CHAPTER 3 – FIELD STUDY AND ANALYSIS PROGRAM

INSTALLATION, TESTING, AND ANALYSIS PROGRAM

The FHWA approached the International Association of Foundation Drilling (ADSC) Anchored Earth Retention (AER) Committee to coordinate an effort to look at the feasibility of using HBSNs on permanent soil nail wall construction. The AER Committee selected Schnabel Engineering (Schnabel) as the Principal Investigator for the activity. Using preliminary installation and test protocols developed by an ADSC AER Task Force and FHWA personnel, Schnabel finalized a work plan consisting of site selection, soil nail installation techniques, and testing procedures. Working with the ADSC AER Committee and with the aid of ADSC-experienced contractors around the United States, Schnabel identified the following four sites, which were suitable for installation and testing of HBSNs for this investigation:

Site 1: City Creek Center, Block 76 (Block 76 Site), located in Salt Lake City, Utah
Site 2: Posillico Storage Yard (Posillico Site), located in Bohemia, New York
Site 3: Sunset Mesa Gravel Pit (Sunset Mesa Site), located in Montrose County, Colorado
Site 4: DIS Wheeler Property (Olympia Site), located in Olympia, Washington

At each site, eight to twelve test soil nails were installed and tested in accordance with the installation, testing, and recording plans established in the program installation protocol (work plan) dated 1/10/2008. The installation, testing, and recording plans are reiterated in this chapter. A comparison was made between the calculated bond strength values from each installation method. In addition, the bond strength values of the test nails were compared to typical bond values from SBSNs using rotary drilled and jet grouted installation methods. The following pages contain pertinent details of each of the test sites, and detailed descriptions of the installation procedures used.

SITE SELECTION

The research team focused on sites where the use of HBSNs would provide practical advantages with respect to conventionally installed SBSNs (for example, sites where readily loosened granular soil deposits were present, which necessitated the use of temporary casing during the drilling and installation of SBSNs). Preferable soil conditions for testing included:

a) Colluvium sites.
b) Sands/Silty sands that are marginally stable for cuts.
c) Clean sands such as coastal beach areas.

It should be noted that HBSNs may be advantageous in other soil deposits not included in this list.

The four sites selected met the above criteria while representing a variety of geographical and geological conditions across the United States. In general, the sites ranged from clayey fine sand to poorly graded gravel containing cobbles and boulders. The following sections provide a brief description of the sites. More detailed information is included in the appended data reports (Appendices 1-4) that were generated after each test program was completed.

It is noted that the applicability of hollow bars is not limited to granular soils. There are possibly a number of other geotechnical conditions where HBSNs would be advantageous over SBSNs, or where SBSNs might require casing for their installation. However, this research focused on sites where HBSNs would prevent the need for casing for the installation of production nails, and limit both the potential for collapse of the hole and development of grout body constrictions.

SITE DESCRIPTIONS

The location and soil deposits for each of the four test sites are described in the following paragraphs. The soil descriptions are based on the soil boring and laboratory test data available for each site, included in Appendices 1-4, and on-site observation noted on installation logs.

Site 1: Block 76 Site (Details are shown in the Appendix 1 on the attached CD ROM)

Test Site 1 was an active construction site known as City Creek Center – Block 76, and is located in Salt Lake City, Utah. The site is at the corner of Maine and ES Temple Streets. A temporary soil nail retaining wall was required for a site access ramp. Nine test nails were installed by Nicholson Construction near the base of this ramp and were exhumed during final construction. The exhumed nails were not logged; however, photographs of the nails are included in the Appendix 1. Based on the observations noted during the installation of the soil nails and available geotechnical borings, the subsurface conditions consisted of moist to wet, poorly to well graded gravel of medium to hard density, with silt, sand, cobbles, and the occasional clay seams. The geotechnical borings are included in the Appendix 1.

Site 2: Posillico Site (Details are shown in the Appendix 2 on the attached CD ROM)

Posillico Construction operates a storage yard in Bohemia, New York, which was used as Test Site 2 for this research study. Based on the geotechnical boring by Schnabel (Schnabel, 2006), this site is underlain by relatively clean, fine to coarse sand with layers containing cobbles, as well as lenses of thin silt or clay. A trench was excavated at this site to allow installation of nails into the trench wall. Peterson Geotechnical and Posillico Construction installed the nails and performed the testing. All nails were exhumed after testing.

Site 3: Sunset Mesa Site (Details are shown in the Appendix 3 on the attached CD ROM)

Test Site 3 was located at the active Sunset Mesa Gravel Pit in Montrose County, Colorado. The gravel pit is used for borrow material on local projects. Based on the geotechnical report by Buckhorn Geotech, Inc. (Buckhorn, 2008) developed for the test area, the geologic stratigraphy consists of uniform poorly graded gravel with sand. Buckhorn Geotech, Inc. describes the soil in which the HBSNs were installed as damp, dense, sandy gravel, cobbles, and boulders with trace fines.

A working bench and excavated face was created by Mountain Highwall Construction and eight nails were installed by Mountain Highwall and TEI Rock Drill for purposes of this testing program. All nails were exhumed after testing; photographs were provided by Mountain Highwall for review.

Site 4: Olympia Site (Details are shown in the Appendix 4 on the attached CD ROM)

Test Site 4 was located in Olympia, Washington, and is known as the DIS Wheeler property at the southeast corner of 14th Avenue and Jefferson Street. The test area was located within the limits of a temporary stormwater retention area constructed on the north side of the site. This area was excavated to a depth of about 10 ft with sloping sides. The test area setup was located along the eastern side of this retention basin and all nails were drilled from the bottom of the basin. As such, the nails entered the slope about two to three feet above the bottom of the basin.

Based on the available geotechnical site investigation report (Haley & Aldrich, 2008), the geologic stratigraphy consists of fill overlying recessional outwash/glacio-lacustrine deposits. The encountered fill material consisted of soft to medium stiff silt and clay with variable debris and organic matter content. The soil nails were installed just below the fill layer in the recessional outwash/glacio-lacustrine deposits, which consist of stratified layers of sand and silt of soft to medium density. Field observation indicated the material into which the soil nails were installed was generally clayey fine sand.

SOIL NAIL INSTALLATION METHODS

Three methods were originally identified and selected for this test program. Method A is a baseline for comparison with the conventional SBSN. Methods B and C were conceived as practical ways to create an unbonded length along a test HBSN. They have been used in some form or another by contractors in past construction projects. In particular, Method C was expected to be a readily constructible production testing protocol. Method D was conceived prior to installation and testing at the fourth site and may be a potential alternate to Methods B and C. Method D offers certain advantages in some cases as described subsequently in this report.

Method A: Traditional Test SBSN Installed Using Casing

This is the typical procedure for installation of test SBSNs, where the free length of the soil nail is achieved with the aid of a temporary casing as shown in Figure 1. For this project, the test SBSNs were drilled using casing and a drag bit or roller bit. The method of casing advancement and bit type are indicated on the installation logs, included in the site reports in Appendices 1-4.

After completion of drilling, the rods and drill bit were withdrawn and the tendon with centralizers was inserted. The tendon was a bare all-thread No. 14 bar (F_y=75 ksi) fitted with a PVC sheath along the intended free (or unbonded) length, as shown in Figure 2. The intended bond length below the bottom of the PVC sheath was tremie grouted while controlling grout volume based on a nominal hole diameter. The casing was then pulled to the top of the bond zone and the grout level was checked; grout was added or flushed as necessary. Upon completion of the soil nail, the temporary casing was withdrawn from the hole, allowing the *in-situ* soil to collapse around the nail and smooth PVC sheath. For the test nails installed following this procedure, there is no grout intentionally surrounding the free length of the SBSN.

Figure 1. Photograph. Installation (Method A) of a solid bar at the Posillico Site.

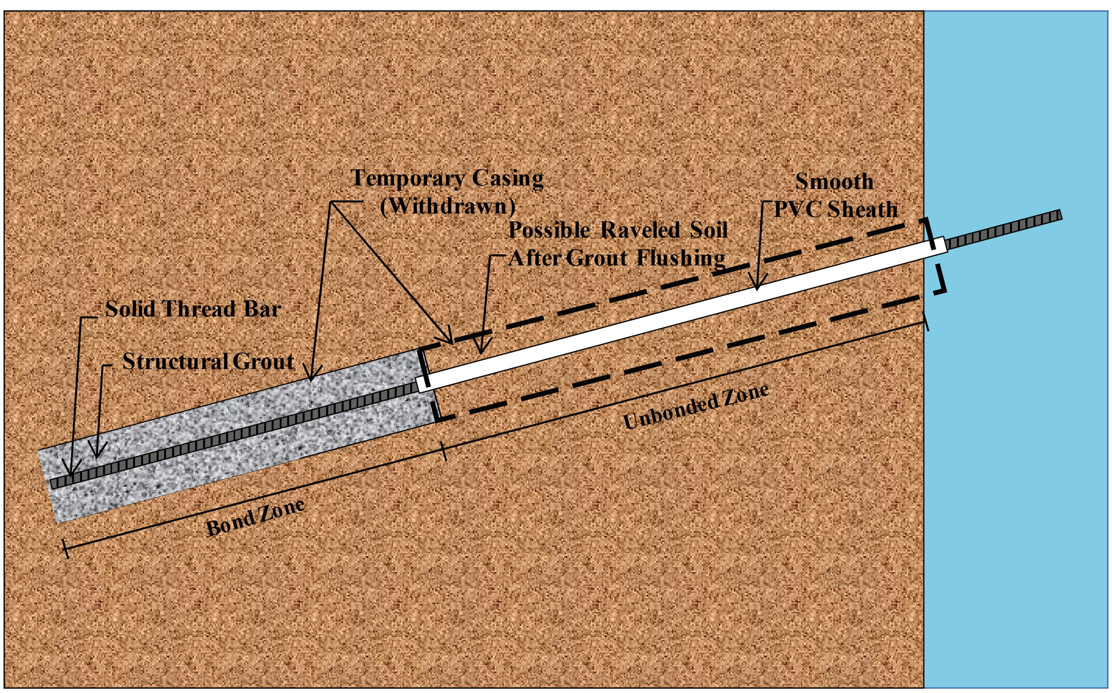

Figure 2. Schematic. Solid bar soil nail installed using Method A.

Method B: Hollow Bar Installed with Debonding Sheath and Water Flushing

For Method B, HBSNs were installed by drilling with a temporary casing and a drag bit or roller bit completely through the unbonded length and stopping at the top of the desired bond zone. The method of casing advancement and bit type are indicated on the installation logs. After the casing was installed and the drill bit withdrawn, the hollow bar with a sacrificial drill bit was inserted into the casing. Drilling continued following typical installation procedures for HBSNs (as discussed in FHWA, 2006).

To ensure the required free length was truly unbonded, the HBSN was fitted with a smooth PVC sheath along the free length only. Once drilling was completed, the grout was flushed from the annular space between the sheath and the temporary casing. In some cases, the smooth PVC sheath was slid over the hollow bar after its installation. Flushing of the unbonded length was performed using a narrow hose and water. Several variations of the flushing tube tips were attempted, including bending them into a "J" shape and cutting several openings in the side of the tube as shown in Figure 3. For each variation of flushing tip, water was not permitted to flow directly toward the grouted bond zone.

Figure 3. Photograph. Outlet end of flushing tube.

After flushing, the casing was withdrawn, allowing the hole to collapse around the PVC and HBSN in the unbonded length. A schematic diagram of an installed Method B HBSN is shown in Figure 4. For the test nails installed following this procedure, there is no grout intentionally surrounding the free length. The depth of flushed grout in the casing was measured using a tape measure or rod during flushing. However, grout was in the withdrawn casing at depths where the nail was expected to be fully flushed. This occurrence is noted on the logs. Of particular note, significant grout remained in the casing at the Sunset Mesa site where the contractor elected to wait until the end of the day to pull all the casing for Method B nails as shown in Figure 5.

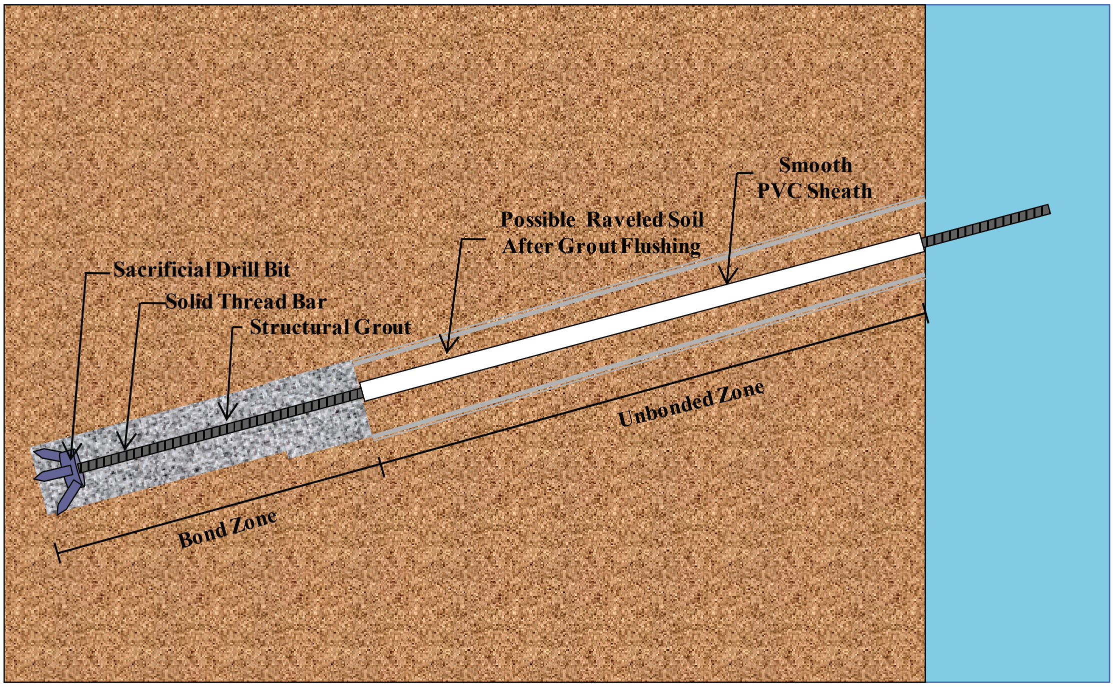

Figure 4. Schematic. HBSN installed using Method B.

Figure 5. Photograph. Grout remaining in the casing after flushing at the Sunset Mesa Site.

Method C: Hollow Bar Installed with Debonding Sheath and Without Flushing

To prohibit grout-to-ground load transfer, it is a common industry practice to place a PVC bondbreaker onto the HBSN along the length of the bar in the unbonded zone. Upon completion of the soil nail installation, a body of grout remains in the annular space around the PVC bondbreaker. For Method C, HBSNs were installed following established installation procedures as noted in the SOP (FHWA, 2006). Efforts were made to monitor the installation rate and grout flow for consistency throughout drilling; however, soil conditions and driller preferences had some impact on the ability to control the consistency of the parameters. Installation rate was generally consistent at a site but varied from site to site. Grout return was maintained throughout all drilling.

The structural grout mix was used during drilling and final grouting. Using a single grout mixture was considered to be a more conservative approach for two reasons: (1) the thinner grout (typically used during drilling) is more likely to penetrate deeper into granular soils, resulting in larger grouted zones and thus increased nail capacity, and (2) the single grouting methods are often utilized by contractors.

Debonding of the hollow bar along the intended free length was accomplished by fitting the bar with a smooth PVC sheath, which was secured to the coupler using duct tape. Grease was applied to the surface of the bar before installation of the smooth PVC sheath. A schematic diagram of an installed Method C HBSN is shown in Figure 6. Only at the Olympia Site, the smooth PVC sheath was pushed over the bar and through the grout after drilling. Installation of the smooth PVC sheath after grouting was possible because there was no tendency for collapse of the drill holes as observed during nail installation using Methods A and B. It is the experience of the authors that inserting the smooth PVC sheath after installation of the test HBSN may be difficult or impossible at many sites, and should not be relied upon except in cases where the required free length is relatively short.

It is noted that for the test nails installed following this method, there is a substantial annulus of grout that remains around the free length.

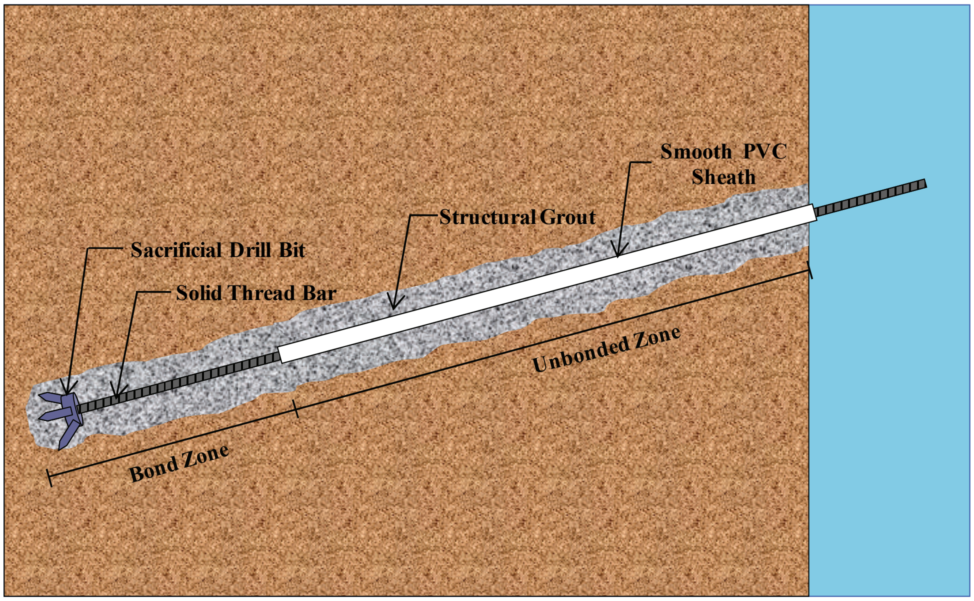

Figure 6. Schematic. HBSN installed using Method C.

Method D: Hollow Bar with Bondbreaker Installed by Re-drilling a Pre-grouted Hole

Method D was performed only at the Olympia Site. The intent of this method was to create a hole that would be resistant to collapsing without the need for temporary casing, and that could be subsequently flushed as described in Method B. For Method D, the installer drilled and grouted the intended free length of the test nail using the same equipment and setup for a typical HBSN installation. Upon completion of the drilling to the top of the bond zone, the hollow bar was retracted and the grout allowed to set over night.

This initial grout body was re-drilled within 24 hours during typical HBSN installation procedures. The intent was to have a soil-cement annulus around the free length of the bar and to allow flushing of the unbonded zone. At the Olympia Site, redrilling through the day-old grout was accomplished with little difficulty. The hollow bar did, however, tend to drift toward the upper left of the initial grout body during drilling, thus resulting in an eccentric annulus with respect to the pre-drilled hole. However, the hole did remain open and flushing was completed successfully. A schematic diagram of an installed Method D HBSN is shown in Figure 7.

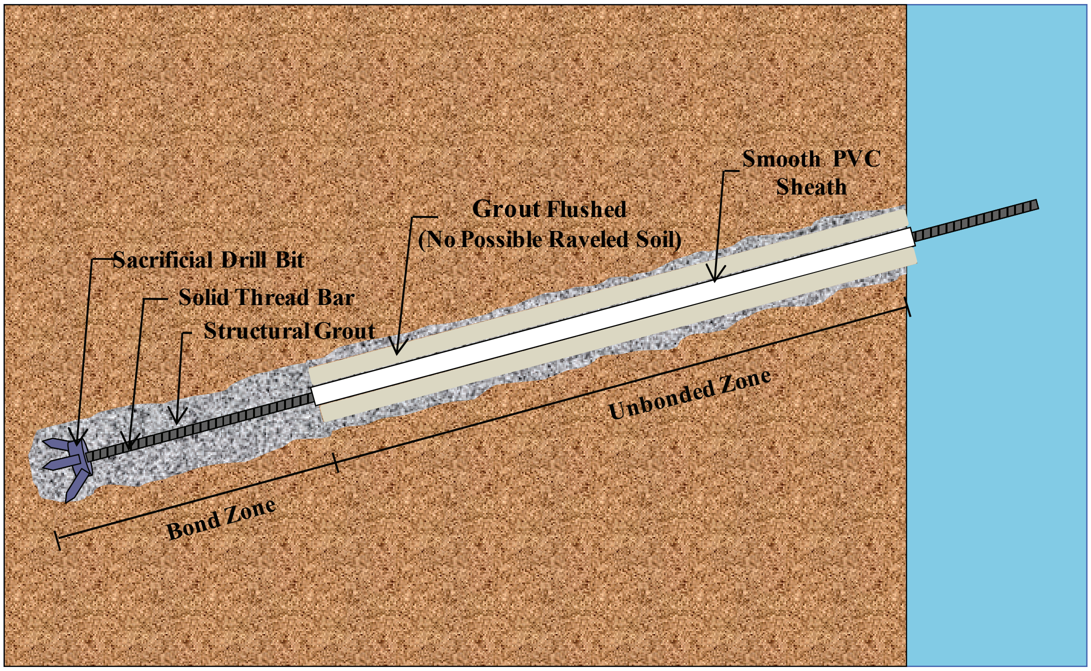

Figure 7. Schematic. HBSN installed using Method D.

CONSTRUCTION DETAILS: MATERIALS, INSTRUMENTATION, AND INSTALLATION

At each site, except as noted on the logs and summary table, both the SBSNs and HBSNs were located in the same geologic material. The soil nails were installed at 3 ft to 5 ft center-to-center spacing along an approximately horizontal line.

Materials

Materials from various suppliers were used. However, they all met certain pre-established criteria. Bar and drill bits were supplied by several manufacturers including Williams Form, Con-Tech Systems Ltd. (CTS), and DSI America. Each bar and drill bit type, size, strength, and manufacturer are noted on the logs. Bar size was determined based on applicability to typical SBSN and HBSN production methods, as well as on the maximum test load that could be applied. In general, larger bars were selected to attempt to induce geotechnical failure of the bond zone of the test nails in order to obtain ultimate bond strength values. Centralizers were installed on all SBSNs and HBSNs with exception of non-CTS HBSNs. Centralizers are not a manufactured component of the bar system. Table 2 summarizes materials and dimensions used at each site for each installation method.

Table 2. Soil nail material summary.

Site	Bit Type	Bit Size (in)	Casing Outer Diameter (in)	Casing Wall Thickness (in)	Bar Type	Bar ID	Bar Supplier
Block 76	Sacrificial Wing/Drag	5	4.5	0.25	Solid	# 14	Williams
	Carbide	4	4.5	0.25	Hollow Core	R51N	Williams
Posillico	Roller	5	7	0.188	Solid	# 14	Williams
	Cross Cut	5.1	7	0.188	Hollow Core	52/26 mm	Con-Tech
Sunset Mesa	Super Jaw	7.75	7	0.43	Solid	# 14	Williams
	Carbide	5	7	0.43	Hollow Core	52/26 mm	Con-Tech
Olympia	--	4	6.25	0.25	Solid	# 14	DSI
	Cross Cut	4.52	6.25	0.25	Hollow Core	R51N	DSI

The grout mix used for this research study was comprised of Type I, Type II, or Type V cement with a target water-cement ratio of about 0.44 (1 bag of cement per 5 gallons of water). The grout was mixed using a high shear mixer group pump (typical pump shown in Figure 8). The specific gravity of the grout was measured before injection into the hole at the end of the tremie tube, or connection of the hose and swivel. Occasionally the specific gravity of the grout return was also measured. For nails where a pre-measured volume of grout was placed, no return was expected or observed. As noted on the drill logs, the specific gravity of the sampled grout was at least 1.8, as measured using a mud balance.

Grout cubes were also collected and tested for strength. The grout cubes were prepared and tested in accordance with ASTM C109/C109M-02, Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (using 2-inch or 50-millimeter cube specimens). As discussed in a previous section, the same grout mix was used during the entire drilling process, for both drilling and final grouting.

Figure 8. Photograph. Obermann high shear mixer grout pump.

Strain Gauges

Based on suggestions developed from the review meeting following completion of testing in the first three sites, strain gauges were utilized only at the Olympia Site. Four Geokon modified Model 4200 strain gauges were installed into one HBSN for each of the methods used (Methods B, C, and D) at the Olympia Site. The use of strain gauges was considered in order to measure axial strain and evaluate the load transfer along the length of the nails.

The strain gauges used were Geokon Model 4200-AX as shown in Figure 9, which have a relatively small diameter (maximum 19 mm). To reduce the cable diameter, the thermistors were not activated. The wings of the dumbbell style strain gauge were notched to allow the cables to pass without having to increase the overall diameter of the strain gauge footprint. On either end of the dumbbell, Geokon welded a nut, which provided a positive connection for a ¼-inch diameter all-thread bar. The ¼-inch diameter all-thread bar was used to space and to plunge the gauges into the grout column within the hollow core bar.

Figure 9. Photograph. Geokon Model 4200-AX strain gauge with threadbar attachment and notched dumbbells.

Equipment and Installation

The equipment for each site depended on subsurface conditions and equipment availability to the contractor. The Sunset Mesa, Block 76, and Posillico sites required two different rigs: one to install the casing as shown in Figure 10, and one to perform the rotary hollow bar drilling. In general, the equipment used at each site was sufficient to successfully complete the installation. The equipment used at each site is listed on the respective drill logs. For the installation of the HBSNs, a pressure gauge was installed at the swivel, as shown in Figure 11. The grout pressure during installation of the HBSNs is noted on the drill logs.

The installation processes for Methods A, B, C and D were relatively consistent. Several factors that may affect the bond stress such as rotation rate, advancement rate, grout pressure, grout flow rate and grout mix data were collected and noted on the drill logs.

Figure 10. Photograph. Casing installation at the Sunset Mesa Site.

Figure 11. Photograph. Top hammer setup used for installation Methods B and C. Note the grout pressure gauge at the swivel and centralizer used to hold PVC in place.

SOIL NAIL TESTING

The soil nails were tested using typical verification testing methods found in GEC 7 (FHWA, 2003). Typically, verification tests are completed on "sacrificial" nails prior to construction using the same installation methods as production soil nails.

Verification tests are generally intended to verify a factor of safety of the bond strength, or to reach ultimate or pull-out loads. For this study, the bonded lengths and bar sizes were designed to attempt pull-out failure of the test soil nail, based on the presumptive bond strength and drill hole diameters. Per GEC 7 (FHWA, 2003), "pullout failure is defined as the inability to further increase the test load while there is continued pullout movement of the test nail."

For the purpose of establishing load increments, a Design Test Load (DTL) was established for each test, and is used as a reference in the data collection spreadsheets. The value of DTL was equal to the intended maximum test load divided by a factor of two. Since the objective was to reach pull-out failure, the bar was sized to allow the nail to be loaded to more than 150% of the ultimate load capacity given by the presumptive bond strength. However, in several cases, pull-out could not be achieved at these high loads.

The load test schedule in Table 3 was used as a starting point for each load test. Soil nail movement was recorded during each load increment and during creep holds in accordance with FHWA guidelines. As testing was performed at a given site, the subsequent load test increments may have been adjusted to collect intermediate data or data beyond the assumed bond strength or 2x DTL. At low loads this hold time was reduced for some tests (see load test logs in Appendices 1-4). The creep test may have been performed at a different multiple of the DTL, considering anticipated pull-out load, as shown on the test results.

Table 3. Typical verification test load schedule.

Test Load Increment	Hold Time (minutes)
AL (0.05DTL max)	1
0.25DTL	10
0.50DTL	10
0.75DTL	10
1.00DTL	10
1.25DTL	10
1.50DTL (creep test)	60
1.75DTL	10
2.00DTL (maximum load)	10
AL	1

Notes: AL = Alignment load
DTL = Design test load

Load Testing Setup

The load testing setup varied from site to site but consisted of the following critical components: two dial gauges, dial gauge support, jack and pressure gauge, and a reaction frame. Pressure gauges were graduated in increments not greater than 100 psi (689.5-kPa). The dial gauges were capable of measuring to 0.001 inches (0.025 millimeters). The Sunset Mesa typical load test setup is shown in Figure 12.

Figure 12. Photograph. Load test setup at Sunset Mesa Site.

The reaction for the test load was generally provided by a steel plate supported on wood cribbing, which was laid out to provide a flat surface perpendicular to the nail alignment. Cribbing and plates spread the load over an area of at least nine square feet. Where shallow benches were constructed for nail installation, additional efforts were required to prevent passive failure of the wall face during jacking.

Strain Gauge Use at Olympia Site

Four Geokon 4200-AX strain gauges were installed into the HBSNs in order to measure axial strain and evaluate the load transfer along the nails. The gauges were installed inside the hollow portion of the bar after final grouting. The hollow core provided confinement of the grout in which the strain gauges were installed. One gauge was located within the unbonded length, while the remaining four gauges were distributed within the bond zone. The gauge inside the unbonded length was intended to detect load shedding that might occur along the unbonded length.

The load at each strain gauge was calculated using Equation (1):

$$P = \varepsilon_a AE \qquad (1)$$

where:

P = Force in nail
ε_a = Axial strain as measured by the gauge
E = Young's Modulus of steel, 29,000 ksi
A = Cross-sectional area of the steel reinforcing bar

During initial loading of the soil nail, before the grout develops generalized tensile cracking, this equation underestimates the axial load of the soil nail. However, the interpretation of the strain gauge data focused in determining the bond strength along the soil nail under relatively large test loads, and once the contribution of the grout to the axial stiffness has become negligible or zero.