A Review of the Post-Tensioning Institute's Revised Recommendations for Prestressed Rock and Soil Anchors

H. Nierlich* and D.A. Bruce†
* Dywidag-Systems International, USA, Inc., 107 Beaver Brook Road, Lincoln Park, N.J. 07035
† ECO Geosystems, Inc., P.O. Box 237, Venetia, PA 15367

ABSTRACT
In the United States, there is no formal national standard for rock and soil anchors. However, the Post Tensioning Institute have recently issued their completely revised Recommendations, which for the last two decades has filled the need for a common document. This paper highlights the most significant changes and improvements - especially with respect to corrosion protection and acceptance testing. The theme of the revised Recommendations is the enhancement of quality levels in the industry. This is promoted via technical competence and clear communication between the respective partners.

THE REVIEW
In June 1996, the revised Recommendations for Prestressed Rock and Soil Anchors were published in the United States by the Post-Tensioning Institute (PTI) based in Phoenix, Arizona. These new recommendations are an extensive revision of the previous version published in 1986 although they still cover only prestressed cement and resin grouted anchors.

The committee formed by PTI to work on the revised edition comprised representatives of all parties involved in anchor work. On the part of the owners, there were representatives from the Federal Highway Administration, the U.S. Bureau of Reclamation, the Federal Energy Regulatory Commission, and the U.S. Army Corps of Engineers, while design engineers, anchor contractors, and material suppliers were equally strongly represented. The Recommendations were reviewed in draft and endorsed by the Anchored Earth Retention Committee of the International Association of Foundation Drilling in Dallas, Texas. The result of this cooperation between these often conflicting interests is a set of guidelines for the design, installation, and testing of anchors that are intended to be realistic and practical, while still satisfying the concerns for reliability and safety, which are recognized worldwide.

With respect to typical international anchor specifications, the PTI Recommendations may be considered to occupy a middle ground somewhere between the European Standard: "Execution of Special Geotechnical Work: Ground Anchors" (1994) with its precise and factual separation into statements, requirements, possibilities, recommendations, permissions, and application rules, and the "British Standard Code of Practice for Ground Anchors" (1989) which is viewed to be a most systematic and comprehensive exposé on the subject "Anchors" as well as constituting a formal standard. The PTI Recommendations limit themselves to the design of the anchor only, and do not address the design of the entire retained structure.

In summarizing the most important changes and additions to each chapter of the 1986 PTI Recommendations, it should be noted that the former separation into rock, soil, and resin anchors was abandoned, since most aspects apply equally to all three types. Only Chapter 6, dealing with design, still distinguishes between them, out of necessity.

Chapter 1 confirms that the Scope of the work deals with permanent and prestressed rock and soil anchors. Significantly, the units are primarily SI, with imperial (soft) equivalents in parenthesis.

Chapter 2 on Definitions was expanded to include most of the terms used for anchor work in an attempt to standardize these for all parties dealing with them. Particular attention was devoted to this apparently routine section since the Committee felt it was essential to provide clear and comprehensive guidance at a time when ground anchors are being specified, designed, and constructed in ever increasing numbers by a wider-based, generalist population, as opposed to a relatively small number of innovative specialists.

Chapter 3 on Specifications was broadened to list the tasks and responsibilities that need to be allocated for anchor works (Table 3.1). Anchor contractors in the United States often observe that responsibilities were being insufficiently or only vaguely addressed in project specifications. Chapter 3 also makes an appeal to all parties involved for clear communication, close cooperation, and speedy reviews of documents and submittals, especially in the start-up phase of a project. This is in line with the new spirit of “Partnering” which is prevalent in United States construction practice (Nicholson and Bruce, 1992). The chapter identifies the main responsibilities which have to be allocated, and also confirms the fundamental classification of specifications: prescriptive, performance, and open. In this way, regardless of the type of specification decided upon, no critical responsibilities may go neglected, through oversight.

Chapter 4 on Materials was expanded from one to eight pages. Indented strand and epoxy coated strand and bars were added for tendon materials, while reference to wire and compacted strand was dropped due to lack of use in the United States. For evaluating adequate bond behavior of strand, bond capacity tests are now required to be performed by the manufacturer prior to supply to site. In this test, a 15 mm diameter strand (the most widely used strand diameter in the United States for permanent anchor tendons) embedded in a 400 mm long neat cement grout column inside a steel pipe with a grout strength of 25 to 30 MPa must not move more than 0.25 mm at the unloaded end when a 35 kN tensile force is applied to the other end of the strand. For epoxy coated strand, filling of the interstices between wires with epoxy is required, as well as the use of wedges capable of biting through the outer layer of epoxy. Stripping of the epoxy to allow the use of regular wedges is not permitted to prevent damage to the strand and its corrosion protection.

For each component of an anchor tendon, including its corrosion protection system, American Society for Testing and Materials (ASTM) specifications are either defined or recommended. Minimum performance requirements are given for most of the anchor components, including minimum wall thicknesses for the tendon encapsulation, namely 2 to 3 mm.

Table 3.1. Tasks and responsibilities to be allocated for anchor works (after PTI, 1996).

1	Site investigation, geotechnical investigation, site survey and potential work restrictions.
2	Decision to use an anchor system, requirement for a pre-contract testing program, type of specification and procurement method and levels of prequalification.
3	Obtaining easements.
4	Overall scope of the work, design of the anchored structure, and definition and qualification of safety factors.
5	Definition of service life (temporary or permanent) and required degree of corrosion protection.
6	Anchor spacing and orientation, minimum total anchor length, free anchor length, and anchor head.
7	Anchor components and details.
8	Determination of bond length.
9	Details of carrion protection.
10	Type and number of tests.
11	Evaluation of test results.
12	Construction methods, schedule, sequencing, and coordination of work.
13	Supervision of the work.
14	Maintenance and long-term monitoring.
15	Requirements for QA/QC program.

Chapter 5 on Corrosion Protection underwent the most fundamental and controversial changes of all. These, basically, constitute a further step closer to European anchor specifications, but differences in philosophy still remain. While European standards appear to be gravitating towards technically perfect and absolutely reliable solutions for protecting the tendon against corrosion, such as triple protection, or electric isolation testing of the installed and occasionally even the stressed anchor, Americans are more prepared to look at the cost-benefit ratio of the corrosion protection system. Based on published data (FIP, 1986), the number of known anchor failures due to corrosion is a very small percentage of the total number of anchors installed, and provided there are no catastrophic consequences, such a failure rate can be an acceptable construction and performance risk. Considering further that there are almost no failures known in the bond length and few in the free length, electric isolation testing, as a means of confirming the integrity of the installed corrosion protection system, where the tiniest imperfection will result in rejection of the anchor, is considered as too costly and impractical on a routine basis. It is required, however, in the presence of stray electric currents. More emphasis is put on the corrosion protection near the stressing end where statistics show by far the highest frequency of corrosion failures. Strong reliance is placed on the expertise of the tendon fabricator to meet the new criteria, and attention is directed towards satisfying the details as thoroughly as possible.

The corrosion protection decision tree shown in Figure 5.3 of the PTI Recommendation guides the designer in selecting the type of protection to be specified. It fundamentally distinguishes between

Class I (double corrosion protection) and Class II (single corrosion protection). Selection is based on service life, soil aggressivity, consequences of failure, and costs. One notable result is that for permanent anchors, a Class II protection may be used only in non-aggressive soils for anchors where failure does not have catastrophic consequences and where the increase in cost over Class I anchors would result in an unjustifiable and considerable extra expense. Further details are provided in Table 5.1 and Figure 5.2. This approach is already being adopted for the design of large permanent anchors for dams especially in the western states.

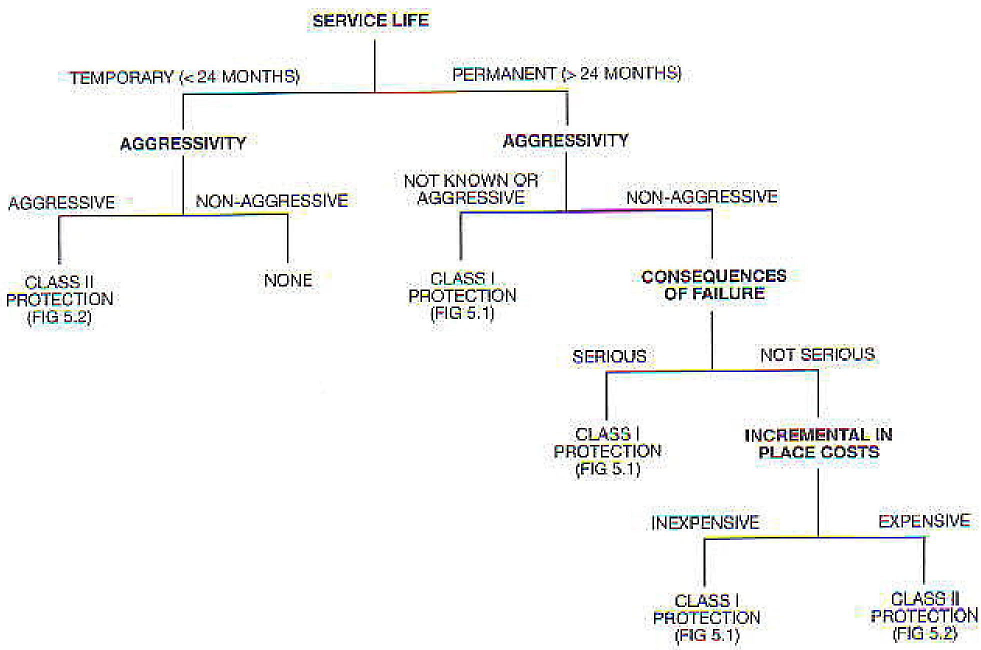

Figure 5.3. Corrosion protection decision tree (after PTI, 1996).

Table 5.1 Corrosion protection requirements (after 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

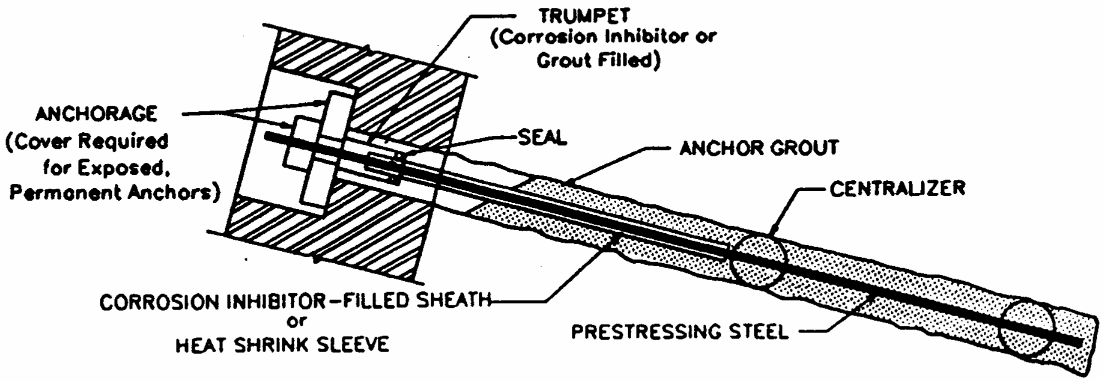

Figure 5.2. Class II protection – grout protected anchor (after PTI, 1996).

Chapter 6 on Design was expanded to include such general considerations as feasibility of anchors, design objectives, fully bonded versus unbonded anchors, restressable, destressable, and removable anchors, and anchor capacity/safety factors. The safety factor on the tendon at the design load is not permitted to be less than 1.67. The guide values for the typical average ultimate bond stresses for rock, cohesive, and noncohesive soil were revised upwards in response to the greater experience available. It is emphasized, however, that actual bond capacity will largely depend on the installation technique and local variations in the actual soil conditions. The value of site specific testing is underlined.

Chapter 7 on Construction follows much of the information given in the 1986 Recommendations, but extra emphasis is placed on proper handling, storage, and insertion of the anchor tendon in order to preserve the corrosion protection system provided, and to avoid contamination of exposed prestressing steel. Guidelines are given for achievable tolerances for drill hole inclination and deviation from its plan location. More practical guidance is provided on rock and soil drilling methods and pressure grouting techniques, including post grouting for anchors in cohesive soils or very weak, argillaceous rocks.

Chapter 8 on Stressing, Load Testing, and Acceptance expands on the reasons for anchor testing, the requirements for the equipment and its setup. While the requirements and procedures for the Performance Test and the Extended Creep Test, required for soils having a Plasticity Index greater than 20, have not changed, for the Proof Test, the additional step of returning to the Alignment Load after the test load period and before off locking the anchor is recommended, especially for cases where the Proof Test results cannot be compared directly with the Performance Test results for equivalent anchors. This extra step will allow the separation of the total movement measured into permanent and elastic components for a more meaningful evaluation of the anchor performance. This proposal, the logic of which has been quickly recognized and accepted by practitioners left confused by “gray areas” in the previous Recommendations, has been long overdue in American practice.

Acceptance criteria are given for creep, movement, and lock-off load. While they do not differ much from the 1986 Recommendations, greater emphasis was put on explaining the reasons behind the acceptance criteria and guidelines are given on what can be done in case an anchor fails to meet these acceptance criteria (Figure 8.4). The new Recommendations point out that the calculated minimum apparent free length of the anchor may need to be set higher than the traditional 80 percent of the designed free length, especially when later a redistribution of the free length friction could cause unacceptable structural movement or where no prestress load is allowed to be transferred in the free length by friction.

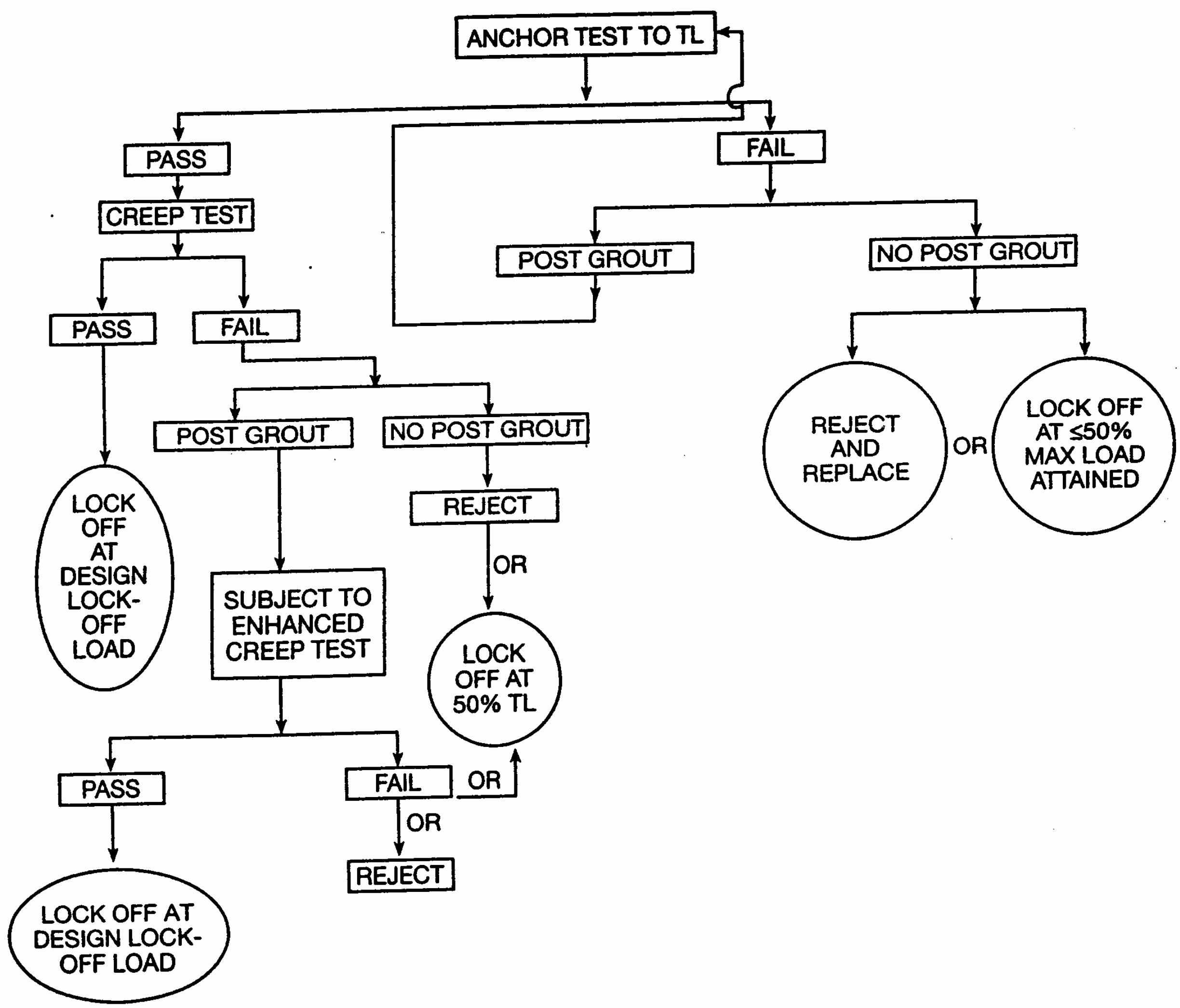

Figure 8.4. Decision diagraph for acceptability testing of anchors (after PTI, 1996).

A new section on “Acceptability Based on Total Movements” was added, defining the criteria for minimum and maximum apparent free length for Proof Tested anchors where no separation of the total movement into residual and elastic movement is possible.

Another new section “Procedures in the Event of Failure during Testing” allows anchors that failed to reach the test load, to be locked off and accepted at half the failure load. Anchors that have failed the Creep Test may also be locked off at 50 percent of the failure load, or when subsequently post-grouted, need then to be subjected to an enhanced Creep Test in which the creep movement between 1 and 60 minutes is not allowed to exceed 1 mm.

It is also explained that the intrinsic creep behavior of epoxy filled strand itself is significant. Since the purpose of the test is to measure plastic movements in the bond zone, the measured creep movements of epoxy coated strand anchors must be adjusted by deducting the creep movement in the epoxy coated strand itself. These movements are conservatively estimated with 0.015 percent of the apparent free length during the 6 to 60 minute log cycle at a test load of 80 percent of the tendon ultimate strength, and 0.012 percent at a 75 percent F_{pu} test load. However, this additional creep movement does not adversely affect the service behavior of epoxy coated strand anchors : only their higher relaxation properties, as defined in ASTM Specification A 882, need to be considered for the long term losses. Again this emphasis has been driven by field observations and professional debate : the use of epoxy coated, epoxy filled strand is rapidly increasing, principally for high quality dam anchorage projects, in which understanding of time dependent behavior - both for acceptance criteria and for assuaging owner concerns - is critical.

The new Recommendations also require wedges for strand tendons to be seated at a minimum load of 50 percent of their ultimate load capacity. Specified lock-off loads of less than that will require shimming and unshimming of the wedge plate. Overlapping wedge bites must be avoided, and are positively discouraged.

The section on “Monitoring Service Behavior” was expanded to include minimum criteria for a monitoring program. It is pointed out that such a program needs to be considered at the design stage. The monitoring program shall include the number of anchors to be monitored (typically 3 to 10 percent) their location, frequency, reporting procedures, and maximum load losses or gains allowed. An anchor monitoring program will also require monitoring the movement of the anchored structure for a proper evaluation of anchor behavior.

A summary of the material and testing specifications referenced in the text, as well as a revised selected bibliography completed these Revisions.

FINAL REMARKS

The new PTI Recommendations are intended to be a practical guide to American anchor practitioners, from owners and designers, to contractors and their field supervisory personnel. Their tone and content have been specifically designed to satisfy the needs peculiar to the contemporary United States anchor market, which does not otherwise enjoy the benefit of an “official” national standard at a time of rapid product expansion. They are in no way intended as a competitor to FIP or national standards - especially those of the Western European countries : the value of these documents as insights and sources of knowledge is universally accepted. However, the Committee feel that they have produced a document which clarifies past inconsistencies and addresses future developments in a pragmatic fashion.

The Committee would like to believe that, upon the occasion of the next edition of the Recommendations being due, the changes will not be as extensive or fundamental as those occasioned by the developments and needs of the preceding ten years.

The address of PTI is 1717 W. Northern Avenue, Suite 114, Phoenix, Arizona 85021.

REFERENCES

1. British Standards Institution. (1989). “Ground Anchorages.” BS8081. BSI, London, England.
2. Draft European Standard. (1994). “Execution of Special Geotechnical Work: Ground Anchors.” European Committee for Standardization, Central Secretariat: Rue de Stassart 35, B-1050, Brussels, Belgium.
3. FIP Commission on Practical Construction. (1986). “Corrosion and Corrosion Protection of Prestressed Ground Anchorages.” Thomas Telford, Ltd., Telford House, London, England.
4. Nicholson, P.J. and Bruce, D.A. (1992). “Opportunities and Constraints for the Innovative Geotechnical Contractor.” ASCE Annual Convention, New York, NY, September 14-17, 20 p.