended by PTI, 1996.

Class	Protection Requirements		
	Anchorage	Unbonded Length	Tendon Bond Length
I Encapsulated Tendon	1. Trumpet 2. Cover, if exposed	1. Grease-filled sheath, or 2. Grout-filled sheath, or 3. Epoxy for fully bonded anchors	1. Grout-filled encapsulation, or 2. Epoxy
II Grout Protected Tendon	1. Trumpet 2. Cover, if exposed	1. Grease-filled sheath, or 2. Heat shrink sleeve	Grout

summarized in Table 1. The acceptability of epoxy protected strand was thereby endorsed by the PTI Committee with respect to its corrosion protection capability.

The PTI guidelines for estimating creep in epoxy protected strand during the load hold test were in fact based on tests conducted by Florida Wire and Cable in 1993. The *Recommendations* consequently state, "The creep behavior of epoxy filled strand itself is significant and the measured anchor creep movements must be adjusted to reflect the behavior of the material. At a Test Load of 80% F_{pu} (GUTS), creep movements of epoxy filled strand are conservatively estimated to be 0.015% of the apparent free stressing length during the 6-60 minute log cycle, but may be higher than this value. For a Test Load of 75% of F_{pu}, this percentage can be reduced to 0.012%. These correction factors are based on limited laboratory tests, but appear to be reasonable based on field observations."

As described in the following sections, issues were encountered regarding the short term performance of a few anchors on certain projects in the early and mid 1990s. Construction deficiencies usually involving "first time user" contractors led to sudden slippage of strands through the wedges, resulting from tendon misalignment and/or dirty or grouted up top anchorage components. Creep losses beyond those allowed for in the then prevailing *PTI Recommendations* (i.e., the 1986 Edition) also created concern among owners otherwise acquainted only with the performance of bare strand tendons. Although general comfort was provided in the 1996 *Recommendations*, certain owners encouraged further research prior to permitting the use of epoxy protected strand.

For example, prior to the anchoring of Minidoka Dam, Idaho, in 1997, Florida Wire and Cable (still at the time the only manufacturer of the product in the United States) had indicated that changes in their manufacturing processes may have reduced the amount of creep in their product. The designers of the Minidoka project therefore required that further creep testing be conducted by the manufacturer on the new strand (Trojanowski et al., 1997). Based on tests on 16-foot lengths, at 80% GUTS, the creep was found to be 0.008% of the free length in the 6-60 minute log cycle. The following formulae were therefore specified for estimating the creep to be expected on the project:

This situation culminated in the formation in 2000 of an Epoxy Coated Strand Task Force, under the auspices of ADSC. (Lang, 2000).

- 1-10 minutes: 0.04% of free length
- 6-60 minutes: 0.01% of free length

Creep amounts so calculated would be subtracted from the total creep recorded in the field, and the net value compared to the limits recommended in PTI (1996) for bare strand.

Adding further fuel to the debate, Lang (2000) cited even more recent test data which indicate creep from 1-60 minutes to be 0.0214 to 0.0557% free length at loads varying from 70 to 80% GUTS.

The catalyst for this current initiative was the case of Wirtz Dam, Texas in 1999. On this major project, several instances were found in early installed anchors of strand slippage within 48 hours of Lock Off, together with observations of epoxy delamination from the strand. All tendons had previously performed well during routine Performance Testing. Closer examination of the tendons also revealed an unacceptably high frequency of "flaws" (Frithiof and Krumm, 2000). Questions were raised regarding the uniformity of the thickness and adhesion of the epoxy coating, and so its ability to behave satisfactorily in the short term during stressing and Lock Off, and to satisfy the long term corrosion protection goals. These problems precipitated detailed forensic investigations by the various parties involved in the Wirtz Dam project and the findings elevated the issue to one of general discussion in the anchor industry (Aschenbroich, 2000).

This situation culminated in the formation in 2000 of an Epoxy Coated Strand Task Force, under the auspices of ADSC: The International Association of Foundation Drilling (Lang, 2000). The impetus for this came primarily from the post tensioning companies who assemble the tendons, provide the top anchorage hardware and jacks, and supply stressing expertise. One of the main goals set by the new chairman of this Task Force, **Christopher Lang**, was to write a supplement to the *PTI Recommendations* of 1996, dealing specifically and solely with issues relating to epoxy coated strand in ground anchors. This is scheduled to be completed by 2003. A further goal of the ADSC Task Force has been to collect published and unpublished data regarding the historical size and value of the epoxy coated anchor tendon market over the years. At the same time, the ASTM A882 Committee has also been active in revising the standard to improve controls over the quality and consistency of the production processes.

Part II of this article, which will appear in the December/January issue of Foundation Drilling magazine, will provide a summary of the major preliminary findings of the Task Force's efforts to date, and is the first in a series of papers to be authored by members of the Task Force.

**Indicates ADSC member.* ■