CHAPTER

11 Ground Anchors & Soil Nails

11-1 Introduction

Chapter 5, *Pile Foundations-General,* classifies ground anchors as special case foundations. Sub horizontal ground anchors, sometimes referred to as tiebacks, are used for earth retaining structures where it is not feasible to excavate and construct a footing foundation or pile cap for a conventional retaining wall. Vertical ground anchors, sometimes referred to as tension piles or tiedowns, are used generally for seismic retrofitting or existing footings where uplift and overturning must be prevented.

11-2 Sub Horizontal Ground Anchors

Sub horizontal ground anchors are used for temporary and permanent structures. The use of sub horizontal ground anchors with sheet pile or soldier beam shoring permits taller walls and deeper excavations than are possible with cantilever type construction–up to 35 feet or so depending on soil properties versus 15 feet for cantilever construction. Walls can be built much higher than 35 feet by using high strength sheet pile or soldier beams with multiple rows, or tiers, of sub horizontal ground anchors.

11-2.1 Components

Sub horizontal ground anchors are constructed by drilling holes at a slight angle (usually 15 degrees) off the horizontal axis. Afterwards a special prestressing system is installed and the tip portion, known as the bonded length, is grouted. The bonded length acts as an anchorage by distributing the prestressing force to the surrounding soil. The unbonded end is secured with an anchor head. Refer to Figure 11-1 for a sub horizontal ground anchor schematic. Refer to *Bridge Standard Detail Sheet (XS)* 12-040 for sub horizontal ground anchor details.

The following list describes various sub horizontal ground anchor components:

Table 11-1. Sub Horizontal Ground Anchor Components

COMPONENT	DESCRIPTION
Prestressing Steel – Support Member	This transfers load from the wall reaction to the anchor zone and is generally a prestress rod or strand.

COMPONENT	DESCRIPTION
Bond Length	The portion of prestressing steel fixed in the primary grout bulb through which load is transferred to the surrounding soil or rock. Also known as the anchor zone.
Unbonded Length	The portion of the prestressing steel that is free to elongate elastically and transmit the resisting force from the bond length to the wall face.
Anchorage	This consists of a plate and anchor head or threaded nut and permits stressing and lock-off of the prestressing steel.
Grout	This provides corrosion protection as well as the medium to transfer load from the prestressing steel to the soil or rock.

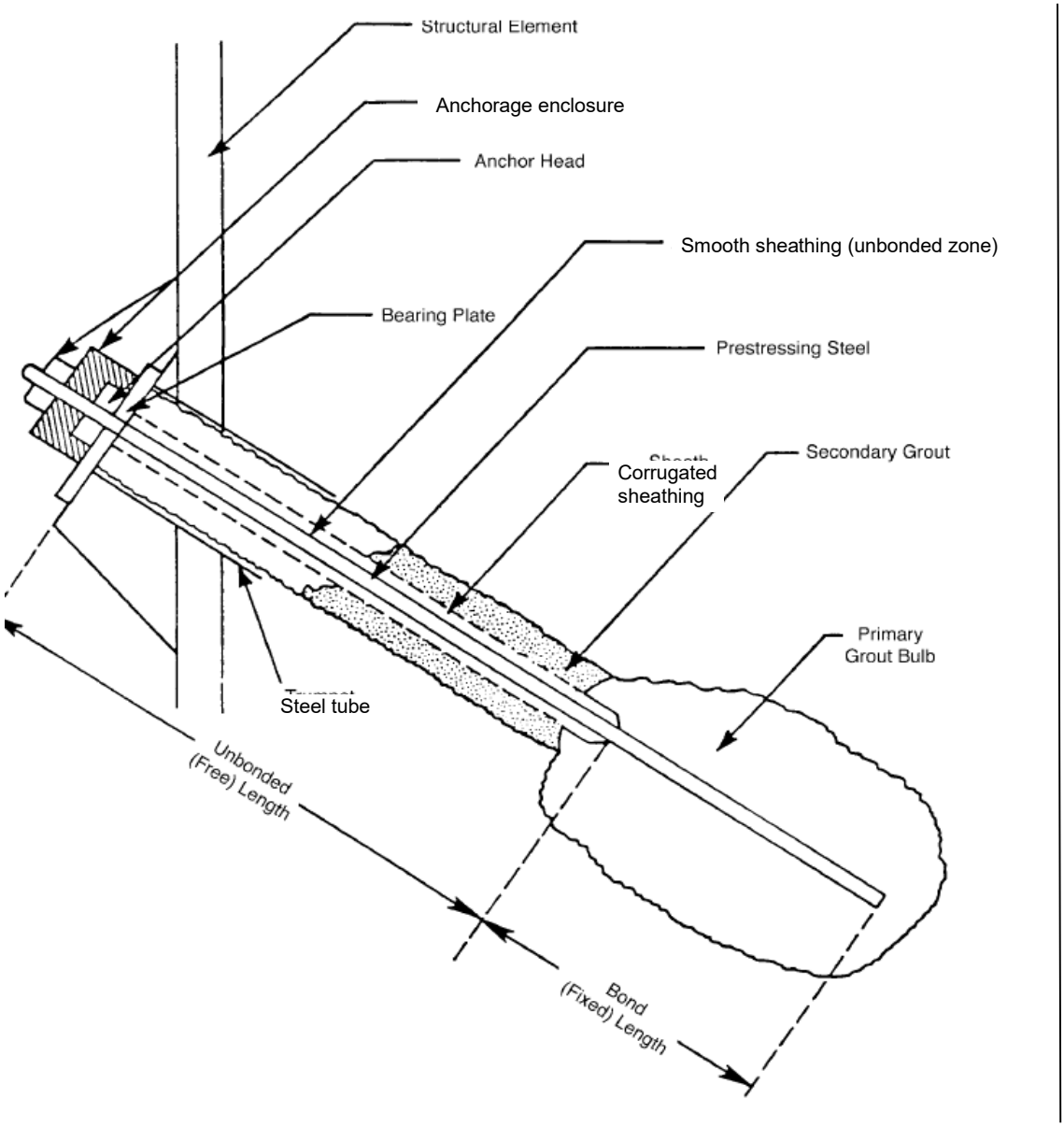

Figure 11-1. Sub Horizontal Ground Anchor Schematic.

In addition to enabling the construction of higher/taller walls and deeper excavations, sub horizontal ground anchors serve another useful purpose. The system provides an open unrestricted work area adjacent to the wall and inside the excavation since the only part of the system that projects beyond the wall is the relatively small anchorage device.

For permanent structures, the Contractor is responsible for providing a sub horizontal ground anchor system that conforms to the design requirements shown on the contract plans and meets or exceeds the testing requirements specified in the contract. Sub horizontal ground anchor shoring designs are often proprietary and require sophisticated engineering techniques and calculations submitted by the contractors and consultants. The designed bonded length is based on site specific soil parameters/mechanical properties. In accordance with the contract specifications[1], the Contractor submits sub horizontal ground anchor shop drawings and design calculations to Structure Design, Documents Unit, for distribution, review, and authorization, and notifies the Engineer of the submittal. The Designer, Geoprofessional, staff specialist for Earth Retaining Systems in Structure Policy and Innovation, the DES Prestressing Committee and Structure Construction field personnel all review the shop drawings. The Designer authorizes the shop drawings based on the recommendations of the individual units reviewing the drawings. These individuals and groups can be consulted for help in answering any questions that may arise in the field during construction. In addition, the Structure Construction Substructure Technical Team is also available to provide assistance.

A *Ground Anchor Wall Construction Checklist* is presented in Appendix K-6 to assist field personnel in preparing documents and inspecting fieldwork to ensure compliance with contract documents.

The contract specifications[2] state the requirements for performance and proof testing of sub horizontal ground anchors. The record of readings from the performance and proof tests performed to verify the adequacy of the system shall be documented by the Contractor and provided to the Engineer. Structure Construction field personnel witness all performance and proof testing of the sub horizontal ground anchors.

11-2.2 Sequence of Construction

Sequence of sub horizontal ground anchor construction is as follows:

Table 11-2. Sub Horizontal Ground Anchor Construction Sequence.

SEQUENCE	DESCRIPTION
1	Drill the holes to the required length and diameter.
2	Install the prestressing steel unit. (Strands or Bar)
3	Place primary grout.
4	Complete performance and proof tests (refer to section on testing later in this chapter).

[1] 2010 SS, Section 46-1.01C(2), *Shop Drawings,* or Special Provisions for contracts using 2006 SS.
[2] 2010 SS, Section 46-2.01D(2), *Load Testing,* or Special Provisions for contracts using 2006 SS.

SEQUENCE	DESCRIPTION
5	Lock-off and stress.
6	Place secondary grout.

Note: Each step must comply with the contract specifications before proceeding to the next step.

11-2.3 Safety

Check the Contractor's construction sequence against the authorized shop drawings. As excavation proceeds from the top down, look for signs of failure in the lagging or changes in the soil strata.

Sub horizontal ground anchors systems use powerful hydraulic rams to prestress or post-tension the system. Safety concerns are similar to those encountered with other prestressing operations. Structure Construction employees should not stand behind the hydraulic ram or cross it while stressing is taking place. The *Prestress Manual* and the *SC Code of Safe Practices* should be consulted for additional safety considerations.

11-3 Vertical Ground Anchors

Vertical ground anchors are similar to sub horizontal ground anchors although they act in the vertical plane. They can be used where site conditions do not allow traditional piles to achieve the necessary tensile capacity. For example, where rock exists close to the ground surface (or scour elevation), piles driven to refusal may be too short to develop sufficient skin friction to resist uplift or tensile loads required by the design. Vertical ground anchors are especially effective when combined with spread footings sitting directly on rock, or as part of a seismic retrofit strategy to add uplift capacity to a footing.

A schematic of a prestressing bar vertical ground anchor for a retrofit application is shown in Figure 11-2. Refer to *Bridge Standard Detail Sheets (XS)* 12-030-1 and 12-030-2 for vertical ground anchor details.

The Contractor is responsible for providing the vertical ground anchor system that conforms to the design requirements shown on the contract plans and the testing requirements specified in the contract. After selecting a vertical ground anchor system, the Contractor sends the shop drawings and calculations to Structure Design, Documents Unit, for distribution, review, and authorization similar to the process outlined above for sub horizontal ground anchors.

The record of readings from the performance and proof tests must be documented by the Contractor and provided to the Engineer. Structure Construction field personnel witness all performance and proof testing of the vertical ground anchors.

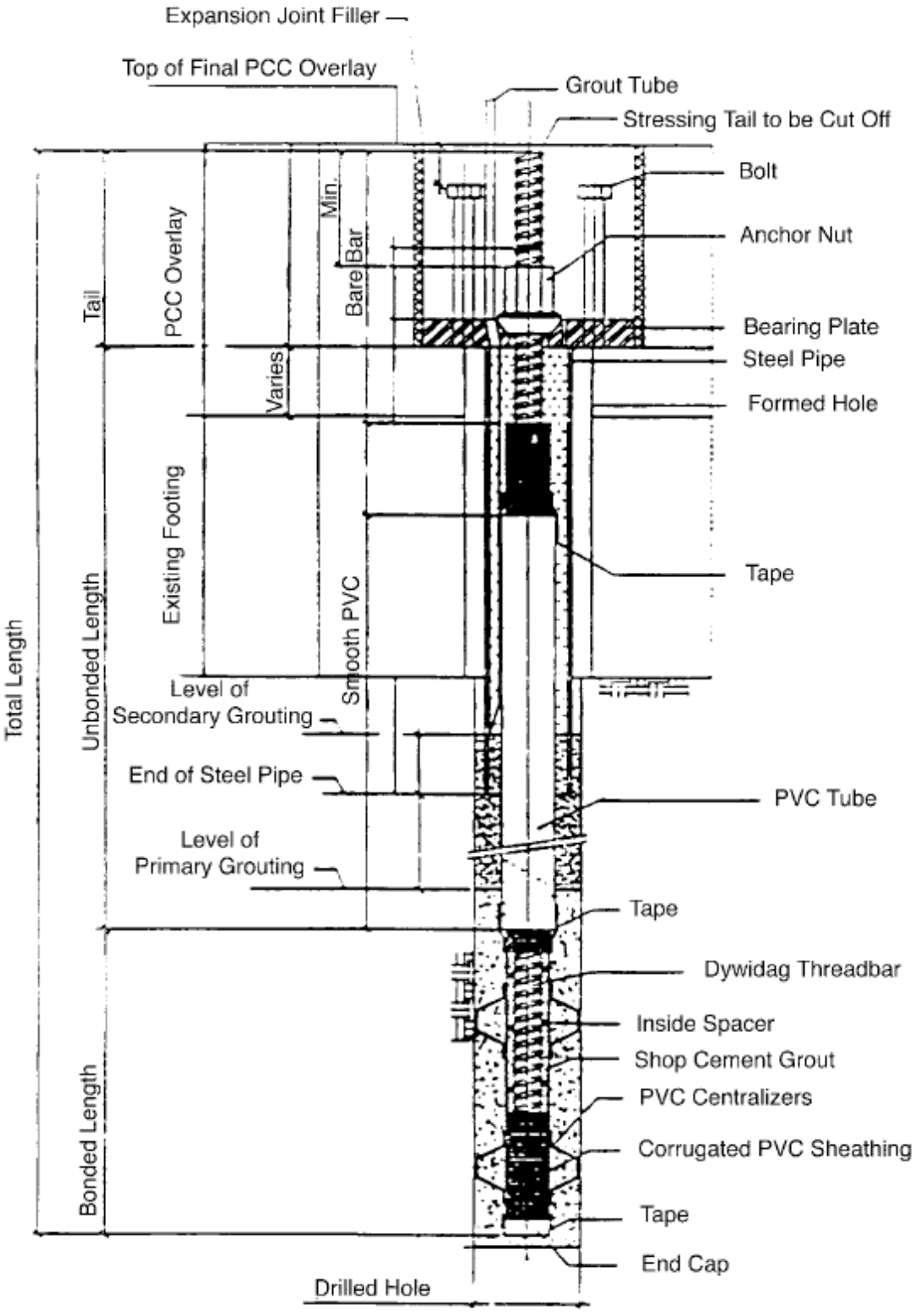

Figure 11-2. Vertical Ground Anchor Schematic.

11-3.1 Sequence of Construction

Sequence of vertical ground anchor construction is as follows:

Table 11-3. Vertical Ground Anchor Construction Sequence.

SEQUENCE	DESCRIPTION
1	Drill the hole the required depth and diameter.
2	Install the prestressing strands or bar.
3	Place primary grout.
4	Complete performance and proof tests (refer to section on testing later in this chapter).
5	Lock-off and stress.
6	Place secondary grout.

Note: Each step must comply with the contract specifications before proceeding to the next step.

11-4 Testing of Ground Anchors

Ground anchors require testing of the in-place anchors. Performance tests are done on a predetermined number of anchors, and proof tests are required on all of the remaining anchors. If the test results indicate that the anchors are not achieving capacity, additional monitoring and testing is required. If they do not pass at that point, a revision to the original design will be required. The redesign should be discussed with the Designer. The specific requirements for testing are provided in the contract specifications[3], the following is a general explanation of the required tests.

11-4.1 Performance Tests

A performance test involves incremental loading and unloading of a production anchor to accurately verify that the design loads will be safely carried by the system, that there is sufficient free length to allow for elastic elongation, and the residual movement of the anchor after stressing is within tolerable limits. Unless otherwise specified in the contract, at a minimum, performance tests are required for at least two but not less than 10% of ground anchors in footings, and at least three but not less than 5% of ground anchors in walls. Do not wait until many ground anchors have been installed before performance testing is conducted as the purpose of these tests is to verify the installation procedure selected by the Contractor. It is in the best interest of both parties to begin testing early and before a large number of anchors have been installed. The contract specifications[3] state the testing and acceptance criteria for each anchor that is performance tested and the number of performance tests required at each location.

A proof test involves incrementally loading a production anchor to verify the design capacity can be safely carried and that the free length is as specified. The proof test is a

[3] 2010 SS, Section 46-2.01D(2), *Load Testing,* or Special Provisions for contracts using 2006 SS.

single cycle test where the load is applied in increments until the specified maximum load value is reached. The contract specifications[4] state the testing and acceptance criteria for each anchor that is proof tested.

11-4.2 General Acceptance Criteria –Performance & Proof Tests

Table 11-4. Acceptance Criteria – Performance Tests.

CRITERIA	PERFORMANCE TESTS
1	Achieve test results that indicate the anchor is capable of supporting 100% of the factored test load for the anchor shown on the contract plans.
2	The measured elastic movement exceeds 80% of the theoretical elongation of the unbonded length plus the jacking length at the maximum test load.
3	The creep movement between one and 10 minutes is less than 0.04 inch.

Table 11-5. Acceptance Criteria – Proof Tests.

CRITERIA	PROOF TESTS
1	Achieve test results that indicate that the anchor is capable of supporting 100% of the factored test load for the anchor shown on the contract plans.
2	The pattern of movement is similar to that of adjacent performance tested ground anchors.
3	The creep movement between one and 10 minutes is less than 0.04 inch.

The contract specifications[5] outline acceptance criteria for these tests, however a performance tested or proof tested ground anchor which fails to meet the third criterion will be acceptable if the maximum load is held for 60 minutes and the creep curve plotted from the movement data indicates a creep rate of less than 0.08 inch for the last log cycle of time between 6 and 60 minutes.

11-4.3 General Construction Control

Table 11-6. Ground Anchor General Construction Tasks.

ITEM	DESCRIPTION
1	Mill certification should be provided for the steel tendons. a) Check the steel for damage. b) Ensure that grease completely fills the free length plastic tube. c) Securely tape the bottom of the free length. d) Compare the actual free length dimensions versus the dimension specified.
2	Double corrosion protection anchors should be completely fabricated before being delivered to the project. Bar anchors are installed full-length into the hole. Record the actual free and bond length for each installed anchor.
3	Tendons must be equipped with centralizers. These centralizer devices are absolutely necessary to center the tendon in the hole and to prevent the tendon from laying on the side of the drilled hole where incomplete grout cover will cause loss of capacity and future corrosion.

[4] 2010 SS, Section 46-2.01D(2), *Load Testing,* or Special Provisions for contracts using 2006 SS.
[5] 2010 SS, Section 46-2.01D(2)(c), *Acceptance Criteria,* or Special Provisions for contracts using 2006 SS.

ITEM	DESCRIPTION
4	Grout tubes are frequently tied to the tendon before inserting in the hole. This helps to ensure that there are no voids in the grout.
5	Testing–check to ensure the tendon is concentrically located in the center hole of the jack and load cell before testing begins. Poor alignment of the testing apparatus will cause eccentric loading on the load cell and jack, which will give erroneous readings. Deflections at the anchor head should be measured with a dial gauge.

11-5 Soil Nails

Soil nailing is a technique used to reinforce and strengthen an existing embankment (Figure 11-3). It can also be used to reinforce excavations to allow steeper cuts and/or deeper excavations. The fundamental concept is that soil can be effectively reinforced by installing closely spaced grouted steel bars, or "nails", into a slope or excavation as construction proceeds from the original ground to the bottom of the excavation or from the top down. Unlike ground anchors, the soil nail bars are not tensioned when they are installed and are grouted along the entire length of the nail. They are forced into tension as the ground deforms laterally in response to the loss of support caused by the excavation. The grouted nails increase the shear strength of the overall soil mass and limit displacement during and after excavation. Soil nails are bonded along their full length and are not constructed with a permanent unbonded length, as are ground anchors. A typical soil nail is shown in Figure 11-4.

Soil nailing is a cost-effective alternative to conventional retaining wall structures for most soils. However they are not practical in loose materials or plastic soils.

Common soil nail wall applications include the following:

Table 11-7. Soil Nail Applications.

APPLICATION	DESCRIPTION
1	Temporary and permanent walls for excavations.
2	Cut slope retention for roadway widening and depressed roadways.
3	Bridge abutments – addition of traffic lanes by removing end slopes from in front of existing bridge abutments.
4	Slope stabilization.
5	Repair or reconstruction of existing structures.

Soil nail wall construction is sensitive to ground conditions, construction methods, equipment, and excavation sequencing. For soil nail walls to be most economical, they should be constructed in ground that can stand unsupported on a vertical or steep slope cut of 3 to 6 feet for at least one to two days, and can maintain an open drilled hole for at least several hours.

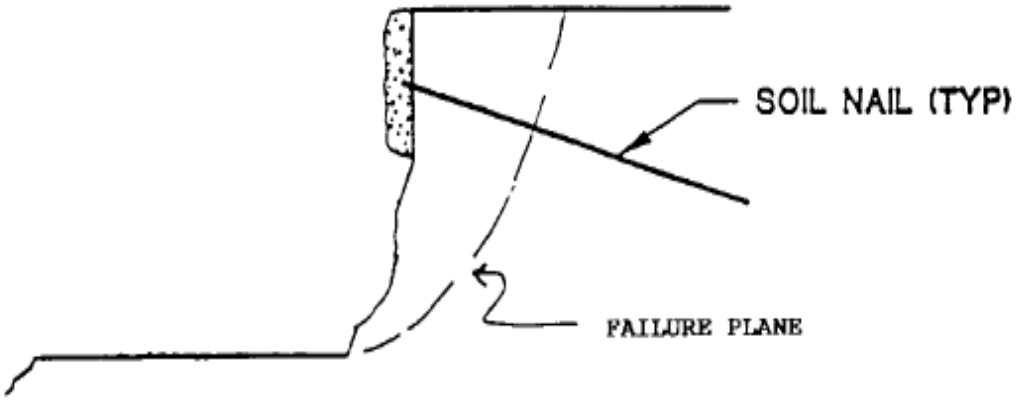

Figure 11-3. Soil Nail Schematic.

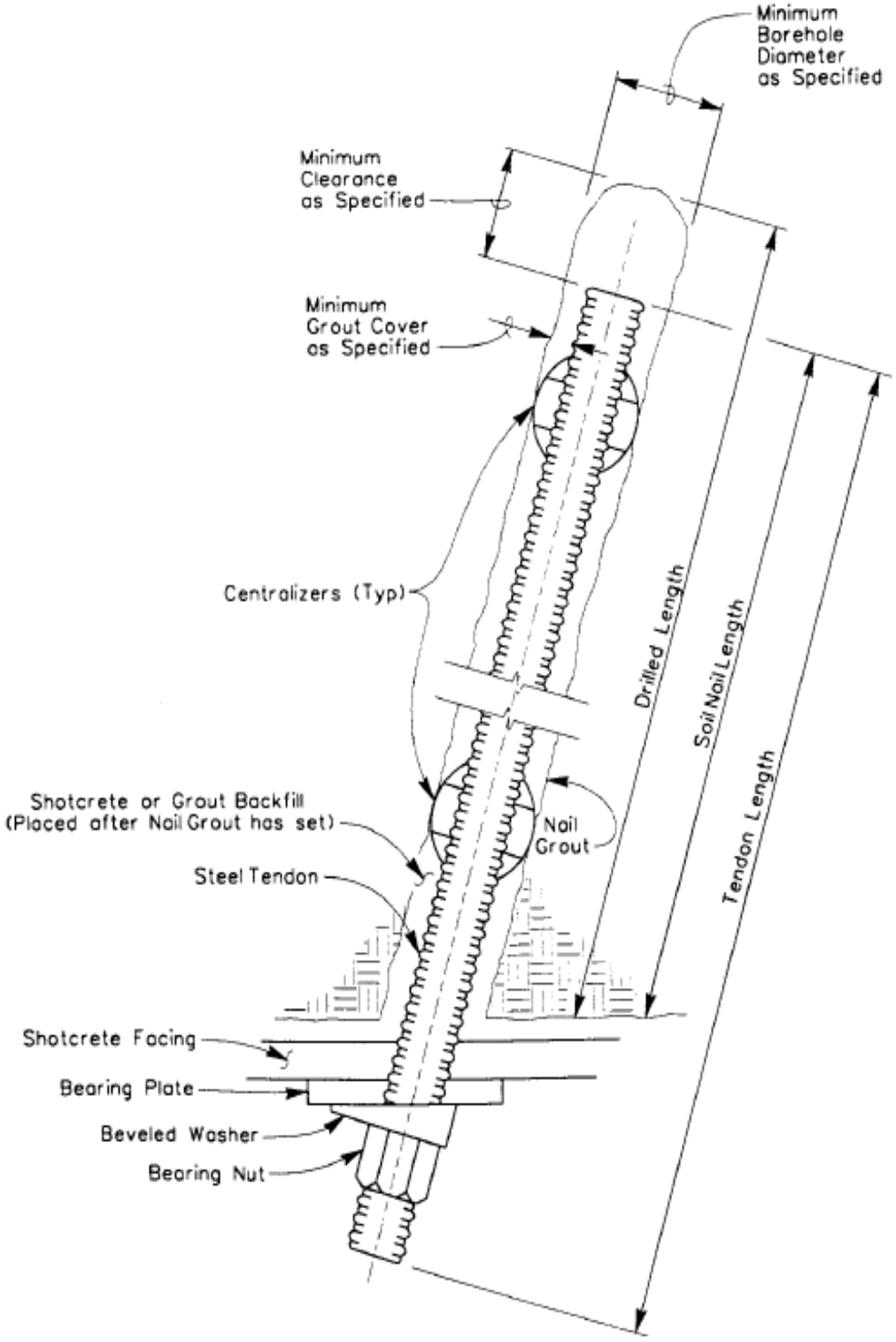

Figure 11-4. Soil Nail Detail.

11-5.1 Sequence of Construction

Soil Nail Wall construction sequence is as follows:

Table 11-8. Soil Nail Construction Sequence.

SEQUENCE	DESCRIPTION
1	Excavate a vertical cut to the elevation of the soil nails.
2	Drill the hole for the nail.
3	Install and grout the soil nail tendon.
4	Place the geocomposite drain strips, the initial shotcrete layer, and install the bearing plates and nuts.
5	Repeat process to final grade.
6	Place the final facing (for permanent walls).

11-5.2 Engineer's Responsibility

The Structure Representative must ensure the soil nail wall is being built in accordance with the contract. Caltrans is responsible for reviewing and authorizing the shop drawings and construction details. The review process is similar to that of ground anchors. One important difference between ground anchor designs and those of soil nails is that of design responsibility. Ground anchors have a grouted length that is designed or determined by the Contractor while soil nail walls do not; they are grouted full length.

Prior to construction, the planned alignment, depth, and layout of the soil nails must be checked in the field for any possible discrepancies. As with any work involving soils or rock, good daily diaries and records must be maintained for all field activities.

A good reference for field personnel is the *Soil Nailing Field Inspectors Manual - Soil Nail Walls – Demonstration Project 103*, Publication No. FHWA-SA-93-068, Federal Highway Administration, U. S. Department of Transportation, 1994, by James A. Porterfield, David M. Cotton, R. John Byrne.

11-5.3 Contractor's Responsibility

The Contractor is responsible for constructing the soil nail wall in accordance with the contract. The Contractor is also responsible for submitting complete details of the materials, procedures, sequences, and proposed equipment to be used for constructing the soil nail assemblies and for constructing and testing the test soil nail assemblies. The Contractor must furnish a complete test result to the Engineer for each soil nail assembly tested.

11-5.4 Testing of Soil Nail Walls–Verification, Proof, and Supplemental

The contract specifications[6] should be consulted for the specific test requirements for your project. Testing involves stressing the nails to simulate design load conditions. The following is a general description of the required tests.

[6] 2010 SS, Section 46-3.01D(2), *Load Testing,* or Special Provisions for contracts using 2006 SS.

11-5.4.1 Verification Nails

Verification nails, sometimes referred to as test nails, are not production nails and are meant to be "sacrificial". They are installed in the same manner as production nails but have an area that is not grouted or bonded. Verification tests should be performed before excavation is continued below the level of the test nail. Once the test is performed, the remainder of the drilled hole is filled with grout. The location of test nails is determined by the Designer and shown on the contract plans. Refer to Figure 11-5 for a test nail detail.

The contract specifications[7] state verification testing is performed to test the soil nail for creep and maximum load. The test involves incrementally loading the test soil nail assembly to the test load, holding it for an hour and then loading the nail to 150% of the test load. Movement of the soil nail end is measured and recorded to the nearest 0.001 inch at each increment of load, including the ending alignment load, relative to an independent fixed reference point. The contract specifications[8] outline acceptance criteria for the verification test nails. The nails need to fulfill these criteria before moving forward with construction of the rest of the wall. Should the nails not meet the criteria, additional tests may be necessary. The nails may fail due to constructability issues or insufficient length. In either case, additional verification tests will be required. The Contractor will need to provide a *Log of Test Borings* of the material removed from the holes for the additional verification test nails. This information should be provided to the Designer and Geoprofessional to help resolve this issue and determine whether the Contractor's means and methods are the cause of test nail failure or if the soil nails require redesign.

[7] 2010 SS, Section 46-3.01D(2)(b)(ii), *Verification Test,* or Special Provisions for contracts using 2006 SS.
[8] 2010 SS, Section 46-3.01D(2)(c), *Acceptance Criteria,* or Special Provisions for contracts using 2006 SS.

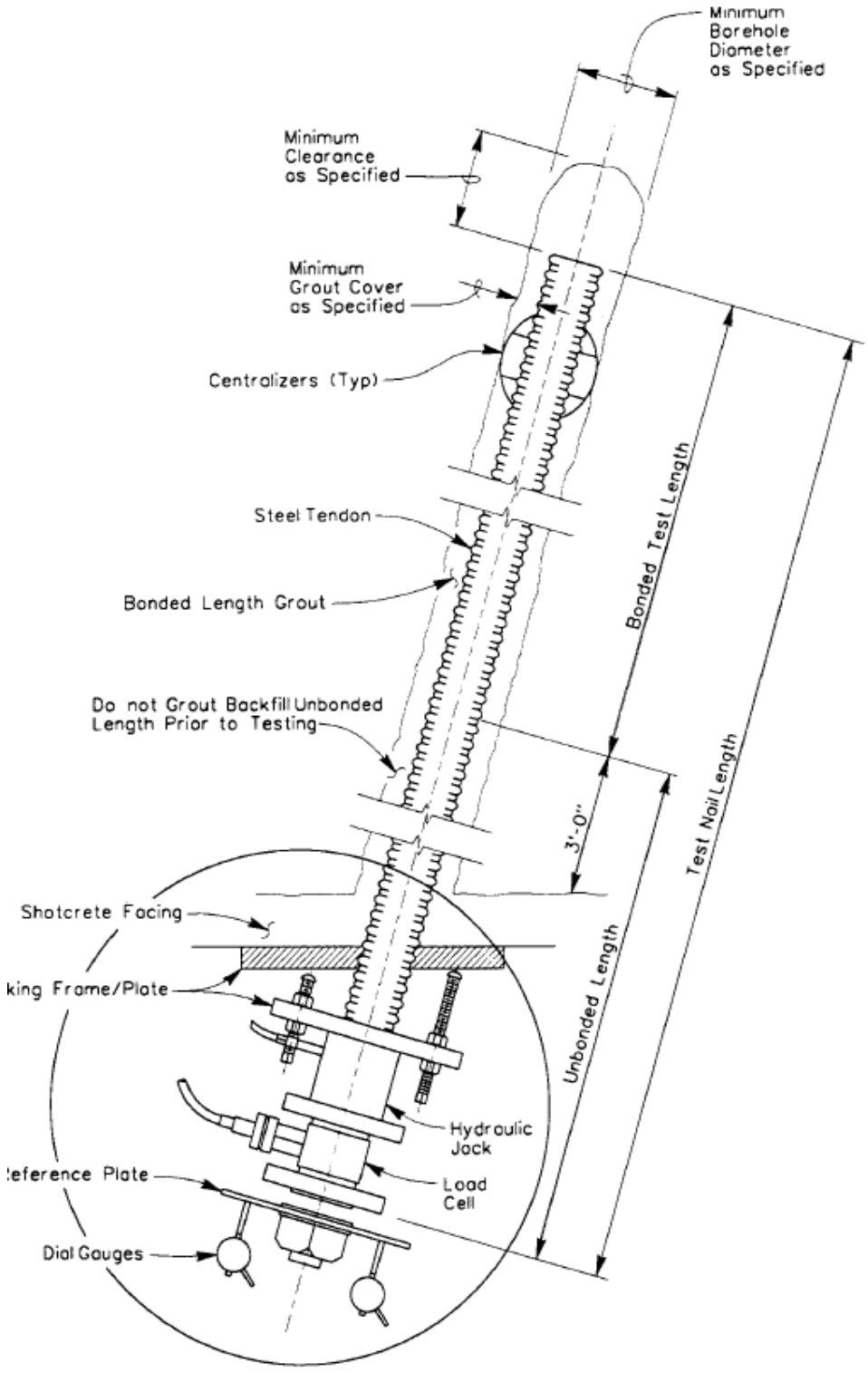

Figure 11-5. Verification/Test Nail Detail.

11-5.4.2 Proof Testing

Proof testing is performed on production nails that are shown on the contract plans and is used to measure creep. The contract plans indicate a specific number of proof tests to be performed at locations shown. The proof testing loading schedule, as well as the acceptance criteria for proof tests, are different than those for verification tests and are outlined in the contract specifications[9].

11-5.4.3 Supplemental Testing

Supplemental testing is done on a specified number of soil nails designated for proof testing (up to one-half of the proof-tested soil nails) and is performed immediately after the completion of proof testing. Supplemental testing is used to ensure pullout failure does not occur. The supplemental testing loading schedule and acceptance criteria are outlined in the contract specifications[10].

11-5.5 Safety

The soil nail wall should be monitored during construction for movement and for signs of failure. Occasionally, poor material will be encountered as the excavation continues downward. This differing condition may require a change to the contract plans or safety provisions in the construction method.

Personnel working around soil nail operations must wear the required Personal Protection Equipment (PPE) to include eye protection and ear plugs.

[9] 2010 SS, Sections 46-3.01D(2)(b)(iii), *Proof Test;* 46-3.01D(2)(c), *Acceptance Criteria;* or Special Provisions for contracts using 2006 SS.
[10] 2010 SS, Sections 46-3.01D(2)(b)(iv), *Supplemental Test;* 46-3.01D(2)(c), *Acceptance Criteria;* or Special Provisions for contracts using 2006 SS.