Presented At

ADSC EARTH RETENTION SEMINAR

Peabody, Massachusetts

Soil Nailing
-
A Contractors Perspective

by
Harry W. Schnabel, P.E.
Schnabel Foundation Company
Boston, MA

Schnabel
FOUNDATION COMPANY

SOIL NAILING – A CONTRACTORS PERSPECTIVE

In recent years the use of soil nailing has become an increasingly accepted and frequently used method for constructing temporary and permanent earth retaining structures. In the right soil and groundwater conditions, soil nailing can offer cost and schedule advantages over conventional earth retaining systems such as soldier beams and lagging or sheet piles. Specialty contractors experienced in the design and construction of soil nail walls have developed new techniques and equipment that make the use of soil nailing an increasingly attractive alternative for excavation support. This paper presents an overview of the soil nailing method along with a discussion of the specific application of the soil nailing method to two projects in New England.

Definition of Soil Nailing:

Soil nailing is a means of reinforcing existing soils in-situ using passive inclusions and a structural facing. Typically, the passive inclusions, or soil nails, consist of drilled and grouted steel bars. Soil nails differ from tiebacks in that they are not tensioned and locked-off after they are installed and they do not have an free stressing length. The structural facing is typically shotcrete reinforced with wire mesh and/or rebar. The shotcrete facing is applied to keep the soil between the nails from raveling and is not designed to resist the full earth pressure. Figure 1 shows an earth excavation supported with soil nailing.

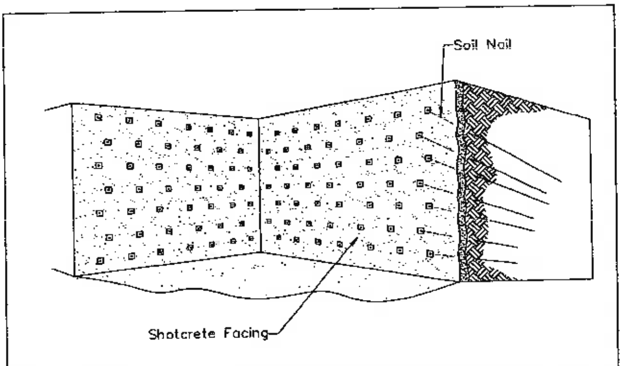

Figure 1 – Excavation Reinforced With Soil Nailing

Soil Nailing Applications:

Soil nailing is normally used when the soil to be supported is cohesive or cemented in nature. This is because the soil must stand vertical or near vertical for the required lift height during nail installation and shotcrete application. Also, it is generally necessary to case holes in granular or cohesionless soil, which, because of the larger number of nails relative to tiebacks in a tieback wall, negates some of the cost advantages of soil nailing. In addition, soil nailing is not recommended for use in plastic and creep susceptible soils.

Soil nailing is often used where restrictions such as low overhead clearance, steep slopes, or numerous boulders or other obstructions make installation of conventional earth retaining systems impractical. The smaller drills used by soil nailing have smaller bench requirements and require less overhead clearance than larger pile driving and drilling rigs. The smaller drill holes required by soil nailing also allow for the use of drill rigs that can drill rock and boulders more efficiently. In

Authored by Harry W. Schnabel, P.E.; Schnabel Foundation Company

addition, soil nails are installed at a relatively flat angle, typically between 15 and 25 degrees from the horizontal. This alleviates some of the problems imposed by overhead restrictions. Figure 2 shows soil nailing applied to a bridge abutment with low overhead clearance and soil nailing on a steep slope with a limited bench.

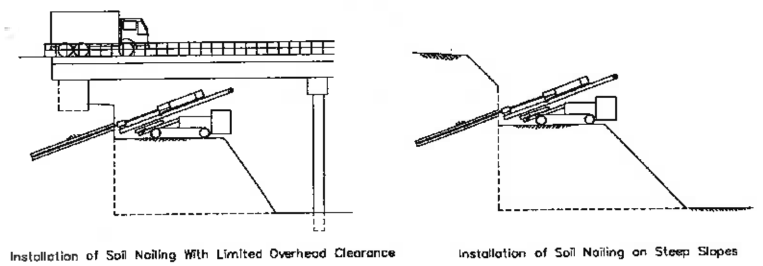

Figure 2. – Typical Applications of Soil Nailing

Soil nailing can be used to construct both temporary and permanent earth support systems. Temporary soil nail walls usually have a thin shotcrete facing and no additional corrosion protection other than the grout around the nail. Temporary soil nailing can be constructed either as "wall line" or "off wall line". Wall line soil nailing is screeded to provide a relatively smooth surface. This allows waterproofing to be applied directly to the face of the shotcrete, and a permanent wall to be poured directly against it with a single sided form. Off wall line soil nailing has a rough, or "gun", finish and a double-sided form is used to construct the permanent wall

Temporary applications include:

- Excavation Support Systems – Soil nailing is used to allow the sides of excavations for basements, underground parking garages, or other underground structures to be cut vertically or nearly vertically. This is important if sloping the sides of an excavation would encroach on adjacent property lines, structures, or utilities. Soil nailing also reduces the amount of excavation and backfilling required.

- Retaining Wall Excavations – Soil nailing is used to temporarily support the earth in areas where a road, rail line, or other improvements are widened into an existing embankment so that a permanent wall, such as a concrete cantilever wall, can be constructed. In these applications a permanent soil nail wall may be a more cost-effective solution, since soil nailing is already being installed as temporary excavation support. The additional cost of providing corrosion protection to the nails and a permanent facing is minimal compared to the cost of constructing and backfilling a new wall.

Permanent soil nail walls usually have a thicker reinforced shotcrete facing or some other type of structural facing such as a cast-in-place wall or pre-cast concrete panels. Permanent walls also require that additional measures be taken to protect the nails from corrosion. These measures may include coating the nail tendon, bearing plate, and anchor nut with epoxy.

Typical applications for a permanent soil nail wall include:

- Highway Walls – Roadways are frequently widened into adjacent hills, embankments, or bridge abutments to allow for more lanes of traffic. Permanent soil nail walls are used to allow the widening of these roadways without the large quantities of excavation and concrete necessary to install cantilever walls.

- Basement Walls – Soil nailing can be used to construct permanent walls for an underground structure as the excavation for the structure is being made. The soil nails can either be permanent or temporary. If the nails are temporary the lateral loads on the walls must eventually be transferred to the floors of the structure.

- Slope Stabilization – Soil Nailing can be used to reinforce existing slopes, which are failing or sloughing.

- Repair of Existing Walls – Soil nailing can be used to reinforce the ground behind existing walls that are failing. Soil nailing has been used to repair failing concrete, masonry, bin and other types of walls.

Limitations of Soil Nailing:

Soil nailing is not suitable in all conditions. Soil nailing should not be used in excavations below the groundwater table. Water flowing through the face of the cut may cause the soil to slough and the shotcrete to peel away from the wall. Experienced soil nail contractors may be able to handle difficult groundwater conditions using specialized techniques and experienced personnel.

It is also difficult to soil nail an excavation when there are numerous utilities behind the wall. The uppermost nail is typically only a few feet down from the top of the wall and soil nails are generally spaced on a 4 to 6-foot grid. This makes missing utilities behind the wall difficult or impossible. Also, utility trenches running parallel to the wall may be filled with granular backfill, which could cause the top of the wall to slough. It may be possible to go under utilities by sloping above the wall and allowing the top nail to be lowered or sloping the nails at a steeper angle.

Cold weather also makes the application of shotcrete more difficult. At temperatures below 40^0F it may be necessary to provide insulation or heated enclosures. The specialty contractor may also incorporate admixtures in the shotcrete to improve its performance in cold weather. These additional measures may negate some of the cost advantages of soil nailing. Also, in very cold climates it may be necessary to provide additional insulation to permanent walls. It is best to consult with a soil nail contractor prior to specifying the use of soil nailing in any application where cold weather is anticipated.

Construction Procedure:

Soil nail walls are constructed in a "top down" manner as an excavation is being made. The basic procedure for constructing a soil nail wall is listed below and is shown in Figure 4. The steps to construction of a soil nail wall are:

Step 1 - Excavate a Lift for Soil Nailing – A soil nail lift is typically 4 to 6 feet high. This height may be reduced if the soil will not stand vertical or if the vertical spacing of the nails is less. In most walls the lift is vertical but it may also be battered to prevent sloughing and undermining of the lifts above. Typically, one row of nails is installed for each lift excavated. The top of the first lift may be sloped to get under utilities and avoid problems with trying to cut surface deposits of fill and topsoil vertically. In marginal soils, a flash coat of un-reinforced shotcrete may be applied to the face of the cut immediately after the cut is made to prevent the soil from drying out and raveling.

Step 2 – Install Soil Nails – Soil nails are installed by drilling a hole using augers or a percussion drill, installing a steel all thread reinforcing bar in the hole, and then placing grout or concrete in the annulus between the bar and inside of the hole. Other methods of installing soil nails, such as driving the nails into the ground and using casing, are also used in some situations. Figure 3 shows a specialized rig manufactured by Schnabel Foundation Company to drill soil nails.

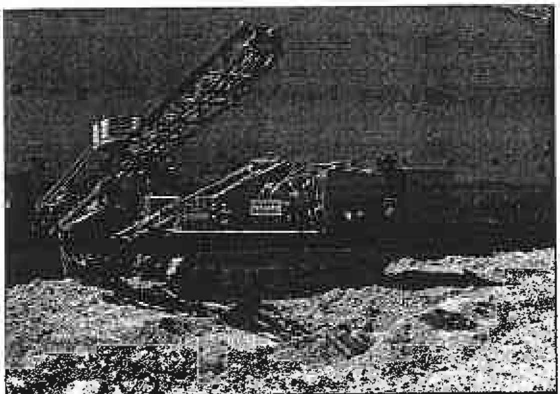

Figure 3 – Specialized Soil Nail Drill

Step 3 – Install Wire Mesh and Drainage Board to Face of Cut – Drainage board is placed directly against the face of the soil behind the wire mesh to prevent the build up of hydrostatic pressure on the back of the shotcrete. Alternately, weep drains may be placed at selected locations based on the conditions encountered. The wire mesh may be augmented by installing reinforcing steel running horizontally behind the bearing plates.

Step 4 – Apply Shotcrete to Face of Cut – Shotcrete is typically applied using the "wet" method. The shotcrete is delivered to the site pre-mixed with water in a concrete truck. Admixtures may be added to the shotcrete based on the contractor's experience to alter the shotcrete properties. At the site a pump is used to pump shotcrete to the nozzle. Compressed air is introduced at the nozzle to blow the shotcrete onto the wall.

Step 5 – Install Bearing Plate and Nut – A bearing plate is placed on the wall before the shotcrete has fully hardened to ensure full bearing. The nut should be able to develop the full strength of the bar and be in complete contact with the bearing plate. The nut is hand tightened with a large wrench. Either a rounded anchor nut or standard nut with a wedge washer is used to insure full contact.

Step 6 – Repeat Steps 1 to 5 for next lift – Steps 1 to 5 are then repeated until the bottom of wall is reached.

At the completion of steps 1 through 6 a permanent face can be constructed in front of the temporary shotcrete face for permanent wall applications. The permanent face can be constructed of shotcrete, pre-cast panels, cast-in-place concrete or other materials. In some instances, the permanent face is constructed as the excavation is made and there is no temporary shotcrete.

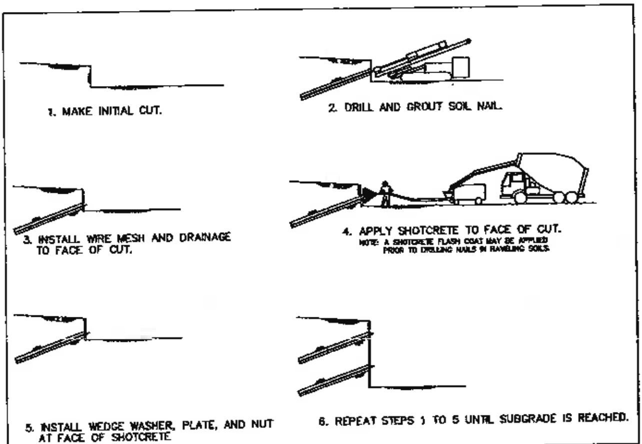

Figure 4 – Steps in Constructing a Soil Nail Wall

Soil Nail Testing

A limited number of nails are tested to verify the soil to grout adhesion value assumed in the design. Typically 5 to 10 percent of the soil nails are tested. Tests should also be performed whenever soil conditions or drilling procedures change. The installation procedure for test nails is identical to that of production nails except the grout for a specified length in the front of the nail is left out or a bondbreaker is placed over the nail to prevent the nail from bearing on the back of the bearing plate. The nails are tested to 150% of the design adhesion value in increments of 25% of the design value. Threshold values of creep rate and total movement are compared against the test data to determine whether the assumed adhesion value used in the design is appropriate. Typically a value of .08" per log cycle of time is used as a threshold value of creep.

If a soil nail fails to attain the maximum test load, then the following procedures should be implemented.

1. Install and test additional test soil nails if the test results were believed to be in error.
2. Determine if the cause was due to a variation of the soil conditions, installation procedure, or materials.
3. Re-evaluate the soil properties if differing soil conditions were encountered and/or redesign the wall. This may involve lengthening succeeding nails and/or installing additional nails.

The decision on which procedure to follow must be done quickly to prevent costly delays to the project. This usually requires that the contractor and engineer be in close contact during construction. This is one of the reasons why experienced design build contractors construct most soil nail walls.

Soil Nailing Design:

The design of soil nailing requires that both the internal and external stability of the block of soil reinforced with soil nailing be checked. The internal stability is typically analyzed using a limit equilibrium analysis. One popular computer program used to analyze the internal stability of the soil nail wall is SNAIL. The California Transportation Department (CALTRANS) developed this program. SNAIL uses a bi-linear wedge analysis for failure planes exiting at or below the toe. The forces acting on these wedges are illustrated in Figure 5. The analysis of the soil nail wall's internal stability takes into account the various possible modes of failure. These include:

- Pull Out of the Nail – This occurs when the tensile force imposed on the soil nail by the failure wedge exceeds the pullout capacity of the portion of the nail behind the failure surface. Pull out failure can be prevented by making the nails longer or increasing their adhesion value.

- Punching Shear – The allowable punching shear must be determined to prevent the soil nail plate from punching through the shotcrete at failure. Punching failure can be avoided by increasing the size of the bearing plate, the thickness of the shotcrete, or by adding reinforcing steel behind the plate.

- Failure of the Nail Tendon – If the tensile force in the nail exceeds the strength of the steel the bar tendon will yield. Yielding can be avoided by increasing the size or yield strength of the nail tendon.

The interaction of all of these factors make the determination of an optimal and safe design a complex task best left to engineers experienced in soil nailing design and construction.

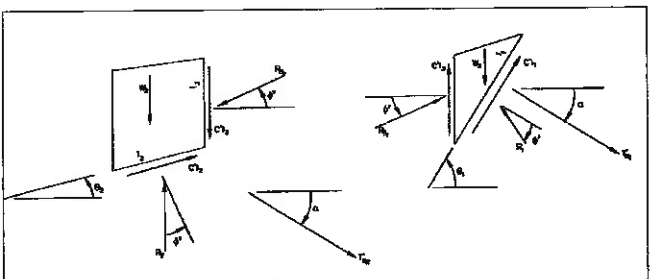

Figure 5 – Design Analysis

The factor of safety used in soil nailing design is typically 1.5 for the final case with all nails installed and 1.2 for the most critical stage, which usually occurs immediately after the final cut is made prior to installing the bottom row of nails.

The external stability of the soil nailed block of soil is analyzed by checking over turning about the toe of the wall, and sliding along the base.

Applications in New England

The use of soil nailing in New England is appropriate whenever the criteria discussed previously for suitable conditions are met. Two common applications for soil nailing in New England are when shoring is required in glacial till or in granular material with numerous boulders.

Glacial till is typically very dense and may contain boulders. This makes driving piles impractical and drilling expensive. The density of the till combined with a high percentage of fines make glacial till an ideal candidate for soil nailing. Also because smaller drills are used to install the soil nails then are used to install piles, the drilling of rock is much easier. If a high groundwater table is located in the till, the specialty contractor should review the soils information thoroughly to determine whether soil nailing is appropriate.

Granular material with boulders can sometimes be shored with soil nailing. Although this material does not meet the criteria discussed previously, in some cases it may be the only feasible option. It may be necessary to install vertical nails, or batter the soil nailing to prevent sloughing of the face of the excavation in less cohesive deposits. It is also difficult and expensive to provide a wall line finish in granular soil mixed with boulders.

Case Studies

Two case studies are presented below. The first case study involves a project that was originally designed as a permanent tieback wall on a steep slope in glacial till. Schnabel value engineered the wall to a permanent soil nail wall. The second case study involves a project where Schnabel was involved in the design process and worked with the engineer to design a permanent soil nail wall.

Hancock Street Salt Storage Facility – Dorchester, Massachusetts

Construction of a salt storage facility in Dorchester, Massachusetts required the construction of a permanent retaining wall to allow the facility to be built into a hillside. The borings showed the hill to consist of a surficial layer of fill over dense glacial till. Groundwater was anticipated to be near the bottom of the cut. Contract drawings supplied by the City of Boston included a tiedback soldier beam and lagging wall using a cast-in-place concrete face. Schnabel value-engineered this design to a permanent soil nail wall with a shotcrete face at a considerable cost and schedule savings. A section through the soil nail wall is attached as Figure 6.

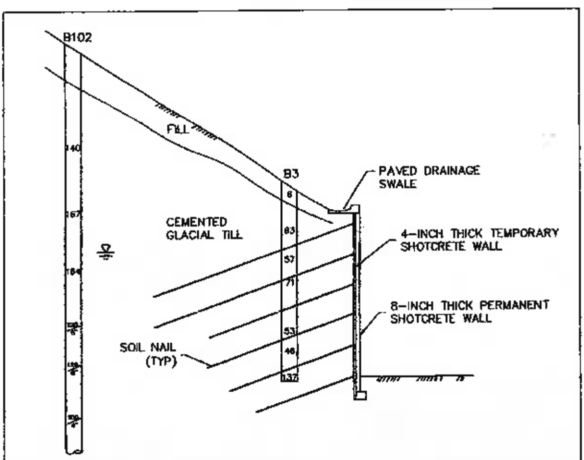

Figure 6 – Section Through Hancock Street Soil Nail Wall

Soil nail wall construction is generally easier and more cost effective than soldier beam and tieback wall construction for a side hill cut. One of the reasons is that nailing and shotcrete work uses smaller equipment than that required for soldier beam installation, and therefore simplifies the benching required on the hillside. The soil nail wall was constructed by first installing permanent soil nails and a temporary 4-inch shotcrete facing down to subgrade. The permanent nails had studs welded to the bearing plates to attach the permanent structural shotcrete to the soil nails. Portions of the wall were constructed in fill. Vertical soil nails were installed in these areas to maintain a vertical excavation face. The temporary shotcrete facing and permanent soil nails are shown in Figure 7.

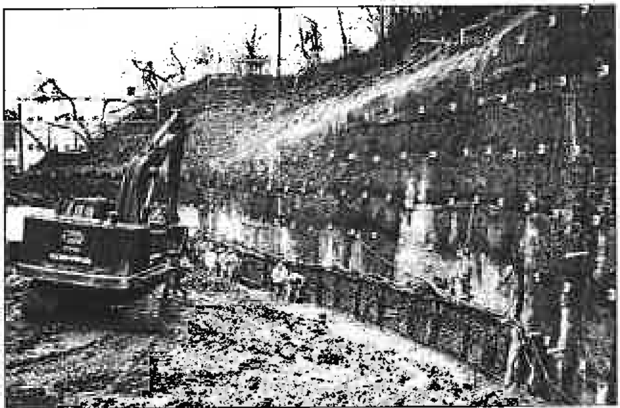

Figure 7 - Construction of Soil Nail Wall

Problems occurred during construction of the wall when greater than anticipated groundwater flows came through the till at one location and prevented the shotcrete from sticking. The foreman at the job, who had experienced this problem before, installed weep drains at the locations of heaviest flow to keep the water pressure off the back of the wall. This allowed the wall to be completed on schedule.

Once excavation was complete, a permanent reinforced shotcrete facing was constructed in front of the temporary shotcrete. The shotcrete was reinforced with a single mat of reinforcing steel. The permanent shotcrete facing was constructed in 30-foot wide sections, between construction joints, for the full height of the cut. Figure 8 shows the application of the permanent shotcrete facing to the temporary wall.

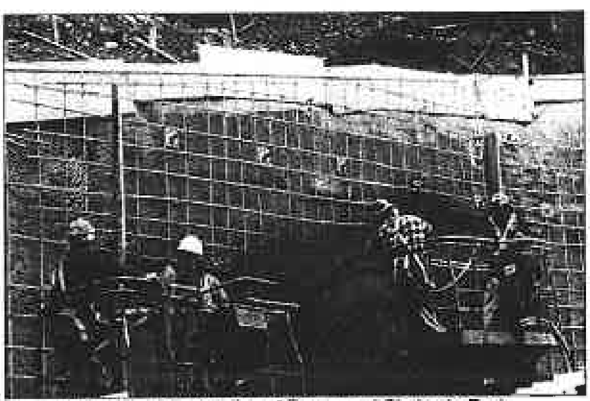

Figure 8 – Construction of Permanent Shotcrete Facing

Around 200 soil nails, 4,920 ft^2 of temporary 4-inch shotcrete facing, and 4,600 ft^2 of permanent reinforced 8-inch shotcrete with a wood float finish were constructed. The wall stands 15 to 32 feet in height. The completed wall is shown in Figure 9.

Figure 9 – Completed Hancock Street Soil Nail Wall

CVS Pharmacy – New London, Connecticut

Construction of a new CVS Pharmacy in New London, Connecticut required excavation into a hillside so that the site could be leveled. Schnabel worked with the design team to design and construct a permanent soil nail instead of conventional temporary shoring and a new permanent wall. The soil nailing consisted of a temporary 4-inch shotcrete facing with permanent epoxy coated soil nails. Studs were attached to the bearing plates to allow a structural cast-in-place facing to be attached to the nails. Around 160 soil nails, 3,000 square feet of shotcrete were installed with heights varying from 3 to 18 feet. A section through the wall is shown in Figure 9.

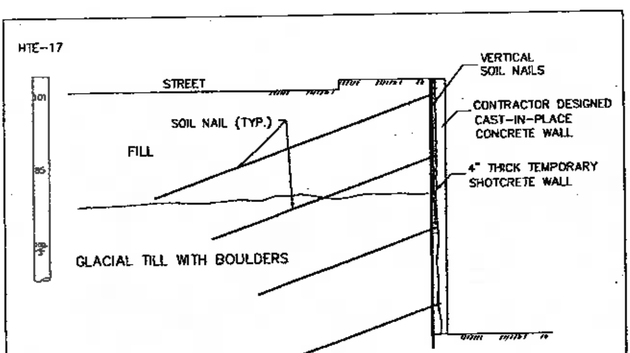

Figure 9 – Section through CVS Soil Nail Wall

At this site, the borings indicated that bedrock was to be encountered before subgrade was reached. The use of soil nailing had the advantage over piles because the piles would have to be drilled or driven into the rock to obtain capacity at the toe. It was discovered during excavation; however, that the rock encountered in the borings was actually boulders in the till. The job was quickly redesigned by the specialty contractor to account for the differing conditions with minimal impact to cost and schedule.

Figure 10 shows the construction of the wall prior to the installation of temporary shotcrete facing. The wire mesh, drain board, and nails are all visible. PVC pipes have been placed over the soil nails to keep them clean during the application of shotcrete.

Figure 10 – Soil Nail Wall Under Construction

The owner in this case opted to pour his own structural cast-in-place facing against the soil nailing rather than install a structural shotcrete face. The completed wall is shown in Figure 11.

Figure 11 – Completed Soil Nail Wall

Summary and Conclusions

- Design-build contracting procedures for earth retention systems can offer significant savings to owners by allowing specialty foundation contractors to incorporate their experience from many other sites and ground conditions. In particular, the design and construction of soil nail walls should only be attempted by experienced specialty contractors.
- Soil nailing, when used in the proper ground conditions, can offer substantial savings when compared to other earth retention systems.
- For hillside cuts, soil nailing is generally easier to install then soldier beams and tiebacks, because smaller and lighter equipment is used, and benches for the equipment can be smaller.
- Soil nailing may be used in areas with low overhead clearance since the soil nails are installed at a relatively flat angle.
- When soil nailing and tieback work is contracted on a design-build basis, modifications in the design that are necessitated by changes in subsurface conditions can be made without significant impact on production or schedule.
- Soil nailing can be productive and reliable, excavation support system under the right conditions and when installed by an experienced specialty contractor.