Snail User Guide

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1 Introduction

Snail is a geotechnical engineering software developed and maintained by Geotechnical Services, Division of Engineering Services, California Department of Transportation (Caltrans). This software was developed to assist users in performing stability analyses of soil nail walls and analyses of structural facing of soil nail walls. The first version of Snail was first developed and maintained by Caltrans circa 1989. The software runs under the Windows 7, 8 and 10 operating systems on a personal computer (PC) only.

The previous versions of the software have been validated by:

- *WA-RD 371.1 Evaluation of Design Methodologies for Soil-Nailed Walls* (7/1998)
- *FHWA-IF-99-026 Design & Construction Monitoring of Soil Nail Walls* (Demonstration Project 103) (12/1999)
- *FHWA0-IF-03-017 Soil Nail Walls (Geotechnical Engineering Circular No. 7)* (3/2003)

Snail performs stability analysis of a soil nail wall based on force limit equilibrium. For both geotechnical soil nails and structural facing analysis, Snail follows the procedure presented in *Soil Nail Walls Reference Manual, FHWA-NHI-14-007, FHWA GEC 007, February 2015 (GEC No. 7 2015)*.

Snail includes the following main features:

- Options of using Load and Resistance Factor Design (LRFD, GEC No. 7 2015 approach) or Allowable Stress Design (ASD) for both geotechnical soil nails and structural facing analysis and design
- Performs soil nails analysis using bi-linear or tri-linear search surfaces
- Performs structural facing analysis with or without soil nails analysis
- Presents the controlling modes in soil nails analysis
- Graphically presents the calculated most critical search surface or any user selected search surface, and corresponding factors of safety (FoS) or capacity demand ratios (CDR)
- Allows parametric study of inter-slice force inclination
- Allows both U.S customary and metric units
- Provides graphic and text outputs

2 How to Use Snail

Snail has seven main menus: ***File, Settings, Input, Facing, Action, View, and Help*** (Figure 1). The ***Action*** menu is available only after geometry or reinforcement information is entered.

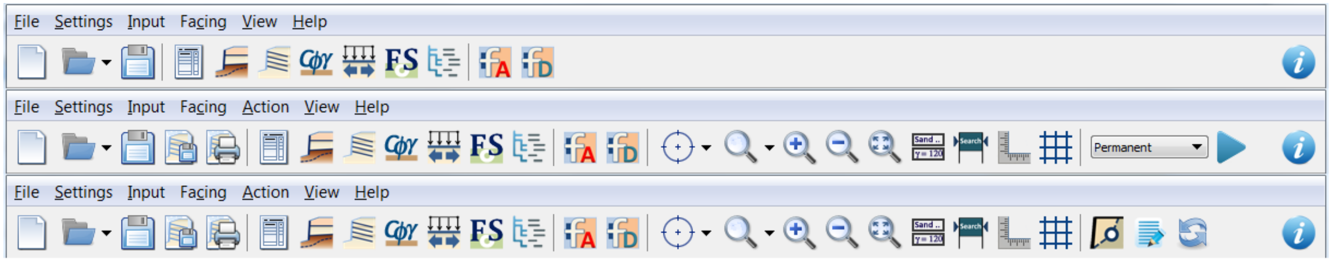


Figure 1 Snail Menus and Toolbars

File

The ***File*** menu includes standard file handling functions usually found in Windows-based programs: *New, Open, Save, Save As, Save as Image File, Print, and Exit*.

Settings

The ***Settings*** menu allows users to select

- Analysis method: allowable stress design (ASD) or load and resistance factor design (LRFD); and
- Units: English or SI.

When analysis method ASD is selected, the icon for the entry of factors of safety for ASD  will appear in the toolbar. When the analysis method LRFD is selected, the icon for the entry of load and resistance factors for LRFD  will appear in the toolbar.

Input

The ***Input*** menu is for entering information required for soil nail wall analyses. The ***Input*** *menu* has six submenus: ***Project Information***, ***Geometry***, ***Soil Nails***, ***Soil Properties***, ***Loads***, ***Factors of Safety*** *or* ***Load and Resistance Factors***, *and* ***Search Options***.

Project Information

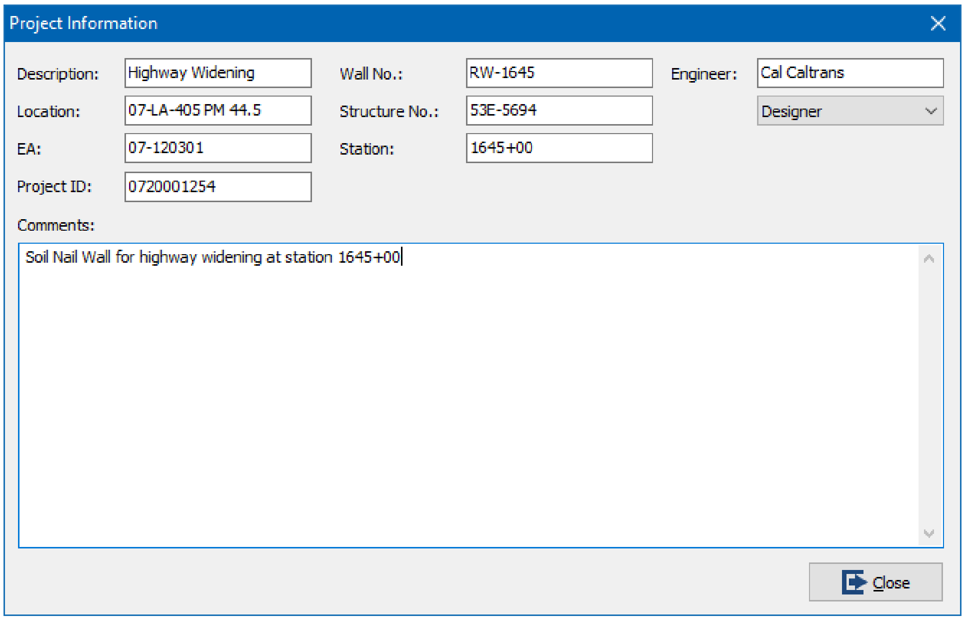


Figure 2 Project Information

Project information is the input screen to enter project name or description, location, expenditure authorization (EA) number, project ID, wall number, structure number, station, the user's name, and function (Figure 2). The *Comments* field can be used for project and site descriptions.

Geometry

Geometry includes four tabs: ***Layout***, ***Ground Surface***, ***Soil Layers***, *and* ***Ground Water*** (Figure 3).

- ***Layout***

  Snail uses the combination of an origin point, reference point, wall height, and facing angle or batter to establish the wall geometry. The origin point can be any point as defined by the user.

  The reference point must be at one of two locations, at the top of the wall or the toe of the wall, as shown on Figure 6. Assign the coordinates of the reference point, either the toe or top of the wall, based on the horizontal distance (x) and the vertical distance (y) from the origin point.

❖ <u>*Reference point*</u>

- *At:* Set the reference point at either the *Top of Wall* or the *Toe of Wall* (Figure 6).
- *Distance from Origin:* Enter x-coordinate of the reference point
- *Elevation above Origin:* Enter y-coordinate of the reference point

❖ <u>*Wall Dimensions*</u>

- *Wall Height:* Enter the wall height
- *Facing Angle*: Enter the wall inclination in degrees, measured from the horizontal axis with counter-clockwise direction as positive (Figure 6), or
- *Facing Batter:* Enter the horizontal "x" value for the wall facing Batter of x:12 (H:V) .(The angle is automatically calculated based on the ratio of the horizontal distance and the vertical distance.)

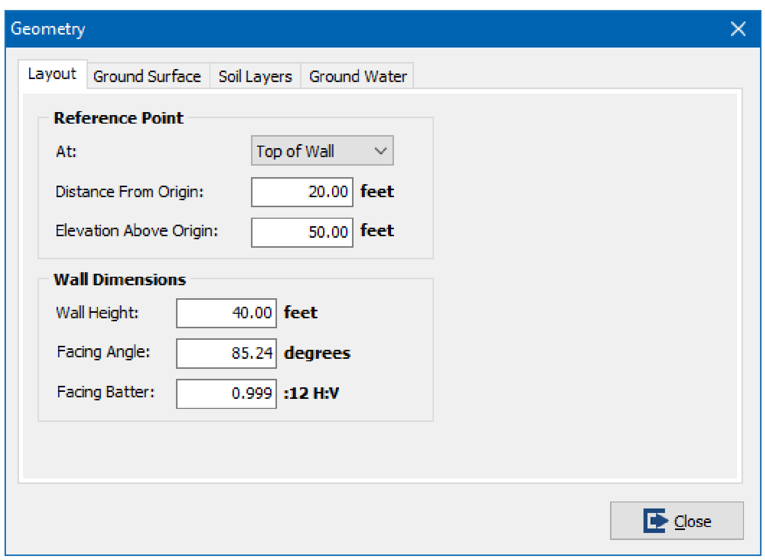


Figure 3 Geometry - Layout

Based on the reference point coordinates, either the top-of-wall or toe-of-wall coordinates will be determined by the wall height and facing angle or facing batter. If the *facing angle* is entered, the *facing batter* will be automatically calculated and shown on the input screen or vice versa.

➢ ***Ground Surface***

- *Number of lines that define the ground surface above the wall:*
  Use up to 19 line segments

- *Angle:* Enter the inclination angle (from horizontal) of each line segment with the above horizontal line direction as positive for the ground surface above the wall and in front of the toe (Figure 6).

- *Distance:* Enter the length of each line (Figure 6)

The number of inputs for *Angle* and *Distance* (Figure 4) must match the value entered for *Number of lines that define the ground surface above the wall*. The first ground surface line starts from the top of wall; the second line starts from the end point of the first line etc. From the entered angle and length for each line, the x and y coordinates of the points connecting the lines will be calculated and the surface lines will be shown on the graphic screen (Figure 6). The *Distance* for the last entry is internally calculated and projected to the limits of the model by the software.

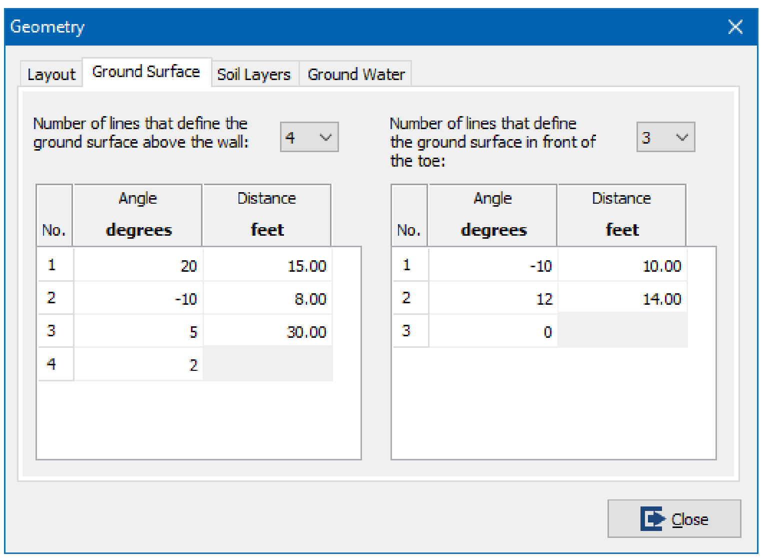


Figure 4 Geometry - Ground Surface

If a below toe search (with *Perform below Toe Search of Search Options* selected) is to be performed, enter the *Number of lines that define the ground surface in front of the toe.* The first ground surface line in front of the wall starts from the toe of the wall, the second line starts from the end point of the first line and continues until the last line.

➢ *Soil Layers*

- *Number of Layers:* Select number of layers – up to 7
- *Distance:* Enter x-coordinate of Point 1 and Point 2 of the top of each layer
- *Elevation:* Enter y-coordinate of Point 1 and Point 2 of the top of each layer

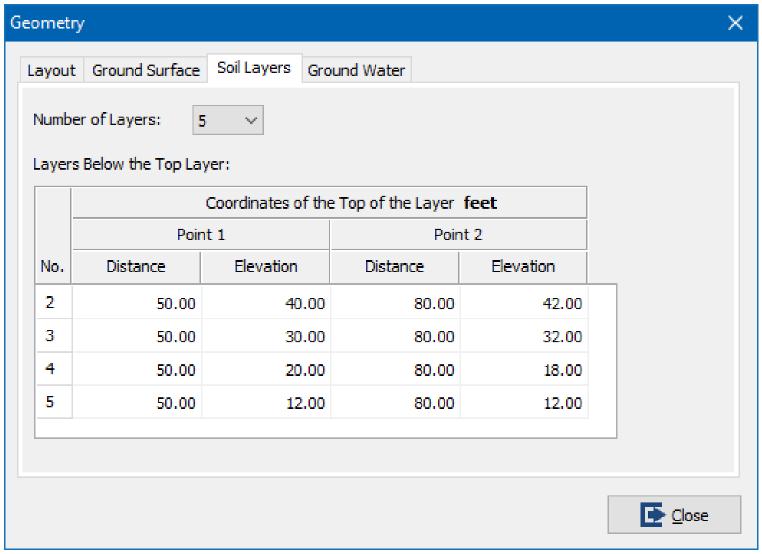


Figure 5 Geometry - Soil Layers

Enter the top of each soil layer (Figure 5), starting from the top of the second layer, as the top of first layer has been defined by the ground surface. Enter coordinates of Point 1 and Point 2 that form a straight line that defines the top of each soil layer (Figure 6). The location of these points must be below the defined ground surface lines, behind the wall face, and inside the wall model area. To ensure the points are behind the wall, placing the points at a discernible distance behind the wall face.

The lines and their projection must not intersect each other within the model boundaries. Snail will calculate the coordinates of the points where the lines intersect the wall face and model boundaries based on the inclination projection of the defined straight lines.

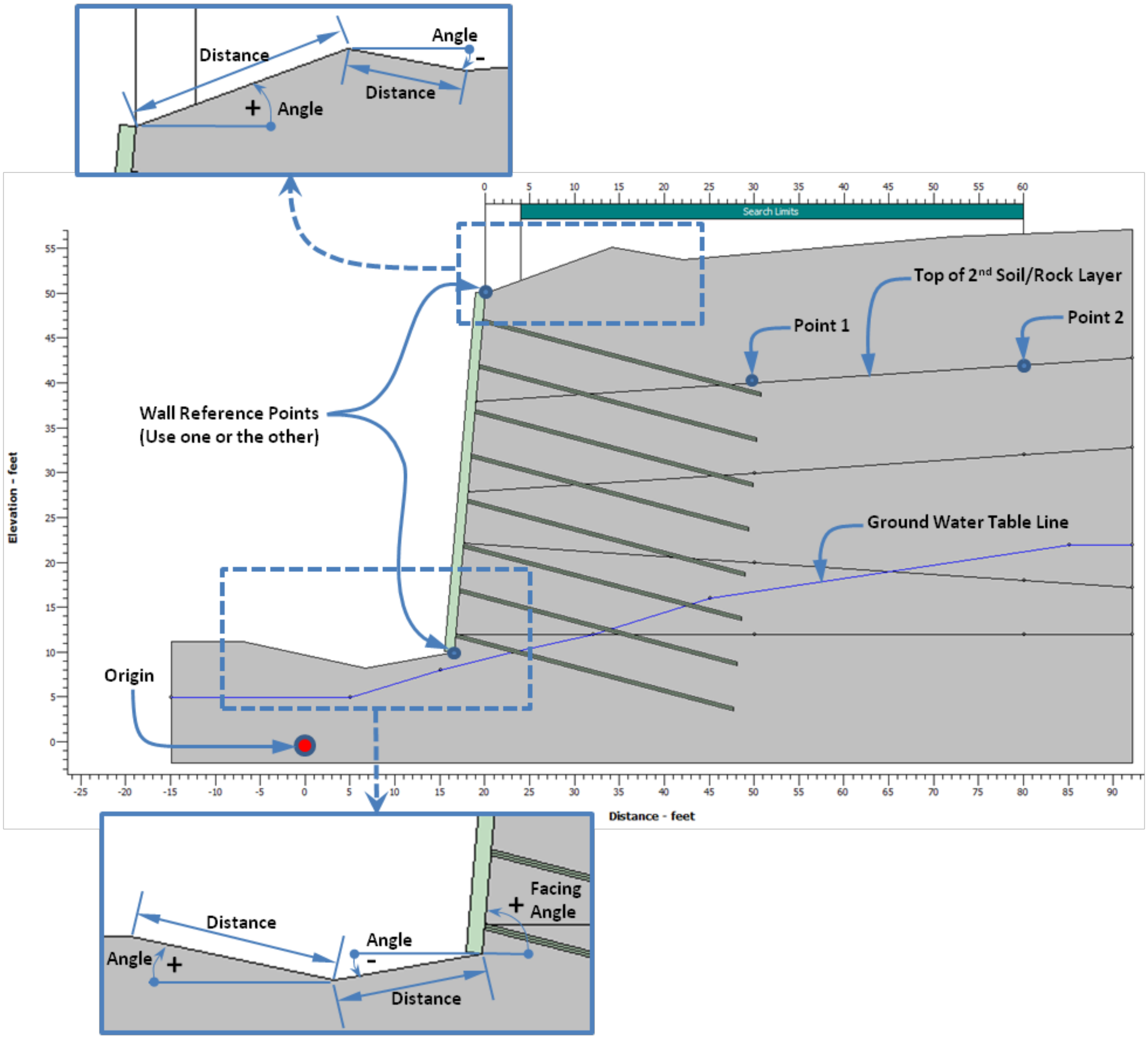


Figure 6 Geometry - Graphical Presentation of Input Variables

➢ ***Ground Water***

- *Include Ground Water:* Check the box (Figure 7) when ground water is considered in the analysis
- *Number of Points:* Select the number of points that define the ground water surface – up to 18
- *Distance:* Enter the x-coordinate of each point
- *Elevation:* Enter the y-coordinate of each point

The number of inputs for *Distance* and *Elevation* must match the value selected in the *Number of Points*. Ensure the ground water line is below the ground surface. The ground water table will project horizontally outward from the first and last points (Figure 6).

- *Phreatic Correction:* Check the box to apply phreatic surface correction

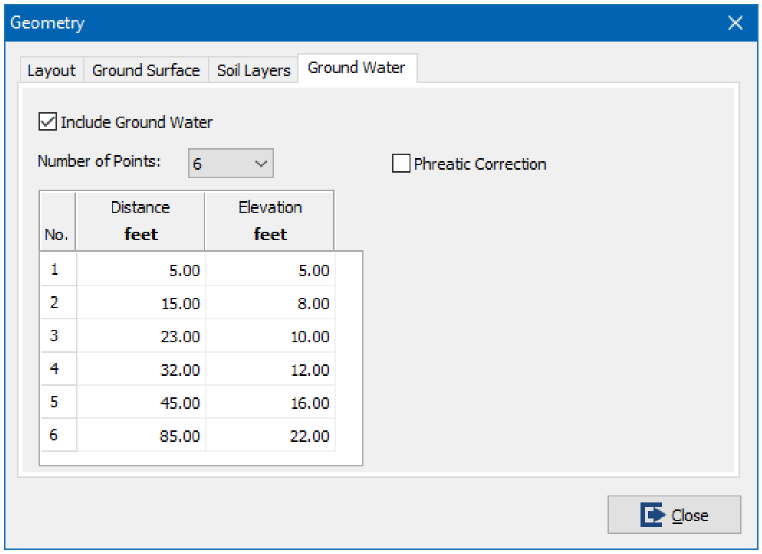


Figure 7 Geometry - Ground Water

For a ground water system under hydrostatic condition, the pore-water pressures may be calculated by multiplying the vertical distance between the ground water surface and the slice base mid-point (H_w) and the unit weight of water (γ_w).

$$p_w = H_w \times \gamma_w$$

However, when there is a sloping ground water condition (Figure 8), using the vertical distance to calculate pore-water pressures will result in a higher pore-water pressure than necessary. To take into account the sloping piezometric profile for more accurate calculation of pore-water pressure, the user can apply the phreatic surface correction.

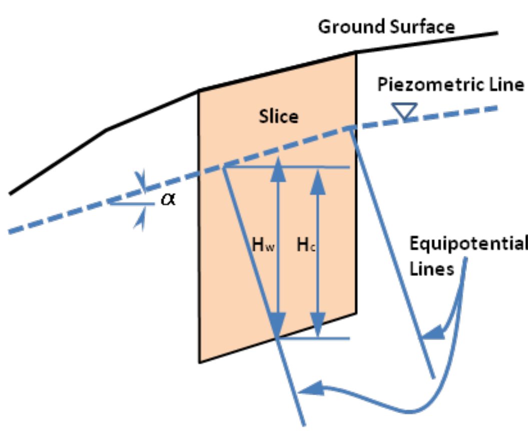


Figure 8 Phreatic Surface Correction

$$H_c = H_w \times \cos^2(\alpha)$$

$$p_w = H_c \times \gamma_w$$

For sloping ground water conditions, the calculation without phreatic surface correction yields a lower factor of safety than when phreatic correction is applied and is erring on the conservative side.

If there are ground water issues for the wall, a soil nail wall may not be a good option.

Soil Nails

Soil Nails has two tabs: ***Dimensions and Properties*** (Figures 9, 10, and 11), and ***Facing Resistance*** (Figure 12).

- ***Dimensions and Properties***

- *Diameter of Drilled Holes:* Enter drilled-hole diameter (typical practice uses 6 or 8 inches)
- *Horizontal Spacing:* Enter center to center horizontal distance between nails
- *Maximum Vertical Spacing:* Enter maximum vertical spacing between nails – for T_o calculation (refer to Section 4 – *Tensile Force at Soil Nail Head (T_o)*)
- *Number of Soil Nail Rows:* Select the number of soil nail rows – up to 30
- *Soil Nail Design Parameters:* Select either *Uniform throughout Cross-Section* or *Varying*

For *Soil Nail Design Parameters,* when the *Uniform throughout Cross-Section* option is selected enter the following fields (Figure 9):

- *Soil Nail Length:* Enter soil nail length
- *Inclination From Horizontal:* Enter the inclination angle of soil nails measured from the horizontal axis with clockwise direction as positive (Figure 10) – typically 10 to 15 degrees
- *Vertical Distance from Top of Wall to First Row:* Enter the vertical distance from top-of-wall to the first row of soil nails
- *Vertical Spacing:* Enter the center-to-center vertical spacing between soil nail rows
- *Nail Bar Diameter:* Enter soil nail bar diameter
- *Nail Bar Yield Strength:* Enter soil nail bar yield strength

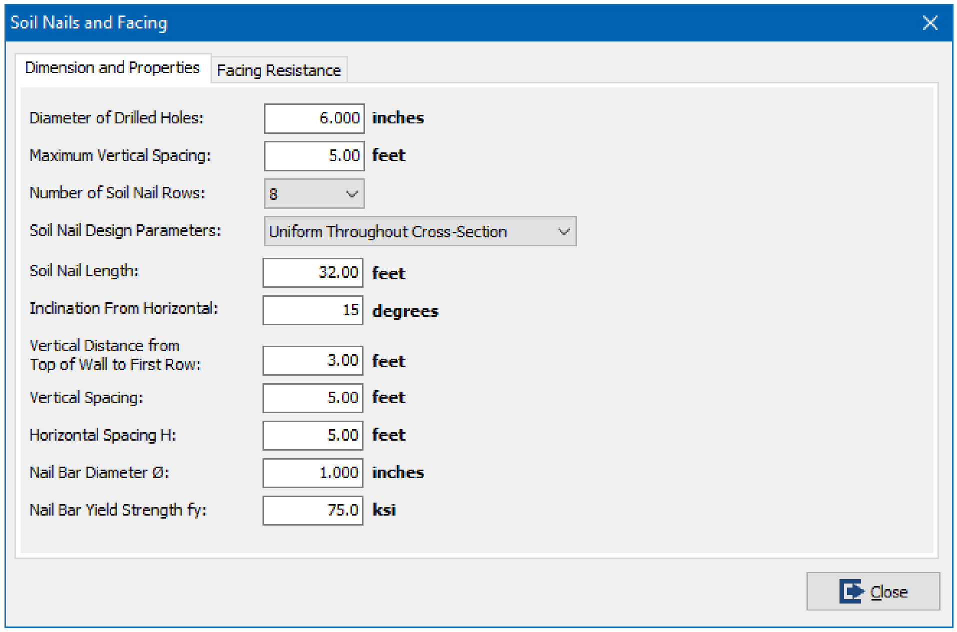


Figure 9 Soil Nails – Uniform Throughout Cross Section Option

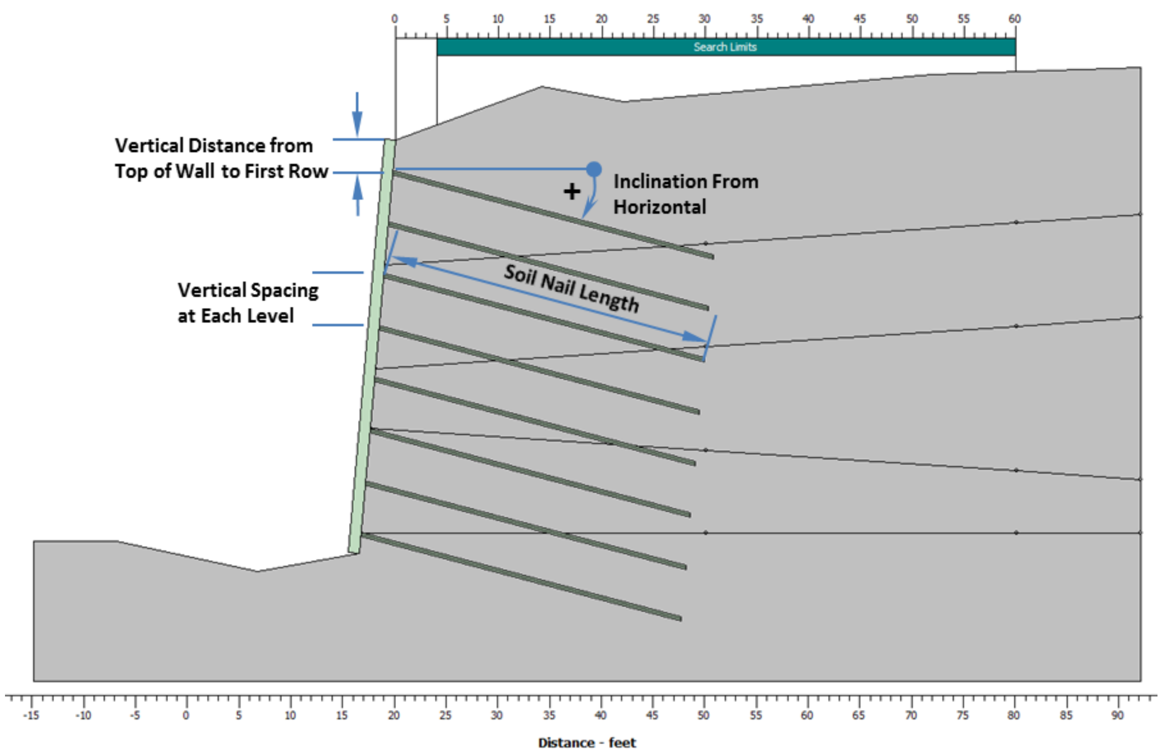


Figure 10 Soil Nails - Graphical Presentation of Input Variable

When the *Varying* option is selected for *Soil Nail Design Parameters*, the lower portion of the window will turn into a table for entry of the parameters for each soil nail row (Figure 11).

In the table, the entries for vertical spacing is the vertical spacing above the corresponding soil nail row. For the first soil nail row, the vertical spacing entry is the vertical distance from top of wall to the first soil nail row.

In the table, the entries for bond strength factor, with defaulted value of “1”, can be used to account for variation of construction methods and scenarios for different soil nail rows, such as localized variations of soil condition in a soil layer.

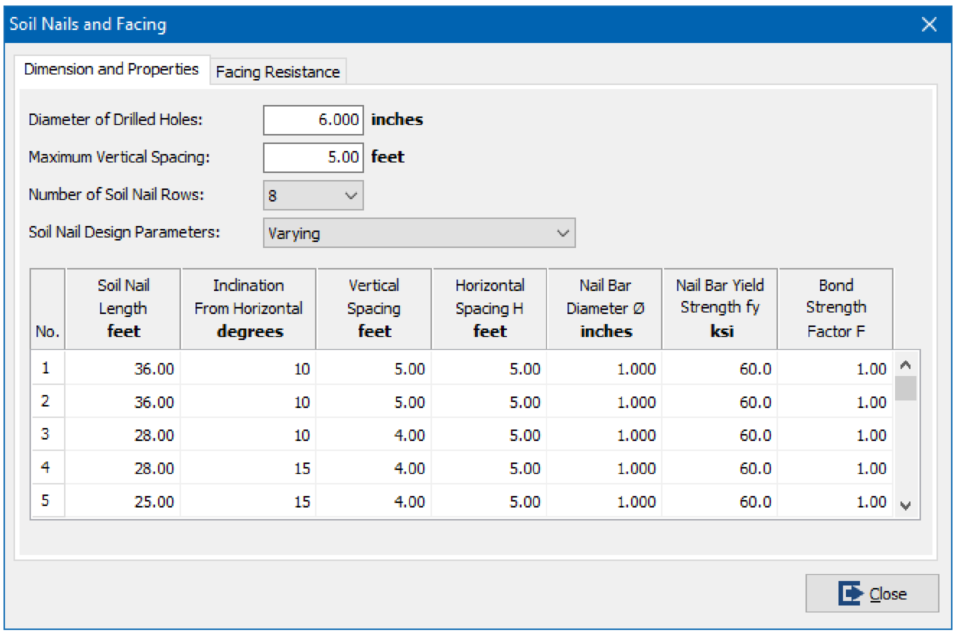


Figure 11 Soil Nails - Varying Option

➢ *Facing Resistance*

Snail offers analyses of both Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD), and for three scenarios: *Temporary, Permanent,* and *Seismic*. Each scenario requires its own set of facing resistance factors for corresponding analysis (Figures 12 and 13).

❖ <u>*Allowable Stress Design (ASD)*</u>

- *ASD Allowable Facing Resistance:* Enter the ASD allowable facing resistance for the three scenarios or select *Facing Design Tool*
- *Facing Analysis:* Click the button to have Snail perform facing analysis and calculate the factored facing resistances and automatically transfer the calculated factored facing resistance parameters to the corresponding fields above

- *Suggested Facing Design:* Click the button to select one of the suggested facing designs and automatically transfer the factored facing resistances of the selected facing design to the corresponding fields above

The *ASD Allowable Facing Resistance* can be entered by the user, calculated by *Facing Analysis*, or obtained from *Selected Facing Design* features in Snail and automatically transferred to the corresponding fields for soil nail wall analysis. *Facing Analysis* and *Suggested Facing Design*, as activated by clicking the respective buttons (Figure 12), are stand-alone structural facing analyses tools. The required input parameters for facing design and analysis are described in the *Facing Analysis* section.

ASD allowable facing resistances are factored strength values that accounts for uncertainties associated with structural facing design and facing strength properties.

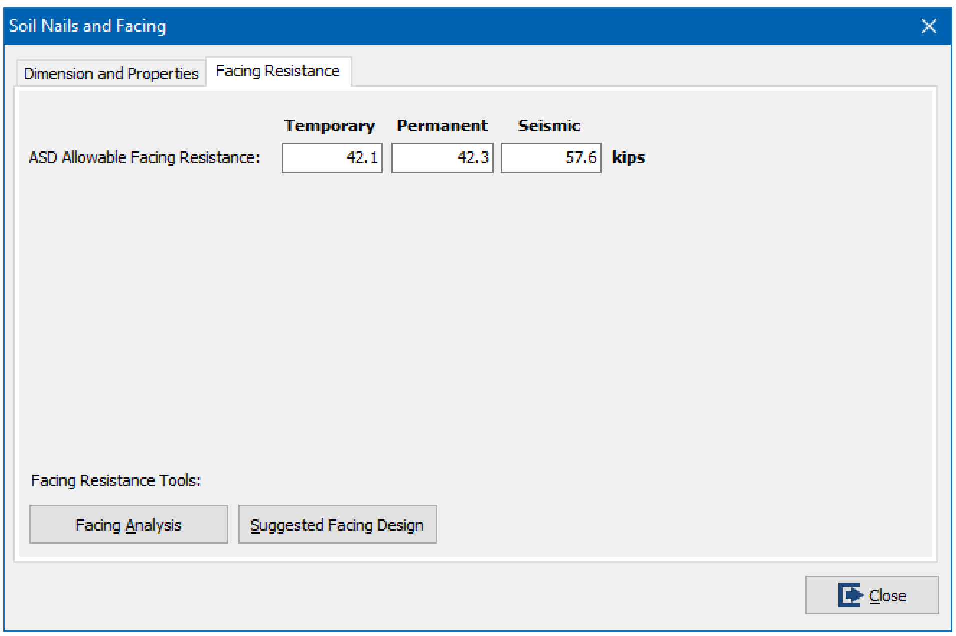


Figure 12 Facing Resistance Tab in Soil Nails Menu – ASD

❖ *Load and Resistance Factor Design (LRFD)*

For LRFD analysis, enter *LRFD factored facing resistance* for each of the three scenarios: *Temporary, Permanent,* and *Seismic* (Figure 13). *LRFD factored facing resistances* are factored strength values that accounts for uncertainties associated with structural facing design and facing strength properties.

The *LRFD factored facing resistances* can be entered by the user, calculated by *Facing Analysis*, or obtained from *Selected Facing Design* features in Snail and automatically transferred to the corresponding fields for soil nail wall analysis.

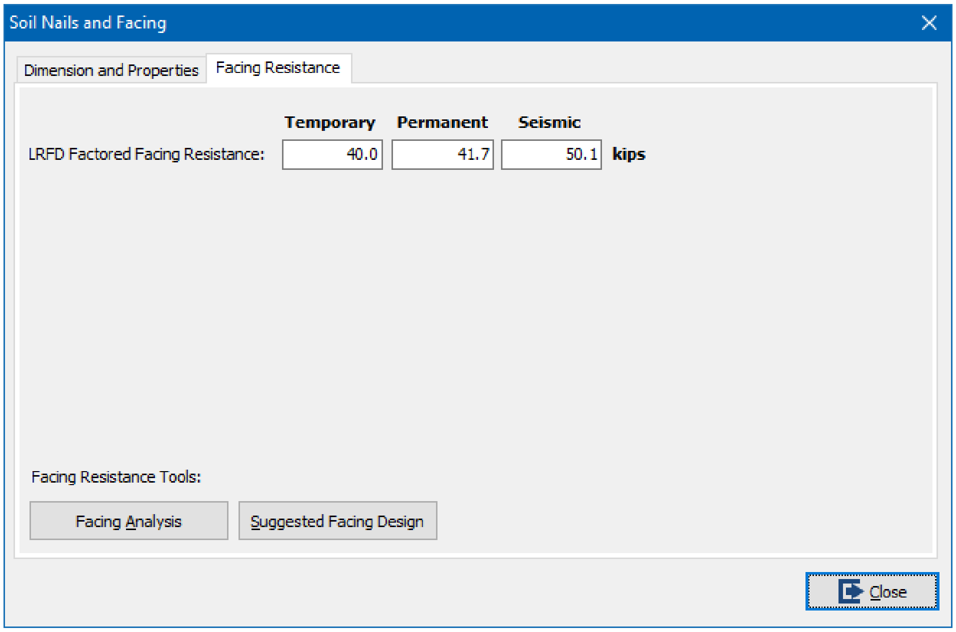


Figure 13 Facing Resistance Tab in Soil Nails Menu – LRFD

Soil properties

The number of sets of *soil properties* inputs (Figure 14) must match the *Number of Layers* selected in *Soil Layers* tab in *Geometry* menu.

- *Description:* Enter the description for each soil layer
- *Unit Weight:* Enter the unit weight for each soil layer
- *Friction Angle:* Enter the friction angle for each soil layer
- *Cohesion:* Enter the cohesion for each soil layer
- *Nominal Bond Strength:* Enter nominal bond strength for each soil layer

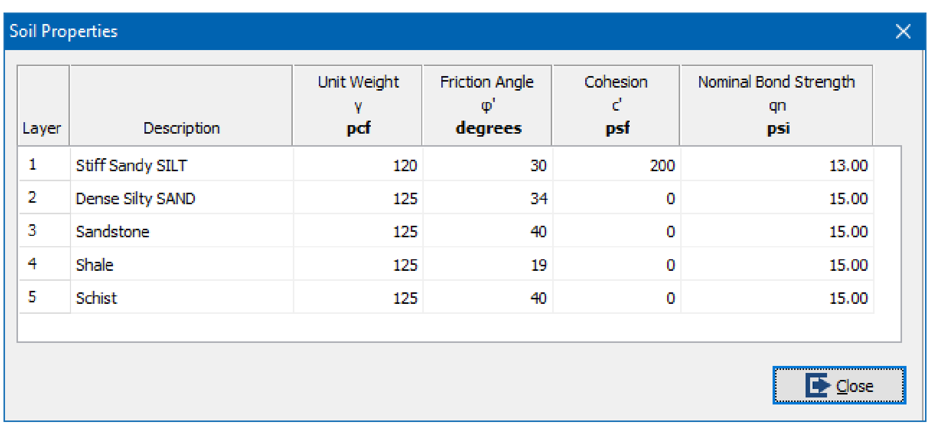


Figure 14 Soil Properties

Loads

Snail offers three different load options: *Seismic, External and Surcharge* (Figures 15 and 16).

- ***Seismic***

  - *Horizontal Seismic Coefficient:* Enter the horizontal seismic coefficient. The horizontal seismic coefficient must be provided if seismic analysis is to be performed. The effect of vertical seismic force on a wall is typically negligible and is not considered.

- ***External***

  - *Apply External Load:* Check the box when there is an external load onto the wall face.
  - *Load:* Enter the external load
  - *Angle:* Enter the inclination angle of external load direction measured from the horizontal axis with counter-clockwise direction as positive. (Figure 16).

  Note: The location of the external load on the wall face is not needed because the analysis is performed using force equilibrium method.

- ***Surcharges***

  - *Apply Surcharges:* Check the box when there are distributed loads on the ground above the wall
  - *Number of Surcharges:* Select a value – up to 2
  - *Distance from Top of Wall:* Enter the distances of begin point and end point of each distributed load from top of wall
  - *Load:* Enter the distributed loads at begin point and end point of each distributed load

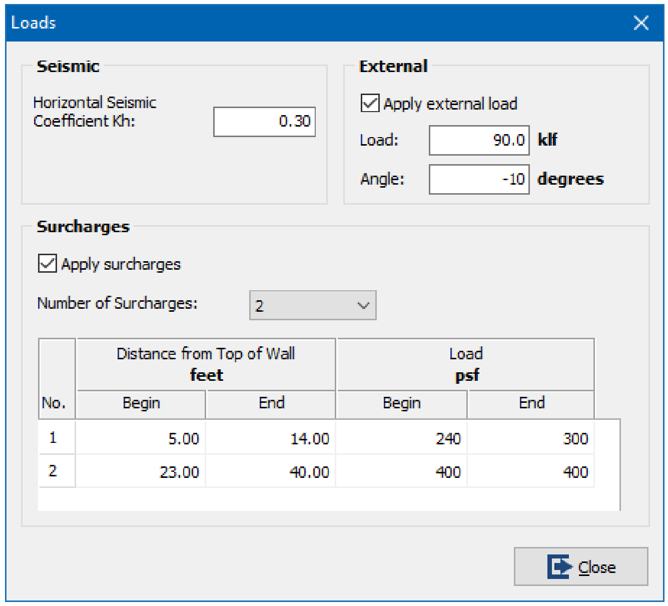


Figure 15 Loads

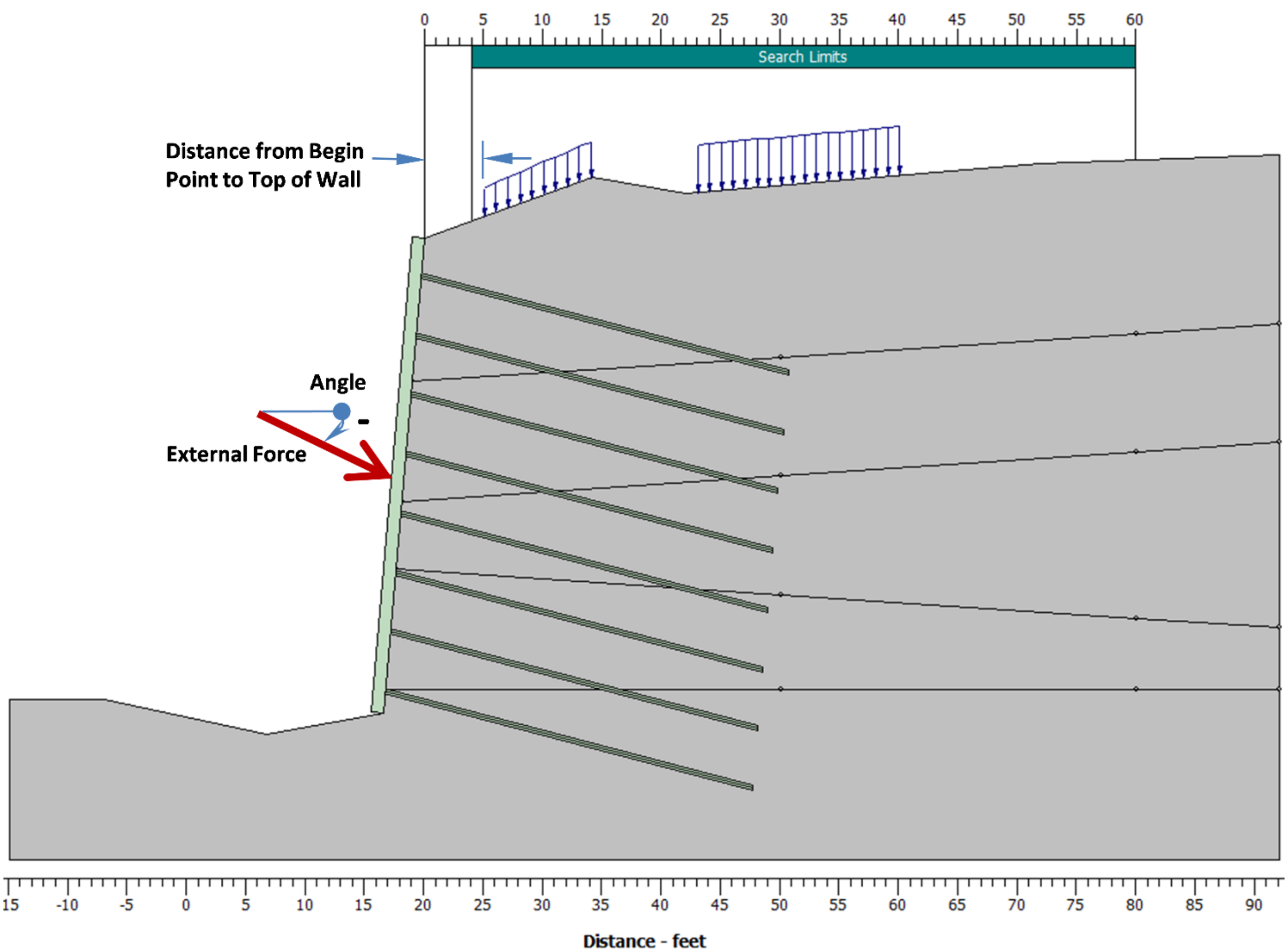


Figure 16 Applied Loads - Graphical Presentation of the Input

Factors of Safety – for ASD

Enter *Factors of Safety* for the *Temporary, Permanent,* and *Seismic* scenarios. Each scenario requires its own set of factors of safety for corresponding analysis (Figure 17).

- *Pullout (Distal):* Enter the factors of safety to be applied to the pullout capacity of soil nail grout / soil interface at the distal section of the soil nails.
- *Pullout (Proximal):* Enter the factors of safety to be applied to the pullout capacity of soil nail grout / soil interface at the proximal section of the soil nails.
- *Nail Bar Yield:* Enter the factors of safety to be applied to soil nail bar yield

  Note: The introduction of separate resistance factors for distal and proximal pullout capacities is for future implementation to take into account the difference in the reliability of the estimated pullout capacities.

  The estimated pullout capacity at the section near the soil nail tip (distal) should be more reliable, as it will be verified and proved by pullout test during construction. Therefore, the resistance factors applied to the distal pullout capacity may be greater than those applied to the proximal pullout capacity. To assign different pullout resistance factors for proximal and distal sections, a more rigorous pullout test regime during construction should be implemented.

For recommended factors of safety, please refer to [Table 5.1](), *GEC No. 7 2015*. As explained above, the confidence on the estimated pullout capacities depend on the rigorousness of pullout test during design and specified during construction. Factors of safety values other than those recommended by GEC No. 7 2015 may be considered if rigorous pullout test regime has been carried out during design or to be performed during construction as specified.

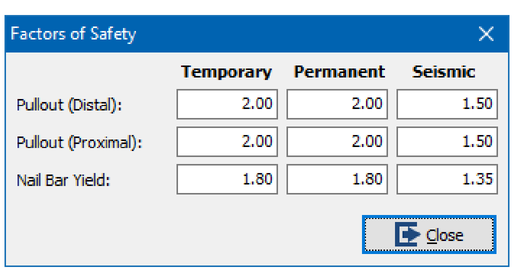


Figure 17 Factors of Safety

Load and Resistance Factors – for LRFD

Load and Resistance Factors includes two tabs: *Load Factors* (Figure 18) and *Resistance Factors* (Figure 19).

➢ ***Load Factors***

Snail offers two options to apply load factors:

- Apply to Soil Nail Tensile Force (FHWA GEC No. 7 2015); or
- Apply to Loads and Soil Weight.

❖ *Soil Nail Tensile Force (FHWA GEC No. 7 2015)*

Enter the load factors to be applied to the soil nail tensile force – recommended option.

Note: The default load factors for *Soil Nail Tensile Force* are derived from the "EV: Vertical earth pressure (ret. walls and abutments)" row of Table 5.3, *GEC No. 7 2015*. The combination of these default load factors (ϕ) and the default resistance factors (γ) applied to soil nail pullout capacities, soil nail bar yield, and facing capacity will arrive at the factors of safety (FoS) for the respective components that are compatible with the FoS used in the ASD method.

These load factors on soil nail tensile force are virtual load factors implemented as an interim solution before there is a decision on load factors for soil mass and external loads.

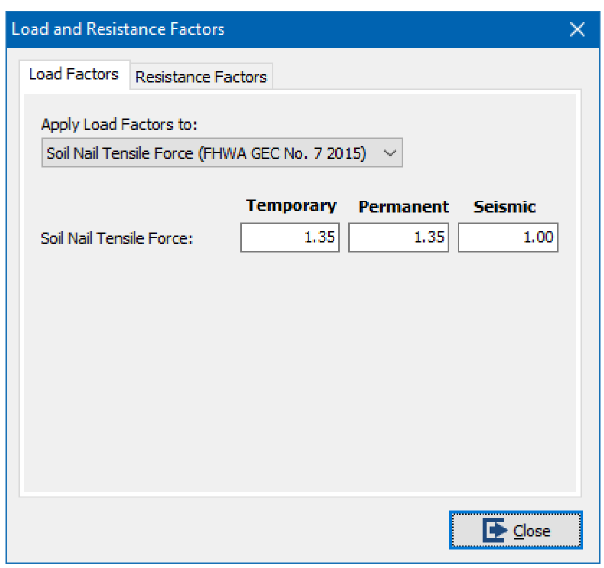


Figure 18a Load Factors – Applied to Soil Nail Tensile Force

Loads and Soil Weight

When this option is selected, Snail can be used to implement LRFD design of soil nail walls. However, policy decision is needed before using this option for actual design work. In the meantime, this option can be used to perform parametric studies.

- *Active Soil Mass Load:* Enter the load factor for weight of soil mass in active zone
- *Passive Soil Mass Load:* Enter the load factor for weight of soil mass in passive zone in front of the toe. This value will only be used when *Perform below Toe Search* in *Search* Option is checked; and should be ≤1.0 since this load is a stabilizing force in the soil nail stability analysis.
- *Surcharge Load 1:* Enter the load factor for Surcharge Load 1
- *Surcharge Load 2:* Enter the load factor for Surcharge Load 2
- *External Load:* Enter the load factor for the External Load. If the load against the slope or wall face acts as a stabilizing force to the slope or wall, the value should be ≤ 1.0.

Please refer to Section 4 Technical Note *Use LRFD Method for Soil Nails* for further discussion of the load factors on soil nail tensile force, soil mass, and external loads.

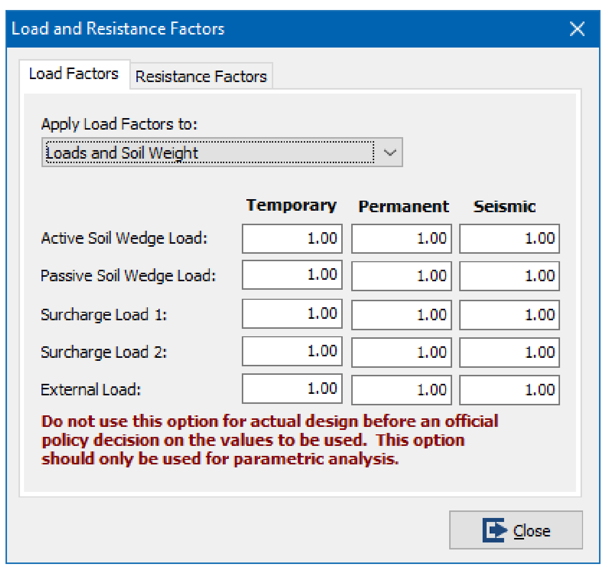


Figure 18b Load Factors – Applied to Loads and Soil Weight

➢ ***Resistance Factors***

- *Pullout (Distal):* Enter the resistance factors for the pullout capacity of soil nail grout / soil interface at the distal section of the soil nails

- *Pullout (Proximal):* Enter the resistance factors for the pullout capacity of soil nail grout / soil interface at the proximal section of the soil nails
- *Nail Bar Yield:* Enter the resistance factors for the soil nail bar yield
- *Friction Angle:* Enter the resistance factor for friction angle
- *Cohesion:* Enter the resistance factor for cohesion
- *Friction Angle:* Enter the resistance factor for friction angle

Note: The introduction of separate resistance factors for distal and proximal pullout capacities is for future implementation to take into account the difference in the reliability of the estimated pullout capacities.

The estimated pullout capacity at the section near the soil nail tip (distal) should be more reliable, as it will be verified and proved by pullout test during construction. Therefore, the resistance factors applied to the distal pullout capacity may be greater than those applied to the proximal pullout capacity.

To assign different pullout resistance factors for proximal and distal sections, a more rigorous pullout test regime during construction should be implemented.

For recommended resistance factors, please refer to Table 6.3, *GEC No. 7 2015*.

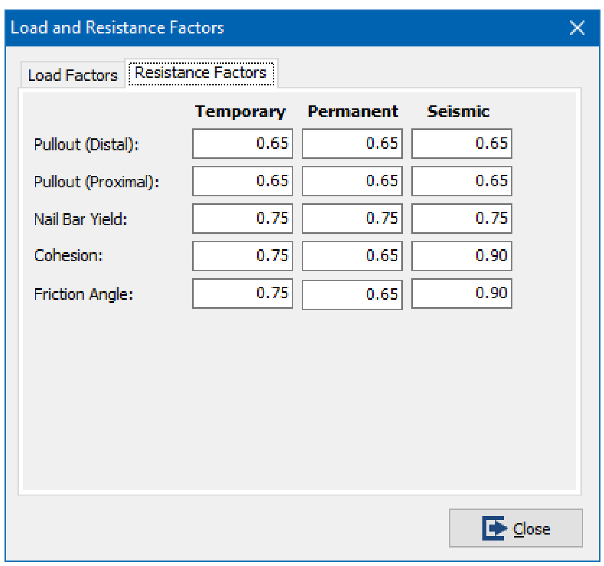


Figure 19 Resistance Factors

Search Options

➢ *Search Limits*

- *Begin:* Enter the horizontal distance between the top of wall and the begin point of the search (Figures 20 and 21)

- *End:* Enter the horizontal distance between the top of wall and the end point of the search

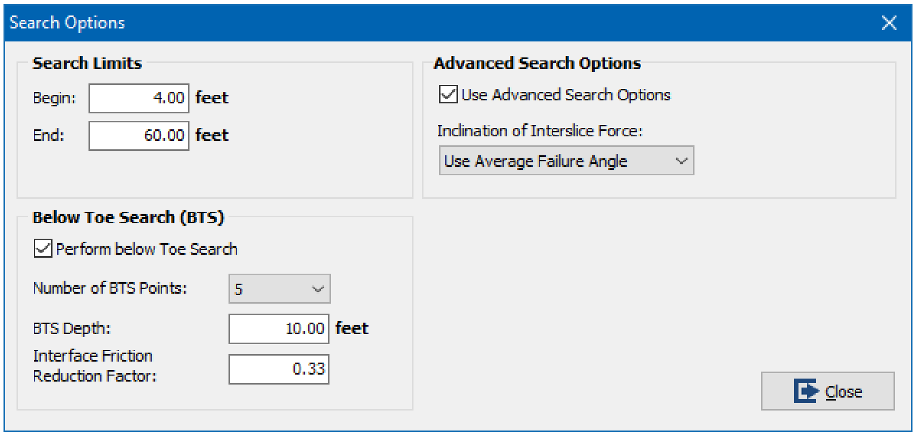


Figure 20 Search Options

The distance between the *Begin* and *End* points of *search limits* will be equally divided into 10 segments to generate eleven search Nodes. From each of these search Nodes, 55 bi-linear search surfaces will be generated with a matrix of 55 Grid Points (Figure 22) to search for the surface with the minimum factor of safety (FoS) or capacity demand ratio (CDR) for each search Node. The minimum factors of safety or capacity demand ratio for each search Node are presented in the Snail text output file.

Snail also allows users to view the calculated factor of safety or capacity demand ratio and geometry of any search surface by selecting the corresponding search Node and Grid Point. This option is described in *View Details* in *Action Menu.*

➢ *Below Toe Search (BTS)*

When the *Perform Below Toe Search* option is selected, *Number of BTS Point, BTS Depth* and *Interface Friction Reduction Factor* are available for entry. Search points for below the toe search will be generated according to the *Number of BTS Points* and *BTS Depth*.

- *Perform Below Toe Search:* Check the box to search for the minimum factor of safety of surfaces that pass through below the toe of wall (Figure 21)
- *Number of BTS Points:* Select the number of search points – up to 5
- *BTS Depth:* Enter vertical extent of the search from the toe of wall – should be less than the wall height

- *Interface Friction Reduction Factor:*

  Enter the reduction factor for the interface friction mobilized by friction angle at the vertical interface between active zone and passive zone – should be 0 ≤ value ≤ 1.0

The use of *Interface Friction Reduction Factor* is to reduce shear resistance at the interface between active and passive sliding wedges. This value is a multiplier to the mobilized shear resistance along the interface contributed by the friction angle. Enter "1.0" to assume a fully mobilized shear resistance from friction angle. The default value is set to 0.33 to be consistent with the previous versions of the software.

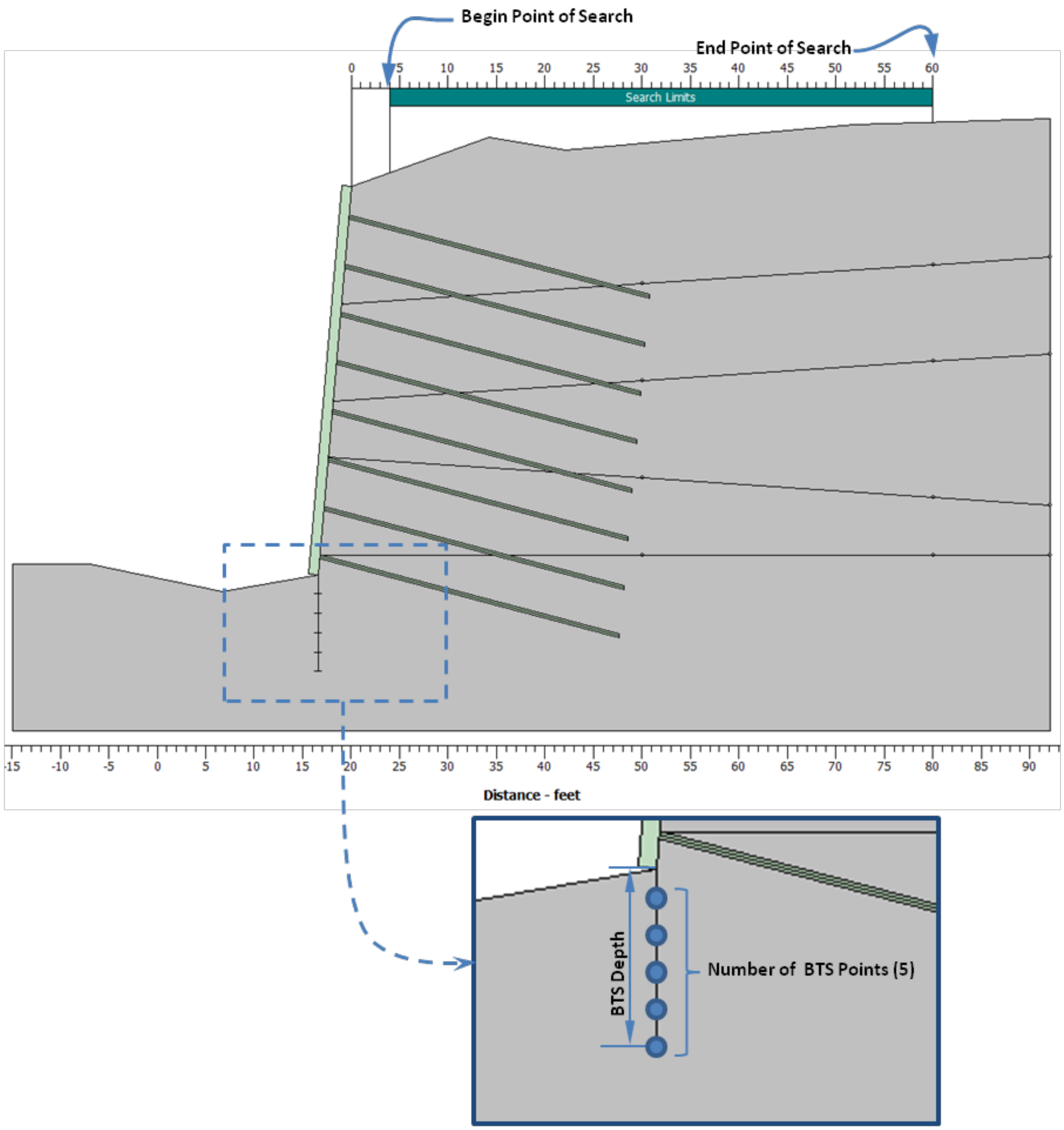


Figure 21 Entries for Below the Toe Search

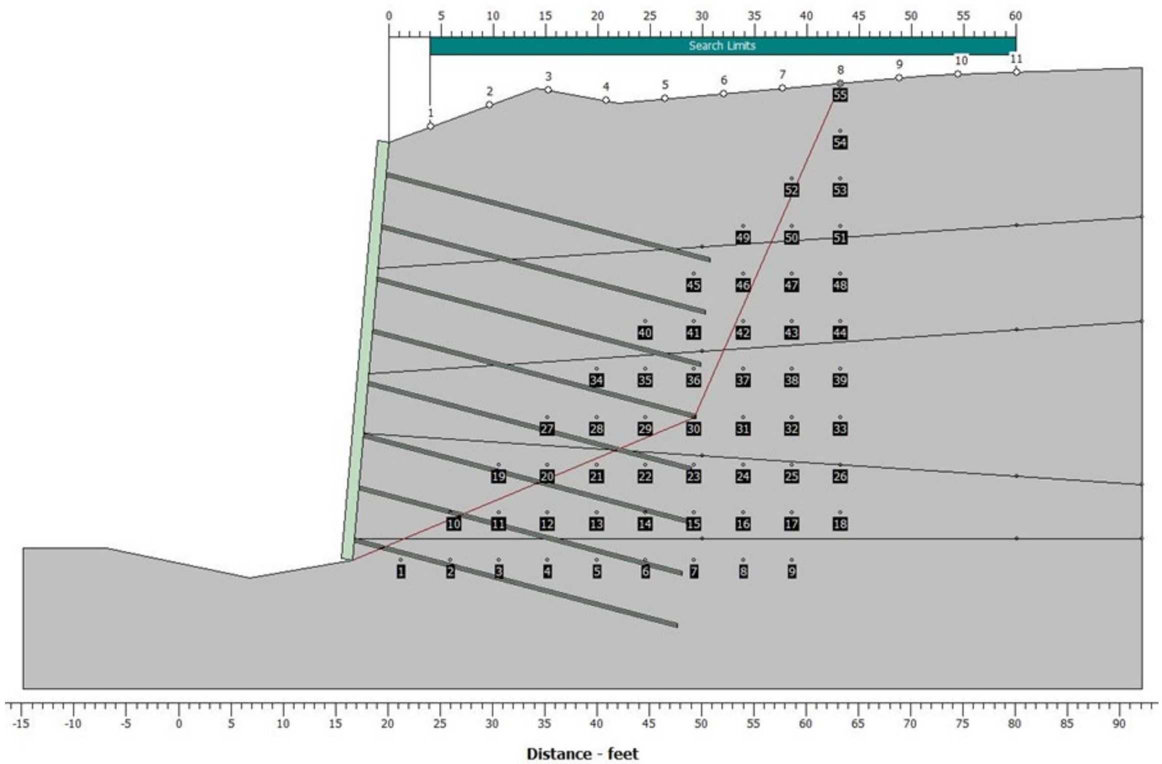


Figure 22 Nodes, Grid Points, and Bi-linear Search Surface

➢ *Advanced Search Options*

Snail also includes advanced search options that allow users to perform parametric studies of the effects of inter-slice force inclination angle on the analysis results.

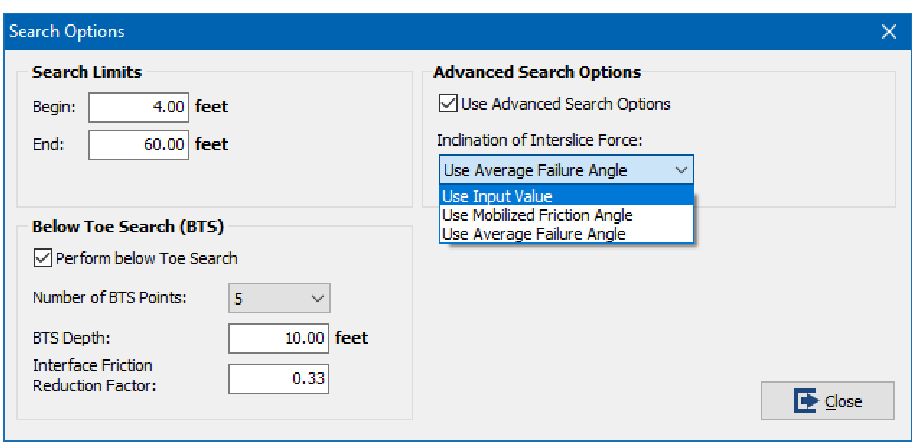


Figure 23 Advanced Search Options

- *Use Advanced Search Options:* Check the box to allow the user to change the inter-slice force inclination angles from default values
- *Inclination of Inter-slice Force:* Select *Use Input Value*, *Use Mobilized Friction Angle*, or *Use Average Failure Angle*.

If *Use Input Value* is selected, a field will appear under the selection for the user to enter the value of the user-defined inclination angle. If *Use Mobilized Friction Angle* is selected, average mobilized friction angles (average friction angle/FoS) along vertical interfaces of slices will be the inter-slice force inclination angle. If *Use average Failure Angle* is selected, the average of base angles of the active wedges of each search surface will be the inter-slice force inclination angle.

In the default setting, without checking the box for *Use Advanced Search Options*, inter-slice forces consist of both the shear force and inclined force components. The shear force component is from the mobilized cohesion (average cohesion/FoS); while the inclined force component is acting at the direction equal to the average mobilized friction angles (average friction angle/FoS).

The inclined force component in the default setting is the same as the inclined force component applied in the *Use Mobilized Friction Angle* in *Advance Search Options*. However, the *Use Mobilized Friction Angle* in *Advance Search Options* does not account for the mobilized cohesion.

Action

The *Action* menu has two options before performing the analysis: *Select Analysis Scenario* and *Run*; and three options after the analysis: *View Details*, *Create Report*, and *Clear Results*.

- *Select Analysis Scenario:* Select an analysis scenario – temporary, permanent, or seismic
- *Run:* Click to run the selected analysis scenario
- *View Details:* Click to view details of calculated results
- *Create Report:* Click to create and view the report. Then, the user can save or print the report. *Clear Results:* Click to clear calculated result, so that the *Run* function in Snail can be available again

After running an analysis, Snail will display the calculated minimum Factor of Safety (FoS) or Capacity Demand Ratio (CDR), the check of entered Factored Facing Resistance ($F_{factored}$) vs. the calculated Service Load at Soil Nail Head (T_o), and corresponding graph (Figures 24a, 24b, and 25). Please refer to Technical Notes for the background of checking $F_{factored}$ vs. T_o.

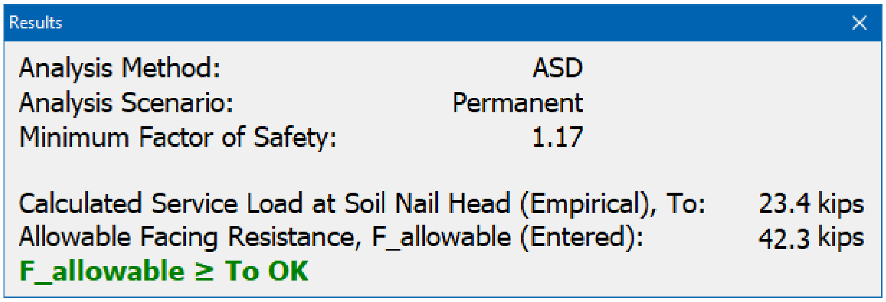


Figure 24a Results – ASD

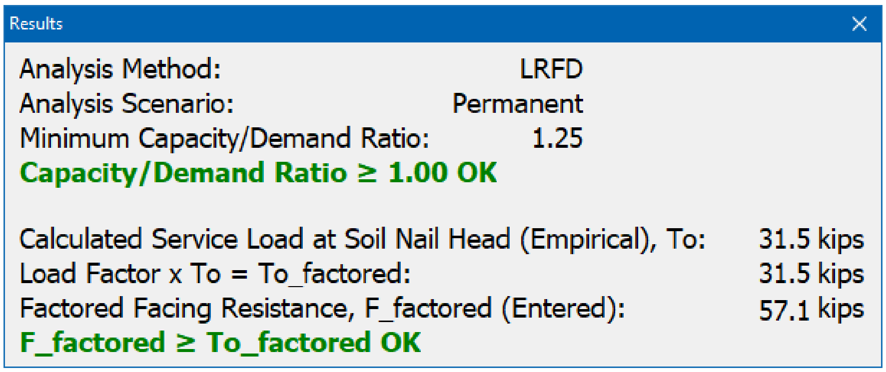


Figure 24b Results – LRFD

Details of any search surface can be examined by selecting *View Details*. A 2-pane window will open as shown in Figure 25.

The left pane includes a table showing the calculated factors of safety for all the search surfaces. Above the table are three pull-down lists, *Node*, *Grid Point, and BTS Point* that allow users to select and view the calculated factor of safety, and geometry of any search surface on the right pane. To view a particular search surface, select the values available in the pull-down lists.

Node is the Node number, between 1 and 11, to be selected to view the search surface passing through the search Node. Node 1 is the begin point; and Node 11 is the end point of the search limits.

For each selected Node, 55 Grid Points and associated calculated factor of safety and the search surface corresponding to the selected Grid Point are shown graphically on the right pane (Figures 25 and 27).

BTS Point can be selected to view a search surface passing below the toe. When *BTS* is not performed, the value shown on the window is set to “0”. When *BTS* is performed with the “N” *BTS Points*, select a value between 0 and N with “0” representing the search surfaces passing through the toe, and “N” representing the search surface passing through the lowest extent of the *BTS*.

Tables of unsorted and sorted calculated factor of safety are available for viewing by selecting among the corresponding tabs.

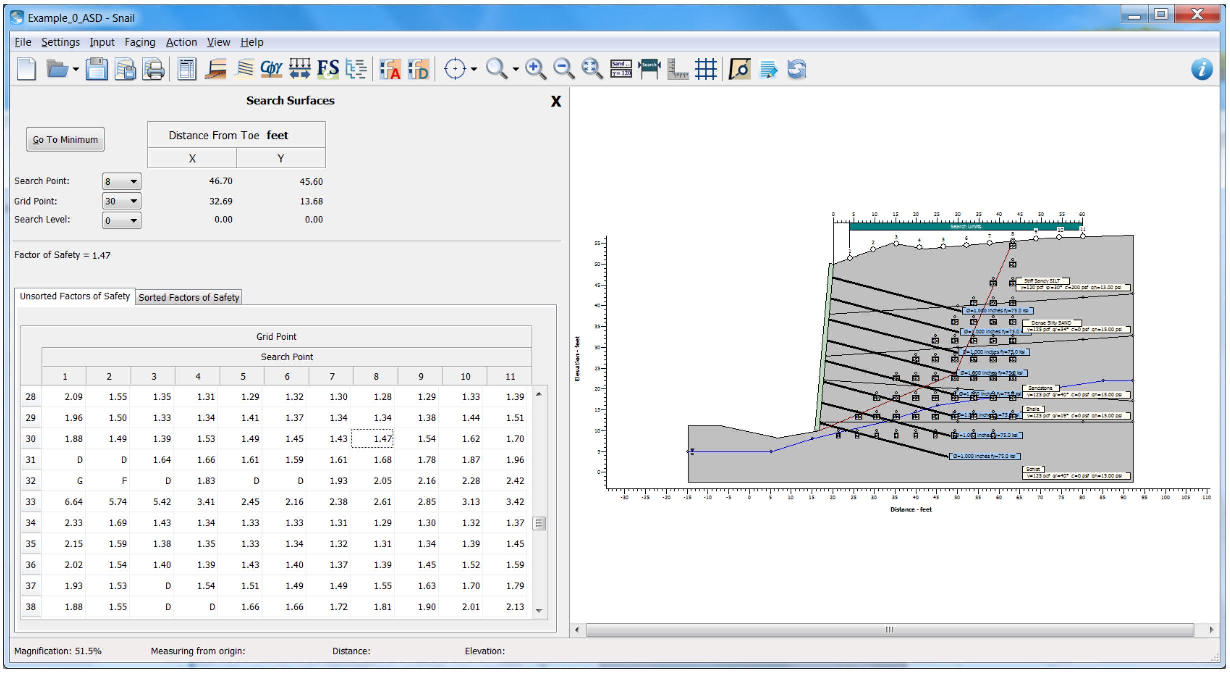


Figure 25 View Details

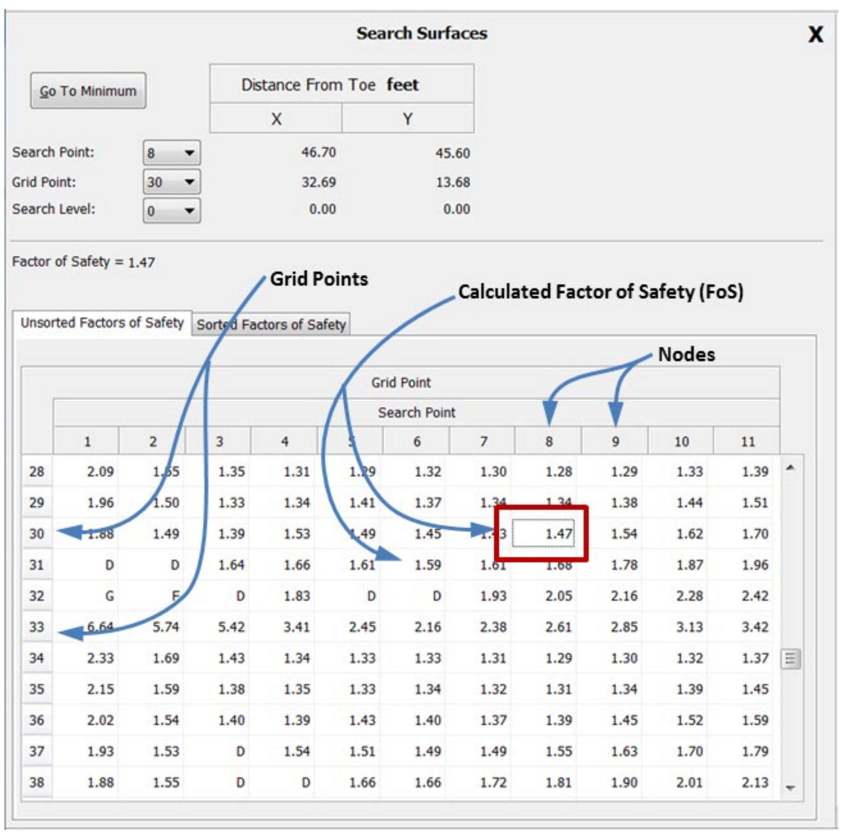


Figure 26 View Details Left Pane – Table Presentation

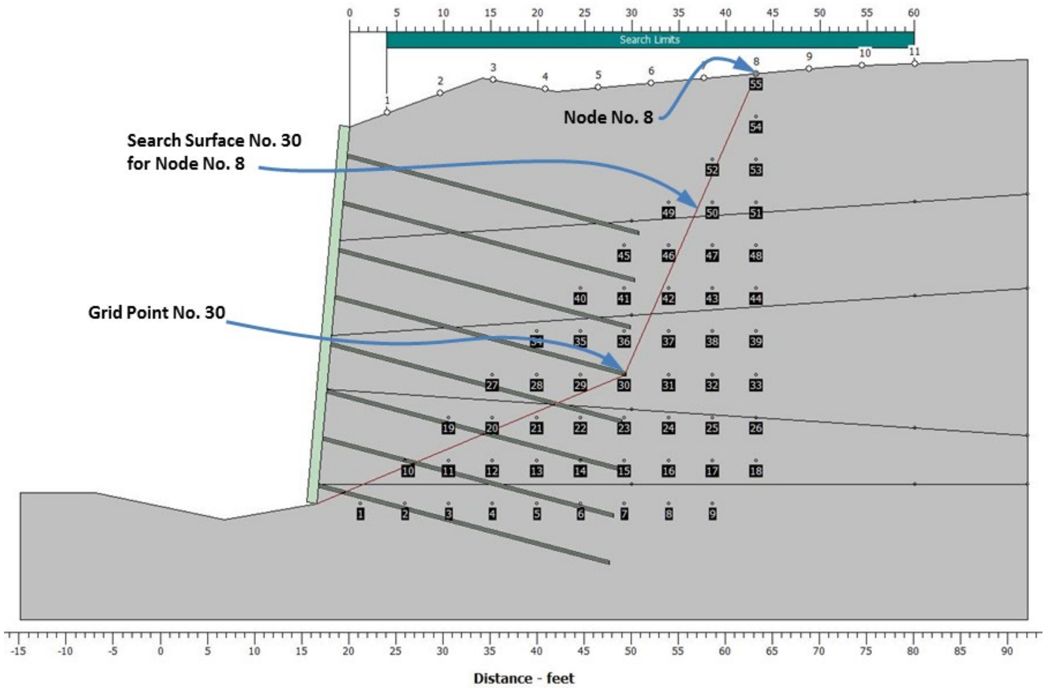


Figure 27 View Results Right Pane – Graphical Presentation

Facing

The *Facing* menu includes two options: *Facing Analysis* and *Suggested Facing Design*. The factored facing resistance calculated by *Facing Analysis* or by the *Suggested Facing Design* can be automatically transferred to the factored facing resistance entry for soil nail analysis.

Snail implements the facing analysis and design procedure presented in *Soil Nail Walls Reference Manual, FHWA-NHI-14-007, FHWA GEC 007, February 2015*. Users are advised to have *GEC No. 7 2015* available while using this module. This Guide provides the section and table numbers of the subject matter described in *GEC No. 7 2015* after each of the following entry descriptions.

Facing Analysis

Facing Analysis can be used as a stand-alone module. Snail calculates factored facing resistances for the three scenarios: *Temporary, Permanent* and *Seismic* using entered design parameters (Figure 28). The results can be saved to the active input file and re-loaded for soil nail stability analysis.

The required entries for *Facing Analysis* are organized into seven tabs. The Results tab shows the results and allow the user to transfer the results for analysis of soil nails.

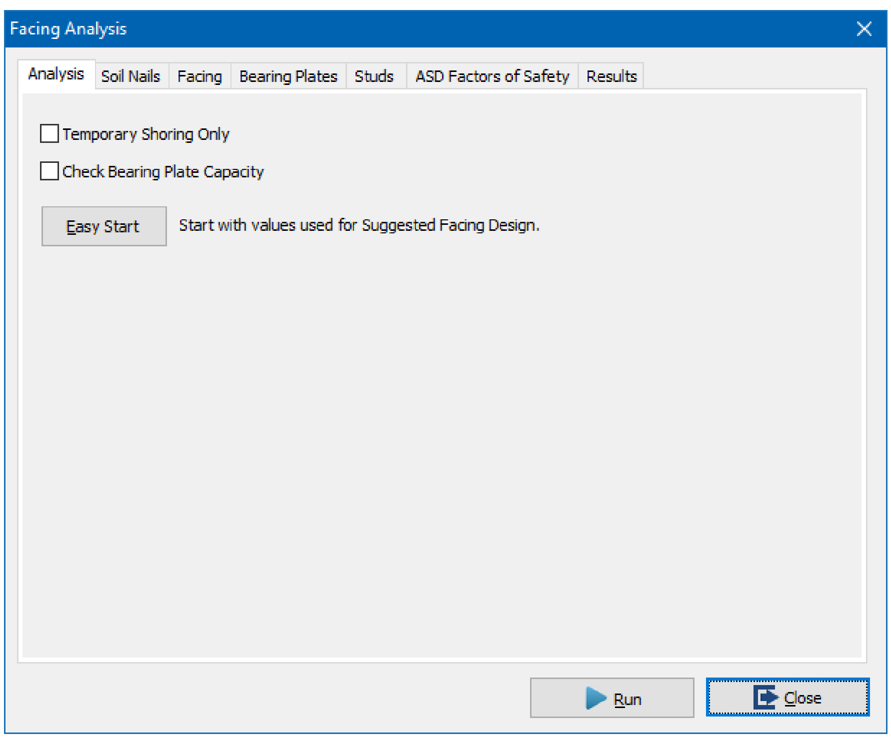


Figure 28 Facing Analysis – Analysis

➢ ***Analysis***

- *Temporary Shoring Only:* Check the box if the facing is for temporary shoring only; Snail will turn off the entry fields for permanent facing design values.
- *Check Bearing Plate Capacity:* Check the box if bearing plate design details were available and needed to be checked. Snail will turn on 5 additional fields under *Bearing Plate* tab, and 4 additional fields under *ASD Factors of Safety* or *LRFD Resistance Factors* tab for entry of bearing plate design details and perform the analysis. This option is mostly for checking shop drawings, as bearing plate design details are mostly not available during design, and mostly determined and provided by the contractor in shop drawing.
- *Easy Start:* *Easy Start* offers users a convenient way to quickly start manipulating and fine-tuning structural facing design parameters for analysis. After clicking the *Easy Start* button, the user can select one of the seven designs in Suggested Facing Design (Figures 40 and 41). The values for the selected design will be pre-populated to all the *Facing Analysis* fields; and the user can then fine-tune these values before performing facing analysis.

➢ ***Soil Nails***

- *Horizontal Spacing:* Horizontal spacing of soil nails
- *Vertical Spacing:* Vertical spacing of soil nails

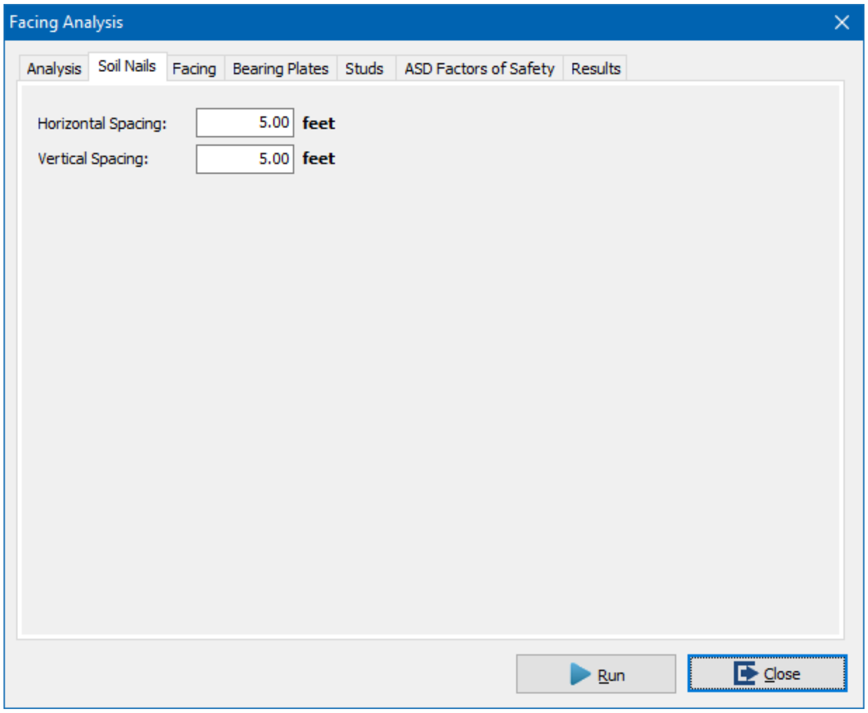


Figure 29 Facing Analysis – Soil Nails

- ***Facing***

  - *Facing Thickness (Temporary):* **h** as shown in Figure 31
  - *Facing Thickness (Permanent):* **H** as shown in Figure 35

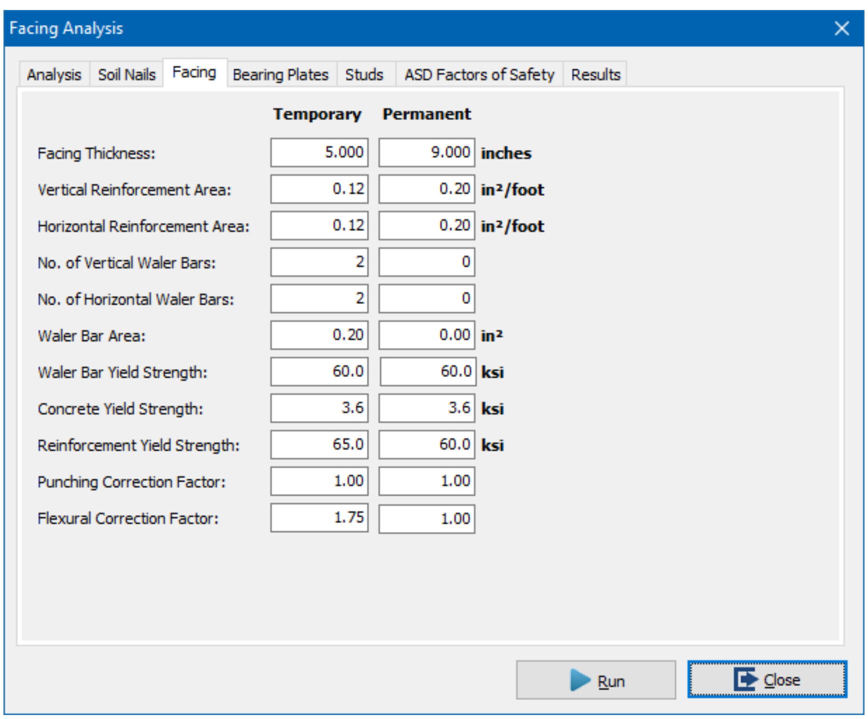


Figure 30 Facing Analysis – Facing

- *Vertical and Horizontal Reinforcement Area:* Reinforcement cross sectional area per unit width in the vertical/horizontal direction – for welded wire mesh, obtained by dividing the wire cross-sectional area by the mesh opening size (Tables A.5 and A.6, *GEC No. 7 2015*)
- *No. of Vertical and Horizontal Waler Bar:* The number of vertical and horizontal waler bars
- *Waler Bar Area:* The cross sectional area of waler bar assuming the same size bar is used both horizontally and vertically as shown in Figure 26 (Table A.6, *GEC No. 7 2015*)
- *Concrete Yield Strength:* Concrete yield strength
- *Reinforcement Yield Strength:* Reinforcement yield strength
- *Punching Correction Factor:* Factor to account for soil pressure distribution behind the facing (Section 6.6.6, *GEC No. 7 2015*)
- *Flexural Correction Factor:* Factor to account for soil pressure distribution behind the facing (Table 6.5 and Section 6.6.5b, *GEC No. 7 2015*)

➢ ***Bearing Plates***

- *Width/Height:* $\mathbf{L_{BP}}$ as shown in Figure 31
- *Thickness:* $\mathbf{t_P}$ as shown in Figure 31

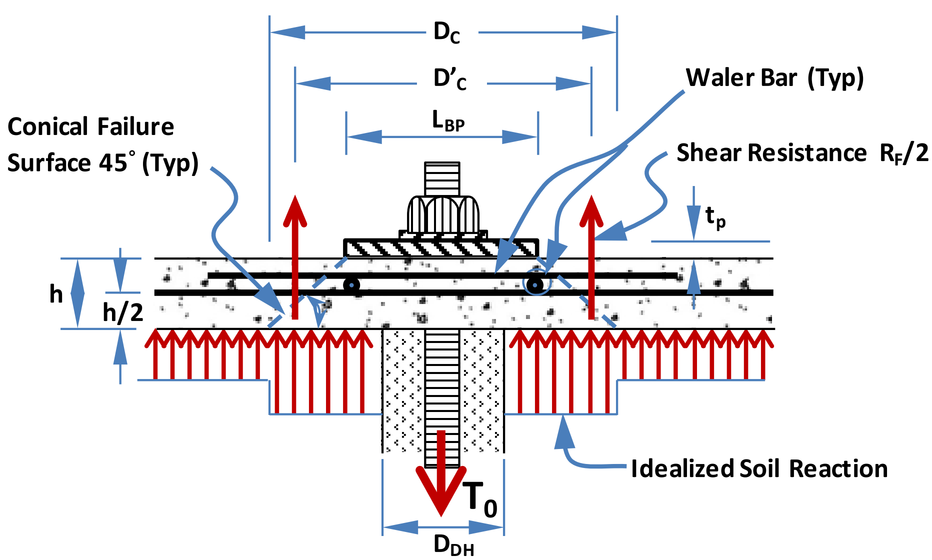


Figure 31 Temporary Bearing Plate Connection

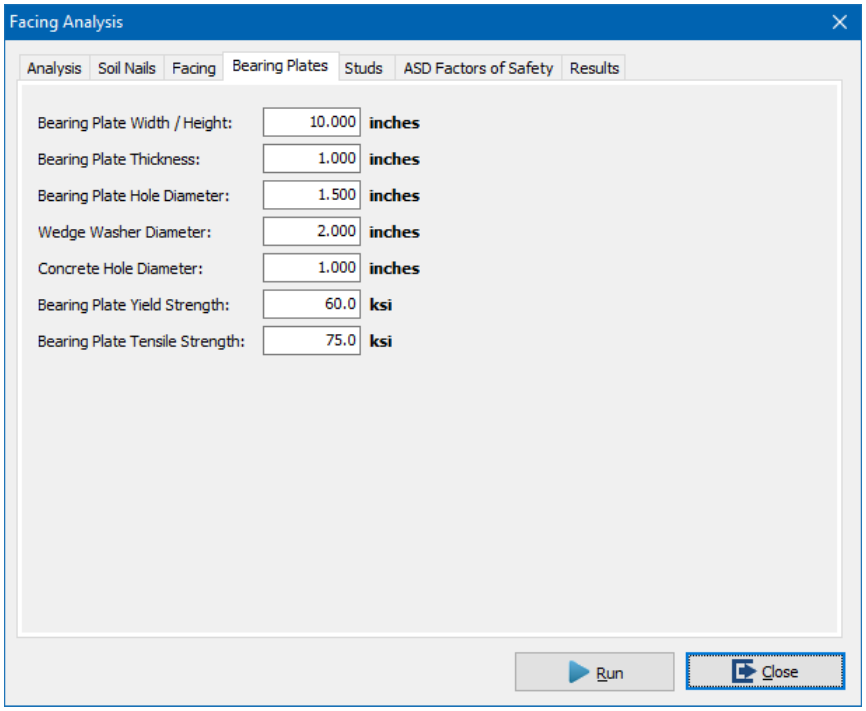


Figure 32 Facing Analysis – Bearing Plates

Additional 5 fields are available for entry if *Check Bearing Plate Capacity* box under *Analysis* tab is checked

- *Bearing Plate Hole Diameter:* $\mathbf{D_B}$ as shown in Figure 33
- *Wedge Washer Diameter:* $\mathbf{D_W}$ as shown in Figure 33
- *Concrete Hole Diameter:* $\mathbf{D_{Concrete}}$ as shown in Figure 33 (may also be soil nail sheathing diameter)
- *Bearing Plate Yield Strength:* Bearing Plate Yield Strength
- *Bearing Plate Tensile Strength:* Bearing Plate Tensile Strength

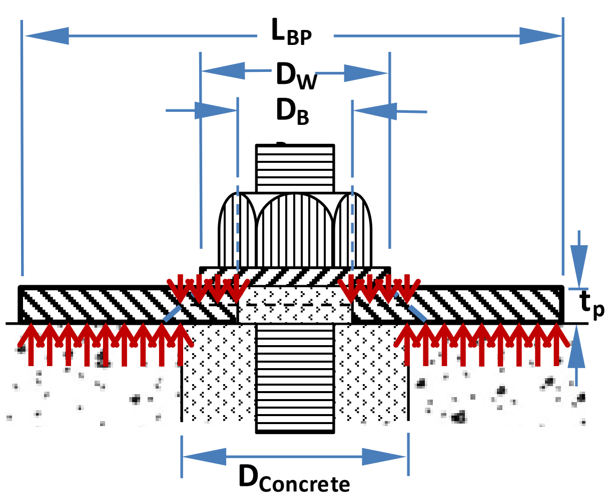


Figure 33 Bearing Plate Details (mostly from Shop Drawing)

- ***Studs***

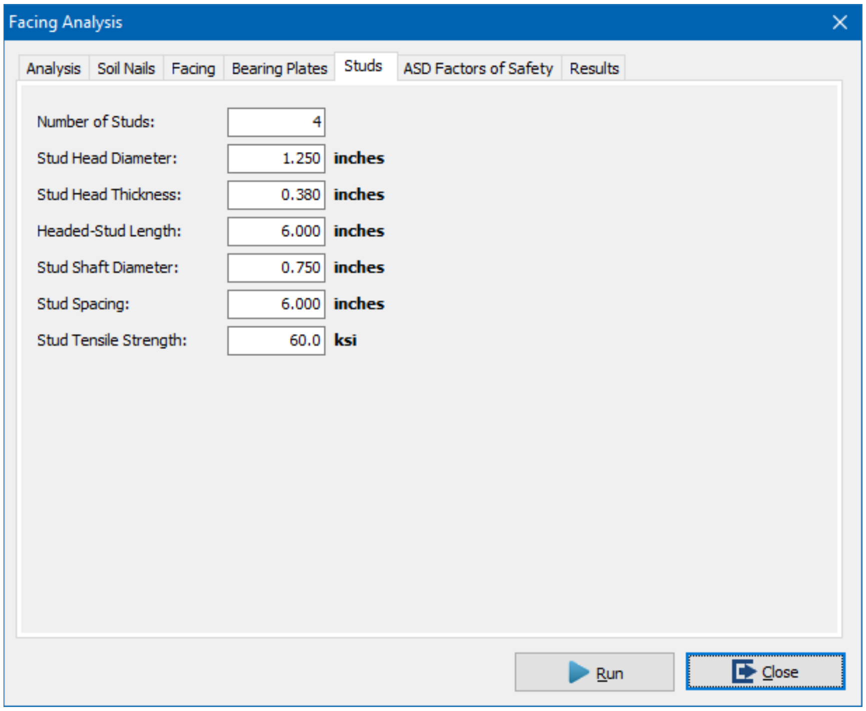


Figure 34 Facing Analysis – Studs

- *Number of Studs:* Typically 4 (Table A.7, *GEC No. 7 2015*)
- *Stud Head Diameter:* $\mathbf{D_H}$ as shown in Figure 36 (Table A.7, *GEC No. 7 2015*)
- *Head Thickness:* $\mathbf{t_H}$ as shown in Figure 36 (Table A.7, *GEC No. 7 2015*)
- *Head-Stud Length:* $\mathbf{L_S}$ as shown in Figure 36 (Table A.7, *GEC No. 7 2015*)
- *Stud Shaft Diameter:* $\mathbf{D_S}$ as shown in Figure 36 (Table A.7, *GEC No. 7 2015*)
- *Stud Spacing:* $\mathbf{S_{HS}}$ as shown in Figure 35 (Table A.7, *GEC No. 7 2015*)
- *Stud Tensile Strength:* Stud tensile strength

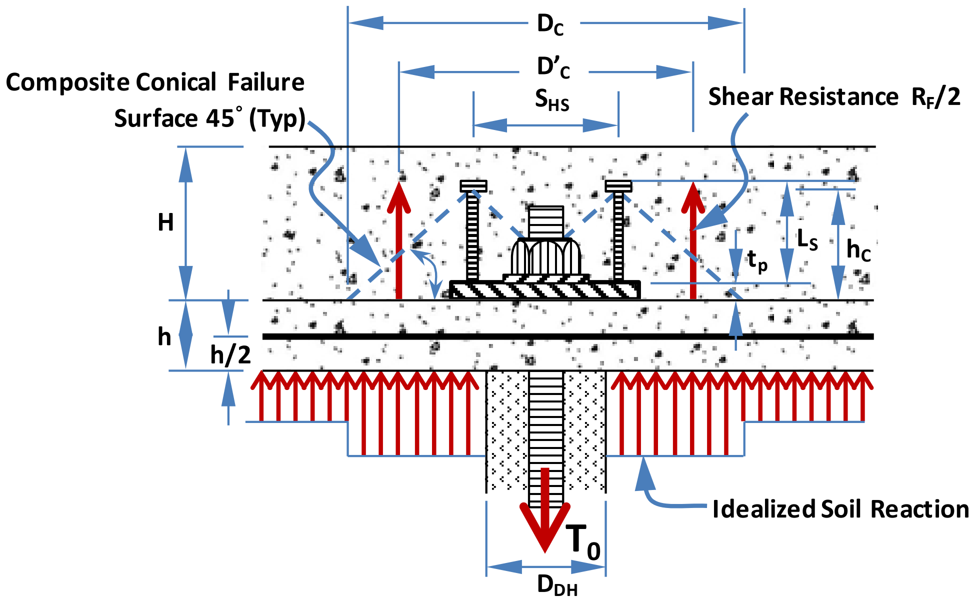


Figure 35 Permanent Head-Studded Connection

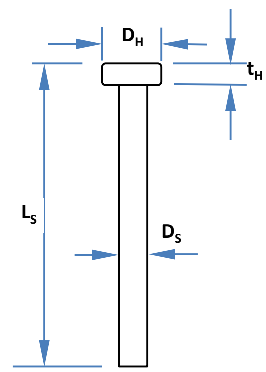


Figure 36 Head Stud

- ### *ASD Factors of Safety*

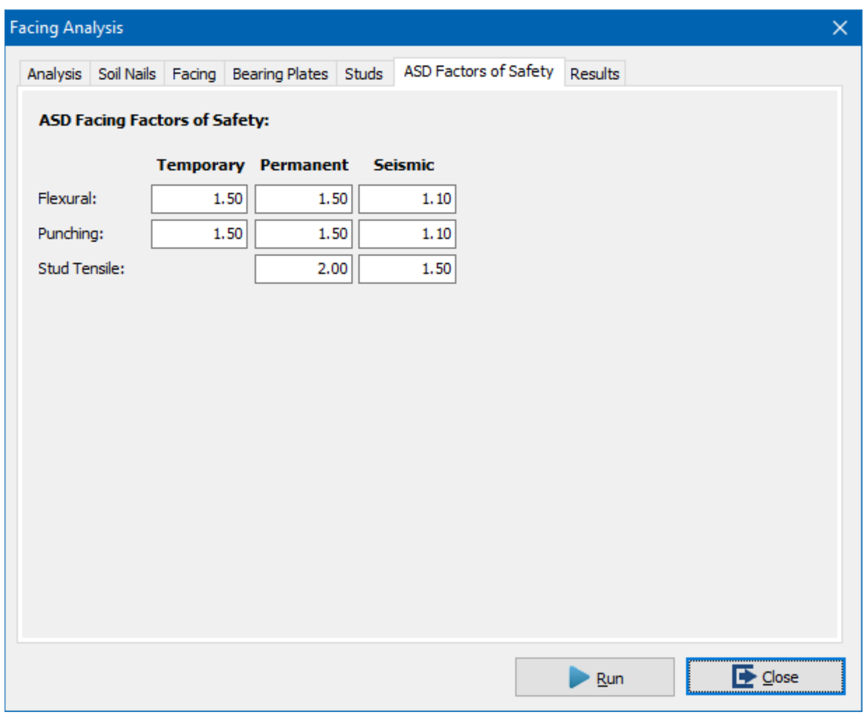


Figure 37 Facing Analysis – ASD Factors of Safety

- *Flexural:* The factors of safety to account for uncertainties associated with design and strength properties
- *Punching:* The factors of safety to account for uncertainties associated with design and strength properties

- *Stud Tensile:* The factors of safety to account for uncertainties associated with design and strength properties

Additional 4 fields are available for entry if “Check Bearing Plate Capacity” box under Analysis tab was checked

- *Tensile Stress:* The factors of safety to account for uncertainties associated with design and strength properties
- *Flexure:* The factors of safety to account for uncertainties associated with design and strength properties
- *Bearing Stress of Steel* The factors of safety to account for uncertainties associated with design and strength properties
- *Bearing Stress of Concrete/Shotcrete:* The factors of safety to account for uncertainties associated with design and strength properties

➢ *LRFD Resistance Factors*

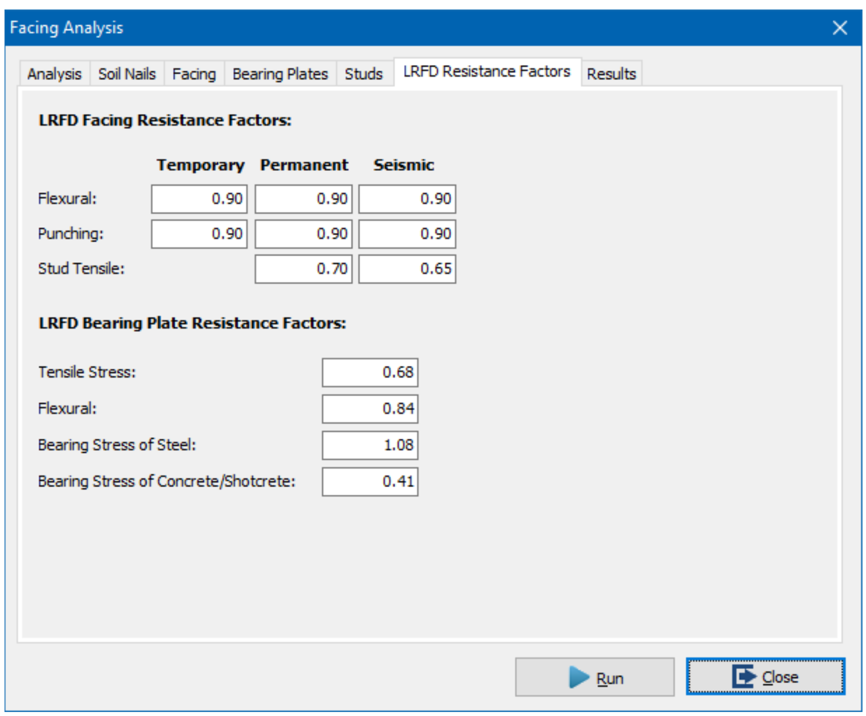


Figure 38 Facing Analysis – LRFD Resistance Factors

- *Flexural:* The reduction factor to account for uncertainties associated with design and strength properties
- *Punching:* The reduction factor to account for uncertainties associated with design and strength properties

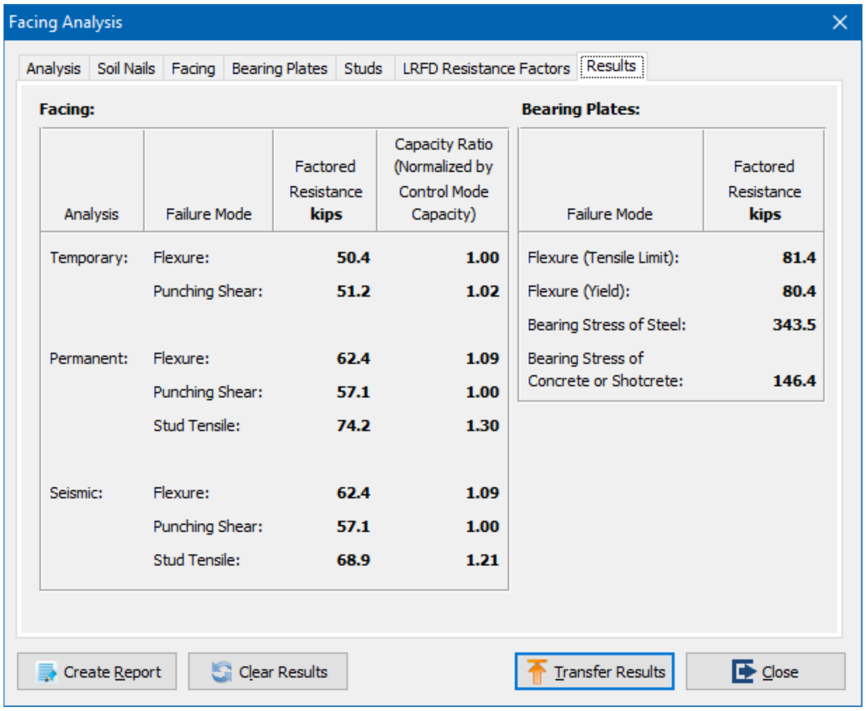
- *Stud Tensile:* The reduction factor to account for uncertainties associated with design and strength properties

Additional 4 fields are available for entry if *Check Bearing Plate Capacity* box under *Analysis* tab was checked

- *Tensile Stress:* The reduction factor to account for uncertainties associated with design and strength properties
- *Flexure:* The reduction factor to account for uncertainties associated with design and strength properties
- *Bearing Stress of Steel* The reduction factor to account for uncertainties associated with design and strength properties
- *Bearing Stress of Concrete/Shotcrete:*
  The reduction factor to account for uncertainties associated with design and strength properties

➢ ***Results***

- *Allowable or Factored Resistance:*
  For Temporary, Permanent, and Seismic scenarios (Figure 39)
- *Capacity Ratio:* Display the capacity ratio (normalized by control mode capacity). The presentation of the capacity ratio shows which design modes are over capacity and by how much. The design mode with capacity ratio equals to one is the controlling mode for the respective analysis scenario.
- *Allowable or Factored Bearing Plate Resistance:*
  Display factored bearing plate resistances
- *Create Report:* Click to create and view the report. Then, the user can save or print the report.
- *Clear Results:* Click to clear calculated result, so that the *Run* function in Snail can be available again
- *Transfer Results:* Click the button to transfer the controlling allowable or factored facing resistances of respective scenario to the *Soil Nail* input form as input for soil nail stability analysis



Facing:

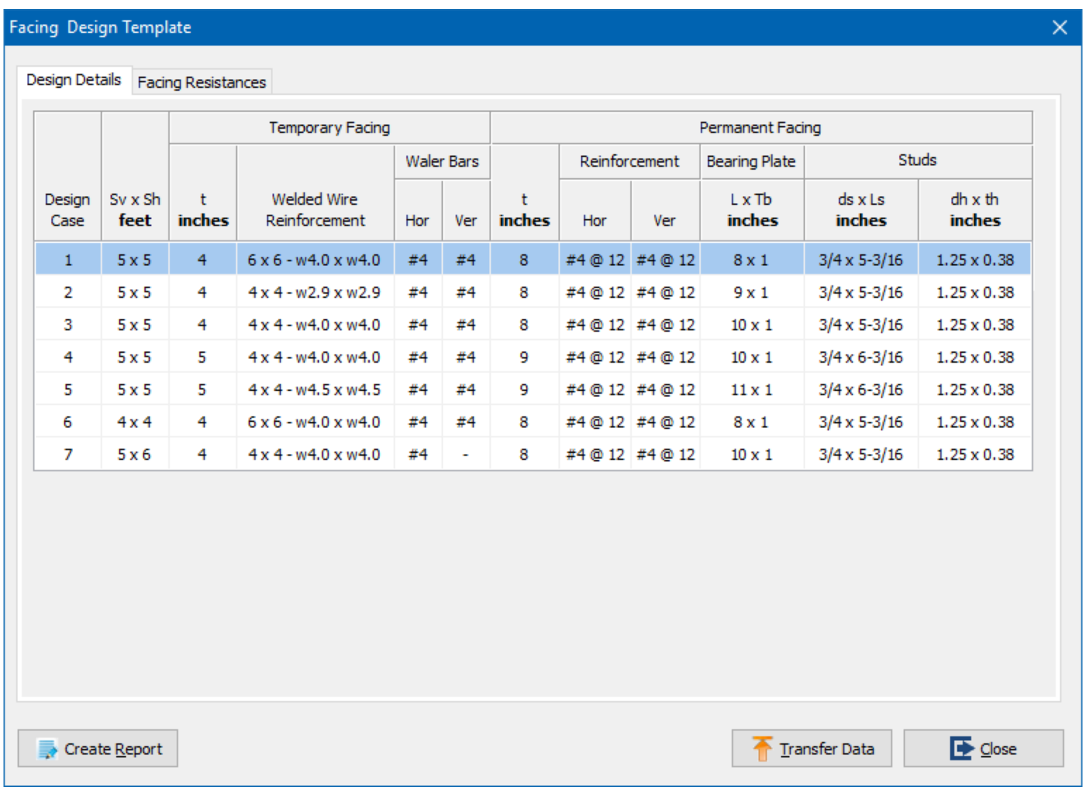
Analysis	Failure Mode	Factored Resistance **kips**	Capacity Ratio (Normalized by Control Mode Capacity)
Temporary:	Flexure:	**50.4**	**1.00**
	Punching Shear:	**51.2**	**1.02**
Permanent:	Flexure:	**62.4**	**1.09**
	Punching Shear:	**57.1**	**1.00**
	Stud Tensile:	**74.2**	**1.30**
Seismic:	Flexure:	**62.4**	**1.09**
	Punching Shear:	**57.1**	**1.00**
	Stud Tensile:	**68.9**	**1.21**

Bearing Plates:

Failure Mode	Factored Resistance **kips**
Flexure (Tensile Limit):	**81.4**
Flexure (Yield):	**80.4**
Bearing Stress of Steel:	**343.5**
Bearing Stress of Concrete or Shotcrete:	**146.4**

Figure 39 Facing Analysis – Results

Suggested Facing Design



		Temporary Facing				Permanent Facing					
				Waler Bars			Reinforcement		Bearing Plate	Studs	
Design Case	Sv x Sh **feet**	t **inches**	Welded Wire Reinforcement	Hor	Ver	t **inches**	Hor	Ver	L x Tb **inches**	ds x Ls **inches**	dh x th **inches**
1	5 x 5	4	6 x 6 - w4.0 x w4.0	#4	#4	8	#4 @ 12	#4 @ 12	8 x 1	3/4 x 5-3/16	1.25 x 0.38
2	5 x 5	4	4 x 4 - w2.9 x w2.9	#4	#4	8	#4 @ 12	#4 @ 12	9 x 1	3/4 x 5-3/16	1.25 x 0.38
3	5 x 5	4	4 x 4 - w4.0 x w4.0	#4	#4	8	#4 @ 12	#4 @ 12	10 x 1	3/4 x 5-3/16	1.25 x 0.38
4	5 x 5	5	4 x 4 - w4.0 x w4.0	#4	#4	9	#4 @ 12	#4 @ 12	10 x 1	3/4 x 6-3/16	1.25 x 0.38
5	5 x 5	5	4 x 4 - w4.5 x w4.5	#4	#4	9	#4 @ 12	#4 @ 12	11 x 1	3/4 x 6-3/16	1.25 x 0.38
6	4 x 4	4	6 x 6 - w4.0 x w4.0	#4	#4	8	#4 @ 12	#4 @ 12	8 x 1	3/4 x 5-3/16	1.25 x 0.38
7	5 x 6	4	4 x 4 - w4.0 x w4.0	#4	-	8	#4 @ 12	#4 @ 12	10 x 1	3/4 x 5-3/16	1.25 x 0.38

Figure 40 Suggested Facing Design Template – Design Details

Suggested Facing Design allows users to select from typical facing design developed by Caltrans (Figures 40 and 41). The users can select a facing design from the *Facing Design Template* and click on the *Transfer Data* button. Then, the Allowable Facing Resistances (for ASD) or the Factored Facing Resistances (for LRFD) of the design for temporary, permanent and seismic scenarios are automatically transferred to the *Soil Nails* input form as input for soil nail stability analysis.

There are two tabs in *Suggested Facing Design – Design Details* and *Facing Resistances*.

- ***Design Details***

Design Details shows the detailed configuration of each typical facing design.

- ***Facing Resistances***

Facing Resistances (Figure 41) includes two parts – the *Facing Resistances Table*, and the *Factors of Safety* or *Reduction Factors*.

- *Facing Resistances Table:*

  Display both *Nominal Facing Resistances* and *ASD Allowable Facing Resistances* or *LRFD Factored Facing Resistances*. The *ASD Allowable Facing Resistances* or *LRFD Factored Facing Resistances* are calculated based on the *Nominal Facing Resistances* and values entered into the *Resistance Factors* fields.

- *Factors of Safety / Resistance Factors:*

  Default values of ASD Factors of Safety and LRFD Resistance Factors are prepopulated. These default values are the recommended values from Table 5.1 and Table 6.3, *GEC No. 7 2015*.

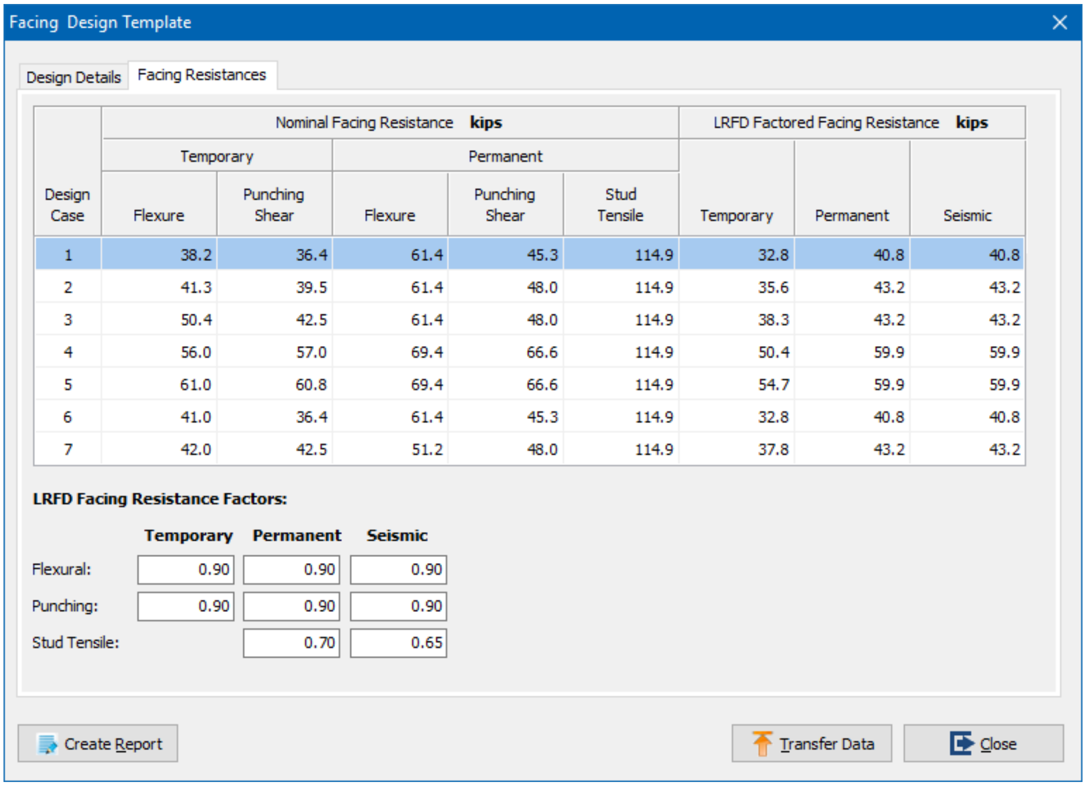
  Snail allows users to adjust these values for special design cases. When the values were adjusted from the default values, the values under *ASD Allowable Facing Resistances* or *LRFD Factored Facing Resistances* will be automatically updated. Meanwhile, the background of the adjusted fields will turn light yellow and Snail will prompt the notice of “Not a Default Value”. Users may click on the “Reset to Default Values” button to reset the values to the default values.

- ***Create Report***

Click the *Create Report* button to create and view the report for the selected facing design. Then, the user can save or print the report.

➢ *Transfer Data*

Click the *Transfer Data* button to transfer the allowable facing resistances or factored facing resistances to the *Soil Nails* input form as input for soil nail stability analysis.



Design Case	Nominal Facing Resistance **kips**					LRFD Factored Facing Resistance **kips**		
	Temporary		Permanent					
	Flexure	Punching Shear	Flexure	Punching Shear	Stud Tensile	Temporary	Permanent	Seismic
1	38.2	36.4	61.4	45.3	114.9	32.8	40.8	40.8
2	41.3	39.5	61.4	48.0	114.9	35.6	43.2	43.2
3	50.4	42.5	61.4	48.0	114.9	38.3	43.2	43.2
4	56.0	57.0	69.4	66.6	114.9	50.4	59.9	59.9
5	61.0	60.8	69.4	66.6	114.9	54.7	59.9	59.9
6	41.0	36.4	61.4	45.3	114.9	32.8	40.8	40.8
7	42.0	42.5	51.2	48.0	114.9	37.8	43.2	43.2

LRFD Facing Resistance Factors:

	Temporary	**Permanent**	**Seismic**
Flexural:	0.90	0.90	0.90
Punching:	0.90	0.90	0.90
Stud Tensile:		0.70	0.65

Figure 41 Suggested Facing Design Template – Facing Resistances

View

The *View* menu has twelve options for viewing the created wall model and to toggle on or off the toolbar and status bar.

The *View* menu options are:

- *Measure From:* Select *Origin*, *Top of Wall*, or *Toe of Wall* to change the coordinate reference of the model view
- *Magnification:* Select the magnification of the view
- *Zoom In:* Click to zoom in
- *Zoom Out:* Click to zoom out
- *Fit:* Click to fit the whole model into view
- *Show/Hide Input Values:* Click to show/hide input values
- *Show/Hide Search Limit:* Click to show/hide search limit
- *Show/Hide Scale:* Click to show/hide scale
- *Show/Hide Gridlines:* Click to show/hide grid
- *Toolbar Button Size:* Select *Large* or *Small* button size – *Small* button size is recommended for using Snail in a laptop computer
- *Hide/Show Toolbar:* Click to toggle Toolbar on/off
- *Hide/Show Status Bar:* Click to toggle Status Bar on/off

Help

The *Help* Menu includes *Snail Home Page*, *Snail User Guide*, and *About.*

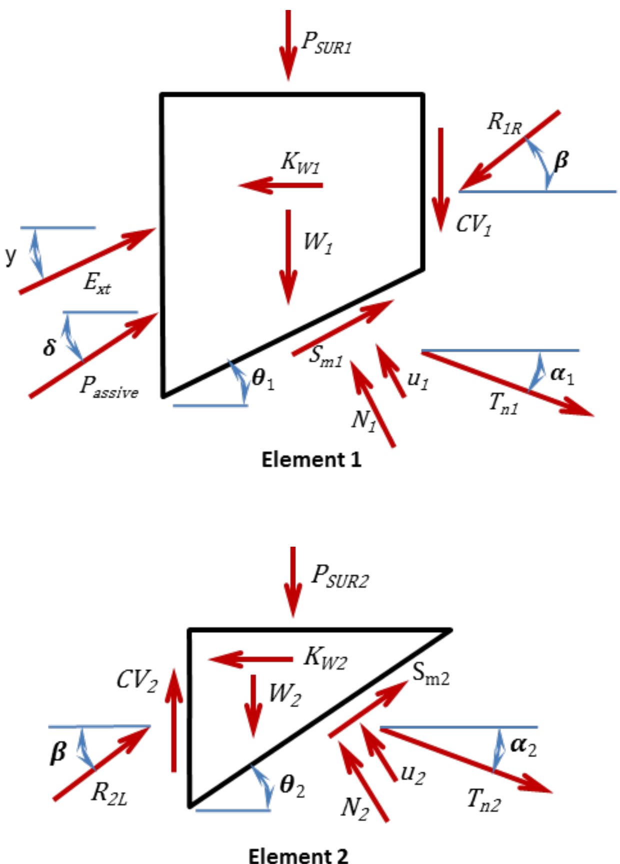
- *Snail Home Page:* Click to open the Snail home page via hyperlink.
- *Snail User Guide:* Click to open this User Guide on line via hyperlink. The file can be navigated using the bookmarks created for the file. The user should check this hyperlink for the latest revision of the User Guide.
- *About:* Click to see the Snail version, Legal Notice, and copyright information

3 Theory

Snail analyzes soil nail wall system stability based on force limit equilibrium. The software generates bi-linear surfaces through the toe of wall, or tri-linear surfaces which pass below the toe and daylight in front of the wall, to calculate and search for the minimum factor of safety of the selected analysis scenario. Even though Snail can perform stability analysis for "deep-seated" failure modes using a tri-linear wedge search, it is not suitable for global slope stability analysis. Global stability of soil nail walls should be analyzed using slope stability software.

For ease of discussion and presentation, the term *factored resistances* used in this section refers to the resistances that have been factored, i.e. divided by the FoS (for ASD), or multiplied by the resistance factor, ϕ (for LRFD).

Derivation



$$S_{m1} = \frac{C_1 \times L_1 + (N_1 - u_1) \times \tan(\phi)}{FoS_1}$$

$$S_{m2} = \frac{C_2 \times L_2 + (N_2 - u_2) \times \tan(\phi)}{FoS_2}$$

Figure T-1 Forces and Directions on Bilinear Wedge Elements

The above figure (Figure T-1) shows the two wedge elements and associated forces generated by Snail for the bi-linear surface mode calculation.

The following is the derivation of equations used by Snail:

$\uparrow \sum F_{N1} = 0$

$$\Rightarrow \quad -(E_{xt} \times \sin(\theta_1 - \psi)) - (W_1 \times \cos(\theta_1)) + (K_w \times \sin(\theta_1)) + (P_{assive} \times \sin(\delta - \theta_1)) - (T_{n1} \times \sin(\alpha_1 + \theta_1)) - (P_{sur1} \times \cos(\theta_1)) - (CV_1 \times \cos(\theta_1)) + (R_{1R} \times \sin(\theta_1 - \beta)) + N_1 = 0$$

$$\Rightarrow \quad N_1 = (E_{xt} \times \sin(\theta_1 - \psi)) + (W_1 \times \cos(\theta_1)) - (K_w \times \sin(\theta_1)) - (P_{assive} \times \sin(\delta - \theta_1)) + (T_{n1} \times \sin(\alpha_1 + \theta_1)) + (P_{sur} \times \cos(\theta_1)) + (CV_1 \times \cos(\theta_1)) - (R_{1R} \times \sin(\theta_{1-}\beta))$$

Equation 1

$\rightarrow \sum F_{t1} = 0$

$$\Rightarrow \quad (E_{xt} \times \cos(\theta_1 - \psi)) - (W_1 \times \sin(\theta_1)) - (K_{W1} \times \cos(\theta_1)) + (P_{assive} \times \cos(\delta - \theta_1)) + (T_{n1} \times \cos(\alpha_1 + \theta_1)) - (P_{sur1} \times \sin(\theta_1)) - (CV_1 \times \sin(\theta_1)) - (R_{1R} \times \cos(\theta_1 - \beta)) + \frac{\left(C_1 \times l_1 + \left((N_1 - u_1) \times \tan(\phi)\right)\right)}{FoS_1} = 0$$

$$\Rightarrow \quad FoS_1 = [C_1 \times l_1 + \left((N_1 - u_1) \times \tan(\phi)\right)]/[-(E_{xt} \times \cos(\theta_1 - \psi)) + (W_1 \times \sin(\theta_1)) + (K_{W1} \times \cos(\theta_1)) - (P_{assive} \times \cos(\delta - \theta_1)) - (T_{n1} \times \cos(\alpha_1 + \theta_1)) + (P_{sur1} \times \sin(\theta_1)) + (CV_1 \times \sin(\theta_1)) + (R_{1R} \times \cos(\theta_1 - \beta)))]$$

$$\Rightarrow \quad R_{1R} = \frac{A - B}{\cos(\theta_1 - \beta)}$$

Equation 2

where

$$A = (E_{xt} \times \cos(\theta_1 - \psi)) + (P_{assive} \times \cos(\delta - \theta_1)) + (T_{n1} \times \cos(\alpha_1 + \theta_1)) + S_{m1}$$

$$B = \left((CV_1 \times sin(\theta_1)\right) + \left(W_1 \times sin(\theta_1)\right) + \left(K_{W1} \times cos(\theta_1)\right) + \left(P_{sur1} \times sin(\theta_1)\right))$$

$$\uparrow \sum F_{N2} = 0$$

$$\Rightarrow \quad -(W_2 \times \cos(\theta_2) + (K_{w2} \times \sin(\theta_2)) - (T_{n2} \times \sin(\alpha_2 + \theta_2)) - (P_{sur2} \times \cos(\theta_2)) + (CV_2 \times \cos(\theta_2)) - (R_{2L} \times \sin(\theta_2 - \beta)) + N_2 = 0$$

$$\Rightarrow \quad N_2 = (W_2 \times \cos(\theta_2) - (K_{w2} \times \sin(\theta_2)) + (T_{n2} \times \sin(\alpha_2 + \theta_2)) + (P_{sur2} \times \cos(\theta_2)) - (CV_2 \times \cos(\theta_2)) + (R_{2L} \times \sin(\theta_2 - \beta))$$

Equation 3

$$\rightarrow \sum F_{t2} = 0$$

$$\Rightarrow \quad -(W_2 \times \sin(\theta_2)) - (K_{w2} \times \cos(\theta_2)) + (T_{n2} \times \cos(\alpha_2 + \theta_2)) - (P_{sur2} \times \sin(\theta_2)) + (CV_2 \times \sin(\theta_2)) + (R_{2L} \times \cos(\theta_2 - \beta)) + \frac{\left(C_2 \times l_2 + \left((N_2 - u_2) \times \tan(\phi)\right)\right)}{FoS_2} = 0$$

$$\Rightarrow \quad FoS_2 = ((C_2 \times l_2 + ((N_2 - u_2) \times \tan(\phi)\ )))/((W_2 \times \sin(\theta_2) + (K_{w2} \times \cos(\theta_2)) - (T_{n2} \times \cos(\alpha_2 + \theta_2)) + (P_{sur2} \times \sin(\theta_2)) - (CV_2 \times \sin(\theta_2)) - (R_{2L} \times \cos(\theta_2 - \beta)\ )\ )$$

$CV = CV_1 = CV_2; \qquad R = R_{2L} = R_{1R};$

$$FoS = \frac{\sum Resistance\ Force_{Soil\ Strength}}{\sum Driving\ Force_{Soil\ Mass + External\ Loads} - \sum Factored\ Resistance\ Force_{Soil\ Nails}};$$

$FoS = FoS_1 = FoS_2;$

$$FoS = \frac{U}{L}$$

Equation 4

where

$$U = \sum_{i=1}^{2} (C_i \times l_i + (N_i - u_i) \times \tan(\phi))$$

$$L = \sum_{i=1}^{2}[(w_i \times \sin(\theta_i)) + (K_{w_i} \times \cos(\theta_i)) + (P_{sur_i} \times \sin(\theta_i)) - (T_{n_i} \times \cos(\alpha_i + \theta_i))]$$
$$+ \{R \times [\cos(\theta_1 - \beta) - \cos(\theta_2 - \beta)]\} + (CV \times (sin\theta_1 - sin\theta_2)) - (E_{xt} \times \ (\cos(\theta_1 - \delta))$$
$$- (P_{assive} \times (\cos(\alpha - \theta_1))$$

Average equilibrium condition over two wedges is assumed for Equation (4).

$W =$ Weight of each slice of soil

$K_W =$ Seismic force on each slice

$E_{xt} =$ External load applied on the wall face

$T_n =$ Total resistance from soil nails over each slice

$N =$ Normal force acting on sliding surface

$u =$ Water pressure acting on sliding surface

$P_{sur} =$ Surcharge load acting on ground surface

$\phi =$ Friction angle

$C =$ Cohesion

$R = R_{2L} = R_{1R} =$ Inter-slice shear force acting on the interface between two slices

$CV = CV_1 = CV_2 =$ Inter-slice shear force due to cohesion term acting along the interface between two slices

$P_{assive} =$ Passive force, active if below toe search is performed

$\delta =$ Inclination of passive force

$\psi =$ Inclination of external load

$\theta =$ Inclination of sliding surface

$\alpha =$ Inclination of soil nail

$\beta =$ Inclination of inter-slice force

From Equation 4, the factor of safety (FoS) is calculated through the following iterations, since normal forces in Equations 1 and 3, and inter-slice forces in Equation 2 are also a function of FoS:

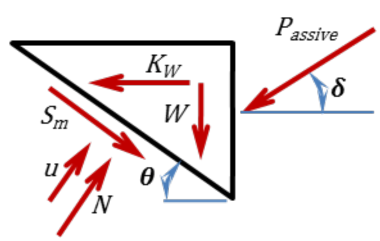
1. Calculate the initial normal force of each slice with no inter-slice force
2. Calculate the initial FoS with normal forces calculated in step 1, with no inter-slice force
3. Update inter-slice force with the FoS calculated in step 2
4. Update normal forces with inter-slice force and FoS calculated in steps 2 and 3
5. Update FoS with normal forces and inter-slice force calculated in previous steps
6. Calculate tolerance, $|FoS_{new} - FoS_{pre}|/|FoS_{new}|$
7. Iterate until tolerance calculated in step 6 is less than the defaulted tolerance

Depending on user's selection on the inclination of inter-slice force in *Advance Search Options* as shown in Figure 23, β can be a user input, the averaged mobilized friction angle, or the averaged failure slope.

For LRFD analysis of soil nails reinforced system, Snail use the same seven interactive steps as described above to calculate the Capacity Demand Ratio (CDR), while the forces are factored by load or resistance factors.

Passive Resistance

The following figure, Figure T-2, shows the passive wedge element in front of the toe of the wall used by Snail to analyze tri-linear surfaces.



Passive Wedge Element

$$S_m = \frac{C \times L + (N - u) \times \tan(\phi)}{FoS}$$

Figure T-2 Forces and Direction on Passive Wedge Element

$$\nearrow \sum F_N = 0;$$

$$\Rightarrow \quad -(W \times \cos(\theta)) - (K_w \times \sin(\theta)) - (P_{assive} \times \sin(\delta + \theta)) + N = 0$$

$$\Rightarrow \quad N = (W \times \cos(\theta)) + (K_w \times \sin(\theta)) + (P_{assive} \times \sin(\delta + \theta))$$

Equation 5

$$\nwarrow \sum F_t = 0;$$

$$\Rightarrow \quad -\big(W \times \sin(\theta)\big) + \big(K_W \times \cos(\theta)\big) + (P_{assive} \times \cos(\delta + \theta)) - \frac{Cl + (N-u) \times \tan(\varphi)}{FoS} = 0$$

Insert *N* from Equation 5 into

$$\nwarrow \sum F_t = 0$$

$$\Rightarrow \quad [-(W \times \sin(\theta)) + (K_W \times \cos(\theta)) + (P_{assive} \times \cos(\ \delta + \theta))] \times FoS - Cl - [(W \times \cos(\theta)) + (K_W \times \sin(\theta)) + (P_{assive} \times \sin(\delta + \theta)) - u] \times \tan(\varphi) = 0$$

$$\Rightarrow \quad P_{assive} = \frac{w(\sin(\theta) \cdot FS + \cos(\theta)\tan(\varphi)) - Kw(\cos(\theta) \cdot FS - \sin(\theta)\tan(\varphi)) + Cl - \mathrm{u}\tan(\varphi)}{\{\cos(\delta+\theta) \cdot FS - \sin(\delta+\theta) tan\varphi\}}$$

Equation 6

The minimum P_{assive} is searched by incrementally changing the inclination angle of the passive sliding surface, θ.

<u>Calculation of FoS</u>

In deriving the equation for FoS of a soil/rock slope or wall embedded with reinforcements, the resistance force of the reinforcements may be placed in the numerator as an addition to the resistance forces, or in the denominator as a reduction to the driving forces.

In Snail, the pre- factored soil nail resistance forces are placed in the denominator as a reduction to the driving force, as shown in the following equation.

$$FoS = \frac{\sum Resistance\ Force_{Soil\ Strength}}{\sum Driving\ Force_{Soil\ Mass+External\ Loads} - \sum Factored\ Resistance\ Force_{Soil\ Nails}}$$

The reasons that the factored soil nail resistance forces (Factored Resistance Force$_{\text{Soil Nails}}$) are placed in the denominator are:

- (Factored Resistance Force$_{\text{Soil Nails}}$) is mobilized at smaller strains than that of (Resistance Force$_{\text{Soil Strength}}$)
- (Factored Resistance Force$_{\text{Soil Nails}}$) has been reduced by prescribed resistance factors (1/FoS) in Snail for the 3 control modes (refer to the following section for details):

- Factored facing resistance ($F_{factored}$) and active zone sliding,
- Factored tensile yield of soil nail tendons ($R_{factored}$), and
- Factored soil nails pullout ($P_{factored}$)

(Factored Resistance Force$_{\text{Soil Nails}}$) should therefore not be placed in the numerator that will result in double reduction

This arrangement of equation for calculating FoS also aligns with the implementation of soil nail LRFD design.

Factored Soil Nail Resistance

Snail calculates the contributing soil nail tensile force and determines the controlling failure mode of a soil nail reinforcement based on a conceptual strength envelope as presented by the thick red line in Figure T-3. This strength envelope is determined by three components:

(1) Factored structural facing resistance ($F_{factored}$),
(2) Factored soil nail bar resistance ($R_{factored}$), and
(3) Factored pullout resistance ($P_{factored}$) between the grout and the soil/rock, where

$$F_{factored} = \phi_F \times F_{nominal}$$

ϕ_F = resistance factor for soil nail wall facing

$F_{nominal}$ = nominal facing resistance

$$R_{factored} = \phi_R \times (A_t \times f_y)$$

ϕ_R = resistance factor for soil nail bar

A_t = soil nail bar cross sectional area

f_y = soil nail bar yield strength

$$P_{factored} = \phi_P \times \pi \times D_{DH} \times Q_n$$

ϕ_P = resistance factor for pullout resistance

D_{DH} = soil nail drill hole diameter

Q_n = nominal bond strength

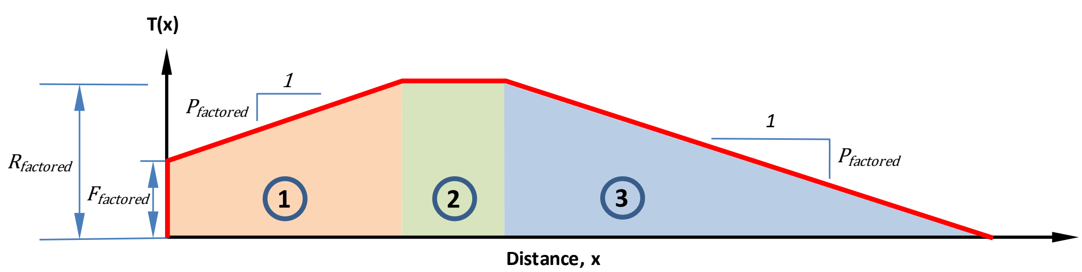


Figure T-3 Conceptual Factored Soil Nail Strength Envelope

Where a search surface intersects a soil nail in the yellow (1) section, factored structural facing resistance and the pullout resistance of soil/grout interface along the length between the intersect and the head of the soil nail is assumed to be fully mobilized (Figure T-4); and the soil nail tensile strength is assumed to be controlled by structural facing resistance. The soil nail tensile force is calculated as follows:

$$T = F_{factored} + P_{factored\_proximal} \times L_{intersect}$$

$; L_{intersect} =$ distance between the intersect and the head of the soil nail

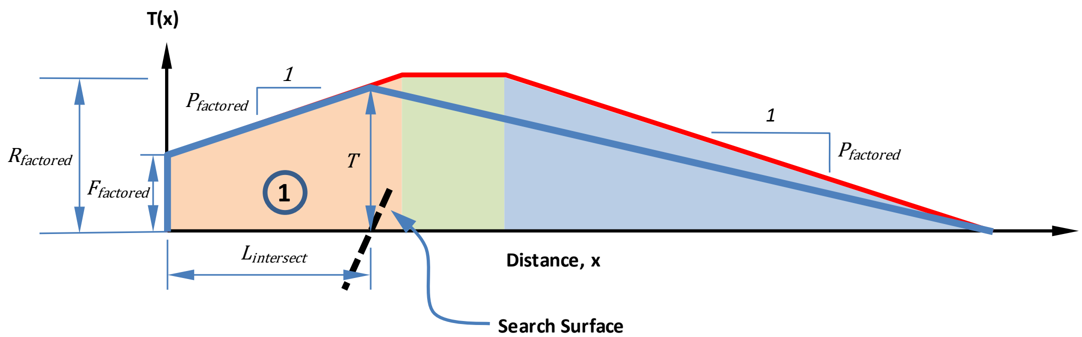


Figure T-4 Soil Nail Tensile Force – Search Surface Intersect at Structural Facing Resistance Control Section

Where a search surface intersects a soil nail in the green (2) section, the factored soil nail bar resistance is assumed to be fully mobilized; and the soil nail tensile strength is assumed to be controlled by the soil nail bar resistance (Figure T-5). In this case, the soil nail tensile force is:

$$T = R_{factored}$$

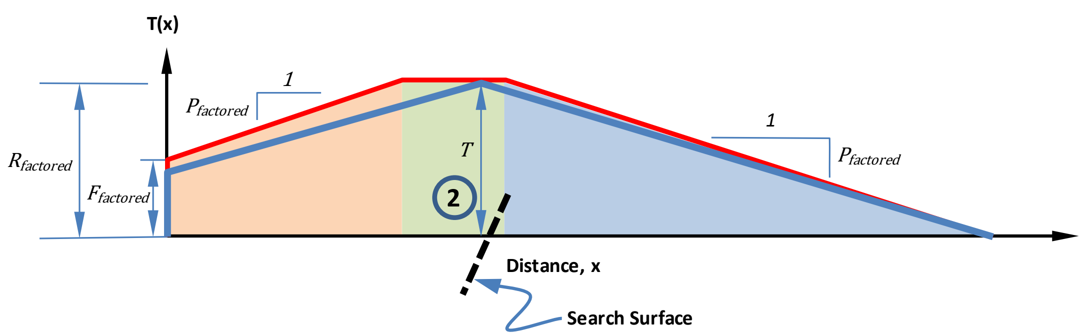


Figure T-5 Soil Nail Tensile Force – Search Surface Intersect at Soil Nail Bar Resistance Control Section

Where a search surface intersects a soil nail in the blue (3) section, the factored pullout resistance of the soil/grout interface is assumed to be fully mobilized along the length between the intersect and the tip of the soil nail (Figure T-6); and the soil nail tensile strength is assumed to be controlled by the soil/grout pullout resistance. The soil nail tensile force is calculated as follows:

$$T = P_{factored\_distal} \times L_{intersect}$$

$; L_{intersect} =$ distance between the intersect and the tip of the soil nail

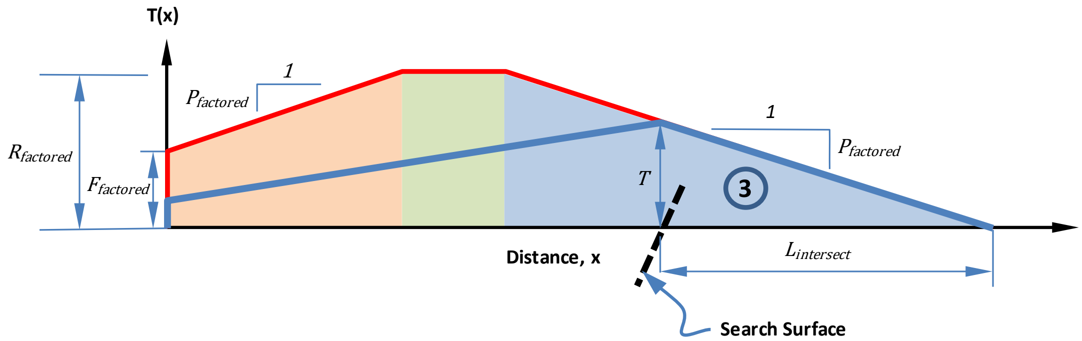


Figure T-6 Soil Nail Tensile Force – Search Surface Intersect at Soil/Grout Pullout Resistance Control Section

Multiple Layer Scenario

For multiple soil layers, a sliding wedge element is divided into multiple sub-wedges when the wedge is intersected by soil layer boundaries. The weighted averages of soil strength properties, i.e. cohesion and friction angle are calculated based on the contributing lengths of the sliding interface of the sub-wedges.

4 Technical Notes

Carrying out the Intent of Design in Construction

This software is a tool that assists designers to analyze and design soil nail walls using a simplified model.

However, installing soil nails into the earth to construct a wall or stabilize a slope effectively creates a composite mass. The mechanism and interaction between different parts of the composite mass at different locations and at different times is complex and takes some effort to comprehend.

Designing a soil nail wall should not stop at completing the calculation or drafting the plans. The designer should understand how soil nails work in the system, and the meaning of values entered into the software, or derived by the software and their implications during construction and service life. The values the designer used or calculated during design are inherently tied to or affected by the contract specifications, construction, and construction quality control. The designer, especially the geotechnical designer, should be involved in the drafting of the specifications, and implementation of the specifications and quality control or quality assurance during construction to ensure the intent of design has been carried out.

Options for Parametric Studies

Snail has several features and options that allow users to perform parametric studies. For typical soil nail wall design and analysis these features and options are not needed and should be left inactive or to the default values.

Service Load at Soil Nail Head (T_o)

Snail calculates the service load at soil nail head (T_o) using the formula (Equation 5.1, *GEC No. 7 2015*) first recommended by Clouterre (1991) based on observation of a few experimental walls and empirical inference, and later adopted by *GEC No. 7 2003*. This formula has been generally accepted and proven to work, even though it is overly simplified and considered by some experts to be conservative. Should there be a need to analyze the load at soil nail head more closely, a geotechnical numerical analysis using a 2-D or 3-D model is recommended.

Calculated service load at soil nail head (T_o) should be used only by the geotechnical designer to check whether the entered allowable facing resistance ($F_{alloawable}$) or factored facing resistance ($F_{factored}$) is sufficient, as shown in Figures 24a and 24b. The calculated T_o value should not be transferred to the structure designer for any design purposes. The reasons are explained in the subsequent technical notes.

Design Communication

The design of a soil nail wall includes both structural facing design and soil nail design. The only information needed to be transferred between structure facing design and soil nail design for design calculation are:

1. Soil nail horizontal spacing;
2. Soil nail vertical spacing; and
3. The factored facing resistance ($F_{factored}$) – i.e. the allowable or factored facing capacity.

The soil nail horizontal spacing and vertical spacing are typically determined by the geotechnical designer for the soil nail design.

A preliminary value of factored facing resistance ($F_{factored}$) is needed for the geotechnical designer to enter the value into Snail to perform soil nails stability analysis. This value is needed by Snail to develop the factored soil nail strength envelope for each soil nails as described in Section 3 Theory.

Therefore, contrary to typical engineering practices, the designer, for either the soil nail or structural facing, needs to start the design with an assumed factored resistance (capacity) of the facing, instead of being given a set of demands (loads) from the soil nails.

The geotechnical designer may initiate the design process by means of try-and-error and arrive at the required factored facing resistance ($F_{factored}$) and select a facing design that meet required minimum $F_{factored}$ from the Snail facing design template and send both the $F_{factored}$ and the selected facing design set to the structure designer for concurring or refining the design. The suggested procedure for the geotechnical designer to perform try-and-error method is provided in the following technical notes, "*Search for the Required Minimum Factored Facing Resistances by the Geotechnical Designer*".

Service Load at Soil Nail Head (T_o) ≠ Geotechnical Factored Facing Resistance ($F_{factored\ Geotechnical}$), $F_{factored\ Geotechnical} = F_{factored\ Structure} = F_{factored}$

There is a misconception that the calculated T_o should be provided to the structure designer as the facing demand for structural facing analysis and design. As shown in the following figure (Figure T-7), using T_o as the facing demand for structural facing design will alter the factored soil nail strength envelope developed and used by the geotechnical designer. It can reduce the global FoS that already calculated by Snail.

$$Substitute\ F_{factored_{Geotechnical}}\ with\ T_o \Rightarrow \downarrow T \Rightarrow \downarrow FoS$$

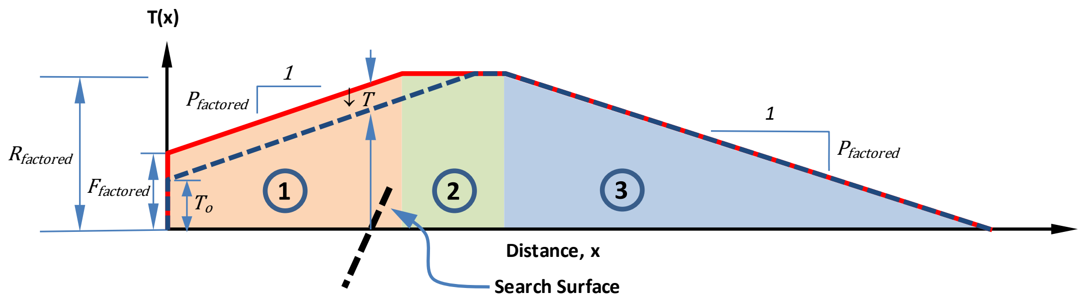


Figure T-7 Reduced Soil Nail Tensile Force – Consequence of Substituting $F_{factored}$ with T_o

Rather, structure designer and geotechnical designer should use, or arrive at, the same factored facing resistance ($F_{factored}$) to ensure consistency of the entire design. The following technical note presents a procedure the geotechnical designer may use to arrive at the required minimum factored resistances, including factored facing resistance.

Search for the Required Minimum Factored Facing Resistances by the Geotechnical Designer

Step 1. Set the factored facing resistance ($F_{factored}$) and the factored bar yield strength ($R_{factored}$) to be higher than the highest possible force generated by pullout resistance ($P_{factored\_distal}$)

$$F_{factored} \text{ and } R_{factored} > (P_{factored\_distal} \times L)$$

, where $L = Soil\ Nail\ Length$

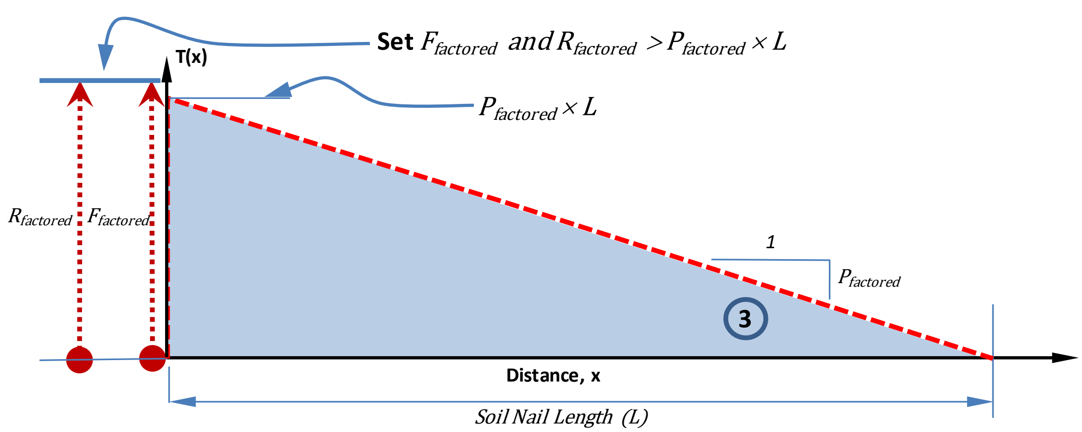


Figure T-8 – Step 1 Set High $R_{factored}$ and $F_{factored}$

Step 2. Adjust and optimize soil nail lengths for the targeted FoS, but

- Maintain proper soil nail lengths to ensure tolerable wall displacement

- ➢ Pay attention if the subsurface materials are high plastic clay or competent soils and rocks
  - In high plastic clay, there is a high potential of creep along the interface of grout and clay
  - In competent soils and rocks, the tolerance for error in soil nail length will be very slim because there is much shorter embedded soil nail length in the mobilized zone, and uncertainties in the design will be substantially amplified

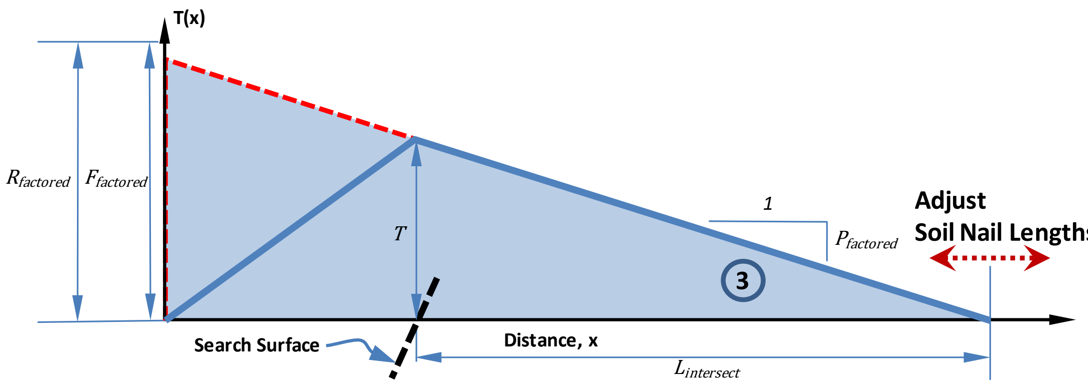


Figure T-9 – Step 2 Adjust Soil Nail Lengths

Step 3. Reduce the factored facing resistance ($F_{factored}$) until the control mode turn to "facing" in Snail while the calculated FoS slightly reduced but remain ≥ targeted FoS

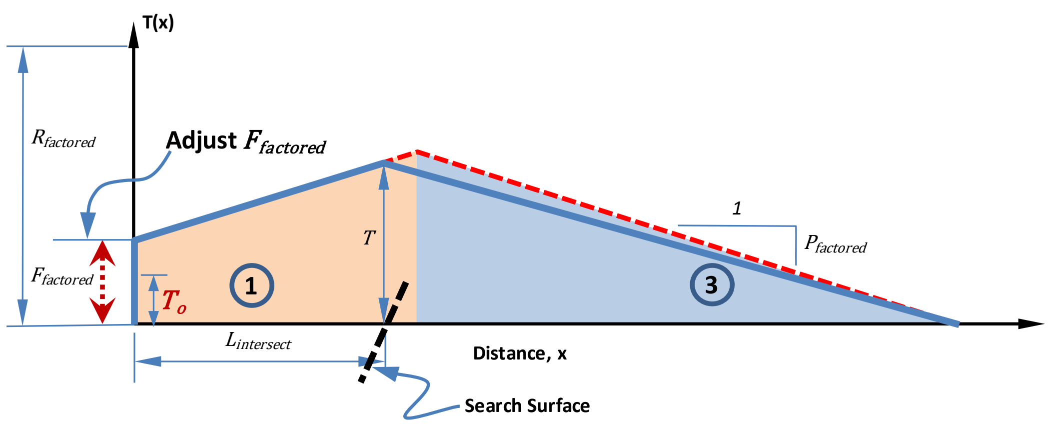


Figure T-10 – Step 3 Adjust $F_{factored}$

Step 4. Check if entered $F_{factored}$ ≥ calculated service load at soil nail head (T_o), i.e. ($F_{factored}$ ≥ T_o)

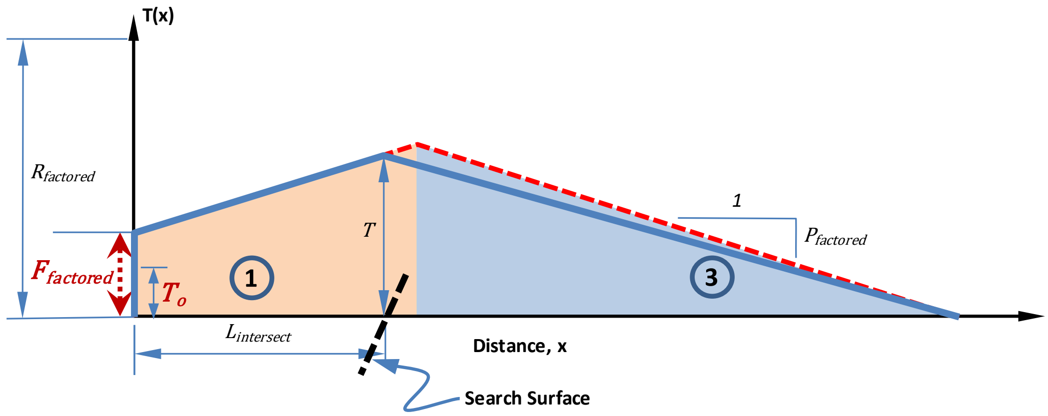


Figure T-11 – Step 4 Check if $F_{factored}$ ≥ T_o

After arriving at a satisfactory factored facing resistance, the geotechnical designer may select, from the design templates provided by Snail, the facing design with the closest and higher factored facing resistance, and use the factored facing resistances associated with the design. Communicate with structure designer which facing design set should work.

Step 5. Reduce the factored bar yield strength ($R_{factored}$) until the control mode turn to "bar yield" in Snail while the calculated FoS slightly reduced but remain ≥ targeted FoS

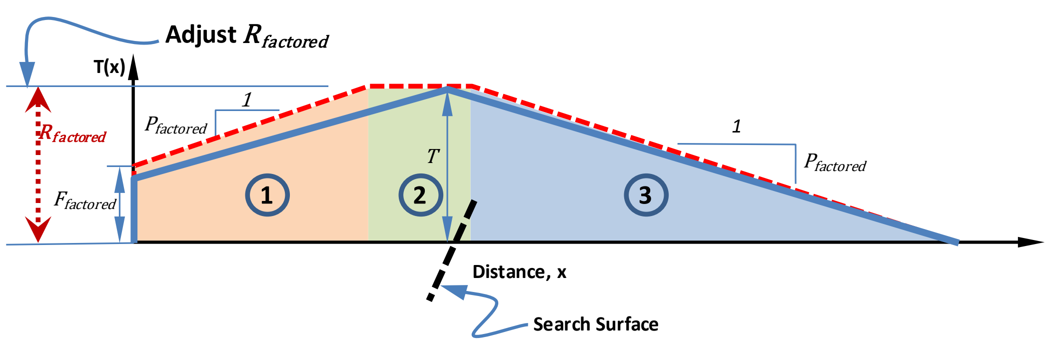


Figure T-12 – Step 5 Adjust $R_{factored}$

Nominal Bond Strength and Nominal Pullout Resistance

Clear understanding of the terms "nominal bond strength" and "nominal pullout resistance" of soil nails and their implication during construction is critical. During design and analysis, each term used in Snail is entered and calculated as a value. In addition, Snail applies a reduction factor or a factor of safety on the nominal bond strength and nominal pullout resistance during calculation.

However, strength of a given lot of a material, whether they are man-made or natural occurrence, should fall into a distribution instead of being a singular value that is customarily assigned to for analysis and design. The actual pullout capacity of constructed soil nails should also fall into a distribution, such as that shown in the following figure (Figure T-13). The nominal pullout resistance may then be determined to be the mean of the distribution or the lower confidence bound, which can be a value a few standard deviations lower than the mean.

Unfortunately, very few statistically meaningful distributions of measured soil nail pullout resistance in various soils and rocks exist.

For the lack of a better means of specifying quality control terms, construction contracts typically refer to nominal pullout resistance or terms referenced to nominal pullout resistance as the acceptance criteria during construction. (Note: Caltrans currently uses nominal pullout resistance as the acceptance criteria for sacrificial verification and proof test nails.)

Because the contract will only accept test nails with pullout resistance greater than the acceptance criteria, almost all the installed soil nails should have a pullout resistance greater than the acceptance criteria. As a result, current contracting practice in effect drive the actual pullout resistance distribution away from (and higher than) the acceptance criteria, even though acceptance criteria, and by extension the nominal pullout resistance, should be a characteristic value that is statistically associated with the pullout resistance distribution of the soil nail population in a wall system.

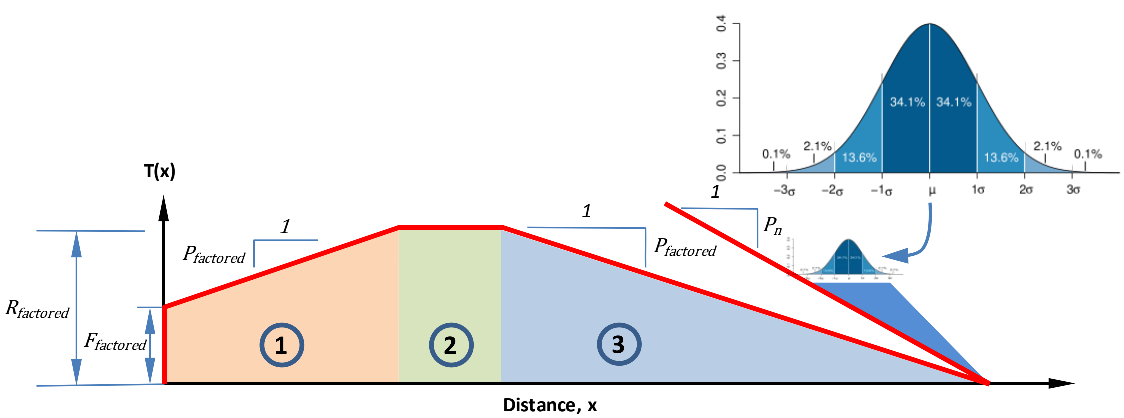


Figure T-13 Soil Nail Nominal Pullout Resistance and its Distribution

Unlike materials produced to specifications such as concrete and steel that have a narrow distribution of engineering properties, in-situ soils and rocks inherently have a much wider distribution of engineering properties. As pullout resistance of soil nails is a function of soil and rock properties, the actual pullout resistance of a given lot of soil nails should fall into a relatively wide distribution.

To obtain the distribution of actual pullout resistance, soil nail construction specifications should require testing of selected sacrificial test nails to failure, after the test nails pass the acceptance criteria. Only after enough data is gathered and distributions of soil nail pullout resistance are well understood, resistance factors of soil nail resistances can be discussed, calibrated, and determined for full implementation of LRFD design of soil nail walls. This above described testing schedule will be implemented in Caltrans construction specifications shortly. The geotechnical designer should work closely with the construction contract administrator to gather as much information as possible during construction to facilitate the development of LRFD design of soil nail walls.

This above discussion does not imply that the acceptance criteria of soil nail pullout resistance specified for construction may be revised down. The current soil nail design procedure and construction specifications have proven that they work as a whole. Even though some parameters and formulae used in calculation may appear to be overly conservative, the implemented design may not be overly conservative during construction and the life time of the soil nail wall.

Rather, the above discussion tries to bring attention to the need for gathering additional data and information from the soil nail tests during construction and quality control, so that the values used and obtained in subsurface exploration, analysis, design, and construction can be calibrated to arrive at a more refined and robust soil nail wall analysis and design approach.

Pullout Control vs. Soil Nail Bar Yield Control

There is a common misconception that soil nail bar yield should be avoided at all cost when designing a soil nail wall.

As shown in the following figure (Figure T-14), there are four options to avoid or eliminate soil nail bar yield, green (2) section, in the Snail calculation:

1. reduce facing resistance (Option 1);
2. increase soil nail bar yield strength or size (Option 2);
3. reduce soil nail length (Option 3); and
4. reduce pullout resistance, $P_{factored}$, – flatten the slope in the figure.

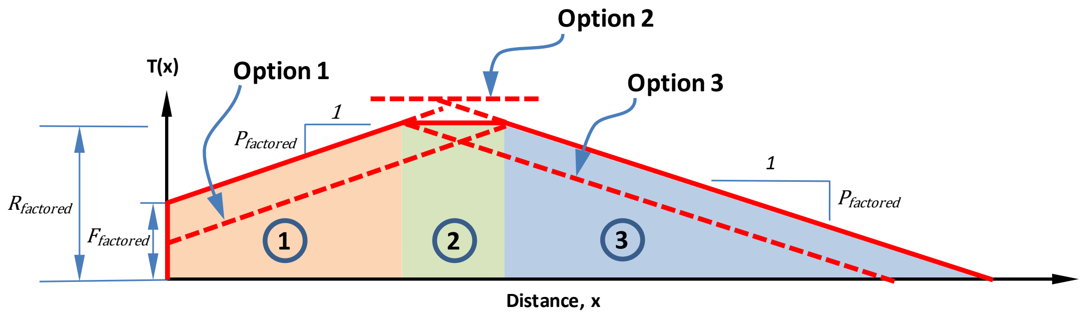


Figure T-14 Options to Manipulate Soil Nail Tensile Strength Envelope

Options 1 and 4 are not viable. Reducing soil nail length and increasing soil nail bar yield strength or size seems to be the options available to eliminate soil nail bar yield control.

However, one should recognize that the strength envelope is composed by factored strengths. The actual strengths are what count in reality. Even though the actual, un-factored, bar yield strength is larger than the factored bar yield strength, the nominal pullout resistance and actual average pullout resistance (Figure T-15) will substantially affect the potential mode of failure. The following figure shows that in the probable actual/average strength envelope, the section with soil nail bar yield control can be much greater than the factored strength envelope suggests.

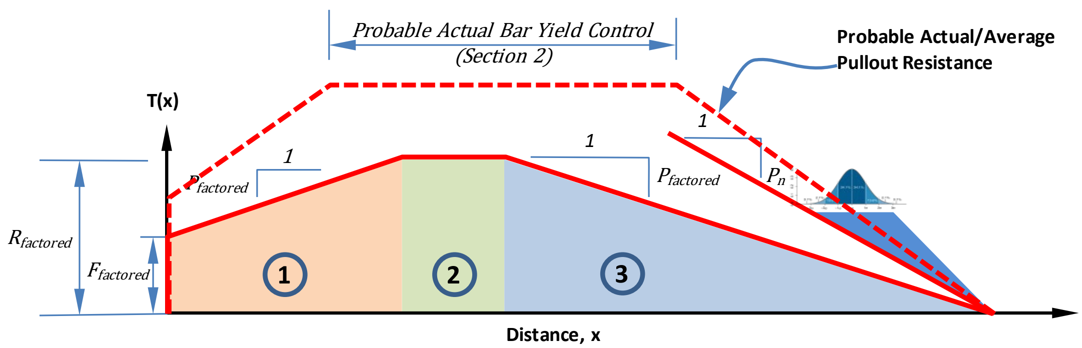


Figure T-15 Probable Actual/Average Strength Envelope

Therefore, one should not blindly increase the soil nail bar yield strength or size simply for the purpose of eliminating soil nail bar yield control, and have the false sense that soil nail bar yield will not happen since the software says so.

One should also not blindly reduce the soil nail length for the same purpose. The designer should consider the value and effects of nominal pullout resistance on the whole system to determine if it makes sense to eliminate soil nail bar yield control by reducing soil nail length. For example, for soil nails in very competent soil or rock, the nominal pullout resistance can be very large and the actual average pullout resistance will be even larger. The embedment length required to eliminate soil nail bar yield control can be very short. As a result, the tolerance for error will be very slim due to much shorter embedded soil nail length in the mobilized zone, and uncertainties in the design will be substantially amplified. Even though reducing soil nail length can produce an efficient design, it may inherently increase the horizontal displacement of the wall face.

In summary, do not blindly avoid soil nail bar yield control mode during design. The soil nail bar yield control prompted by Snail simply indicates that there may be room to reduce soil nail length to achieve a more efficient design. The designer should evaluate all the components and factors to determine whether and how much the soil nail length can be reduced, in addition to the calculated factor of safety.

Use LRFD Method for Soil Nails

To use LRFD method for soil nail analysis and design, Snail users are advised to thoroughly study *GEC No. 7 2015*, and articles on LRFD principles.

LRFD method can be fully implemented on structural facing analysis and design of a soil nail wall.

However, there are unresolved problems in implementing LRFD for geotechnical analysis and design of soil nails using Limit Equilibrium analysis. These problems stem from the difficulty in determining which soil mass and which external loads are driving force (demand), and which contribute to the resistance force (capacity) in Limit Equilibrium analyses and applying corresponding load factors or resistance factors accordingly. The matter is further complicated by that the resistance forces are the function of driving forces in Limit Equilibrium analyses.

For soil nails analysis, *GEC No. 7 2015* recommends performing Allowable Stress Design (ASD), then checking the results against the recommended load and resistance factors.

Snail provides the LRFD option that allows users to partially implement LRFD method. However, since Snail's algorithm is based on Limit Equilibrium, the unresolved problems persist. One interim solution, as implemented in *GEC No. 7 2015*, is to apply virtual load factors to soil nail tensile force. The combination of these virtual load factors (ϕ) and the resistance factors (γ) applied to soil nail pullout capacities, soil nail bar yield, and facing capacity will arrive at the factors of safety (FoS) for the respective components that are compatible with the FoS used in the ASD method.

For parametric analysis of LRFD implementation, Snail allows users to apply load factors to soil mass and external loads. This option may be used to study the effects of various combinations of load factors on the analyses.

One option may be contemplated is to apply statistical parameters, means and standard deviations, to the loads, weights, and resistances. Then, perform Limit Equilibrium analysis using Monte Carlo simulation to arrive at the Reliability Index, the fundamental and governing parameter of the LRFD method, for the system. By doing so will do away with the load factors and associated conundrums.

Corrosion Protection of Soil Nails

Corrosion protection of soil nail bars is critical for the long-term stability and durability of a soil nail wall or slope.

Contrary to some other geotechnical constructions, the grout surrounding the soil nails and ground anchors should not be relied on as a water barrier and part of corrosion protection. The inherent function of soil nails and ground anchors is to develop pullout resistance through the grout, a medium between the soil/grout interface and soil nail bar and ground anchor tendons. The grout column will sustain tensile stress and ultimately develop tensile 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 and ground anchor tendons.

An excellent and comprehensive research has been conducted by Belgian Building Research Institute and three-volume articles were published (2008) that provide 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 interactions are the same for both ground anchors and soil nails, and applicable to soil nails.

Based on above discussion and findings, soil nails without positive corrosion protection, such as epoxy coating with corrugated sheathing, should not be used for long-term applications in a corrosive environment.

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 is 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. Recognizing the importance of gathering data of the actual pullout resistance of soil nails, Caltrans will implement shortly the requirements of pulling verification test nails and selected proof test nails to failure, and the requirements of reporting the test results in a consistent electronic format.

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 are at with respect to 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. When referencing the values presented in these tables, geotechnical engineers need to be aware of this potential disconnect.

Thus, 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 establish a more refined design practice and 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.

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