

## 1.9 Helical Soil Nails

Soil nailing is a method of earth retention that relies on a grid of individual reinforcing members installed within a soil mass to create an internally stable gravity wall/retaining system. Soil nail wall technology began in Europe with use of the New Austrian Tunneling Method in rock formations in 1961. The technology then carried over to applications involving unconsolidated soil retention, primarily in France and Germany. Soil nail walls were first used in North America for temporary excavation support in the late 1960s and continued to gain recognition and acceptance during the 1970s and 1980s for higher profile projects including highway applications. Much of the soil nail wall research performed in North America was funded by the Federal Highway Administration (FHWA) and other state highway agencies during the 1990s. Although helical piles have been used as tiebacks since the early 1950s, helical soil nails are a relatively new alternative to their grouted counterparts.

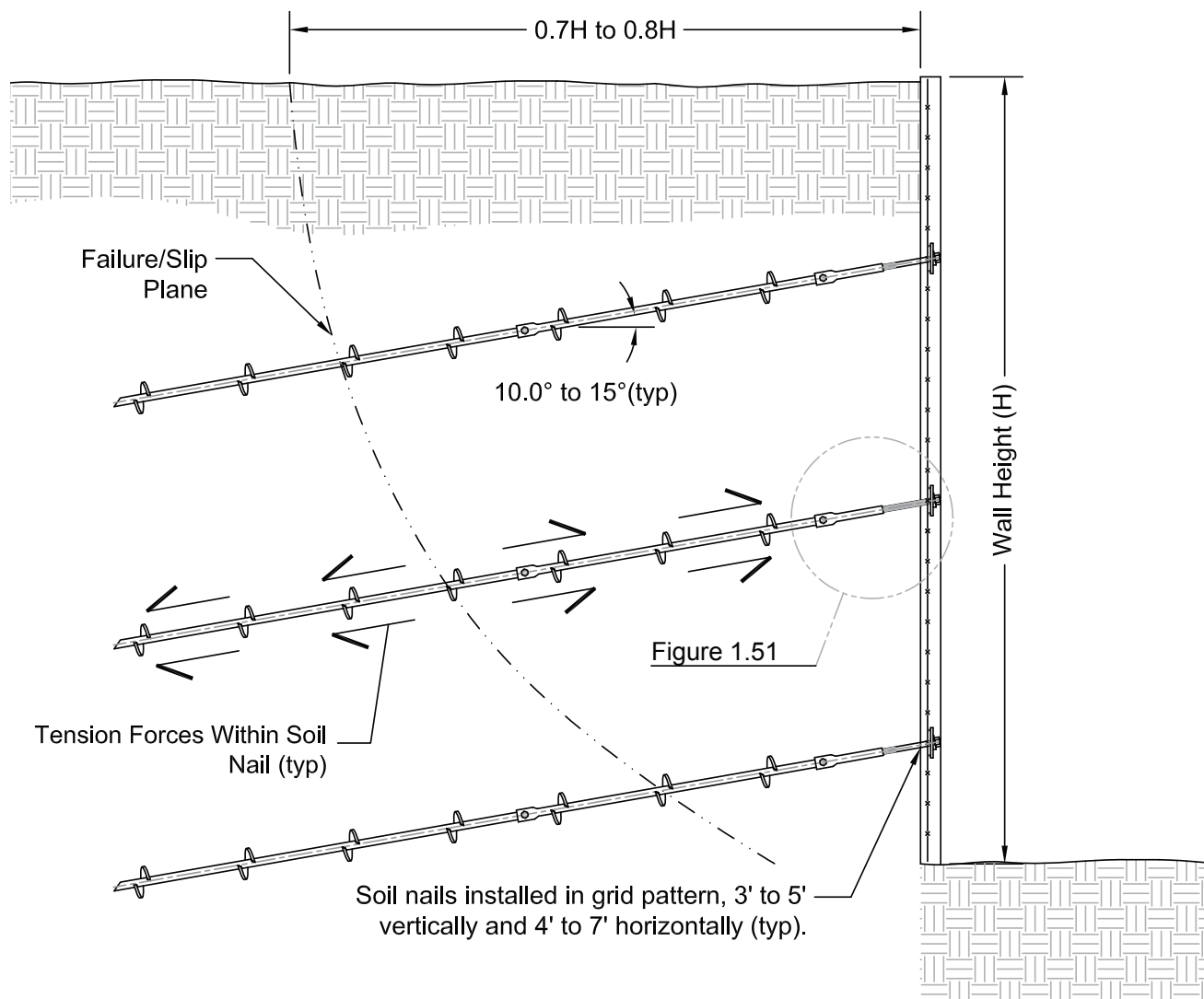
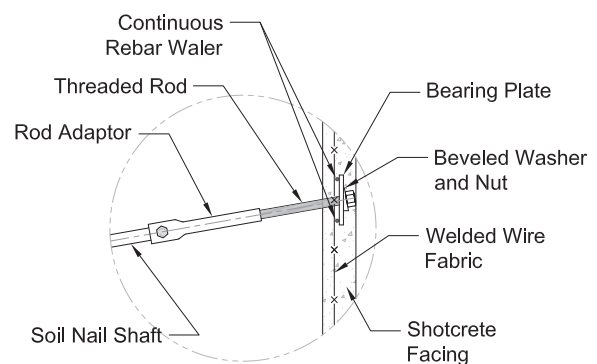


Figure 1.50 Helical soil nail wall installation

Soil nail walls offer the following advantages over tieback walls as well as other top down construction techniques:

- Soil nail walls are more economical than conventional concrete gravity walls and are often more economical than tieback walls due to reduced wall facing requirements. There would likely be more soil nails than tiebacks for a given project, but this additional cost for the nails is outweighed by the difference in cost of a shotcrete facing versus a more substantial soldier pile, sheet-pile, or reinforced concrete wall detail.
- Soil nails are typically shorter than tiebacks for similar wall heights so there will be reduced right-of-way (ROW) requirements.
- There is less impact to adjacent structures since soil nail walls are not installed with vibratory energy like soldier piles or sheet piles.
- Overhead clearance requirements are less than driven soldier pile or sheet-pile wall construction. Soil nail walls can therefore be installed easily below bridges and even within existing buildings.
- There is no need to embed structural elements below the proposed ground surface elevation on the low side of the soil nail wall. Soldier pile and sheet-pile walls require minimum embedment depths for wall stability.
- Soil nail wall construction is typically quicker than other earth retention methods.
- Soil nail walls can be constructed in remote areas with smaller equipment.
- Soil nail walls have performed well during seismic loading events due to the overall system flexibility.

A helical soil nail typically consists of square shaft lead and extension sections with small diameter (6 to 8 inches) helix plates spaced evenly along the entire shaft length (*Figure 1.50* and *Figure 1.51*). The helical soil nail is installed by application of torque, similar to the installation of a helical tieback. The helical soil nail is a passive bearing element, which relies on movement of the soil mass and active earth pressures to mobilize the soil shear strength along the nail. In contrast, a tieback is pretensioned to mobilize the soil shear strength around the helix plates. Excavation, soil nail installation and application of wall facing is completed in steps from the top of the wall downward.



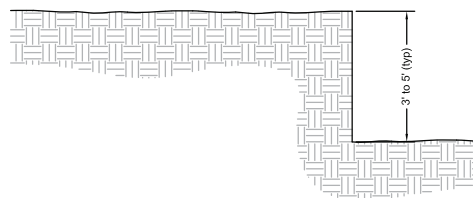
**Figure 1.51** Nail head to wall detail

## 1.9.1 Construction Methodology

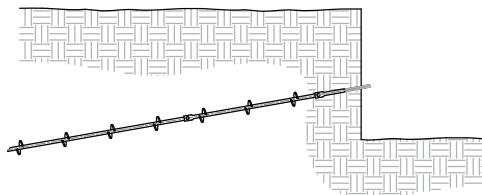
Soil nail walls are constructed from the top down where the excavation proceeds as shown in *Figure 1.52*. The construction sequence for a typical helical soil nail wall includes:

- Initial excavation about 3 to 5 feet deep depending upon design parameters and soil conditions
- Installation of the first row of helical soil nails to the required inclination angle, torque and embedment length

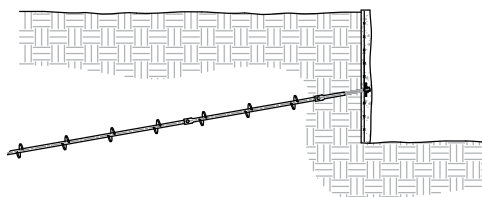
- Placement of drainage medium (if required)
- Placement of wall reinforcement and bearing plates
- Placement of shotcrete to the required design wall thickness
- After shotcrete has cured, repeat sequence for successive rows of soil nails. Continue process to the final design depth (wall height).



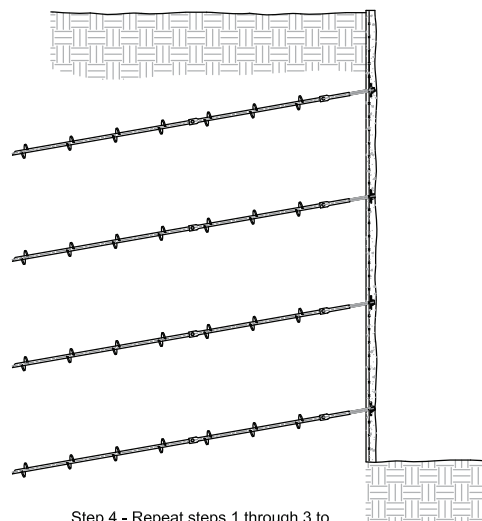
Step 1 - Initial Excavation



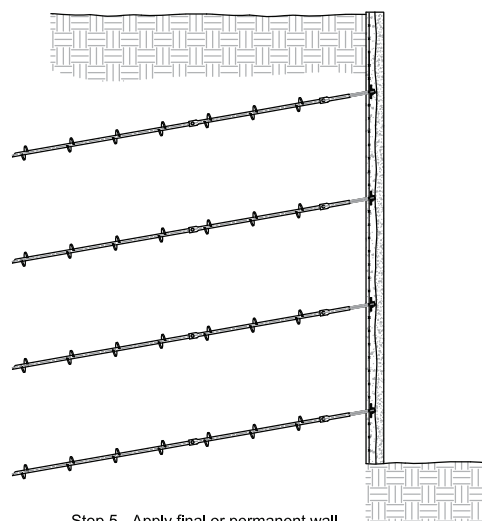
Step 2 - Install top row of soil nails



Step 3 - Install drainage strips, reinforcing steel and anchor plates, and apply initial shotcrete layer.



Step 4 - Repeat steps 1 through 3 to bottom of wall.



Step 5 - Apply final or permanent wall facing, if required.

Figure 1.52 Typical soil nail wall installation sequence

## 1.9.2 Design Considerations

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Helical soil nails are passive bearing elements which rely on movement of the soil mass to mobilize the soil shear strength along the nail. As a result, soil nail walls typically experience more lateral movement than tieback walls of similar height. By allowing this movement, the highest stress in the soil nail is near the failure plane, centered between the opposing tensile forces. Conversely, the highest stress in a tieback is at the wall face. Therefore, soil nails have less nail head force than tiebacks for a similar size wall, which results in potential cost savings by using soil nails due to reduced wall thickness requirements.

The following should be considered when designing soil nail walls.

- Not all soil conditions are suitable for construction of helical soil nail walls. Excavations are generally made in 3 to 5-foot steps, depending upon soil type and strength. The soil should be able to stand unsupported for a period of at least one day after the vertical cut is made. Soil conditions that may not be favorable for helical soil nail wall construction include:
  - Dry, poorly-graded cohesionless soils, e.g., clean sands or sands with SPT N-values less than 5 blows/foot
  - Highly plastic clays, expansive soils, organic soils, or soils with a liquidity index of 0.2 or greater
  - Clays with SPT N-values less than 4 blows/foot
  - Soil profiles with high groundwater levels - dewatering may be required to facilitate installation
  - Soil with cobbles, boulders or weathered rock lenses
  - Highly corrosive soils
  - Collapsible soils
  - Very dense sands and hard clays - may be difficult to penetrate without predrilling a pilot hole
- A failure plane generally develops at the top of the wall at a horizontal distance of about 0.7 to 0.8 times the height of the wall away from the wall face (Lazarte, Elias et al. 2003). This distance may be reduced by battering the wall face. Any structure, utility, roadway, etc. that would be impacted by the wall movement and/or failure plane should be considered during the design phase.
- Top of wall lateral movements on the order of 0.2% to 0.3% of the wall height should be expected with soil nail lengths to wall height ratios between 0.7 to 1.0, negligible surcharge loading and a design including a global factor of safety of at least 1.5. As a general guide, the soil mass located between the failure plane and the wall facing may slump approximately 1/8-inch laterally and 1/8-inch vertically for each 5-foot depth of excavation.
- Soil nail walls may be designed with a slight batter to account for anticipated lateral wall movement.

- There may be restrictions to the design soil nail lengths, including property lines, ROW, underground utility corridors, bridge abutments or existing structures.
- Consider temporary and/or permanent surcharge loads from adjacent structures, roadways, construction equipment, fill placement, etc.
- Maximum wall heights for helical soil nail walls are practically limited to 20 to 30 feet. Increased heights may be considered with a stepped wall design.
- Helical soil nails are typically installed in a grid pattern, spaced 3 to 5 feet vertically and 4 to 7 feet horizontally.
- Helical soil nails are typically installed at an angle of 10 to 15 degrees downward from horizontal, although a batter is not required. The downward installation angle is a carryover from grouted nail design where an angle is required to limit wet grout from flowing out the hole.
- Soil nails may be installed with consistent lengths for all rows, or be longer at the top of the wall, becoming shorter with successive rows toward the bottom. Nail length determination depends upon soil strength parameters, location of the failure plane, and design for critical limit states as discussed in *Section 1.9.2.2*.

The design procedure for helical soil nails is similar to that for grouted nails. For a helical soil nail, the bond stress with the soil is assumed to act along a cylindrical surface area defined by the outside edge of the helix plates. Bearing capacity of the soil nail is determined using the Individual Bearing Method described in *Section 1.7* and is correlated to bond stress by:

$$q_u = Q_u / L\pi D_h FOS$$

**Where,**

- $q_u$  = Ultimate Bond Stress (psi)
- $Q_u$  = Ultimate Capacity of the Helical Soil Nail by Individual Bearing Method (lb)
- $L$  = Soil Nail Length (in)
- $D_h$  = Helix Diameter (in)
- $FOS$  = Factor of Safety for Uncertainties in Soil Conditions (Typically 1.5 to 2.0 Based on Quality of Soil Information)

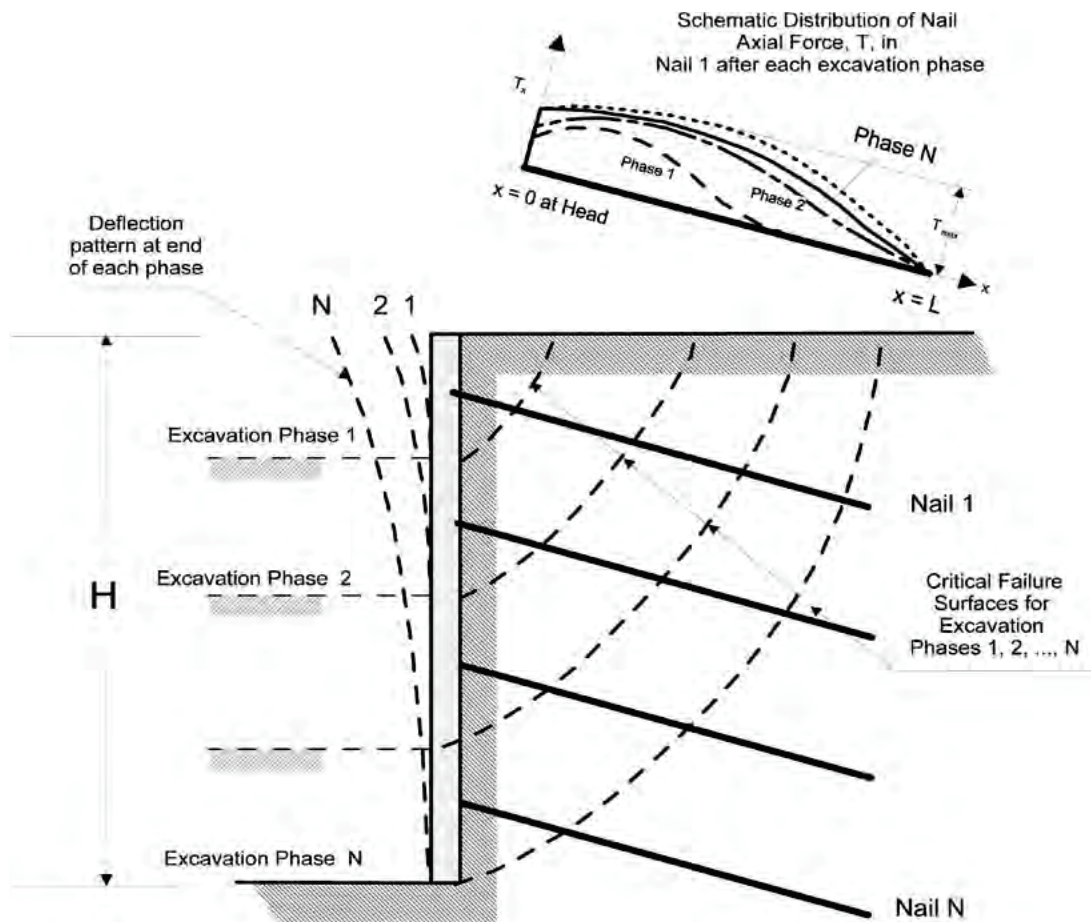


Figure 1.53 Potential failure surfaces and soil nail tensile forces (Lazarte, Elias et al. 2003)

As the construction of the wall progresses, the upper soil nails become less important for the stabilization of the soil mass, and depending upon wall height, may not contribute to the global stability at the final excavation phase. However, the upper soil nails are instrumental in providing stability during the early phases of excavation and contribute to limiting wall deflections. *Figure 1.53* shows the distribution of tensile force in Nail 1, cumulative wall movement and the critical failure surfaces as the soil nail wall construction progresses. The upper schematic of *Figure 1.53* illustrates the tensile force distribution along the top soil nail as construction continues through the various excavation phases. The tensile force in Nail 1 is shown to decrease once Phase N is completed due to load redistribution among the lower rows of soil nails as the excavation progresses between Phase 2 and Phase N.

The design of helical soil nail walls should be performed in general accordance with requirements detailed in FHWA Geotechnical Engineering Circular No. 7 (Lazarte, Elias et al. 2003).

FHWA Geotechnical Engineering Circular No. 7 (Lazarte, Elias et al. 2003) provides design tables and charts that can be used for preliminary estimation of the wall design. The tables and charts were developed using SNAIL simulations and include the following assumptions:

- The soil is homogenous (only one soil type and strength parameter)
- There are no surcharge loads or sloped backfill conditions
- There are no seismic forces/loads

- The soil nails are of uniform length, spacing and inclination for each row
- There is no groundwater present

There should always be a final design prior to construction activities which take into consideration any deviations from the assumptions listed above and determination of the Limit States described in *Section 1.9.2.2*.

***The design of helical soil nails should be completed by experienced design professionals. Installation of Foundation Supportworks helical soil nails shall be by certified Foundation Supportworks installing contractors trained specifically for helical soil nail installations. Foundation Supportworks engineers recommend that the wall design follow the general guidelines detailed in the FHWA Geotechnical Engineering Circular No. 7 (Lazarte, Elias et al. 2003).***

***Preliminary design recommendations are available to Foundation Supportworks installing contractors to assist with costing of helical soil nail wall projects. However, the final design must be completed and/or approved by the engineer of record.***

#### 1.9.2.1 Temporary & Permanent Wall Facing

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Helical soil nail walls may be classified as temporary or permanent, and the design of the wall facing and nail head connection details will vary based upon this determination. **Whether the soil nail wall is temporary or permanent, the wall facing and helical soil nail connection detail must be completed and/or approved by the engineer of record.**

Helical soil nail walls are used most often in temporary shoring applications, with reinforced shotcrete the most common temporary wall facing material. Shotcrete is concrete conveyed through a hose and projected through a nozzle at high velocity onto a working surface. The shotcrete is applied/sprayed in thin lifts until the design thickness requirement is met for the wall. For temporary wall applications, the shotcrete is typically applied to a thickness of 3 to 4 inches. Internal reinforcement of the shotcrete may consist of welded wire fabric (WWF), steel reinforcing bars (rebar), or fiber reinforcement. WWF with rebar walers at the nail heads is typically favored due to ease of installation.

Permanent helical soil nail walls may either have an additional thickness of shotcrete applied or another facing attached to the temporary shotcrete layer. For permanent soil nail walls with shotcrete facing, the typical wall thickness varies from 6 to 12 inches, not including the thickness of the temporary facing. Cast-in-place and precast concrete facings can also be used in conjunction with the temporary shotcrete wall facing. Facings can be attached to the shotcrete wall to form decorative facades.

### 1.9.2.2 Limit States

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The design of the helical soil nail wall must consider two distinct limiting conditions; Strength Limit States and Service Limit States. The Strength Limit States refer to failure of the system due to loading forces greater than the strength of the system or its individual components. Specifically, the following potential failure modes must be evaluated:

- External failure modes
- Internal failure modes
- Facing failure modes

External failure modes include global stability, sliding and bearing failure. Internal failure modes include soil nail pullout failure, soil nail tensile failure and soil nail shear failure along the failure plane. Facing failure modes include flexure failure, punching shear failure and head stud failure.

The service limit states do not include failure of the structure, but rather consider serviceability issues such as wall deformation, wall settlements or cracking of the facing.

For further information related to designing for these potential failure modes, please refer to FHWA Geotechnical Engineering Circular No. 7 (Lazarte, Elias et al. 2003).