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**ISSUES REGARDING THE USE OF EPOXY PROTECTED STRAND FOR
PRESTRESSED ROCK ANCHORS^(*)**

Donald BRUCE
President, Geosystems, L.P.
U.S.A.

COMMUNICATION

The process of applying fusion bonded epoxy coating to 15-mm-diameter prestressing strand appears to have been developed commercially in the U.S.A. in 1981. Regarding its application in geotechnical construction, the first use for ground anchors was in 1985, for a small tieback project in Malibu, CA. It was not until early 1991 that the special circumstances of Stewart Mountain Dam, AZ, required the use of the material in long, high capacity tendons for a major seismic retrofit (Bruce et al., 1992).

During the rest of the decade, active promotion by contractors, suppliers, and post tensioning companies (Bonomo, 1994; Bogdan, 2001) led to epoxy protected strand being used frequently on a variety of dam stabilization projects in the U.S.A. and Canada. This popularity was encouraged by the publication in 1996 of the Recommendations for Rock and Soil Anchors, by the Post Tensioning Institute. These Recommendations – the closest U.S. practice has to a nationwide standard – endorsed the use of the material, subject, of course, to sensible observations of proper construction practice at every stage of the construction process, and the realization that creep movements would be greater after lock-off than for bare strand. The use of the material afforded several construction and logistical advantages, which, despite the higher cost of the material, could lead to substantial cost savings in the overall program.

Although there were isolated reports of excessive creep, and/or strand slippage through the permanent wedges after lock-off, it was not until early 1999 that the situation was fundamentally researched.

The catalyst for this initiative was the case of Wirtz Dam, TX, where several instances were found in anchors stressed at the beginning of the project of wedge slippage within 48 hours of lock-off, together with observations of epoxy delamination from the strand. All tendons had previously performed well during

**(*) PROBLEMES LIES A L'UTILISATION DE CABLES PROTEGES A LA
RESINE EPOXY POUR LES TIRANTS D'ANCRAGE DANS LE ROCHER.**

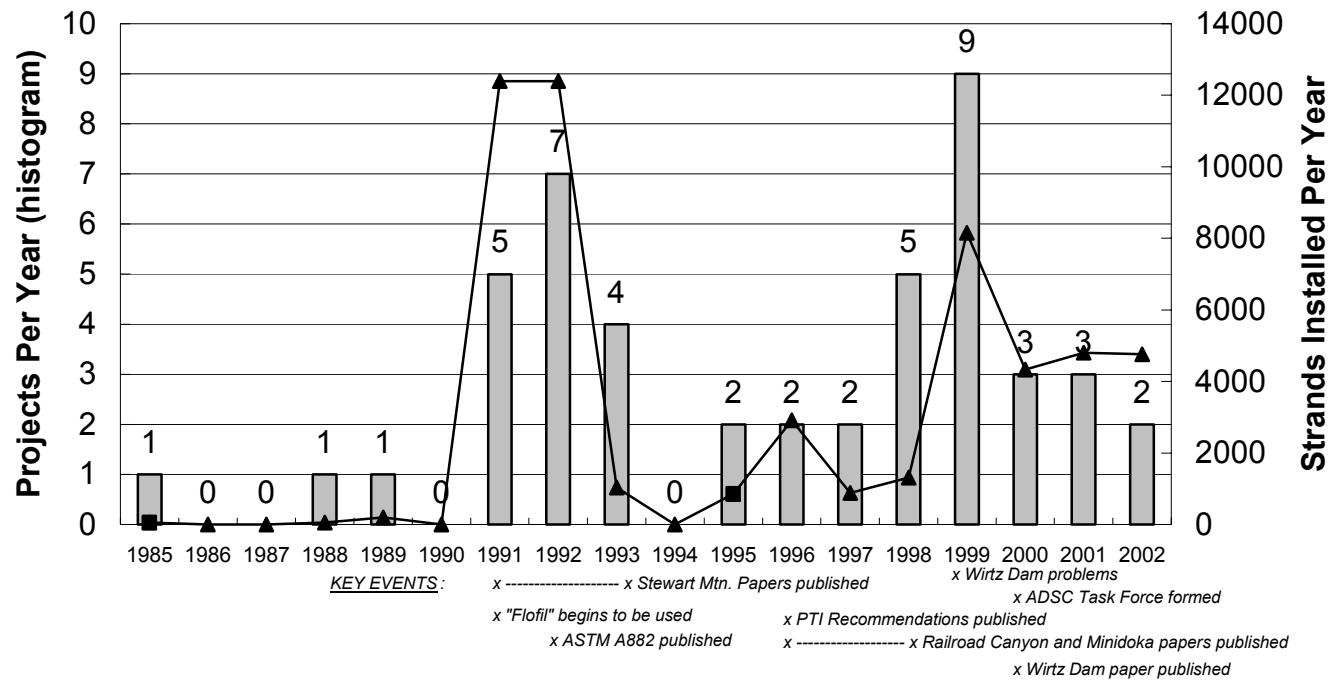
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routine Performance Testing. Closer examination of the tendons also revealed an unacceptably high frequency of “holidays.” Questions were raised regarding the uniformity of the thickness and adhesion of the epoxy coating, and so its ability to behave 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.

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. 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 Task Force 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 mid 2002. 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 in the light of current industry concerns.

Figure 1 is based on a survey of suppliers, owners, consultants, and contractors, supplemented by published data and the proceedings of successive Task Force meetings. 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.

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 1. 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.



KEY TO GRAPH:

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

LEGENDE:

- Histogrammes du nombre annuel de projets
- cables mis en place chaque année
 - Quantités approximatives ou estimées
 - ▲ Quantités déterminées avec plus de précision

Figure 1. Epoxy protected strand usage for prestressed anchor applications, United States.
 Utilisation de câbles protégés à la resine epoxy. Application aux ancrages de précontrainte, US

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Table 1. Data on Japanese usage of epoxy protected strand in ground anchors.
Données sur l'utilisation de câbles protégés à la résine epoxy au Japon pour les tirants d'ancrage.

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.

The following conclusions may be drawn from a review of published and anecdotal data:

1. "Excessive" creep (relative to contemporary PTI Recommendations for bare strand) was first recognized as a phenomenon in 1991, but was rationalized in the laboratory test data first published in 1994 (Bonomo).
2. Strand slippage has invariably been found to be due to one or a combination of factors including
 - Misalignment of strands and stressing equipment, and improper stressing procedures.
 - Grout, corrosion, or dirt in the wedges and/or anchor head.
 - Use of inappropriate wedges.
 - Variations in the thickness and adhesion of the epoxy coating (especially since 1999).
3. Slippage was typically recorded on the first anchors installed and stressed on a particular project, often by crews previously inexperienced in its use.
4. The actual number of strands recorded to have slipped upon lock-off is a very small percentage of the total installed and otherwise successfully performing (less than 0.2%). However, the technical, contractual, and financial impacts arising from these isolated occurrences have been disproportionately high, and have created unease about the use of the product in certain circles.

It is firmly believed that there are effective remedies for the problems reported to date, and that if these are routinely implemented, epoxy protected tendons will perform to the same levels of short and long term expectations as normally achieved by bare strand tendons. In particular, the following practical recommendations are made:

Epoxy Protected Strand: must be manufactured to acceptable and constant standards of quality, consistent with its known application. This requires assurance of appropriate thickness and adhesion especially. Reliable, non-ambiguous data are required on samples of representative length to confirm the creep performance at different stress levels. All manufacturers' data are to be reaffirmed at regular intervals, and especially if significant manufacturing process changes have occurred.

Tendon Installation and Grouting: strands should be correctly spaced in the free lengths, and first stage grouting must not be conducted within at least 12 m of the anchor head.

Stressing Preparation and Execution: all lock-off components (wedges and wedge plates) must be free of grout, rust or any other dirt or debris prior to stressing, and must be properly lubricated. Wedges should be placed only before lock-off, and must be of a design specific for epoxy strand. Removal of the epoxy coating must not be permitted. All components must be correctly aligned.

Anchor Acceptance: when assessing performance at Lock-Off, utilize relevant "correction factors" to account for the creep losses due to the intrinsic properties of the epoxy protected strand itself.

Finally it must also be acknowledged that significant changes and additions to ASTM A882 will need to be made before consultants will feel comfortable with professional liability issues potentially involved in specifying the product.

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SUMMARY

Epoxy protected strand has been used in dam remediation in the U.S. since 1991, and accounts for about one-third of all anchors installed in that period. Although the material offers considerable technical, logistical, and economic

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benefits, there have been reports of problems associated with the short term load holding ability of the strand immediately after lock off. A review of industry practice indicates that there are several causes for this, associated partly with variations in the quality and consistency of the coating application, but largely with construction related issues. Provided proper steps are taken, it is believed that the material remains an attractive choice for dam anchor tendons.

RESUME. L'utilisation de cables protégés à la resine epoxy pour la réparation de barrages aux USA remonte à 1991 et correspond environ à un tiers du total des tirants installés pendant cette période. Bien que le matériau présente des avantages technique, logistique et économique considérables, des problèmes ont été mentionnés concernant la capacité du cable à garder la charge à court terme juste après la mise en tension. Une étude des méthodes utilisées indique que plusieurs causes en sont à l'origine, associées partiellement à la variation dans la qualité et la continuité de l'application de la resine mais plus largement à des problèmes de mise en oeuvre. Sous réserve que des précautions particulières soient prises, on pense que le matériau demeure un choix attractif dans la construction de tirants de barrage.