Soil Nail Walls

Soil nails are passive reinforcing elements that are installed and grouted in sub-horizontal drilled-holes to form a composite mass. Soil nails can be effective in increasing stability of a slope, or in constructing a wall that requires top-down excavation.

In addition to this module, the documents that govern or guide the investigation, design, and reporting for Soil Nail Walls include:

- FHWA Geotechnical Engineering Circular (GEC) No. 7 (2015)
- Memos to Designers 5-19, Earth Retaining Systems Communication
- Geotechnical Manual, Foundation Reports for Earth Retaining Systems

Design and performance advantages of soil nail walls include:

- Less right of way needed than competing systems, such as ground anchors;
- Less disruptive to traffic and cause less environmental impact;
- Relatively fast construction;
- Cost effective at remote sites and sites with difficult access;
- Effective in landslide repair above the landslide scarp;
- Relatively flexible and can accommodate relatively large total and differential movements;
- Good performance under seismic loading;
- Have more redundancy than ground anchors because of the larger number of reinforcing elements per unit area; a passive system with relatively lower tensile stress sustained by the reinforcing elements; and have an established construction quality assurance program.
- More economical than conventional earth retaining systems taller than 15 feet; and
- Typically are equivalent or more cost-effective than ground anchor walls.

Soil nail walls are not feasible when there are:

- Stringent requirements that limit the wall movement during construction, (e.g., the proposed wall is adjacent to and below a critical structure, such as a bridge abutment);
- Utilities behind the wall and within the soil nails reinforced zone; or
- Difficulty to obtain permanent easements.

Favorable subsurface conditions for soil nail wall construction include:

- Excavated face can stand unsupported and stable until the facing is structurally complete;
- Stiff cohesive soil or soil with sufficient apparent cohesion; weathered rock with favorable bedding planes; and well-graded and well-compacted backfill;
• Drilled-holes can remain open and stable without casing until the nails are installed and the drilled-hole is grouted; or
• The toe of wall is above groundwater table.

Unfavorable subsurface conditions for soil nail wall construction include:
• Poorly graded loose sand; soft highly plastic clay; organic soil; collapsible soil; expansive soil; cobbles and boulders; weathered rock with unfavorable bedding planes;
• Groundwater table is above the toe of wall; or
• Corrosive soil and groundwater.

The geotechnical tasks for the investigation, design, and construction of soil nail walls include:
1. Working with other project development team (PDT) members to evaluate and select the appropriate wall type;
2. Evaluation of available information;
3. Performing subsurface exploration;
4. Performing design and analysis;
5. Issuing a geotechnical report
6. Assisting in developing and reviewing the PS&E package, and
7. Providing construction support.

Project Initiation
The design of a soil nail wall requires close cooperation among the PDT, especially among the Geoprofessional, Structure Designer, and District Project Engineer. During project initiation, the need for a wall will be identified by the District. Upon request, the Geoprofessional should perform preliminary assessment of the site and issue a preliminary geotechnical report that provides an evaluation of feasible wall types and a recommended wall type.

During the Type Selection process, close communication should proceed among District Project Engineer, Structure Designer, and Geoprofessional to select the preferred wall type. Constructability, constraints, and cost should be discussed and evaluated to arrive at the preferred option.

Literature Review
Refer to the Geotechnical Investigations module for direction on performing a literature search, and evaluate available information for applicability to the soil nail wall design. Obtain and evaluate the general plans and cross sections of proposed walls from District or Structure Design (SD).
Subsurface Investigation

Subsurface exploration for soil nail wall design should obtain essential information for design, including:

- Soil and rock stratigraphy,
- Soil and rock engineering properties, including unit weight, shear strength, orientation and spacing of bedding, and estimated nominal pullout resistance,
- Groundwater elevation,
- Information that may assist in deducing and evaluating potential construction issues, such as difficulties of excavating the wall face and drilling the holes should also be retrieved as much as practically possible.

To plan for and carry out subsurface exploration, including laboratory testing, refer to the applicable Geotechnical Manual modules and:

- FHWA Geotechnical Engineering Circular (GEC) No. 7
- FHWA NHI-01-031 Subsurface Investigations – Geotechnical Site Characterization

Designing and constructing a soil nail wall along a highway often require excavating the lower portion of a native slope that extends far above the highway. Access to the steep slope behind the wall layout line can be a challenge and often times impracticable. An alternative option is to perform subsurface exploration in front of the proposed wall by means of trench excavation, geotechnical and geological mapping, and horizontal drilling.

Perform at least one, if feasible, horizontal boring into the slope that is to be excavated and drilled for soil nail wall construction to obtain soil and rock specimens, and evaluate the cave-in potential of drilled-holes during construction.
Design and Analysis

To perform geotechnical analysis and design of the soil nails, *Snail Software*, which is owned and maintained by Caltrans, is recommended. The current version of Snail implements the design methodologies of GEC No. 7, and includes features for the design and analysis of the soil nails and structural components of the wall face.

Before using Snail, review the *Snail User Guide* and example files. Select representative and critical cross sections by reviewing the layout and elevation views of the soil nail wall. Consider applicable excavation heights, geometry, soil and rock profiles, subsurface conditions, and design efficiency when selecting the representative cross sections.

The procedures and issues discussed in this module and GEC No. 7 cover the internal and external (sliding and overturning) stability of soil nails. Global stability of the soil nail wall system is not addressed in this module or GEC No. 7. Global stability analysis must be performed for all earth retaining systems, including soil nail walls.

Typical Design Configuration and Parameters

The following are recommended parameters for starting the design using the Snail software.

- **Drilled-hole Diameter:** 6 inches; increase to 8 inches or larger if necessary, however, drilled-hole diameter greater than 6 inches is not common in construction. The drilled-hole diameter entered into the input is only used for calculation, and must NOT be presented in the Foundation Report or the Contract Plans. According to Caltrans contracting practice, selection of drilled-hole diameter is the contractor’s responsibility, and the contractor must demonstrate the selected drilled-hole diameter and associated drilling and grouting methods can provide required nominal pullout resistance, $Q_d$, via verification and proof tests. To implement this contracting practice, Snail output only shows nominal pullout resistance, $Q_d$, calculated from the drilled-hole diameter and nominal bond strength. The Snail output can be included as an attachment to the Foundation Report.

- **Soil Nail Length:** 0.7 to 1.0 times designed excavation height, increase as necessary. To facilitate ease of construction and inspection, use a uniform nail length throughout a cross section.

- **Soil Nail Inclination:** 10° to 15° from horizontal. According to *CIRIA C637 Soil Nailing - Best Practice Guidance*, a soil nail installed at 15° below the horizontal has an efficiency of 64% of the nail installed at the optimum angle (35° above horizontal). However it has nearly twice the length in the resistant zone and more than four times the average overburden. Therefore, a soil nail inclined slightly downwards is actually more effective. As a soil nail inclines steeper than 15° the efficiency decreases rapidly without any increase in pullout length or
significant increase in overburden. Therefore, the optimum soil nail inclination angle
should be between 10° and 15°.

Nail inclination angles less than 10° should be avoided to prevent voids in the grout
and an extended “bird’s beak” at the nail head. Voids can reduce the pullout
resistance and decrease corrosion protection.

- Wall Face Batter: 1(H):12(V) or any batter angle to account for lateral displacement
  of the wall face during construction. As a passive reinforcing system, soil nails are
  expected to be strained during construction. A soil nail wall face that rotates outward
  from vertical may appear unstable even though the wall is still sound and stable.

- 1st Soil Nail Row: 2.5 feet from the top of excavated face.

- Soil Nail Spacing: 5 feet for both horizontal and vertical spacing; with columnar
  layout to facilitate the placement of geocomposite drains.

- Nail Bar Diameter and Grade: Use No. 8 and Grade 75 bar;

- Nominal Bond Strength, qₜ: Refer to FHWA GEC No. 7 (Tables 4.4a, 4.4b, 4.5, and
  4.6) for suggested nominal bond strength ranges for different soil, rock, and
  conditions.

  The nominal bond strength entered into the Snail input is only used for calculation,
  and must NOT be presented in the Foundation Report or Contract Plans. Instead, the
  nominal pullout resistance, Qₜ, which is a combined function of nominal bond
  strength and drilled-hole diameter, should be presented in the Foundation Report and
  Contract Plans.

- Horizontal Seismic Coefficient: Follow the GEC No. 7 procedure. Use Caltrans ARS
  Online using Vₛ₃₀ to determine the Peak Ground Acceleration (PGA) and 1-second
  response acceleration (S₁). Obtain acceptable wall displacement due to seismic
  events from the owner of the project or wall, so that the corresponding horizontal
  seismic coefficient can be determined for the seismic analysis and design of the wall.

- Surcharge: Include live and dead loads, such as traffic and structure loads; consult
  with Structure Design or District Design.

Design Considerations

There are a variety of issues to be considered during the design of a soil nail wall. Some
of these issues have been addressed in GEC No. 7. The following are additional
considerations.

- For a soil nail wall with a steep slope above the wall, potential rock fall and mud flow
  issues should be addressed (see Rockfall module).

- In limit equilibrium analysis, the resulting most critical surface must be conclusively
  within the set search limits to ensure that the search has yield the most critical surface,
and there is no other surfaces outside of the search limits have a lower FoS than the most critical surface found within the set search limits. When the most critical surface is found lay on the edge of the set search limits, the search limits should be extended or moved in order to capture the definite most critical surface.

When analyzing soil nails with sloping ground above the wall, sometimes the upper point of most critical surface may persistently lay on the point that defines the upper search limit. As a result, the upper search limit need to be continually moved further up-slope while the most critical surface cannot be found. When encountered this situation, extend the search limit only to 3 times the excavation height horizontally away from the wall face. The reason for limiting the search to 3 times the excavation height horizontally is that the analysis of soil nails only addresses internal and external stability of the soil nail wall system. A search beyond that is considered an analysis of global slope stability, and should be carried out using a slope stability analysis tool, such as Slope/W or Slide.

- For global slope stability analysis, use a horizontal seismic coefficient equal to 1/3 PGA.
- If there are structures or facilities above or behind the soil nail wall that may be affected by the lateral displacement of the wall and the settlement of the ground above the soil nail wall, numerical analysis using the software, such as Plaxis and FLAC, should be performed. These working stress analyses are needed to estimate the expected lateral displacement and settlement of the wall, and to analyze possible excavation and construction options to limit the displacement and settlement.

Communication with Structure Designer

Communicate with the Structure Designer via emails or Foundation Report (Draft), and provide the following information as the first step of design iterations:

1. Layout and limits of wall zones on the elevation-view plan sheets,
2. Instruction for placement of soil nails, including
   - Nail array pattern, use columnar layout to facilitate the placement of geocomposite drains,
   - Maximum horizontal and vertical soil nail spacing,
   - Vertical distance of the soil nails from the top of the excavated face, 2.5 feet (typical), and the bottom of the wall, 2.5 feet (typical),
   - Horizontal distance from the ends of the wall, 2.5 feet (typical),
   - Minimum spacing between soil nails, 2.5 feet (typical), when adjusting soil nail spacing near the bottom and ends of the wall, and
   - Minimum clearance between soil nails and utilities or obstructions, 2.5 feet (typical), and the allowable horizontal and vertical rotation of soil nails from design orientation, 20° (typical), to provide clearance for utilities or obstructions.
3. Schedule of soil nail lengths,
4. Inclination of the soil nails measured from horizontal,
5. Wall face batter measured from vertical,
6. Calculated Factor of Safety for internal and global stability (per Table 5-1, GEC 7)
7. Estimated static lateral displacement, if applicable. If the soil nail wall design satisfies the stability requirements of soil nails, then the lateral displacement may be assumed acceptable.
8. Nominal pullout resistance $Q_d$ of soil nails in force/unit length,
9. Soil nail bar ASTM designation and grade that arrived at the bar yield strength, the bar diameter entered into Snail, and the required Factor of Safety provided by the Structure Designer,
10. Allowable facing resistance ($F_{\text{allowable}}$) used in Snail calculation, and
11. Layout of proof test nails, on the provided elevation-view plan sheets of the wall that are 8 percent of the total number of production soil nails for each wall zone; be aware of the typical location of the geocomposite drains.

Work with the Structure Designer to arrive at an agreed upon allowable facing resistance ($F_{\text{allowable}}$) used for both geotechnical and structure design.

Obtain plan sheets from the Structure Designer, and review delineation of wall zones, soil nails and proof test nails layout to ensure the geotechnical design information and recommendations are implemented on the plan sheets.
Reporting

Soil Nail Wall recommendations must be reported in a Foundation Report in accordance with *Foundation Reports for Earth Retaining Systems* and the requirements herein.

The *Geotechnical Recommendations* section conveys design information to the Structure Designer, whereas the *Construction Consideration* conveys information and instruction to the Specifications Engineers so the Special Provisions are properly prepared.

Provide the following information in the *Geotechnical Recommendations* and *Construction Considerations* sections of the Foundation Report.

*Geotechnical Recommendations*

1. Description or schematic design cross sections showing the structure elements, loads, and interpreted subsurface profiles with soil types and layers. For each soil layer, include interpreted soil total unit weights, shear strength parameters, and groundwater conditions,
2. Layout and limits of wall zones,
3. Instruction for placement of soil nails, including
   - nail array pattern,
   - the maximum horizontal and vertical soil nail spacing,
   - the maximum vertical distance of the soil nails from the top of the wall, and the bottom of the wall,
   - the maximum horizontal distance from the ends of the wall,
   - the minimum spacing between soil nails when adjusting soil nail spacing near the bottom and ends of the wall, and
   - The minimum clearance between soil nails and utilities or obstructions; and the maximum allowable horizontal and vertical rotation of soil nails from design orientation to provide clearance for utilities or obstructions.
4. Schedule of soil nail lengths,
5. Inclination of the soil nails measured from horizontal,
6. Wall face batter measured from vertical,
7. Calculated Factor of Safety for internal and global stability,
8. Estimated lateral displacement, if calculated
9. Nominal pullout resistance $Q_d$ of soil nails in force/unit length,
10. Nail bar yield strength, the bar diameter entered into Snail, and the required Factor of Safety provided by the Structure Designer,
11. Required minimum allowable facing resistance ($F_{allowable}$) used to satisfy geotechnical design requirements. The Structure Designer must ensure that structural facing design meets or exceeds $F_{allowable}$.
12. Layout of proof test nails, on the provided elevation-view sheets of the wall that are 8 percent of the total number of production soil nails.
Do not layout the verification test nails on the Plans. The locations of verification test nails in each wall zone are to be determined by the contractor, because it is the contractor who determines which location and direction to start constructing each wall zone.

Following example reporting formats may be used to convey the recommended soil nail design information.

**Example 1**

**General Design Information:**

1. Excavation height is the vertical distance from the original grade behind the wall to the bottom of excavation for the wall.
2. Use columnar nail layout pattern.
3. Set soil nail inclination angle at 15 degree from horizontal.
4. Set wall batter at 1(H):12(V).
5. Place the first row of soil nails no more than 2.5 feet below the original grade behind the wall for nail spacing of 5 feet. Place the first row of soil nails no more than 2.0 feet below the original grade behind the wall for nail spacing of 4 feet.
6. Place the bottom row of soil nails no more than 2.5 feet above the bottom of excavation of the wall.
7. Nominal pullout resistance of soil nails should be verified and proven by verification and proof tests described in Standard Specifications.
8. For structural wall facing design, apply appropriate structural factor of safety to the required minimum allowable facing resistance provided in the following table.

**Table 1: Section Specific Design Information**

<table>
<thead>
<tr>
<th>Design Excavation Height (ft)</th>
<th>Min. Nail Length (ft)</th>
<th>Max. Vertical Nail Spacing (ft)</th>
<th>Max. Horizontal Nail Spacing (ft)</th>
<th>Nail Bar</th>
<th>Min. Allowable Facing Resistance (kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Yield Strength (ksi)</td>
</tr>
<tr>
<td>Up to 10</td>
<td>12</td>
<td>5</td>
<td>5</td>
<td>75</td>
<td>1.0</td>
</tr>
<tr>
<td>10 to 16</td>
<td>18</td>
<td>5</td>
<td>5</td>
<td>75</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**Table 2 – Nominal Pullout Resistance for Wall Zones**

<table>
<thead>
<tr>
<th>Wall Zone</th>
<th>Station (M Line)</th>
<th>Nominal Pullout Resistance Qd (lbf/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>634+12.09 to 635+57.04</td>
<td>2720</td>
</tr>
<tr>
<td>2</td>
<td>638+37.28 to 639+82.69</td>
<td>2720</td>
</tr>
</tbody>
</table>
Example 2

General Design Information:
1. Excavation height is the vertical distance from the original grade behind the wall to the bottom of excavation for the wall.
2. Use columnar nail layout pattern.
3. Set soil nail inclination angle at 15 degree from horizontal.
4. Set wall batter at 1(H):12(V).
5. Place the first row of soil nails no more than 2.5 feet below the original grade behind the wall for nail spacing of 5 feet. Place the first row of soil nails no more than 2.0 feet below the original grade behind the wall for nail spacing of 4 feet.
6. Place the bottom row of soil nails no more than 2.5 feet above the bottom of excavation of the wall.
7. Nominal pullout resistance of soil nails should be verified and proven by verification and proof tests described in Standard Specifications.
8. For structural wall facing design, apply appropriate structural factor of safety to the required minimum allowable facing resistance provided in the following table.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2093+75 to 2101+00</td>
<td>8.5</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>75</td>
<td>1.0</td>
<td>2,720</td>
</tr>
<tr>
<td></td>
<td>2101+00 to 2109+00</td>
<td>7.7</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>75</td>
<td>1.0</td>
<td>2,720</td>
</tr>
<tr>
<td></td>
<td>2109+00 to 2121+00</td>
<td>11.7</td>
<td>20</td>
<td>5</td>
<td>5</td>
<td>75</td>
<td>1.0</td>
<td>2,720</td>
</tr>
<tr>
<td>2</td>
<td>2121+00 to 2127+50</td>
<td>34.5</td>
<td>35</td>
<td>5</td>
<td>5</td>
<td>75</td>
<td>1.0</td>
<td>3,200</td>
</tr>
<tr>
<td></td>
<td>2125+00 to 2127+50</td>
<td>34.5</td>
<td>35</td>
<td>5</td>
<td>5</td>
<td>75</td>
<td>1.0</td>
<td>3,200</td>
</tr>
<tr>
<td></td>
<td>2127+50 to 2127+96</td>
<td>34.4</td>
<td>30</td>
<td>5</td>
<td>5</td>
<td>75</td>
<td>1.0</td>
<td>3,200</td>
</tr>
<tr>
<td>3</td>
<td>2128+50 to 2129+50</td>
<td>30.5</td>
<td>25</td>
<td>4</td>
<td>4</td>
<td>75</td>
<td>1.0</td>
<td>3,200</td>
</tr>
<tr>
<td></td>
<td>2129+50 to 2130+50</td>
<td>26.6</td>
<td>20</td>
<td>4</td>
<td>4</td>
<td>75</td>
<td>1.0</td>
<td>3,200</td>
</tr>
<tr>
<td>4</td>
<td>2130+50 to 2132+50</td>
<td>23.1</td>
<td>15</td>
<td>4</td>
<td>4</td>
<td>75</td>
<td>1.0</td>
<td>3,200</td>
</tr>
<tr>
<td></td>
<td>2132+50 to 2134+73</td>
<td>14.7</td>
<td>10</td>
<td>4</td>
<td>4</td>
<td>75</td>
<td>1.0</td>
<td>3,200</td>
</tr>
<tr>
<td></td>
<td>2134+73 to 2135+08.21</td>
<td>4.5</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>75</td>
<td>1.0</td>
<td>3,200</td>
</tr>
</tbody>
</table>
Construction Considerations

Review the current list of Caltrans **Standard Special Provisions** (SSPs) to select applicable geotechnical related SSPs and provide editing instructions to the Specification Engineer to ensure contract clauses related to geotechnical design and construction are included in the Special Provisions.

The following content and format templates have been compiled and edited based on the latest SSPs, which should be used to prepare the Construction Considerations section of the Foundation Report.

**SS Section 19: Earthwork**

**SS 19-3: Structure Excavation**

Section 19-3.01D(2): Soil Nail Wall and Ground Anchor Wall Zones

- Provide wall zones for each soil nail wall and ground anchor wall using the following table. However, do not include the table if delineation of wall zones is shown on the plans, which is preferred.

<table>
<thead>
<tr>
<th>Wall Zone</th>
<th>Beginning Station</th>
<th>End Station</th>
<th>Upper Elevation (feet)</th>
<th>Lower Elevation (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SS Section 46: Ground Anchors and Soil Nails**

**SS 46-1: General**

Section 46-1.01A: Ground Anchors and Soil Nail Work Sequence

- Provide the instruction on specific work sequencing and issues related to soil nails construction, such as the timing of excavation relative to the construction of other elements.

Section 46-1.03E: Research Investigation

- Provide instruction for research activities, such as survey markers, slope indicator casings and other equipment. Include quantity, locations, and estimated material cost of the installed equipment.
SS 46-3: Soil Nails

Section 46-3.01D(2)(b)(ii)(3): Two Percent of Total Number of Production Soil Nails

- Provide the value equal to 2 percent of the total number of production soil nails for each wall or the entire project. This is the number of proof tests required with locations contractually determined by the Resident Engineer. You may provide the tentative locations to the Engineer by issuing a memo to RE Pending File. The locations of the proof test nails can also be determined during construction at locations that require special attention.

Section 46-3.02A: Corrosive Site

- Ensure corrosivity of the site is included in the report so that a corresponding level of corrosion protection for the soil nail reinforcing bar can be determined.

Section 46-3.03A: Geotechnical Issues during Soil Nail Installation

- If difficult soil nail installation is expected, include notes with locations and a description of the difficult site condition(s).

Geotechnical Review for Final Structure PS&E (Expedite Notice)

According to Structure Design Expedite Notice process, a Geotechnical Review must take place after the issuance of Draft Structure PS&E and before the start of Final Structure PS&E (Expedite Notice) process.

During Geotechnical Review, review and verify whether the draft Plans and Special Provisions have implemented the recommendations of the Foundation Report. Geotechnical reports are part of the contract. Any inconsistency between the geotechnical reports, Plans, and Special Provisions can be a problem during contract execution. To ensure consistency of the geotechnical reports with the contract Plans and Special Provisions, the geotechnical reports should be signed and sealed only immediately before the Plans and Special Provisions are signed and sealed, and before the Step 4 of the Structure Design Expedite Notice process, for which the form can be downloaded from the Structure Design Electronic Forms web page.


**Construction Support**

**Pre-Construction Meeting**

Contact the Resident Engineer (RE) and Structure Representative to request an invitation to attend the pre-construction meeting with or without the Contractor. Be prepared to discuss and answer questions related to the design and construction of the soil nail walls, including Standard Specifications and Special Provisions Sections 19 and 46.

**Shop Drawing Review**

Before construction, the Contractor is required to submit Shop Drawings for review, as described in Sections 19-3.01C(4) and 46-1.01C(2) of Standard Specifications. Review the following items in the Shop Drawings and provide comments relating to errors and/or omissions to the Structure Representative. Do not direct the means and methods of construction as these are the responsibility of the Contractor.

*Under Section 19 Earthwork:*

- Soil parameters used for stability analysis,
- Stability analysis of proposed excavation lifts, and
- Proposed stability test locations.

*Under Section 46 Ground Anchor and Soil Nail Wall:*

Refer to the Contract Plans while reviewing the proposed test nail details in the Shop Drawings, including:

- Proposed drilled-hole diameter,
- Estimated nominal bond strength,
- Converted nominal pullout resistance,
- Verification and proof test details,
- Quantity of test nails, and
- Soil nail bar grade and diameter.

**Collect and Review Test Nail Results**

Request the Structure Representative to forward all soil nail test data to the Geoprofesional, irrespective of whether the test nails passed or failed. Reviewing and collecting test nail data is the only means to evaluate the estimate of pullout resistance during design, and to calibrate for future design.

**Typical Construction Issues**

Site conditions, thoroughness of the design deliberation, and competency of the contractor dictate whether construction difficulties and issues will arise during construction. Typical issues encountered during a soil nail wall construction include:
• Sloughing of excavated face due to dry sandy materials,
• Desiccation, weathering, and instability of the excavated face due to prolonged exposure after excavation,
• Creeping and continual movement of the wall face due to high-plastic clay,
• Difficult drilling through cobbles and boulders,
• Caving in of the drilled-holes,
• Excessive groundwater seepage and poor control of surface water and groundwater,
• Construction mistakes, poor workmanship, and incorrect installation,
• The original grade (OG) line as shown on the Plans does not match and is above the top of the excavated face at the site, and
• Failed verification and proof tests.

Work closely with the Structure Representative, and be prepared to promptly answer calls and address Request for Information (RFI) to resolve construction issues in a timely manner.
Technical Notes

The purpose of this Technical Notes section is to provide the soil nail designer with addition design insight to be considered during design of soil nail walls.

Corrosion Protection of Soil Nails

The long-term stability of a soil nail wall or slope primarily depends on the corrosion protection of the soil nails that protect the structural integrity of the soil nail bars. The grout surrounding the soil nails should not be relied on as a water barrier as the grout column will develop cracks. To develop pullout resistance, the inherent function of soil nails, the grout, as a medium between the soil/grout interface and soil nail bar, will sustain tensile stress and ultimately develop cracks in order to transfer the stress. Subsequently, surrounding water and moisture will infiltrate through these cracks and come into contact with the soil nail bars.

The following three-volume articles published by Belgian Building Research Institute provide excellent and comprehensive detailed pullout test data, physical measurement and photos of the exhumed ground anchors, grout columns, and developed cracks. Even though these articles are solely for ground anchors, the mechanisms of grout/ground and grout/tendon are the same for both ground anchors and soil nails, and applicable to soil nails.


Nominal Strength

Nominal strength can be best defined as: the capacity of a structure or component to resist the effects of loads, as determined by computations using specified material strengths (such as yield strength, $f_y$, or ultimate strength, $f_u$) and dimensions and formulas derived from accepted principles of structural mechanics or by field tests or laboratory tests of scaled models, allowing for modeling effects and differences between laboratory and field conditions.

Nominal strength of a batch of construction material, such as steel and concrete, is a strength value derived from testing to failure of specimens sampled from that batch. Even though the reported nominal strength values are typically the nearest rounded-down customary value from the minimum tested strength values, the reported nominal strength is still inherently correlated to the probability density function of the material. For example, the strength distribution of an ASTM A36 steel production batch should be mostly greater than the nominal yield strength of 36,000 psi; i.e. near 100% probability that the ASTM A36 steel has a yield strength of greater than 36,000 psi, the nominal strength.
There is a much more clearly defined material strength value that is based on statistical concept, the characteristic strength. The characteristic strength is defined as: the strength of the material below which not more than 5% of the test results are expected to fall. Sometimes, the characteristic strength is selected as the nominal strength of a material.

In any event, test-to-failure data is needed to establish the strength probability density function of a construction material or construction components. Establishing a strength probability density function for construction materials and construction components is a major and necessary step to truly implementing LRFD, and also to assigning Factor of Safety under ASD. Without the strength probability density function based on test-to-failure data, the design practice can rely only on theory and combined with observed performance of prior construction.

Among geotechnical construction components, very few, if there is any, have an established and direct probability density function. This is because it is physically, financially, and contractually very difficult to test to failure a geotechnical component, such as a driven pile, let alone to test to failure a batch of these components. Therefore, the nominal strength of geotechnical construction components that actually based on directly measured strength or performance probability density functions is rarely available, if it is not non-existence.

Hence, almost all of the nominal strengths used for geotechnical construction components are established based on theory, inferred from basic soil and rock properties, and combined with observed performance. Very few of these nominal strength values have been verified by test to failure.

Nominal Strength and Pullout Resistance of Soil Nails
In soil nail construction, statistically significant amount of sacrificial soil nails are required to be tested to and pass the nominal pullout resistance in order to satisfy the acceptance criteria. The implemented test regime provides relatively higher confidence for constructed soil nails than that for other geotechnical components.

However, tests that stop short of reaching failure cannot be used to establish the strength probability density function that can verify the reasonableness of the selected nominal pullout resistance.

Improvement in Interpreting Nominal Strength from Subsurface Exploration
The discussion in the previous section has not addressed the issue of how to interpret nominal pullout resistance based on field and laboratory tests during design. Currently, the often quoted references on this subject are the tables (Tables 4.4a, 4.4b, 4.5, and 4.6) from FHWA GEC No. 7. However, the information presented in these tables need to be updated and improved.
First of all, there is a need for clarification and agreement on where the presented strength values reside in terms of the probability density function of the particular soils and rocks. Some may consider these values as the average values compiled from collected data, which is naturally the case when presenting summary of findings. However, during construction, the values selected for design, mostly referenced from these tables, are the construction acceptance criteria – the absolute lower bound according to typical construction contract language and the de facto nominal strength values. Understanding this potential disconnect is needed when referencing these values.

Then, clearly defined nominal strength with respect to the probability density function needs to be established and agreed upon. Meanwhile, we need a concerted effort to continually accumulate engineering properties of soils and rocks from laboratory and in-situ tests, and interpreted nominal pullout strength and associated design parameters of these soils and rocks. Only after we compared the interpreted nominal strengths with the nominal strengths obtained from soil nail pullout tests and other tests during construction, can we calibrate our practice.

This above discussion offers a general direction needed to prepare for the gradual implementation of LRFD for soil nails. It can take years, and probably decades, and requires gradual improvement to our subsurface exploration practice for soil nail design.

Current soil nail design practices all apply various assumptions to simplify a complex composite system to comprehensible models so that workable design procedures can be implemented. Be diligent, aware of these assumptions, and be involved throughout the design, contract development, and construction phases to continually improve on the understanding of soil nail design and construction.