

FOUNDATIONS

Are You Properly Specifying Ground Anchors?

Basic knowledge of industry practices and adherence to guidelines by PTI are critical to specifying anchors.

By Don Dotson, Ph.D., PE, and Donald Bruce, Ph.D., C.Eng.

Ground anchors have been around for a long time as a mechanism to transfer tensile loads into the ground for dams, tunnel roofs, and slope stabilization (Littlejohn and Bruce, 1977). As early as 1872, rock bolts were used at a slate quarry in North Wales (Schach et al., 1979). The French engineer, André Coyne used ground anchors to reinforce La Jument Lighthouse in Brittany in 1930 (Juran and Elias, 1991, Filipot et al., 2019), before stabilizing Cheurfas Dam in North Africa in 1934.

Some of the earliest guidance for ground anchor design and construction was provided by the Prestressed Concrete Institute (PCI, 1974), followed closely by Littlejohn and Bruce (1975a, 1975b, 1976, 1977). The U.S. Army Corps of Engineers published an Engineering Manual with the purpose of outlining “techniques and procedures for rock reinforcement for underground and surface structures in civil engineering works” (USACE, 1980), including both rock bolts and high capacity rock anchors. The Federal Highway Administration published a study outlining the anchor design and construction methods employed by Nicholson Construction Company (Nicholson et al., 1982) followed by a FHWA-sponsored state-of-the-practice design and construction manual for “cement-grouted ground anchors and anchored systems for highway application” (Sabatini et al., 1999).

Starting in 1980, the Post-Tensioning Institute began publishing *Recommendations for Prestressed Rock and Soil Anchors*. The current edition is the fifth edition (PTI, 2014). It is this publication which is often referenced in construction specifications (e.g., Unified Facilities Guide Specifications 31 68 13, “Soil and Rock Anchors,” available at wbdb.org) as PTI DC-35.1-14 (hereafter, PTI) and is the de facto guide for permanent and temporary prestressed rock and soil anchors for use in the U.S., given the absence of recommendations in the *International Building Code* (IBC, 2021) and ACI 318-19 (ACI, 2019). In Canada, engineers

also refer to the *Canadian Foundation Engineering Manual* (CGS, 2023).

For commercial applications, ground anchors are often used to transfer tensile loads from wind or seismic forces to shear walls and other structural elements or structures subject to hydrostatic uplift to the underlying ground. (A discussion of the use of ground anchors in high seismic areas has been published by the New Zealand Geotechnical Society at <https://fl-nzgs-media.s3.amazonaws.com/uploads/2023/05/NZGS-Ground-Anchor-Guideline-Mar-2023-DRAFT-FOR-COMMENT.pdf>.) They are also used for temporary structures such as crane pads, especially when founded on rock; crane pads founded on soil often incorporate piles to carry both tensile, compressive, and lateral loads. Contract Documents typically show the location where ground anchors are to be installed along with the tension loading under delegated design, though sometimes the complete design has been performed by the project structural engineer, generally with bond zone strength recommendations from the geotechnical engineer.

Ground anchors are installed using specialized drilling equipment (Fig. 1). Many engineers are familiar with drilling with augers and diamond core drilling to obtain geotechnical information in soil and rock, respectively. Diamond core drilling uses water or drilling mud to lubricate and cool the core barrels and to return cuttings to the surface. Engineers are also familiar with air track drills used by grading contractors to drill blast holes. Most ground anchors are installed using percussive drilling where the drill bit oscillates up and down by the percussive action of the hammer as well as rotates. A detailed discussion of drilling methods can be found in Bruce (2003). This rotation improves the efficiency of the percussive drilling mechanics. Rotary percussive drilling uses either a top hammer or down-the-hole (DTH) hammer. A benefit of the DTH hammers is that several manufacturers make retractable underreamer systems that allow the hole to be cased as the drill hole is advanced (Fig. 2). Casing the hole is important in soils that “cave” when the drilling tools are extracted. Caving contaminates the bond zone and can also prevent insertion of the tendon and grout.

The first author provides delegated designs to contractors for ground anchors and has reviewed many plans and specifications where ground anchors are required. The quality and consistency of the plans and specifications varies considerably, and many appear to have been developed without knowledge of the requirements of PTI. For example, one provision of PTI is that the center-to-center spacing of anchors should be at least four times the diameter of the bond zone with a minimum spacing of four feet. This is to prevent load transfer interaction between anchors as well as interference during installation as drilling tools tend to drift laterally during drilling depending on ground conditions and driller experience, amongst numerous other factors. Anchors are often placed on either side of the intersection of two shear walls and the spacing between anchors can be too close.

Another requirement in PTI is that the design of anchors must consider the resistance to pullout of the “failure wedge.” Too often, the length of



Fig. 1. Ground anchors are installed with a specialized drill. (Photo courtesy of GeoFirma, LLC)

the bond zone is based solely on the grout-to-ground surface area within the drillhole and the bond strength without consideration of the global resistance to pullout of the rock engaged by the anchor system. PTI establishes minimum bond lengths of 15 feet for strand anchors and 10 feet for bars smaller than 1¾ inch and 15 feet for bars larger than 1¾ inch. Most geotechnical reports will not consider the need for anchors and will not provide recommendations on anchor global stability unless alerted to their inclusion. Guidance for the analysis of global anchor system resistance can be found in USACE (1994) and Sabatini et al. (1999). Failure to consider this failure mode can lead to in-service anchor failure, even though the anchor tests are acceptable. The minimum free stressing length for strand anchors is 15 feet and 10 feet for bar anchors.

The amount of rock included in the failure wedge can be enlarged by increasing the free length which essentially lowers the depth of the bond zone and increases the amount of overburden which provides additional resistance.

Another issue involves pressure grouting of the bond zone of soil anchors to increase the bond strength and reduce the number of anchors. If the overburden pressure of the ground is not sufficient when pressure grouting, the ground can fracture and reduce the bond strength that you are trying to achieve. As a simple example, a grouting pressure of 50 psi in granular, moist soil with a unit weight of 115 pcf would require about 63 feet of overburden to equal the grouting pressure ($h = 144 \text{ p}/\gamma$). The bond zone should be deep enough to compensate for grouting pressures.

When considering ground anchors in commercial buildings, the designer needs to consider whether the anchors should be post-tensioned or not. The purpose of post-tensioning ground anchors is to minimize the movement of the anchored structure under service loading conditions. Depending on the situation, this may or may not be important. Post-tensioned anchors are usually limited to foundations on competent bedrock because post-tensioning loading greatly increases the compressive force on a foundation, often beyond the bearing capacity.

For post-tensioned ground anchor tendons, PTI requires the use of either low-relaxation strand or bar. For commercial use, bar is most often used, generally because the design loads do not warrant high-capacity strand anchors, bar is readily available, and it is relatively easy to install and increase the length of the anchors in the field by adding a coupler. PTI requires that bar used in post-tensioned anchors be ASTM A722, subjected to cold stressing to not less than 80% of the Minimum Ultimate Tensile Strength (MUTS, sometimes referred to as GUTS: Guaranteed Ultimate Tensile Strength) and then stress relieved. One advantage of this requirement is that the cold stressing requirement serves as an early-warning system that the bar is free of imperfections that could lead to a catastrophic failure in service (McCray, 2023).

ASTM A722 bars are either Type I or Type II. Type I bars are plain bars with nominal diameters ranging from 3/4 inch to 13/8 inch. Type II bars are deformed bars with nominal diameters ranging from 5/8 to 3 inches. MUTS of A722 bars is 150 ksi and the minimum yield strengths are 85% and 80% of MUTS for Type I and Type II, respectively. Threads are cold-rolled onto Type I bars and hot-rolled onto Type II bar (McCray, 2023). DYWIDAG product literature states Type II bars have a relaxation tension loss after 1,000 hours of 1.5-2.0% whereas Type I losses are significantly higher.

Another advantage of post-tensioned anchors is that each installed

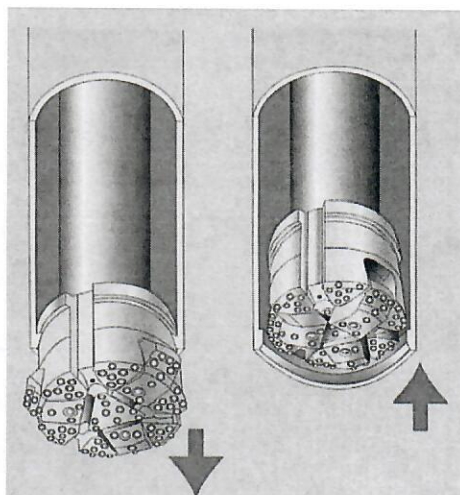


Fig. 2. Retractable underreamer systems like this one allow the drilled hole to be cased, which is important in soils that "cave" when the tool is extracted. (Photo courtesy numahammers.com)

anchor is stressed and tested. Stressing and testing is performed (1) to demonstrate that the anchor meets acceptance criteria and (2) to stress and lock off the anchor at a specified load. Two types of testing are used for commercial applications: Performance tests and Proof tests. Performance tests are conducted on production anchors and the number of tests depends on the size of the project, the likelihood of anchor creep, and the variability of the subsurface conditions. For most projects, the number of Performance tests is between 2-5% of the total number of anchors. According to PTI, the purpose of Performance testing is to determine (a) whether the anchor has sufficient load-carrying capacity; (b) that the apparent free tendon length has been satisfactorily established; (c) the magnitude of residual movement; and (d)

that the rate of creep stabilizes within the specified limits. Performance tests are conducted by cyclically loading and unloading the anchor in six cycles up to 133% the design load (PTI). Once 133% of design load (DL) is achieved the anchor load is held for ten minutes to determine anchor creep. If the amount of creep exceeds 1 mm (0.040 in), the anchor load is held for an additional 50 minutes while keeping the testing pressure within 50 psi of 133%DL. The initial 10 minute hold is called the creep test; the additional 50 minute hold is called the extended creep test.

Proof testing is performed on all post-tensioned anchors that are not performance tested. The purpose of Proof testing is similar to performance testing except that the testing is not cyclical. The anchors are loaded in six increments to 1.33 DL, creep tested for 10 minutes, brought back down the alignment load which is a nominal load applied to an anchor sufficient to keep the testing equipment positioned correctly, and then brought back up to the lock-off load.

Another type of testing is Verification testing which is performed on a sacrificial anchor to verify the bond strength between the ground and the grout. These tests are performed on shortened bond zones and are taken to failure to establish the ultimate ground-to-grout bond strength which can be used to optimize the anchoring system.

Where post-tensioning is not feasible (i.e., to hold down shear wall foundations on soil), passive anchors can be used. Although passive anchors do not strictly fall within the purview of PTI, since they are not post-tensioned, many of the guidelines in PTI should be followed. While ASTM A722 bar can also be used for passive anchors, ASTM A615, grade 75 threaded bar is a viable option that is available from the suppliers of ASTM A722 threaded bar. Like ASTM A722 Type I bars, threads are also cold rolled onto A615 bar. Both ASTM A722 and A615 bars are commonly used in micropile construction (FHWA, 2005). The design of anchors using either A722 or A615 bars is identical; the design load on bars should not exceed 60% of MUTS and test loads should not exceed 80% MUTS. Lock-off loads for bar should not exceed 70% of MUTS.

Where post-tensioned anchors are used, the anchors terminate in a concrete mat or footing with a bearing plate locked off with a nut on top. Often, the bar is extended, and a tension plate located higher in the mat or footing is used to transfer the load from the ground anchor to the mat or footing. The tension plate is sized and located to resist punching shear and often has a full nut above the plate and a half nut below to position the plate during concrete placement. Reinforcement is then cast into the concrete to attach the superstructure to the mat

or footing. This same arrangement should be used for passive anchors, but there is a recent trend to forego the tension plate and extend the anchor bar up into the superstructure, sometimes several stories, using couplers. The authors do not recommend this practice. Installing a single bar in a drill hole, sometimes 50 or more feet into the ground and expecting that the alignment will be perfect enough that the bar can be extended up several stories inside an 8-inch wall is problematic. Bending the bars to keep them inside walls is not a good idea, although ASTM A722 requires that the bars pass a 135° bend test.

Another important component of ground anchors is the grout used to bond the tendon to the ground. Ground anchors are typically grouted with neat cement grout consisting of cement and water without aggregates. Grouts are best mixed on-site by the anchor contractor using high-shear colloidal mixers (Fig. 3).

PTI specifies Type I, II, III, or V Portland cement conforming to ASTM C150 with a minimum compressive strength of 3,000 psi (FHWA requirements are the same). More recently Type 1L has become popular. A recent trend among some structural engineers is to specify grout strengths as high as 8,000–10,000 psi for anchors. This is unnecessary and often unachievable. The PTI commentary states that blended

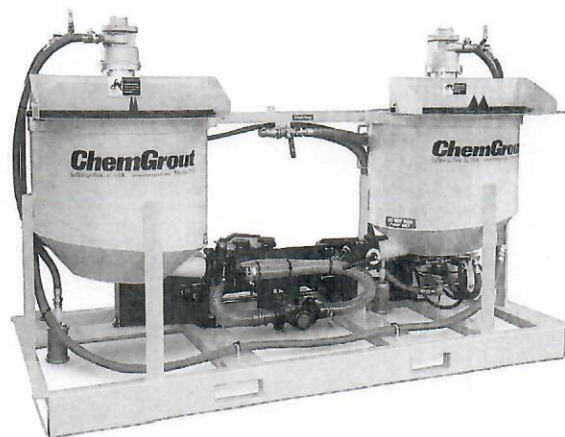


Fig. 3. High-shear colloidal mixers mix grouts on-site. (Photo courtesy Chemgrout.com)

cements are “typically neither necessary nor used for anchors.” A recent trend in some projects is to specify ‘non-shrink grout’ in the bond zone. Non-shrink grouts are covered under ASTM C1107 and are for use under applied load to support structures or machines. While the use of non-shrink grout sounds like a good idea, they are not intended to be tremied into a drillhole to bond steel to the ground, often below the ground-water table, and should not be used. Additionally, non-shrink grouts have not been subjected to

decades of use and testing as have neat cement grouts. Expansive admixtures may be added to neat cement grout only for filling trumpets and anchor covers, but PTI prohibits their use in the bond zone.

Finally, corrosion protection should be considered for permanent anchors, defined by PTI as those having at least a 5-year service life. PTI recognizes two types of corrosion protection: Class I and Class II. Class I has a higher level of corrosion protection than Class II. All permanent anchor installations should use Class I corrosion protection. Class I was often called double corrosion protection and consists of encapsulating the tendon inside a plastic sheath filled with either grout or corrosion-inhibiting compound (Fig. 4). Class I protection can also be provided by epoxy-coating of the tendon and installing the tendon in a grouted drill hole that has been successfully water pressure tested. This

ADVERTISEMENT—For Advertiser Information, visit STRUCTUREmag.org



BULL MOOSE
TUBE

SPENDING GREEN... TO GO GREEN



Bull Moose Tube made a major investment in a new 350,000 ton-per-year facility in Sinton, Texas – with the goal of providing you with the “greenest” steel tube in North America.

- **SUSTAINABILITY-FOCUSED** | Our state-of-the-art facility boasts the lowest carbon footprint for steel pipe & tube in North America. Additional Bull Moose products means a greater range of possibilities for your designs...while helping you achieve your green initiatives.
- **MORE HSS AND NEW PIPE PILE CAPACITY** | Our new mill enables us to produce HSS up to 14" square and 18" round, up to ¾" walls, and the ability to enter the pipe pile market.



ASTM STANDARDS WE MEET: A252 | A500 | A847 | A1085 | CSA G40.20/G40.21 | EN 10219

800.325.4467

BullMooseTube.com

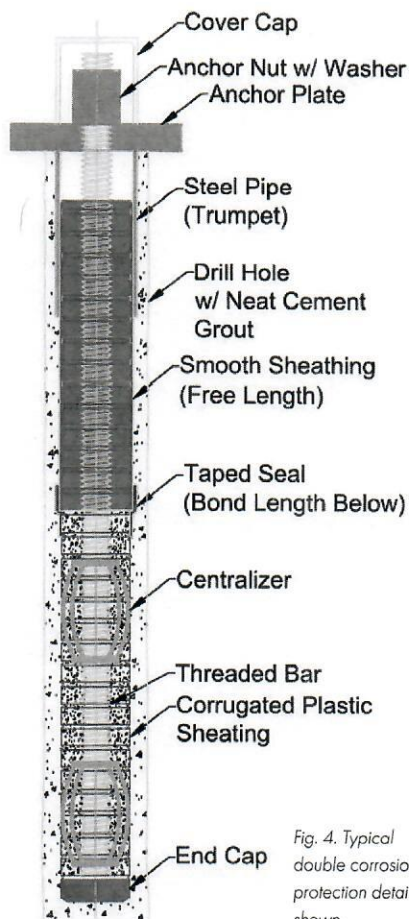


Fig. 4. Typical double corrosion protection detail is shown.

is performed in the bond zone in competent rock and consists of filling the hole with water and applying a constant pressure of 5 psi above hydrostatic for 10 minutes. If leakage exceeds 2.75 gallons of water, then the hole should be grouted, re-drilled, and tested until it passes the test. The purpose of the test is to limit the intrusion of water that can displace the grout or corrode the tendon. This procedure can become very expensive and is primarily used for applications where differential head is present and seepage occurs. PTI states that water pressure testing is not required where there is no seepage or differential head, and the method of grout placement fills the drill hole without loss of grout in the bond zone. On commercial projects, this criterion is often met. In the free length portion of the anchor, the bar manufacturer can provide anchors that are sheathed and filled with a corrosion inhibiting

grease, gel, or wax.

In conclusion, properly specifying ground anchors requires basic knowledge of industry practices and adherence to guidelines that have been established by PTI. Specifying materials and methods contrary to PTI guidelines opens structural engineers up to contractor claims as well as unnecessary liability for poor anchor performance. The authors encourage structural engineers to obtain a copy of PTI and to incorporate its provisions into the plans and specifications that they prepare. ■

Note: Both authors have previously worked for Nicholson Construction Company.

Full references are included in the online version of the article at **STRUCTUREmag.org**.

Don Dotson, PhD, PE, BC.GE. is a partner in the structural engineering firm of Geo/Structural Services Group, LLC in Nashville, Tennessee, specializing in the structural design of deep foundations, substructures, earth retention, and underground works. (Don.Dotson@GeoSSG.com).

Donald Bruce, PhD, BC.GE, CEng, PG, LG, LEG is the president of Geosystems, LP, an independent consultancy located in Venetia, PA offering technical, advisory, and managerial services in the specialty geotechnical aspects of civil, mining, and tunneling engineering. (dabruce@geosystemsbruce.com).

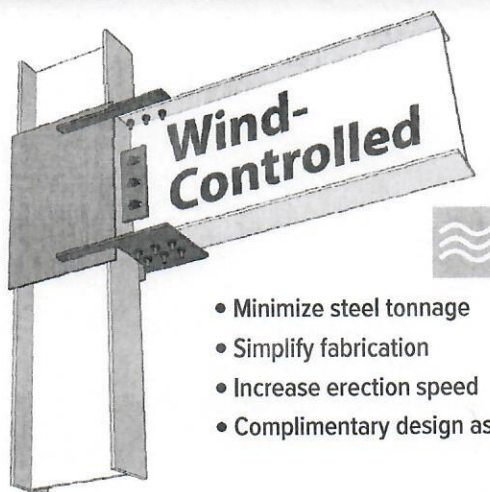
ADVERTISEMENT—For Advertiser Information, visit STRUCTUREmag.org

DURA FUSE
FRAMES

We've got your back for any steel moment frame design



- Resilience through reparability
- Minimize steel tonnage
- Minimize seismic detailing
- Complimentary design assist



- Minimize steel tonnage
- Simplify fabrication
- Increase erection speed
- Complimentary design assist

Find your solution at DuraFuseFrames.com