SNAP_2 (SOIL NAIL ANALYSIS PROGRAM)
User's Manual

U.S. Department
of Transportation
**Federal Highway
Administration**

NHi
NATIONAL HIGHWAY INSTITUTE

Federal Highway Administration
RESOURCE CENTER

FOREWORD

The current design process for soil nail earth retention systems is inefficient because multiple tools are needed for facing, internal/external, and global design. These tools do not communicate with one another, and are often used by different staff members. The main objective of this work is to develop a single State-of-Practice computer program for designing the entire soil nail earth retaining structure, including nail elements, facing elements, global stability, and evaluation of internal and external wall stability based on the current AASHTO design standards. By combining all these assessment tools into one package, we take another step towards assuring high quality and efficient designs and accelerating project delivery.

Amy Lucero
Director, Office of Technical Services

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16. Abstract

Soil nail walls are internally stabilized earth-retaining structures. Soil nail walls use a top-down construction with in situ reinforcement to support temporary or permanent excavations. In certain conditions, soil nailing is a viable alternative to other ground anchor systems, considering technical feasibility, cost, and construction duration.

Although the use of soil nail walls for highway applications has increased dramatically in the past decade, computer programs for the design of soil nail walls are not up to date. The main objective of this work is to develop a state-of-the-practice computer program, SNAP_2 (Soil Nail Analysis Program) for designing all components of soil nail retaining structures, including nail and facing elements. The program will evaluate the internal and external wall stability (including limit-equilibrium global slope stability) based on the current standards in the ASD method. In addition, the program may be used to evaluate verification and proof field test results. All design and evaluation procedures are according to the FHWA guidelines presented in 1) The Manual for Design and Construction of Soil Nail Walls, Report No. FHWA-SA-96- 069R, and 2) Geotechnical Engineering Circular No. 7 - Soil Nail Walls Reference Manual, Report No. FHWA-NHI-14-007.

This user's manual discusses the theoretical basis for the computer program, gives a comparison of available soil nail wall design guidelines, discusses program execution including inputs and outputs, and includes two worked examples to demonstrate use of the program.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ACRONYMS AND ABBREVIATIONS

A	Peak ground acceleration due to seismic loading
AASHTO	American Association of State Transportation Officials
a_w	Angle between phreatic surface and horizontal
ASD	Allowable Stress Design
B	Wall base length
c	Soil cohesion
CalTrans	California Department of Transportation
CIP	Cast-in-place
DOS	Disk Operating System
DTL	Design test load
FHWA	Federal Highway Administration
ft	foot (feet)
ft^2	square feet
ft^3	cubic feet
FS	Factor of Safety
Fy	Steel yield strength
GEC	Geotechnical Engineering Circular
H	Wall height
h_w	Vertical distance between failure surface and phreatic surface
in	inches
in^2	square inches
K_a	Active earth pressure coefficient
k_h	Horizontal seismic coefficient
kip	kilo pound (1000 pounds)
kN	kilo Newton(s), SI unit of force
kPa	kilo Pascal
k_v	Vertical seismic coefficient
lb	pounds of mass
lbf	pounds of force
LRFD	Load Resistance Factor Design
m	meter
m^2	square meters
m^3	cubic meters
MSE	Mechanically Stabilized Earth
N_c	Bearing capacity factor
N_q	Bearing capacity factor
N_γ	Bearing capacity factor
psi	pounds per square inch
SI units	International System of units (e.g. m, N, kPa, etc.)
SNAP_2	Soil Nail Analysis Program
US units	United States customary units (e.g., ft, lbf, psi, etc.)
ϕ	Internal friction angle of a soil
γ	Soil unit weight

CHAPTER 1 – PURPOSE AND SCOPE OF SNAP_2

INTRODUCTION

Background

Because of the advantages of soil nail walls, the Federal Highway Administration (FHWA) has sponsored and coordinated the development of several technical reports and research on soil nail wall projects since the early 1990s (see the Bibliography).

The objective of this document is to present SNAP_2 (**S**oil **N**ail **A**nalysis **P**rogram), a computer program that follows the current FHWA guidelines for designing a soil nail earth retaining structure. This includes the design of all soil nail system components such as 1) nail elements, 2) facing elements, 3) external stability, and 4) global stability. All design and evaluation procedures were developed in general accordance with the FHWA guidelines presented in Geotechnical Engineering Circular No. 7 – Soil Nail Walls Reference Manual (GEC 7), Report No. FHWA-NHI-14-007.

SNAP_2 follows the current allowable stress design guidelines, including internal and external stability evaluation for static and seismic loading. External failure modes include global stability, sliding, and bearing capacity analysis. Internal failure modes include nail pullout and nail tensile failure analysis, along with nail head and facing element analysis for temporary and permanent conditions.

Comparison to GOLDNAIL and SNAIL Programs

Although the use of soil nailing for highway applications has increased dramatically, computer programs for designing soil nail walls have not kept pace with the industry. For the last 20 years, two soil nail specific computer programs were available for determining the length and specifications of the nail components. SNAIL (DOS-based, developed by CalTrans, 1991) and GOLDNAIL (Windows based, developed by Golder and Associates, 1993) were the primary soil nail specific computer programs available for the designer. Both programs have limited use and are mainly designed for checking the soil nail wall stability by varying nail types and sizes, spacing and bond strengths. Neither program is capable of designing wall facing elements, shotcrete, or evaluating the global stability of the wall system with a complex slope profile. Because SNAP_2 uses a limit equilibrium design method (Bishops), soil nail walls are designed using ASD (allowable stress design). Some programs, such as GOLDNAIL allow for the input of resistance factors (LRFD), but internally the program inverses the resistance factors and uses them as safety factors in an ASD design.

Basic Theory

SNAP_2 can evaluate the internal (facing and nail) components of a soil nail wall, external stability, and global stability. The calculations are based primarily on GEC 7. The following sections discuss how each of these components is evaluated, and how groundwater is treated within the program.

Wall Facing Analysis

SNAP_2 can evaluate the internal stability of a soil nail wall for both shotcrete-only facing type and permanent cast-in-place (CIP) concrete facing types. Calculations are based on GEC 7.

For a shotcrete-only facing, SNAP_2 determines the nominal nail head strength by evaluating flexure and punching shear failure modes, based on input from the user. SNAP_2 will calculate the nominal nail head strength for both failure modes, and use the critical value in subsequent global stability calculations. Input parameters include information on the wire mesh, horizontal waler and vertical bearing bars, bearing plate, and shotcrete. Permanent applications of shotcrete facing can be troweled to an acceptable façade or faced with pre-cast panels. For a cast-in-place facing type, typically soil nail walls are constructed with a temporary shotcrete facing. Then the permanent CIP concrete facing is installed and connected to the nails by headed studs on the bearing plates, after completion of the temporary wall facing. When a final facing is evaluated in SNAP_2 (CIP concrete or shotcrete) the strength of the temporary shotcrete facing is neglected under the assumption that the temporary facing strength cannot be relied upon in the long-term. In addition to flexure and punching shear failure modes, headed stud tension failure is evaluated for a permanent facing. The program will calculate the nominal nail head strength for all three failure modes in the permanent facing, and use the critical value in global stability calculations. Input parameters include information on CIP concrete or shotcrete, mesh (if used), horizontal and vertical reinforcement bars, and the headed-stud connection system.

In addition to determining the nail head strength, SNAP_2 performs required design and serviceability checks for both shotcrete and CIP facings as outlined in GEC 7.

Internal Stability Analysis

SNAP_2 evaluates maximum nail loading along the length of each nail using methods outlined in GEC 7. This method is based on applying the Coulomb active earth load uniformly at the back of the wall facing. The program uses the nail head strength determined from the facing analysis, the nail tendon strength entered by the user, the grout-ground pullout strength entered by the user, and the factors of safety entered by the user to generate a nail support diagram for each nail (Figure 1). SNAP_2 then uses the nail support diagram for each nail in the global stability calculations. For each slip circle evaluated for global stability, the program determines the nail loads at the locations where the slip circle intersects each nail, according to each nail's support diagram. These loads are applied to their respective slices in the global FS calculations for each slip circle.

External Stability Analysis

External stability of a retaining structure refers to the potential failure or deformation modes typically associated with conventional gravity or cantilever retaining structures. These failure modes include horizontal sliding of the retaining wall along its base, and foundation bearing failure of the retaining wall associated with overturning. The "slip surface" limiting equilibrium technique, does not entail separate evaluation for sliding stability or overturning stability about the toe of the wall; these failure modes are accounted for in the general slip surface evaluation, which also includes global stability analysis. Foundation bearing failure is evaluated separately, but a complete evaluation is not required for all soil conditions. SNAP_2 performs a complete bearing capacity evaluation for all cases, rather than the rough initial check outlined in GEC 7. Sliding failure along the base of the wall and overturning about the toe of the wall are also evaluated, based on FHWA guidelines for Mechanically Stabilized Earth (MSE) walls. These failure modes are highly unlikely to control stability of a soil nail wall, and are provided primarily for the designer's own information and conformance with AASHTO.
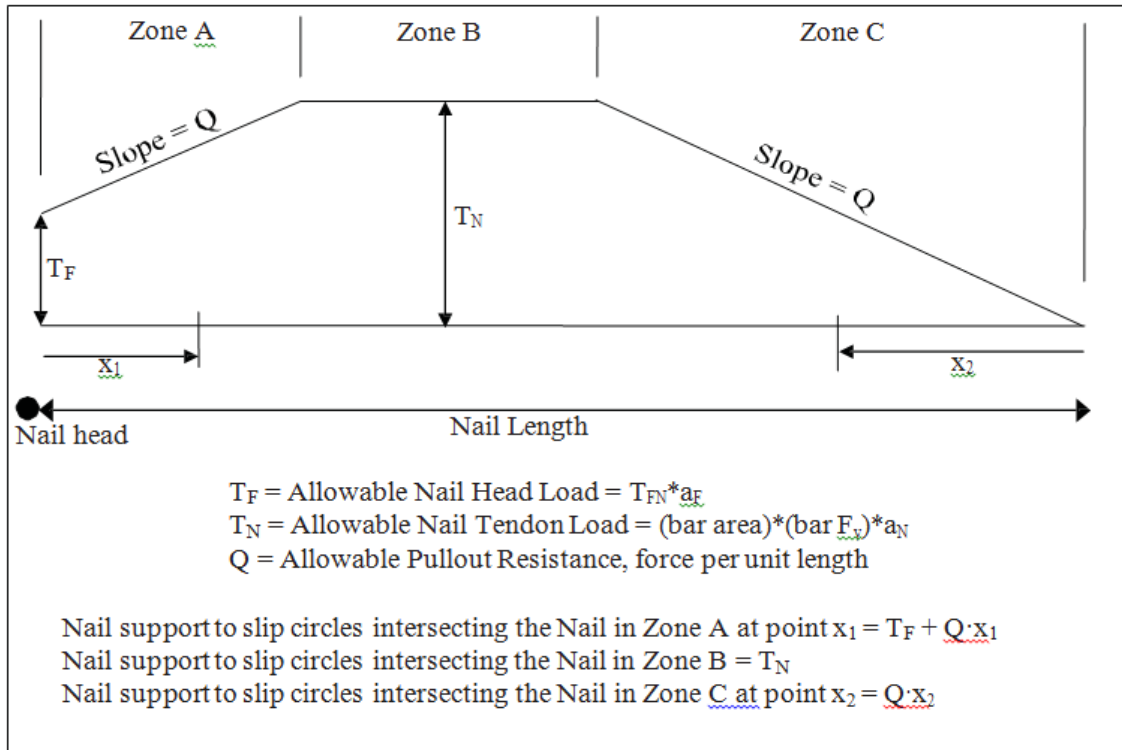
Figure 1 Schematic. Nail Support Diagram used in SNAP_2 (FHWA SA-96-069R)

SNAP_2 includes the effects of seismic forces in external stability calculations if the user inputs required seismic information. Seismic forces are taken into account by including, in addition to the static forces, a horizontal inertial force and a dynamic horizontal thrust force. The dynamic horizontal thrust is calculated using the Mononobe-Okabe method (Mononobe, 1929; Okabe, 1926). This method is applicable to all values of the friction angle, φ, and introduces an additional angle into the calculations for the active earth pressure coefficient, K_a, based on the horizontal and vertical seismic coefficients. The user input for seismic loading can either be the peak ground acceleration, A, or the horizontal seismic coefficient, k_h. SNAP_2 allows the user to input the vertical seismic coefficient, k_v, which is used for both external and global stability calculations.

For all external stability calculations, the passive earth pressure behind the nailed soil mass is calculated using Coulomb's earth pressure coefficient. The wall-soil interface friction angle is taken to be 2/3 of the friction angle, φ. The surface on which passive earth pressure acts (the back surface of the wall) is assumed to always be vertical. SNAP_2 evaluates external stability for the long-term drained case rather than short-term undrained case; therefore, saturated unit weight of the reinforced soil and groundwater uplift forces are not incorporated into the external stability calculations.

Sliding stability is evaluated along the base of the nailed soil mass. The base width of the wall is taken as the horizontal distance between the toe of the wall and the average end of the nails (Figure 2). This method allows the calculation to be consistent whether the user selects uniform or non-uniform nail geometry. The cohesive strength of the foundation soil is included in the resisting forces, but not the shear strength of any nails that may extend below the base of the wall. Overturning (moment) stability is evaluated about the toe of the wall, at the ground surface. Although this is not generally considered for soil nail walls, it has been included for the

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wall designer's information and conformance with AASHTO. This failure mode is highly unlikely to control stability of a soil nail wall.
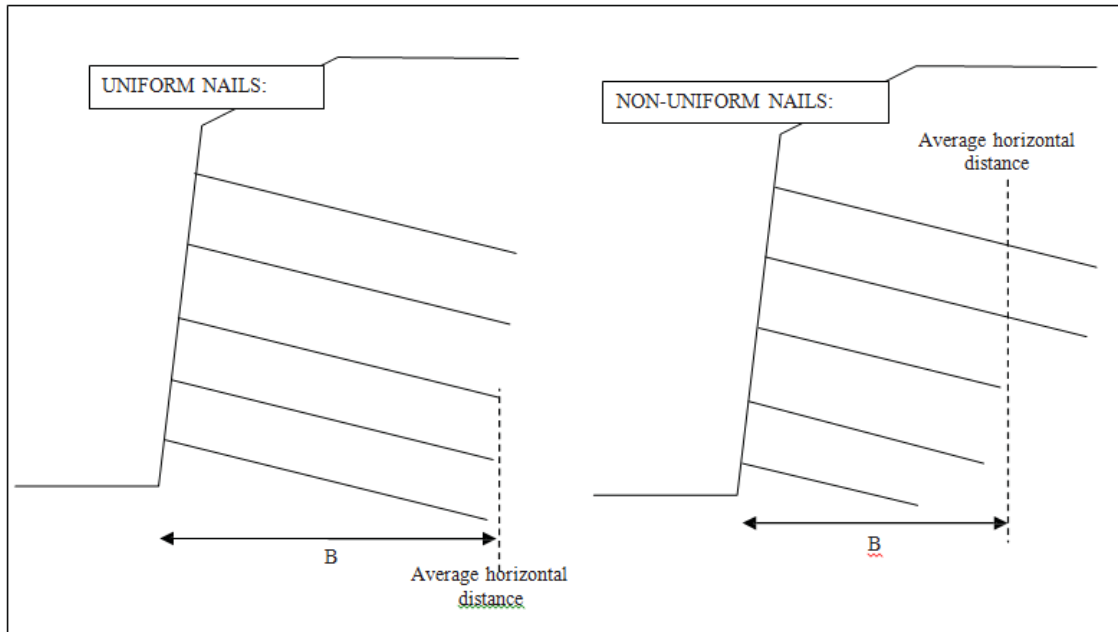
Figure 2. Schematic. Wall base length, B, used for external stability calculations (FHWA CFL/TD-10-004)

Bearing capacity is evaluated using the method outlined in GEC 7. The user must enter bearing capacity factors N_c, N_γ, and N_q, on the Soil input tab, or choose to have the program calculate the bearing capacity factors from the friction angle input by the user. This allows the user to adjust the bearing capacity calculation to account for sloping ground in front of the wall. At this time, groundwater below the base of the wall is not accounted for in the ultimate bearing capacity calculations; if groundwater is anticipated below the soil nail wall, SNAP_2 accounts for this condition in the global stability evaluation.

Global Stability Analysis

SNAP_2 evaluates limit-equilibrium global stability using Bishop's Simplified (Modified) Method. This method accounts for interslice normal forces but ignores interslice shear forces, and satisfies vertical force equilibrium for each slice and overall moment equilibrium about the center of the slip circle. SNAP_2 can evaluate circular-shaped failure surfaces only. The soil mass is divided into approximately 100 slices, and stability is assessed for an average of 5,000 slip circles to find the most critical failure surface and associated factor of safety (FS). SNAP_2 can evaluate stability under seismic loading conditions using a pseudo-static analysis, by including the weight of each slice, reduced by the horizontal seismic coefficient, in the sum of forces and moments. The slip circles for which SNAP_2 calculates a FS are generated automatically by the program. Slip circle centers are located above the top nail and to the left of (down-slope of) the wall face. Circle center points are on a grid with a spacing that is scaled along with the height of the wall.

The global stability calculation includes surcharge loading, nail support loads, pseudo-static seismic loads (if selected), and uplift force at the base of each slice due to groundwater. The added weight of water due to saturated soil is not factored.

The user can specify the minimum height of the failure circle arc to remove small failure circles. The failure surface search algorithm is very robust so that potential failure surfaces, both outside and inside (passing through some or all of the soil nails) the reinforced soil mass are checked. This failure surface is not restricted to pass through the wall facing therefore it may pass below the wall and exit in front of the wall facing. The program will show the critical failure surface (the lowest factor of safety) that encounters the reinforced soil mass. If the critical failure surface does not encounter the reinforced soil mass, that failure surface will also be displayed.

Groundwater

SNAP_2 utilizes a phreatic surface groundwater model (Figure 3). The pore pressure from any point is computed from the difference in head between that point and the phreatic surface. Figure 3 illustrates a phreatic pore pressure calculation. SNAP_2 only uses pore water pressure for calculating global stability. The additional weight of saturated soil below the phreatic surface is not accounted for, however – only the uplift force at the base of each slice due to pore water pressures. SNAP_2 can only accommodate an unconfined aquifer groundwater model. Groundwater is not accounted for in facing, internal, or external stability calculations, including bearing capacity.
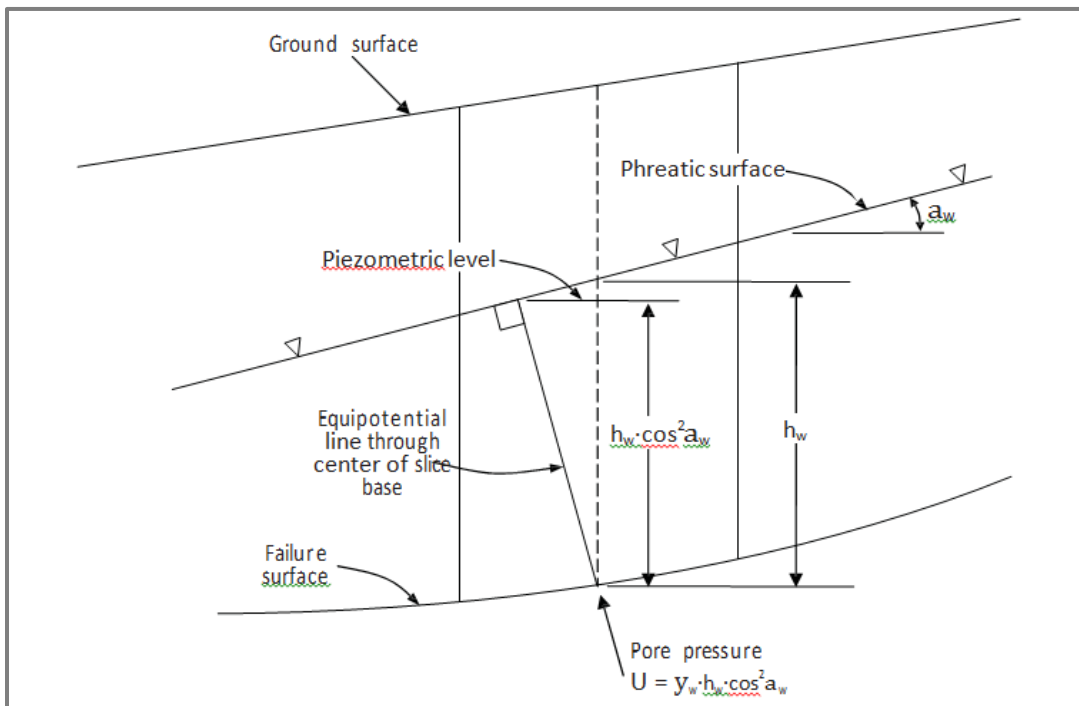
Figure 3. Schematic. Method of pore pressure calculation in SNAP_2 (FHWA CFL/TD-10-004)

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Program Installation

The SNAP_2 computer program is installed by running the executable program **SNAP_2_setup** and following the directions in the Setup Wizard. In the Setup Wizard, the user will select a location for the folder (SNAP_2) that will be installed and contains all the files and subfolders for the SNAP_2 program. The default location is "C:\Programs\SNAP_2," but the user can browse to select any location on their computer. The Setup Wizard will also create a shortcut in the Start Menu and an icon on the desktop.

CHAPTER 2 – INPUT PARAMETERS

SNAP_2 CONVENTIONS

File Management

SNAP_2 does not include conventional file management capability. When a new project is created in SNAP_2, files will be created and saved in a folder with the same name as the project. All project folders are located in the subdirectory called SNAP-2 which is in the main SNAP_2 directory. To make changes to a project without losing the previous data for the project, the original project file can be selected from the Project dropdown menu and new name entered (in the Project – Select screen) and press Return. Appropriate changes can then be made to the project description, material properties and/or geometry. The changes will be saved in a new folder with the new project name.

Program Capabilities

In addition to the standard entry of geometrical and material properties for the ground and soil nails, SNAP_2 requires entry of the facing design parameters including dimensions and strength values for reinforcement, concrete or shotcrete, and facing connections. SNAP_2 calculates the facing strength capacity in flexure and punching for temporary and permanent facing, and the headed stud connection for permanent facing. SNAP_2 allows for complicated slopes, multiple soil nail walls, multiple soil layers, and multiple temporary and permanent facing designs. This allows for the flexibility of assigning different facing designs for each wall. SNAP_2 displays a two-dimensional graphical representation of the data. The graphical display is updated as values are entered into the data boxes.

Tabs and Option Selection

Input parameters in SNAP_2 are organized into a series of tabs and sub-tabs. In addition to the tabs, some options can be changed by clicking on radio buttons or moving sliders. Radio buttons can be toggled between active and inactive status by clicking on the dot, when a radio button is active the dot appears white. The sliders can be moved by placing the mouse icon on the slider and holding down the left mouse button. For example: in the Soils tab, the user can activate a radio button to have the program calculate the bearing capacity factors from the user provided soil friction angle and; in the Slope tab, the user can adjust the scale and reposition the graphical display by clicking and holding the slider and moving it back and forth.

When the mouse icon is placed on any tab, button, or slider, a banner appears across the bottom of the screen with a description for that tab, button, or slider. In some cases, information concerning value or dimensional checks that the program performs automatically will be described in the bottom banner. Tabs that include these automatic checks will display a blue ball if the check is satisfied or a yellow triangle if the check is not satisfied. When the mouse icon is placed anywhere on the graphical display, the X and Y coordinates are displayed in the bottom banner. The data boxes may have both active and inactive dialog boxes. Active dialog boxes allow for the direct entry of data and appear brighter, while the inactive dialog boxes contain values that the program calculates, data cannot be entered directly, and the inactive dialog boxes appear duller. Data is entered into active data boxes by clicking on the box and typing in the

data. Some of the data boxes may partially block the view of the graphical display however the data boxes may be turned off and on by clicking on the associated tab.

Geometry

In SNAP_2, the soil nail wall face is on the left, with the global failure occurring from right to left on the screen. The coordinate system in SNAP_2 is 2-dimensional where the X-axis is horizontal and the Y-axis is vertical. There is no restriction on where the wall(s) can be placed on the coordinate grid. Both positive and negative coordinates are allowed.

Data Entry

The coordinates for points defining the location of slopes, soil layers, groundwater, wall facings, soil nails, and surcharge loads are listed as data boxes with the points shown on the graphical display. Points can be added by either clicking on the plus sign (+) tab on the lower left in the data box or clicking on the graphical display. Coordinates can then be typed into the data box or the point can be moved into position on the graphical display by placing the mouse icon on the point and holding down the left mouse button. A new point or the active point will be displayed pink and the point number will be highlighted in the data box. The active point can be selected by either clicking on the point number in the data box or the point shown on the graphical display. Points can be deleted by either clicking on the point number or on the point shown on the graphical display (making it the active point), and then hitting the Delete key. When a new project is initiated, the screens are preloaded with default values that can then be changed or added to as required.

PROGRAM EXECUTION

Getting Started

Click on the desktop icon to start SNAP_2. The program will take a few seconds to start up. The program initially loads showing the Project tab and Select sub-tab. Clicking on the down arrow in either the Project or Archive date box will reveal a list of previously entered projects. For an immediate example of how the program looks and works, select Example 1 from the Project list and then click through the tabs as outlined below.

SNAP_2 DATA ENTRY TABS

Project - Select

Either type a project name in the Project dialog box or click on the Project down arrow to open the dropdown list of active projects and click the appropriate project name (Figure 4). To move an active project to the Archive list, click the X next to the project name. Click on the Archive down arrow to open the dropdown list of archived projects. Move an archived project to the active project list by clicking on the name, or remove a project from the archived projects list (permanently deleted) by clicking on the X next to the name. For a new project, once the project name is entered into the Project dialog box, press the Enter key to begin entering data.
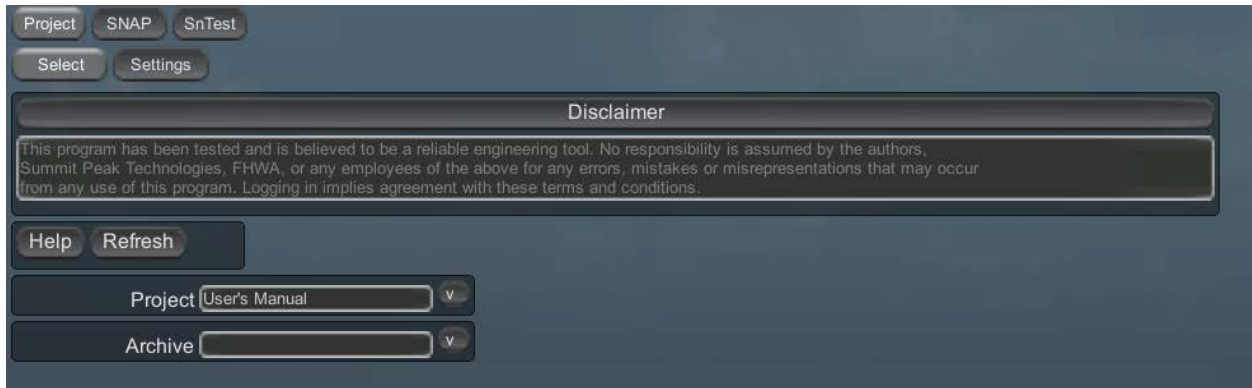
Figure 4. Screen Shot. Opening screen, Project – Select

Project – Settings

Either US or SI units can be selected in the Units data box (Figure 5). (At any time this selection can be switched between US and SI units and all the data will automatically be converted). In the Project Description data box, information about the project and soil nail wall can be input. This information will be included in the report header. Click on the SNAP tab to begin entering geometric data.

Figure 5. Screen Shot. Project – Settings

SNAP – Slope

A graphical display with horizontal and vertical scales is shown with points and lines that define the slope surface (Figure 6). The graphical display is updated as data about the ground conditions and wall configuration are input or changed.

Click on the plus sign (+) to add points to define the original ground surface prior to construction of the soil nail wall. In addition to the coordinate point entry methods described above in **Data Input**, the X and Y coordinates can be imported to the Surface Points data box by coping data from an excel file and then clicking the Paste Points tab. The X and Y coordinates can be exported by clicking on the Copy Points tab and then pasting the coordinates into an excel file. The size and position of the graphical display can be modified by using the sliders in the Scale and Center data boxes. The Scale slider will make the graphical display larger or smaller. The two Center sliders move the graphical display horizontally and vertically.

Figure 6. Screen Shot. SNAP – Slope
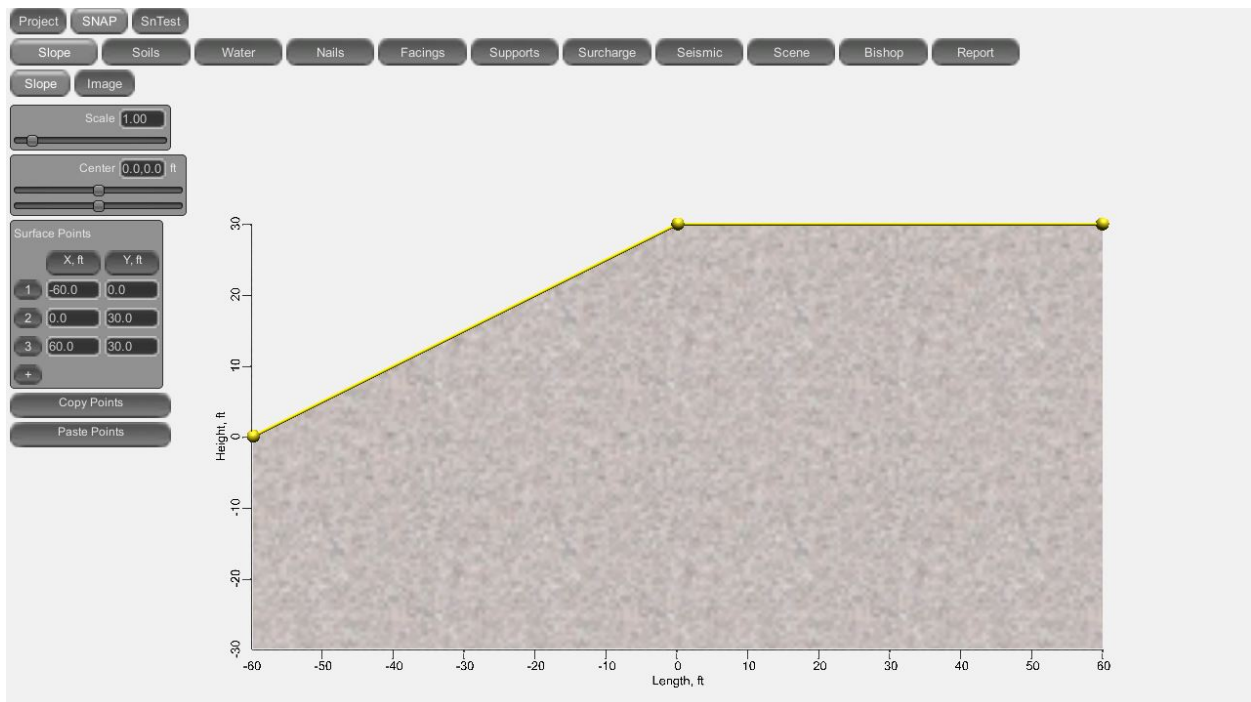
SNAP – Image

To aid in entering slope and wall cross section information, there is an option to import an image over which coordinate points can be placed (Figure 7). Click in the Image tab to select a .png file to import onto the screen. The image will need to be a .png file that has been saved to the folder which is given in the Path data box. Click on the Soils tab to enter soils data.
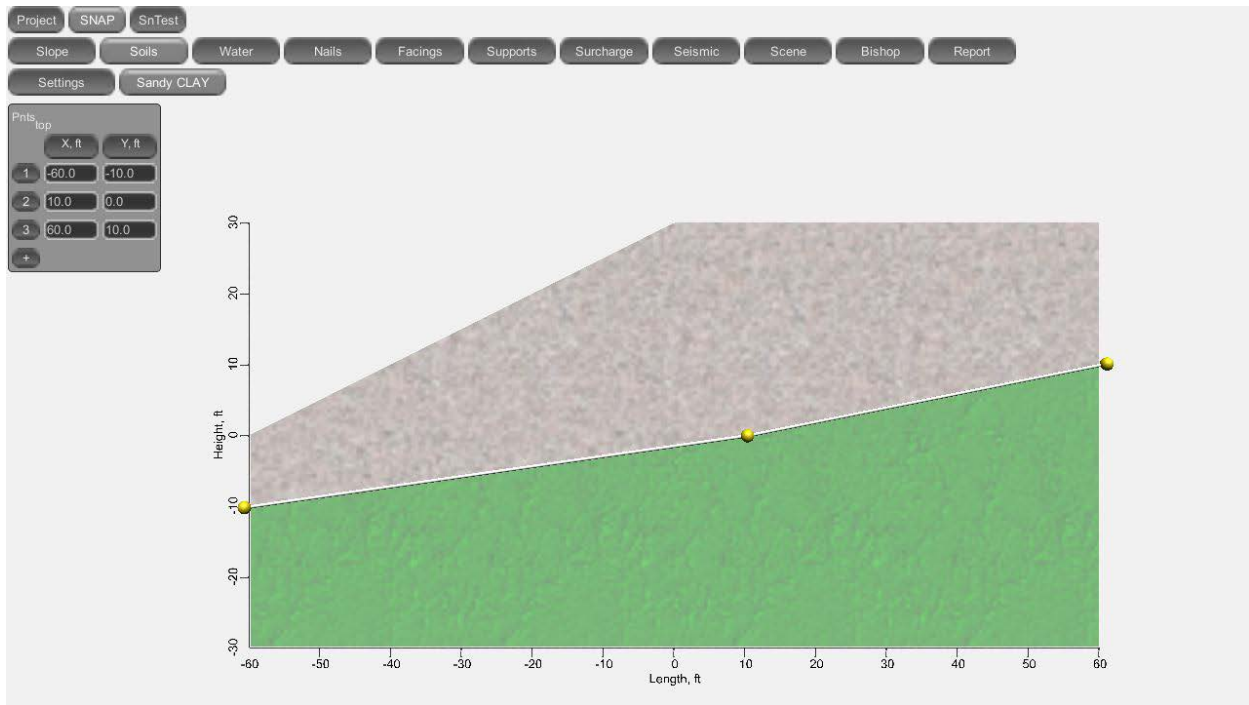
Figure 7. Screen Shot. SNAP – Image

SNAP – Soils

Click on the plus sign (+) tab in the Soils data box to add a soil layer (multiple soil layers can be defined as seen in Figure 8). Click on the soil number in the Soils data box and press the Delete key to delete a soil layer. Soil layers are listed in order with the stratigraphically highest soil layer first and the stratigraphically lowest soil layer last. Click on a Name dialog box and type in a Name such as Silty SAND or Sandy CLAY. Click on the Texture down arrow and select a texture for each soil layer from the drop down menu. The texture selection only affects the way the soil layer is shown in the graphical display. Click on the Color down arrow and select a color for each soil layer from the drop down menu. Type the soil parameters for each soil layer (unit weight, friction angle, cohesion, and ultimate bond strength) into the dialog boxes. The wall-interface friction angle is calculated as 2/3 of the soil friction angle. The bearing capacity factors for each soil layer can be typed into the dialog boxes or the user can activate the radio button in the Calc Bearing Capacity Factors data box to have the program calculate them from the friction angles.
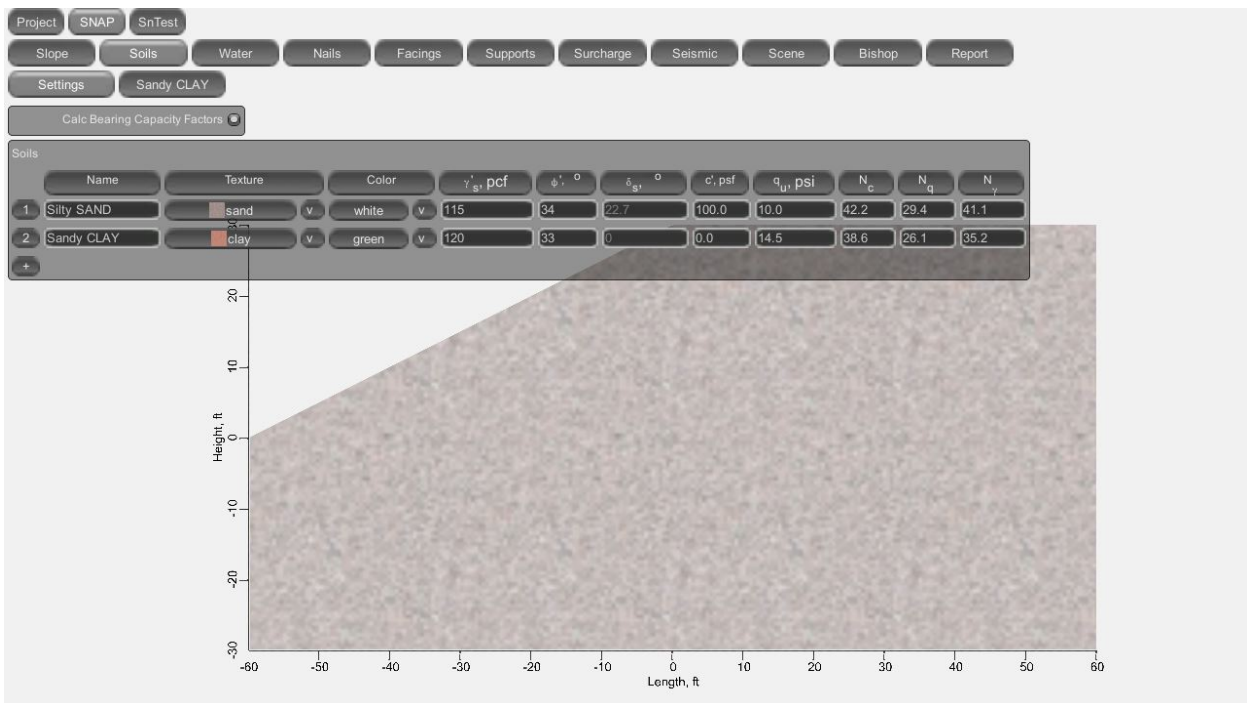
Figure 8. Screen Shot. SNAP - Soils – Settings

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When more than one soil layer is defined, tabs for each additional soil layer appear to the right of the Settings tab. Clicking on a soil layer tab will cause a data box to appear where coordinate points defining the top of the soil layer may be input (Figure 9). (Note: The Surface Slope defines the top of the first soil layer.) Points are added in the same manner as discussed above. The graphical display will show the points with lines separating two soil layers and the program will assign each soil layer a color. Click on the Water tab to enter data on the groundwater level.

Figure 9. Screen Shot. SNAP - Soils - Soil 2

SNAP – Water

Click on the plus sign (+) in the Points data box to add points (Figure 10). If the groundwater level is not included in the problem then no points are added. Coordinate points for the groundwater level can also be copied to and from an excel file as described in **SNAP - Slope**. The groundwater level is shown on the graphical display as a series of blue lines between points. Click on the Nails tab to enter data on bar tendon sets.
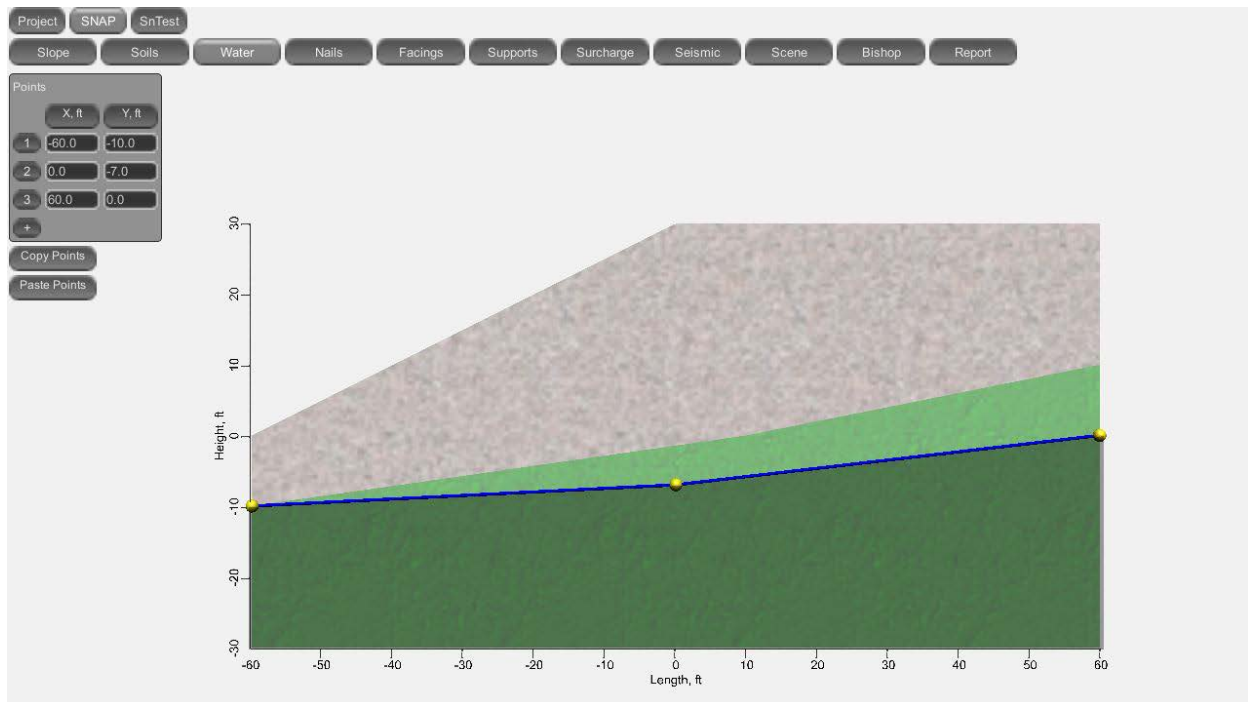

Figure 10. Screen Shot. SNAP – Water

SNAP – Nails

Click on the plus sign (+) in the Nails data box to define a bar tendon set (Figure 11). Multiple bar tendon sets can be defined when bar tendons that vary in size or yield strength will be used on the project being analyzed. To delete a bar tendon set, click on the bar tendon number in the Soils data box and press the Delete key. For each bar tendon set enter the name (default is Bar 1, Bar 2, etc.); the diameter (D) of the drill hole; the outside diameter (D_{out}) of the bar tendon or alternatively, the bar tendon size or number (Bar No, Bar #; these two values are linked); and the yield strength of the bar tendon (F_y). For hollow bar tendons, enter the inside diameter of the bar tendon (D_{in}). For a solid bar, D_{in} is zero. The program automatically makes a check to see that $D > D_{out} > D_{in}$.

Enter the factors of safety for yielding of the bar tendon and the soil nail pullout capacity (i.e., ground-grout bond) for both the static and dynamic conditions. The default values are those recommended in the FHWA manual "GEC 7 Soil Nail Walls Reference Manual". When multiple bar tendon types are defined, there is an option to assign different factors of safety to each bar tendon set. When the Uniform (U) radio button is inactive, the factor of safety tabs to move down to the Nails data box and allow separate factors of safety to be input for each bar tendon set. Click on the TForce Color down arrow and select a color for TForce line from the drop down menu. The user should select a TForce line color that will contrast well with the soil layer colors previously selected. Click on the Facings tab to enter data on the wall facings.
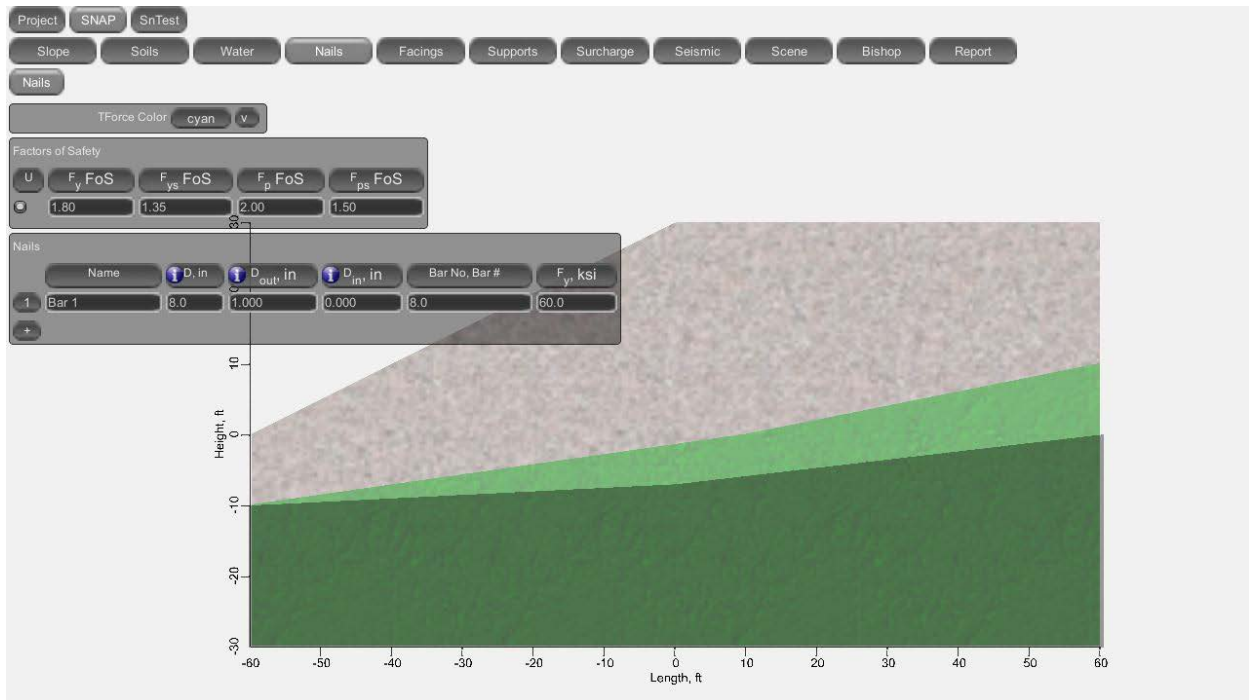

Figure 11. Screen Shot. SNAP - Nails

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SNAP - Facings

Click on the plus sign (+) in the Facings data box to add a single facing or multiple facings, which can be defined as either temporary (shotcrete) or permanent (shotcrete or CIP) (Figure 12). Click on the Type down arrow and select either a temporary or permanent facing. Enter a Name and Description for each facing type in the dialog boxes. As facings are added, tabs with the Name will appear to the right of the List tab. To delete facings, click on the number in the Facings data box and press the Delete key.
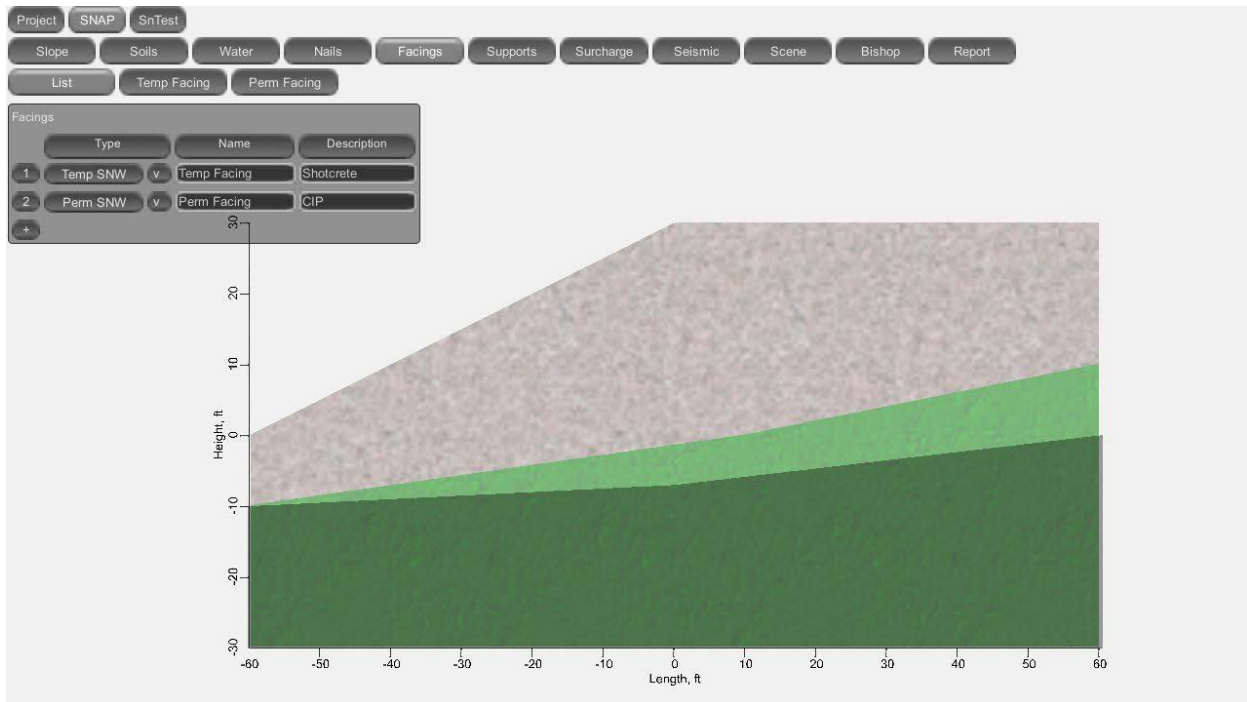

Figure 12. Screen Shot. SNAP – Facings – List

Click on a Facing tab, to the right of the List tab, to activate a set of data boxes used to input reinforcement, concrete and facing connection data.

For a temporary facing, data boxes include Mesh, Bars, Shotcrete, and Plate (Figure 13). When the Mesh or Bars data boxes are made inactive by clicking on the respective radio button, the data box will disappear and the data will not be used in the wall analysis. Mesh data includes the wire spacing, size, and yield strength. Bar data includes number, spacing, size, and yield strength for both the horizontal walers and the vertical bearing bars. Because vertical bearing bars on not typically continuous, the bar length is required. Shotcrete data includes compressive strength, thickness, pressure factors for flexure and shear, and factors of safety for flexure and shear in both static and seismic conditions. Plate data includes the plate dimensions and the nail head service load factor.
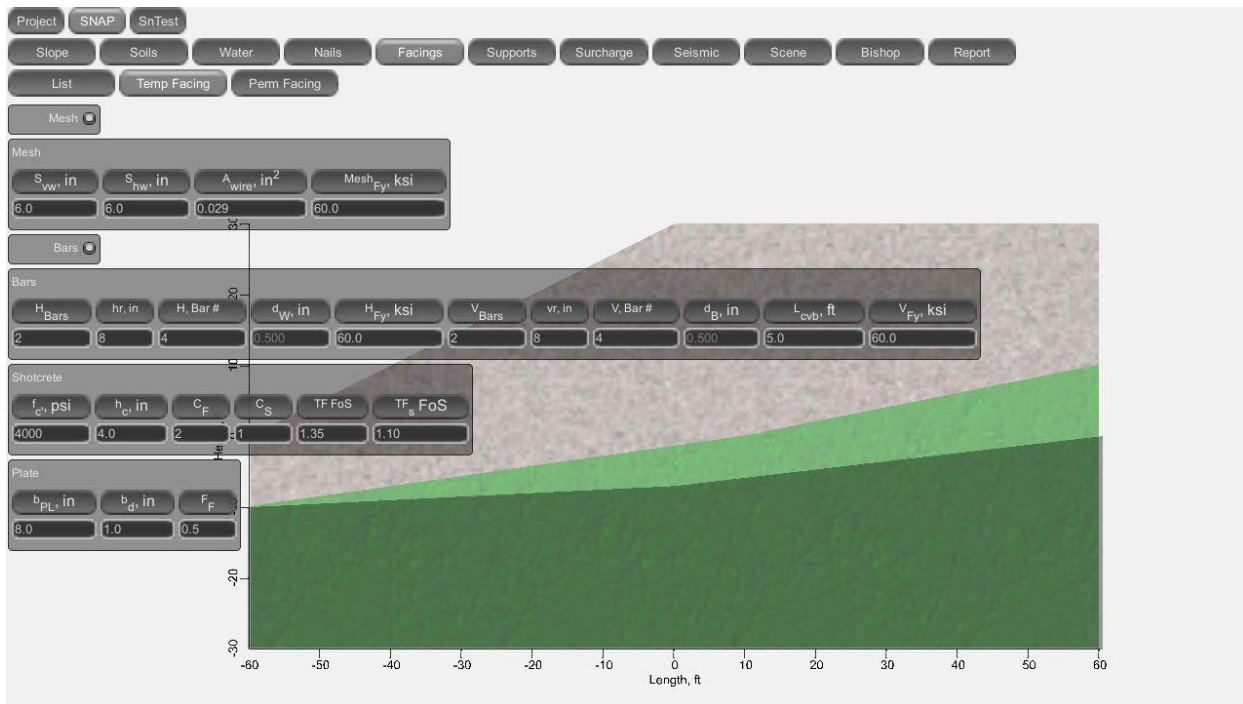

Figure 13. Screen Shot. SNAP – Facings –Temporary Facing

For a permanent facing, data boxes include Mesh, Bars, Concrete, and Studs (Figure 14). When the Mesh or Bars data boxes are made inactive by clicking on the respective radio button, the data box will disappear and the data will not be used in the wall analysis. Mesh input is the same as for temporary facing. Because the reinforcement in the permanent facing is typically continuous, the input includes spacing, size, and yield strength for both horizontal and vertical reinforcing bars. Concrete input includes compressive strength, thickness, pressure factors for flexure and shear, and factors of safety for flexure and shear in both static and seismic conditions. Stud input includes plate thickness (this should be the same value as for the temporary facing), stud number per plate, dimensions, spacing, yield strength, and factors of safety in both static and seismic conditions. Click on the Supports tab to enter data on wall dimensions, construction steps, soil nail dimensions and configuration, and the final ground slope.
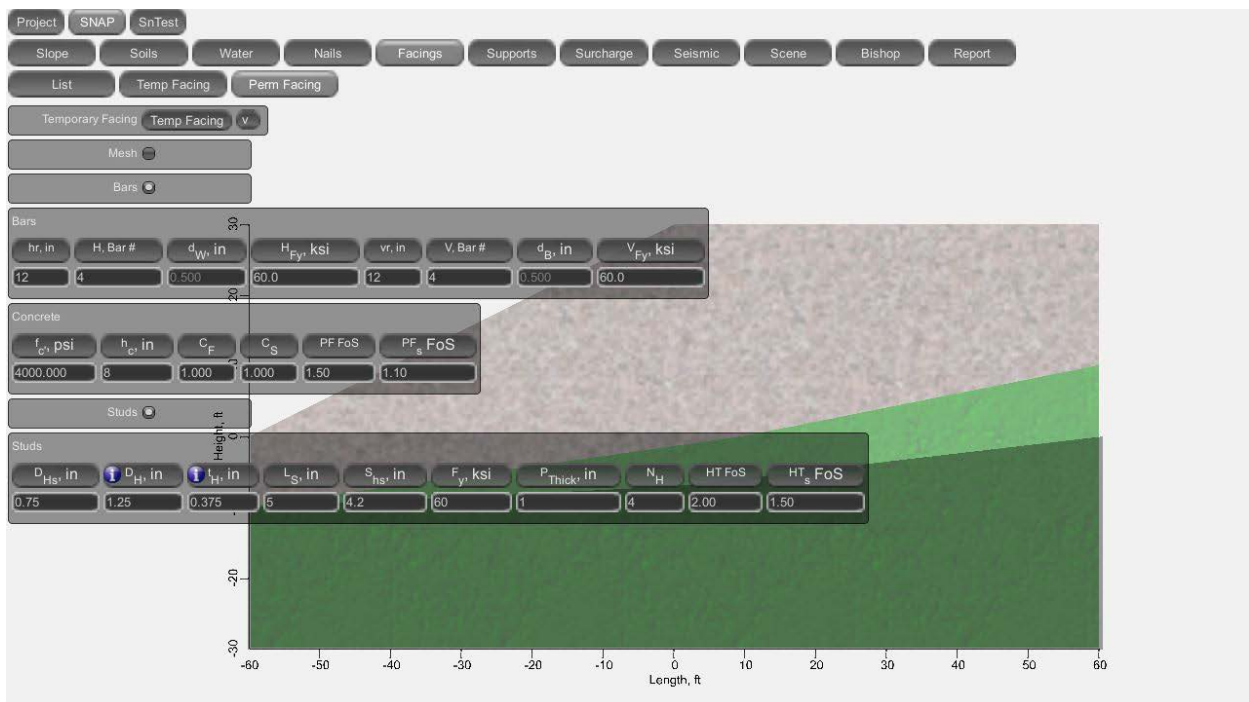

Figure 14. Screen Shot. SNAP – Facings – Permanent Facing

SNAP – Supports

Click on the plus sign (+) in the Support Types data box to define a soil nail wall (Figure 15).
One or multiple soil nail walls (stepped walls in a single cross section) can be defined. Type in a
Name and Description for each soil nail wall in the dialog boxes. The default name for soil nail
walls is SN Wall 1, 2, 3… etc. As soil nail walls are added, tabs with the Name will appear to
the right of the List tab. A default soil nail wall will appear on the graphical display that shows
the wall face in yellow, the soil nails in black, and the TForce in the color selected previously.
To delete soil nail walls, click on the number in the Support Types data box and press the Delete
key. Click on a wall name tab to the right of the List tab and five sub-tabs appear below the List
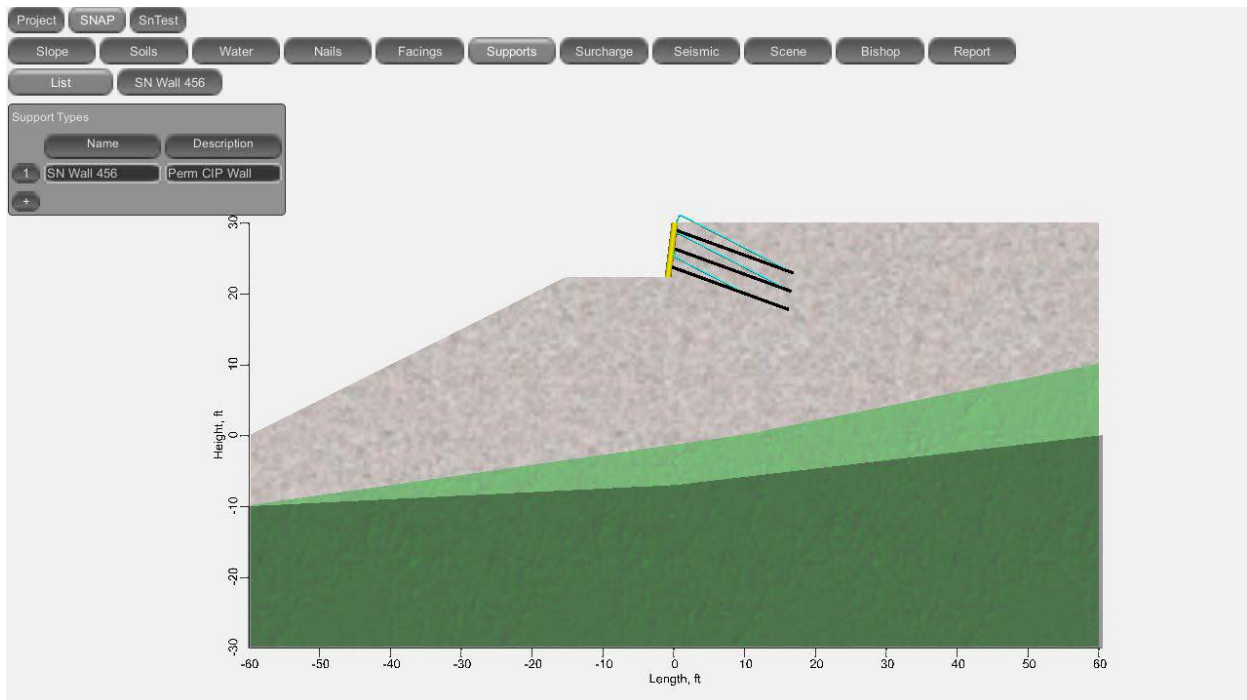tab.

Figure 15. Screen Shot. SNAP – Supports - List

SNAP – Supports - Wall

Click on the Facing down arrow in the Wall data box and select a facing from those entered in
the **SNAP – Facings** screen (Figure 16). Type in dimensional data for the soil nail wall
including Base and Top coordinate points, wall height, wall batter angle, wall embedment, and
the wall width. These values are integrated so that changing a value in one dialog box may cause
value in other dialog boxes to change. For example, changing the wall height (H) will cause the
Y-coordinate for the wall Top to change accordingly. The wall Width value refers to the Z-
dimension in and out of the plane of the cross section and will not affect calculations. It is used
to create the 3-D representation of the wall shown when the Scene tab is activated (this will be
discussed more under **SNAP- Scene**).

The Construction data box has two tabs. The Construction # tab is for selecting the number of
construction steps. This number can be selected by either typing in the number or adjusting the
slider below the dialog box. The maximum number of construction steps is 20. The number of
construction steps will affect how user is able to evaluate the factor of safety for global stability

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and the forces on the various components of the soil nail wall for each stage of construction as the soil nail wall is built in step-wise, top-down procedure. The recommended number of construction steps is the number of nails in the cross section plus one. This will allow the user to evaluate stability and forces as each row of nails is excavated and installed. The Con$_{seq}$ tab is used to establish the step when wall construction begins for each wall. When a single wall is being analyzed this value should be one (1). Click on the Nails tab to the right of the Wall tab to enter data on soil nail dimensions and configuration.
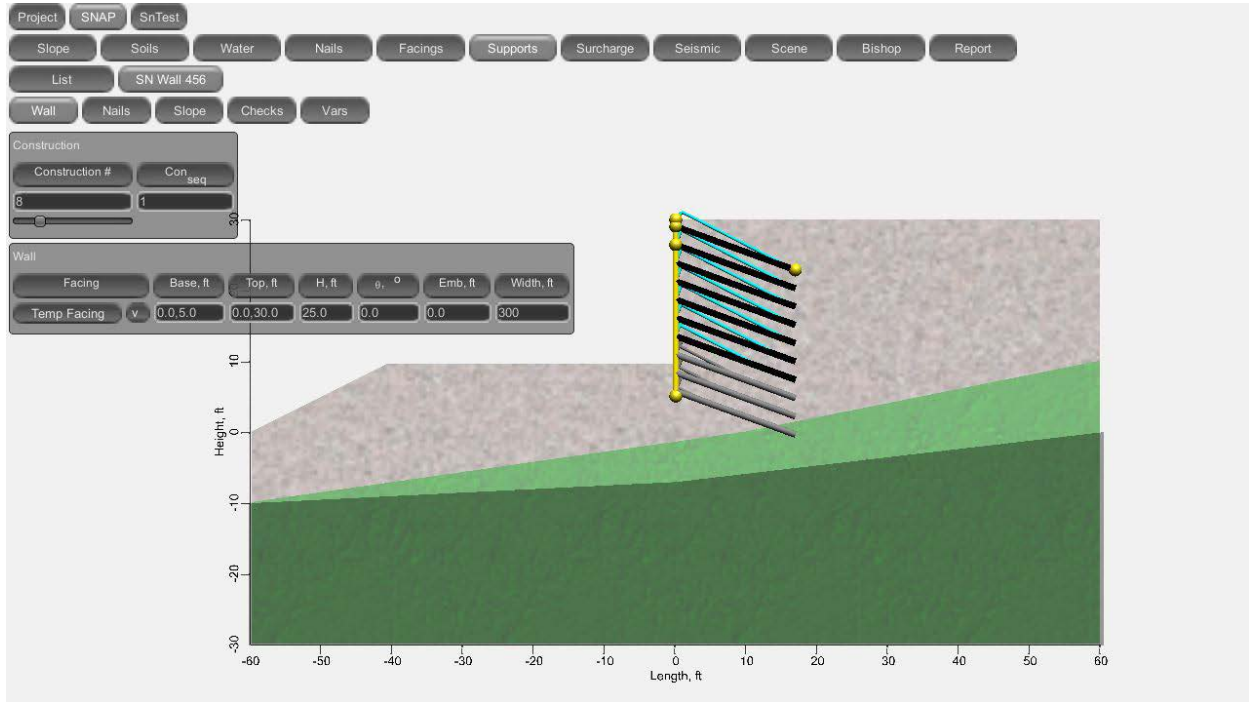

Figure 16. Screen Shot. SNAP – Supports – Wall

SNAP - Supports – Nails

This information is entered separately for each tendon bar set that was defined in the **SNAP – Nails** screen (Figure 17). Enter soil nail length (L), vertical spacing (S_V), horizontal spacing (S_H), inclination (δ), and the cantilever distance (C_d) in the dialog boxes. This is the distance from the top of the wall to the top row of nails. When the Offset (O) radio button is active the nail face pattern is offset (sometimes called triangular), otherwise the nails are in a square pattern. This selection does not affect calculations but will be depicted on the 3-D representation of the wall that is shown when the Scene tab is activated. When the Uniform (U) radio button is active, all of the nails are Uniform, that is, the dimensions in Nails data box apply to all the nails. When the Uniform (U) radio button is inactive, clicking the number tab below the Nail List tab reveals a list of the nails by row that will allow the entry of nail length (L), inclination (δ), vertical spacing (S_V), and bar tendon set for each row of nails.

When the Shorten T_F radio button is active the soil nails in the lower part of the wall will be shortened in accordance with the empirical method describe in Appendix A. This shortening will be shown on the graphical display. The allowable nail load, depicted by the blue line above each soil nail, will be shortened accordingly for the soil nails in the lower part of the soil nail wall. Click on the Slope tab to the right of the Nails tab to enter coordinate points for the final slope configuration.
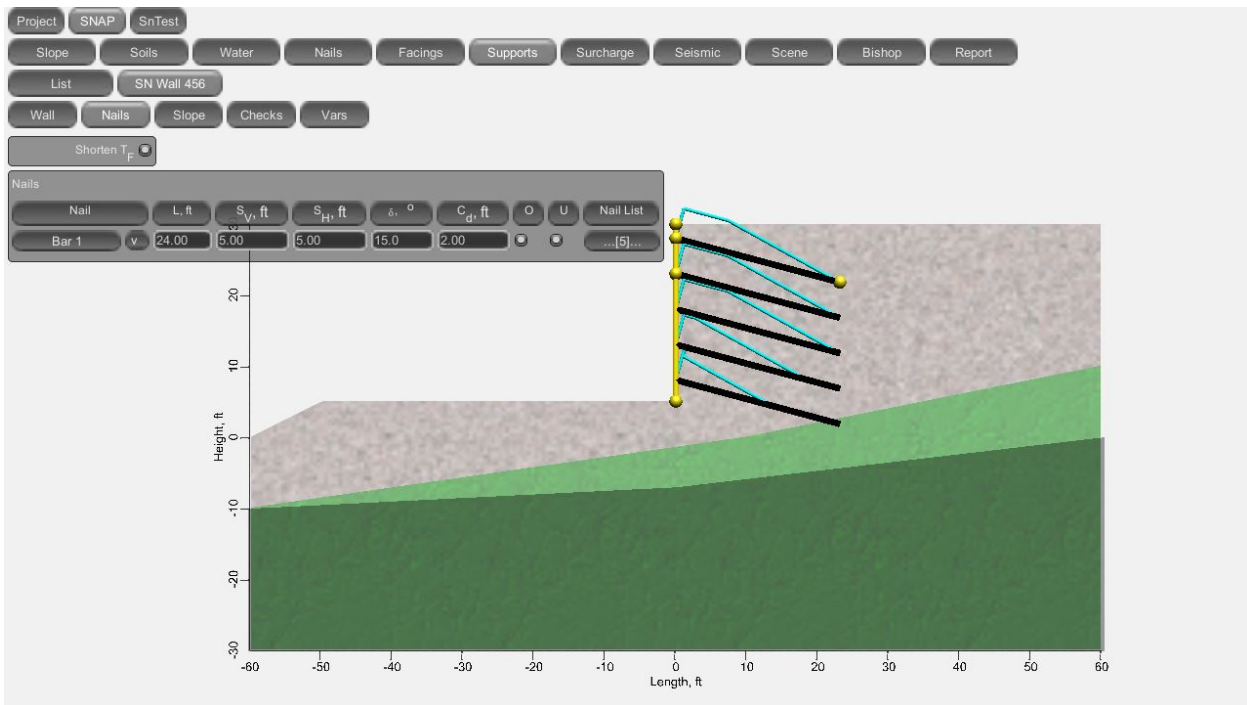

Figure 17. Screen Shot. SNAP – Supports – Nails

SNAP – Supports – Slope

This tab is used to describe the final surface slope following soil nail wall construction when it will be modified from the original surface slope other than what is caused by soil nail wall construction (Figure 18). Click on the plus sign (+) in the Downslope data box to add coordinate points to describe the final slope below (to the left of) the soil nail wall. Click on the plus sign (+) in the Backslope data box to add coordinate points to describe the final slope above (to the right of) the soil nail wall. For both Downslope and Backslope, points are added left to right. The Checks and Vars tabs will be discussed in a later section. Click on the Surcharge tab to enter data on surcharge loads.
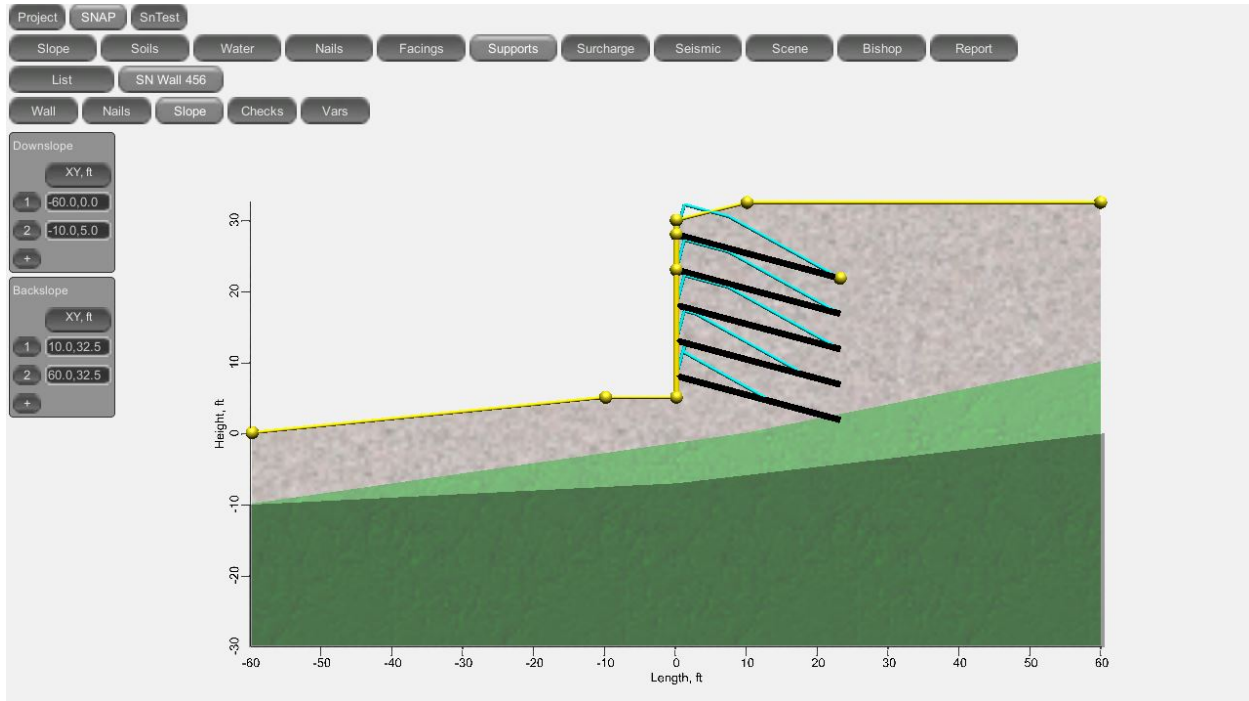

Figure 18. Screen Shot. SNAP – Supports – Slope

SNAP – Surcharge

Click on the plus sign (+) in the Surcharge Points data box to define a surcharge load, multiple surcharge loads can be defined (Figure 19). Enter X-coordinate points into the X1 and X2 dialog boxes to define the left and right extents, respectively, of the surcharge load. Enter the vertical magnitude of a surcharge in the q_s dialog box as either a uniform load (one number) or as a load that varies linearly between X1 and X2 (two numbers). Enter the horizontal magnitude of a surcharge load in the q_{sH} dialog box as either a uniform load (one number) or as a load that varies linearly between X1 and X2 (two numbers). Horizontal surcharge loads can be used to simulate a ground anchor on the face of the wall if the wall is battered. Surcharge loads are depicted on the graphical display as a series of black lines and yellow arrows.

The surcharge can be applied during any construction stages or only after construction is complete, such as structure or traffic loads. Enter the construction step number(s) when the surcharge load will be applied in the Con_{seg} dialog box. To simulate post-construction loading the surcharge load is applied only for the final construction step. The Construction Step # data box is shown to for reference and should not be modified in this screen. Click on the Seismic tab to enter data on seismic loading.
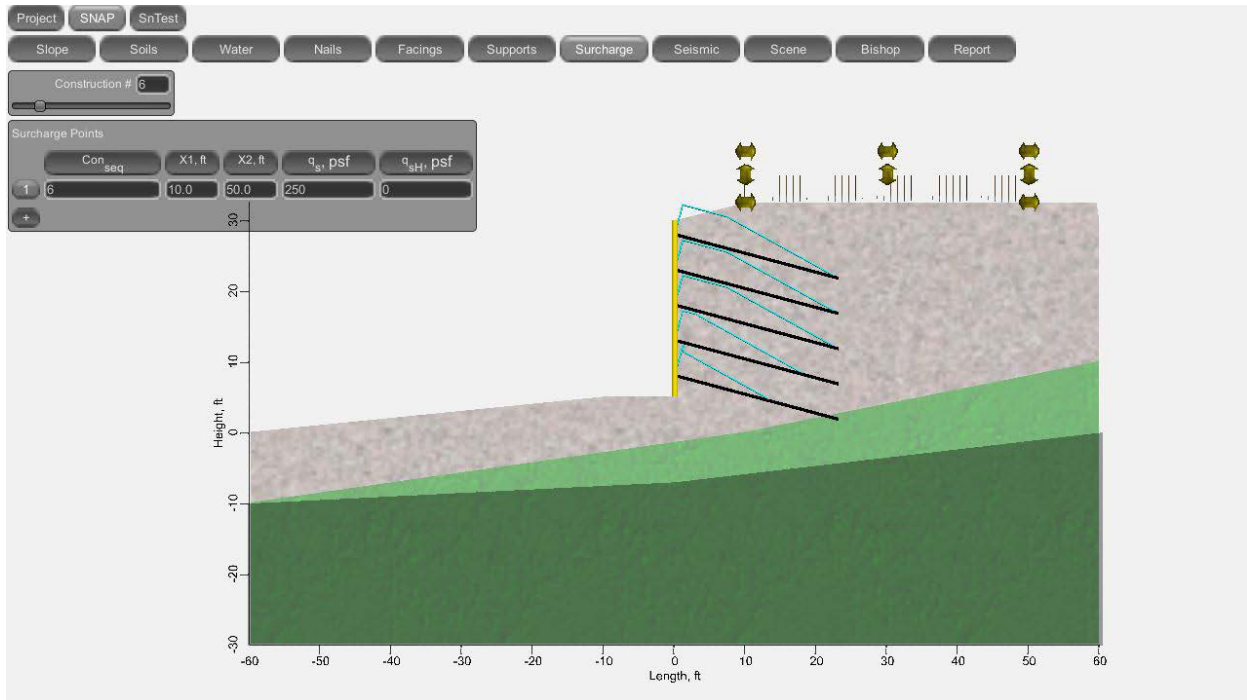

Figure 19. Screen Shot. SNAP - Surcharge

SNAP - Seismic

Click on the Seismic radio button to activate seismic loading (Figure 20). When analyzing static conditions or when there is no seismic loading, the Seismic radio button should be inactive. To enter the horizontal seismic coefficient directly, click on the Calc K_h radio button to make it inactive and then enter the horizontal seismic coefficient in the K_h dialog box. Alternatively, click on the Calc K_h radio button to make it active and then enter the tolerable seismically induced lateral wall movement in the d dialog box and the peak ground acceleration in the A dialog box. The program will calculate the normalized horizontal acceleration, Am. The vertical

seismic coefficient is not usually considered in soil nail wall design but it can be manually entered by the user. SNAP_2 uses the Mononobe-Okabe method to calculate seismic loading on the wall. Click on the Supports tab and then Checks tab.
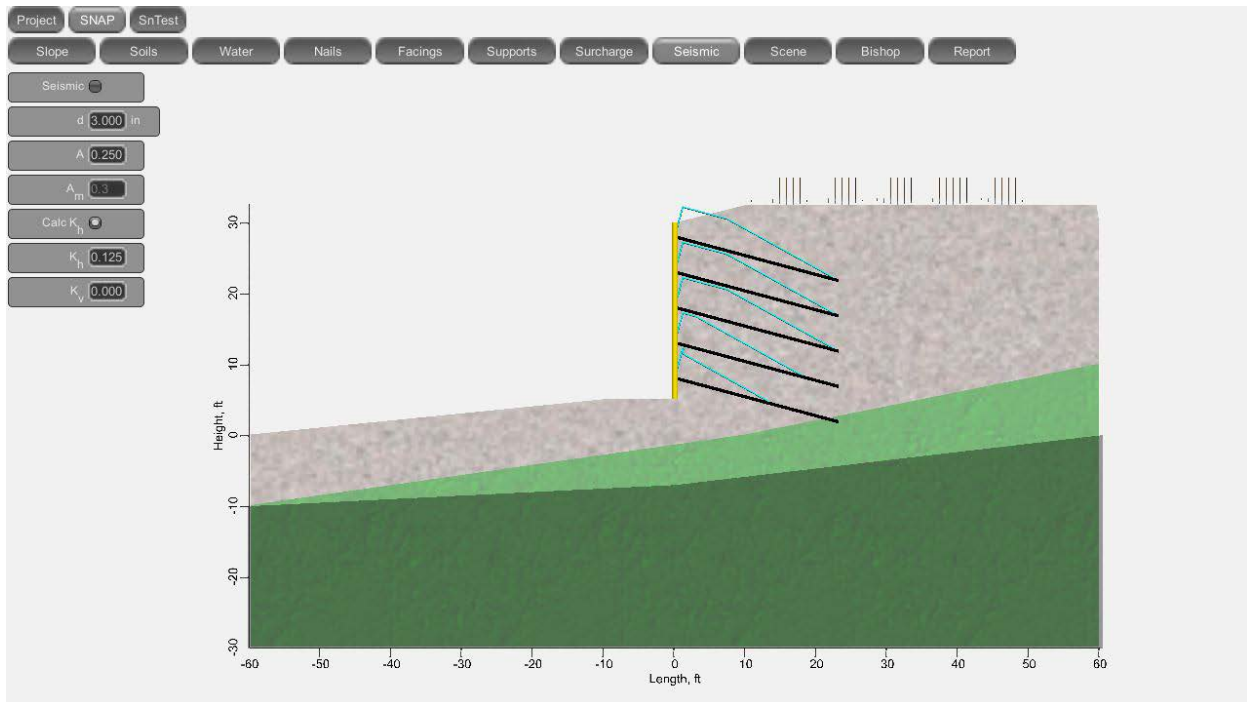

Figure 20. Screen Shot. SNAP – Seismic

SNAP – Supports – Checks

The Checks data box lists checks that are done by the program. Information about each check will appear in the banner at the bottom of the screen when the mouse icon in placed on a tab in the Checks data box.

The Displacement data box presents an estimate of the predicted displacement of the top of the soil nail wall (δ), and the horizontal distance behind the top of the soil nail wall where deformation can be significant (λ). These calculations are based on the empirical equations in GEC #7. Two values need to be entered, the displacement ratio ($\delta_{h/H}$), and the damping coefficient (κ). These values are dependent on the general soil type in the soil nail reinforced mass behind the wall facing. When the mouse icon is place on the $\delta_{h/H}$ tab or the κ tab, the recommended values for the general soil types are listed in the bottom banner.

There are two Checks screens, one for a temporary facing (Figure 21) and one for a permanent facing (Figure 22). To review the checks for either the temporary or permanent facing, click on the Supports tab, the Wall tab, and then the Facings down arrow in the Wall data box and select either Temp Facing or Perm Facing. Then, click the Checks tab to review the checks.
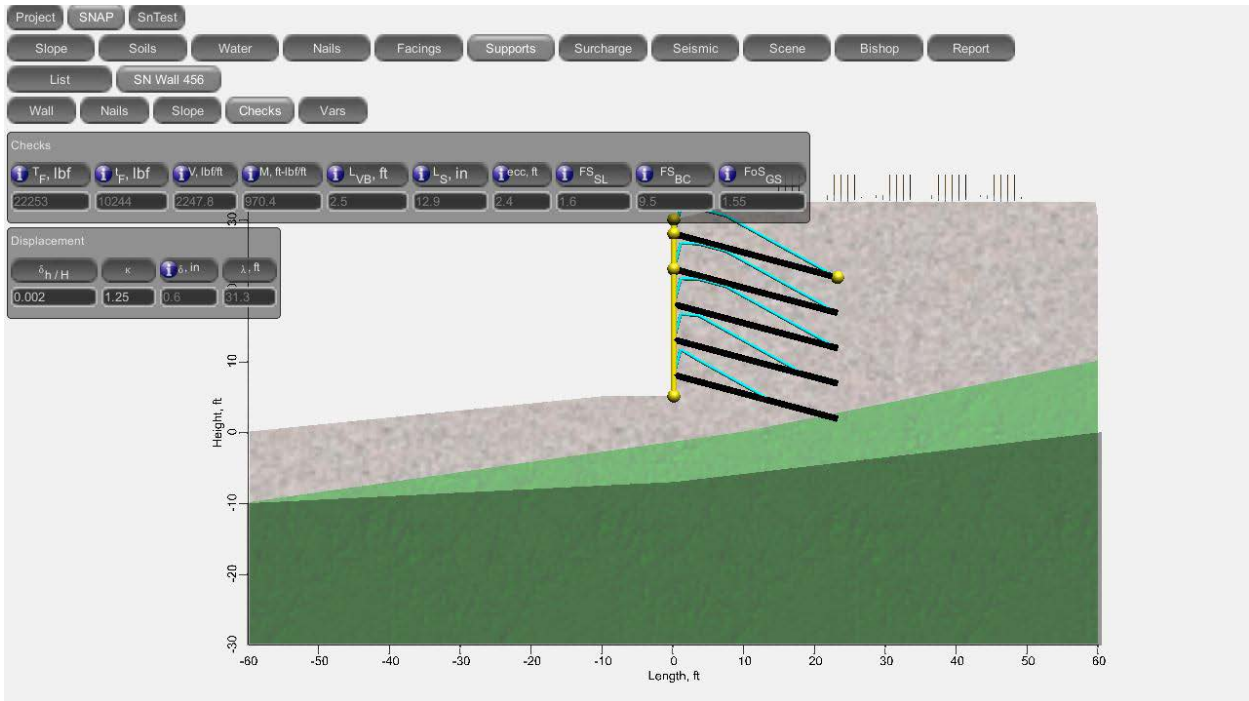
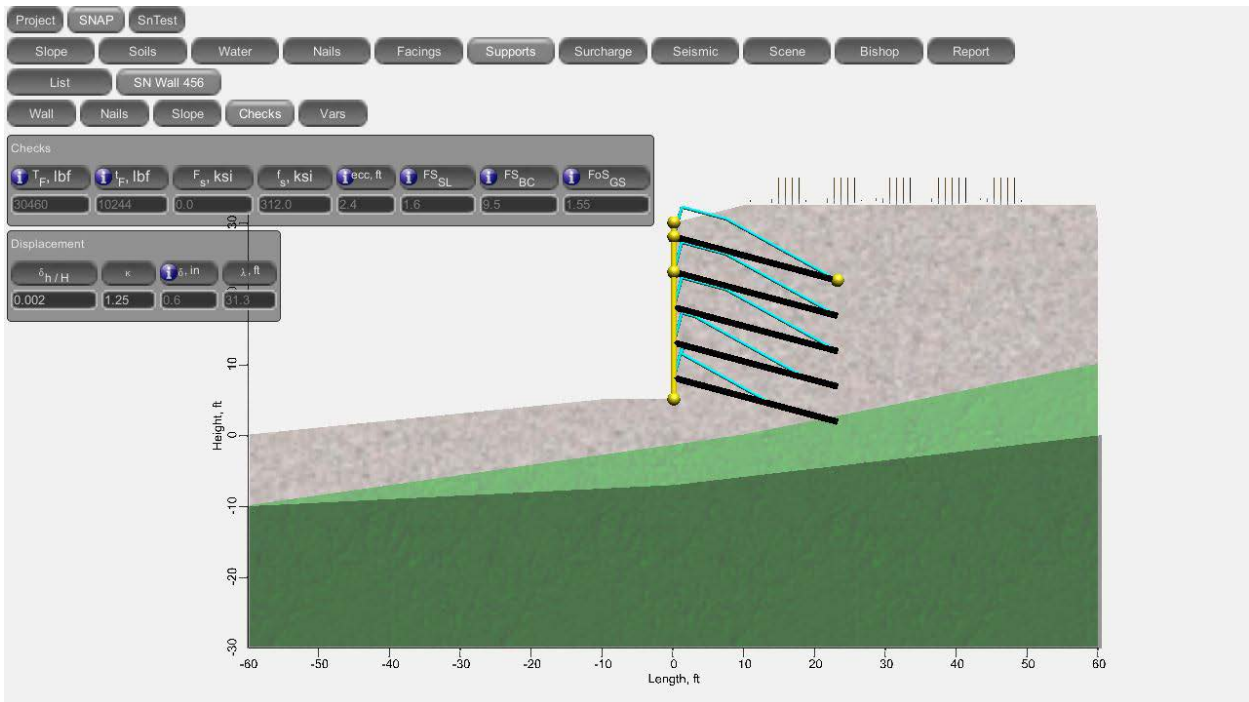**Figure 21. Screen Shot. SNAP – Supports – Checks – SC**

Figure 22. Screen Shot. SNAP – Supports – Checks – CIP

SNAP - Supports – Vars

There are two Vars (variables) screens, one for a temporary facing (Figure 23) and one for a permanent facing (Figure 24). To review the variables for either the temporary or permanent facing, click on the Supports tab, the Wall tab, and then the Facings down arrow in the Wall data box and select either Temp Facing or Perm Facing. Then click the Vars tab to review the variables.

The Vars screens list variables that are either entered by the user or calculated by the program. These variables are used in calculations to determine facing capacity, nail head service load, tendon capacity, and external stability. Also listed are structural checks on the facing that are required by AASHTO. If the data boxes run off the monitor, slider bars will appear at the bottom and/or the right of the screen to allow viewing of all the data boxes full content.
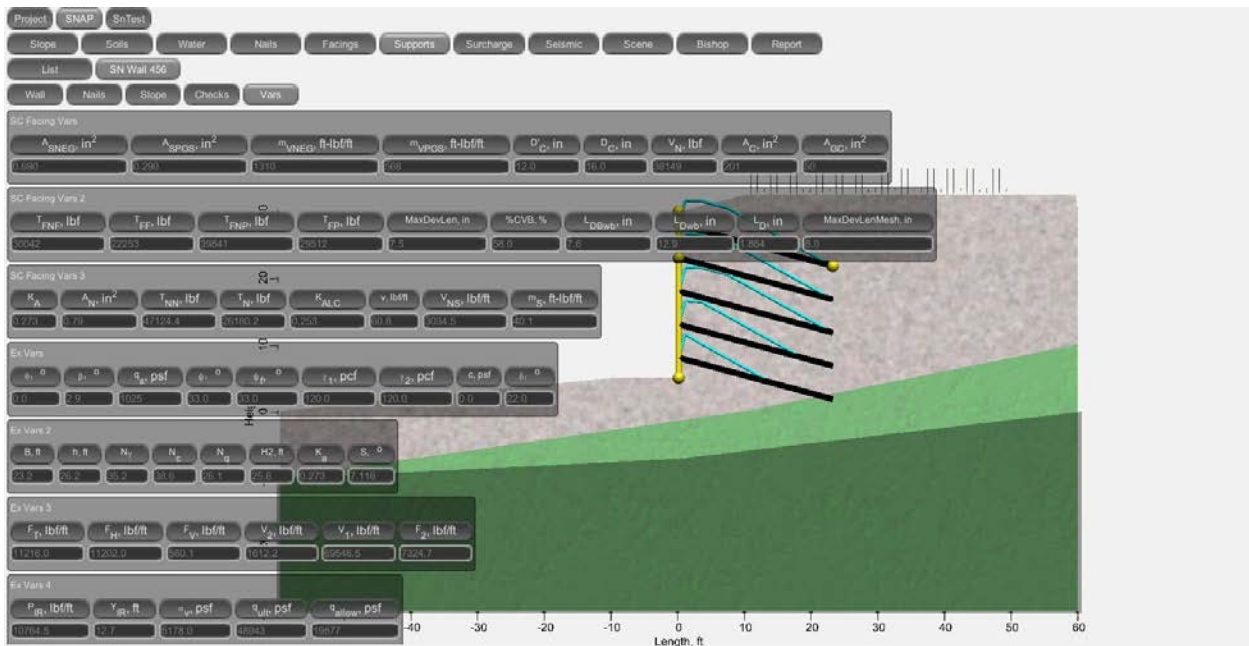

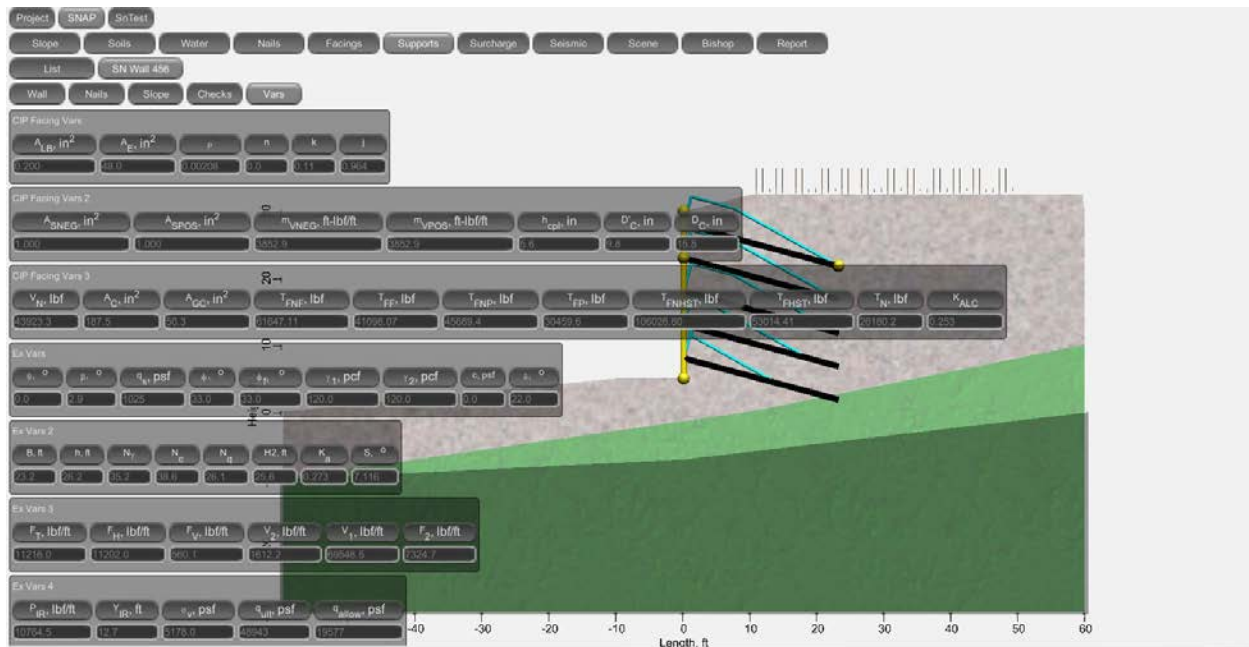**Figure 23. Screen Shot. SNAP – Supports – Vars – SC**

Figure 24. Screen Shot. SNAP – Supports – Vars - CIP

SNAP - Scene

Click the Scene tab to view a 3-D representation of the soil nail wall. There are two Scene screens, one for a temporary facing and one for a permanent facing. To view the soil nail wall with either the temporary or permanent facing, click on the Supports tab, the Wall tab, and then the Facings down arrow in the Wall data box and select either Temp Facing or Perm Facing. Then click the Scene tab to view the soil nail wall.

To navigate around the view, use the arrow keys on the keyboard to move ahead, back, left and right. Hold down the Shift key to move faster. Hold down the left mouse key and drag the mouse to rotate the view up and down or back and forth.

View the wall at various stages of construction by changing the construction number in the Construction # data box. To see the reinforcement in the shotcrete, use the slider in the Shotcrete data box to vary the opacity of the shotcrete. To see the reinforcement in the permanent facing use the slider in the Concrete data box to vary the opacity of the concrete.

This function can be used to visually check that the facing is correct and to save 3-D views for inclusion in the report. To save time, click on the Load tab in the Closeup (Figure 25) or Panorama (Figure 26) data boxes and then the Save tab. These views will be saved to be included in the report.
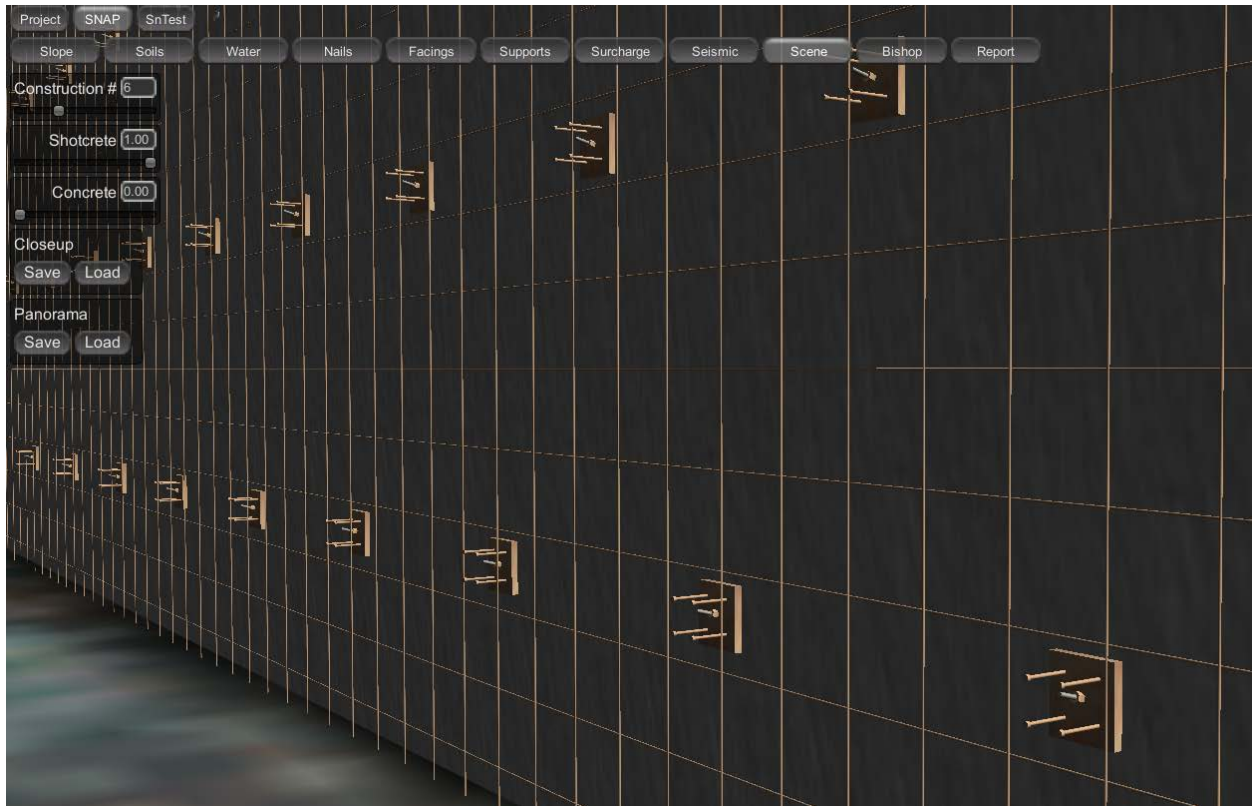
Figure 25. Screen Shot. SNAP –Scene - Closeup

Figure 26. Screen Shot. SNAP – Scene – Panorama

SNAP – Bishop

In the Min_{Depth} data box, input the minimum height of the failure circle arc to prevent small failure circles. Click on the Calc tab to see the critical failure circle and global factor of safety displayed for the static condition (Figure 27). Click the Seismics radio button to see the critical failure circle and factor of safety displayed for the seismic condition (Figure 28). For both static

and seismic conditions, the Center, Radius, and Factor of Safety for the critical failure surface is displayed in the respective data boxes. Adjust the resolution (spacing) of the failure circle centers to find the lowest critical global factor of safety. Note that as the spacing decreases, the time for calculating the global factor of safety will increase exponentially.
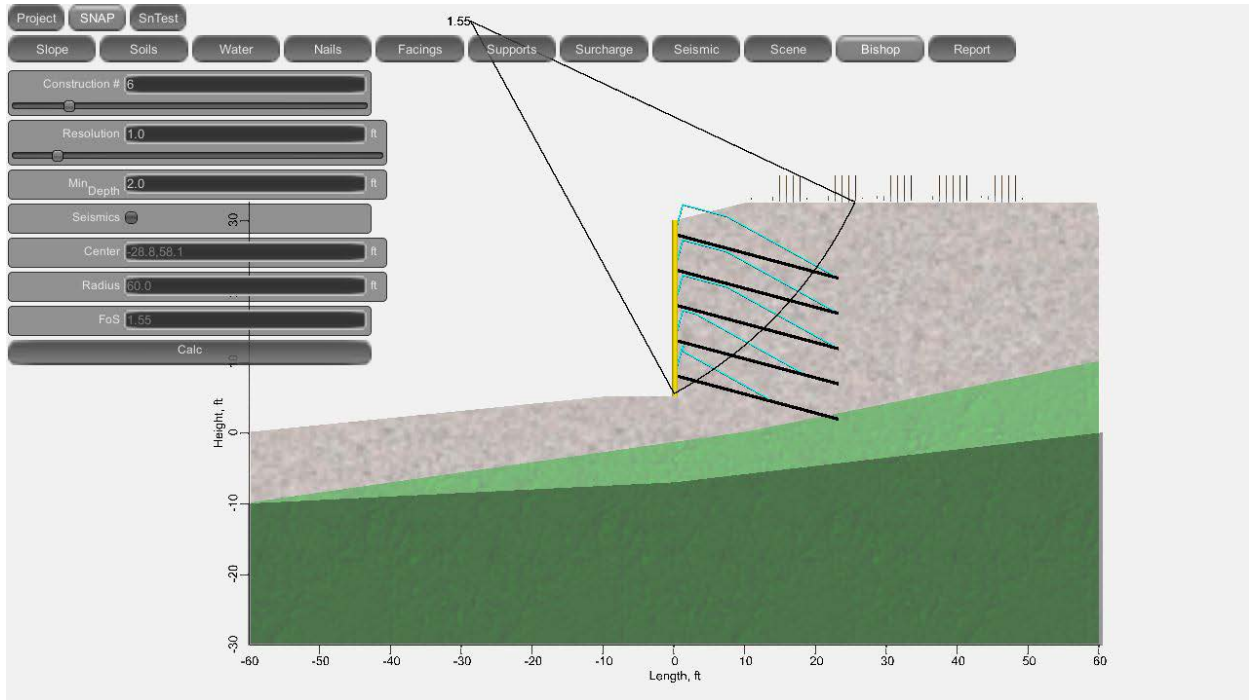

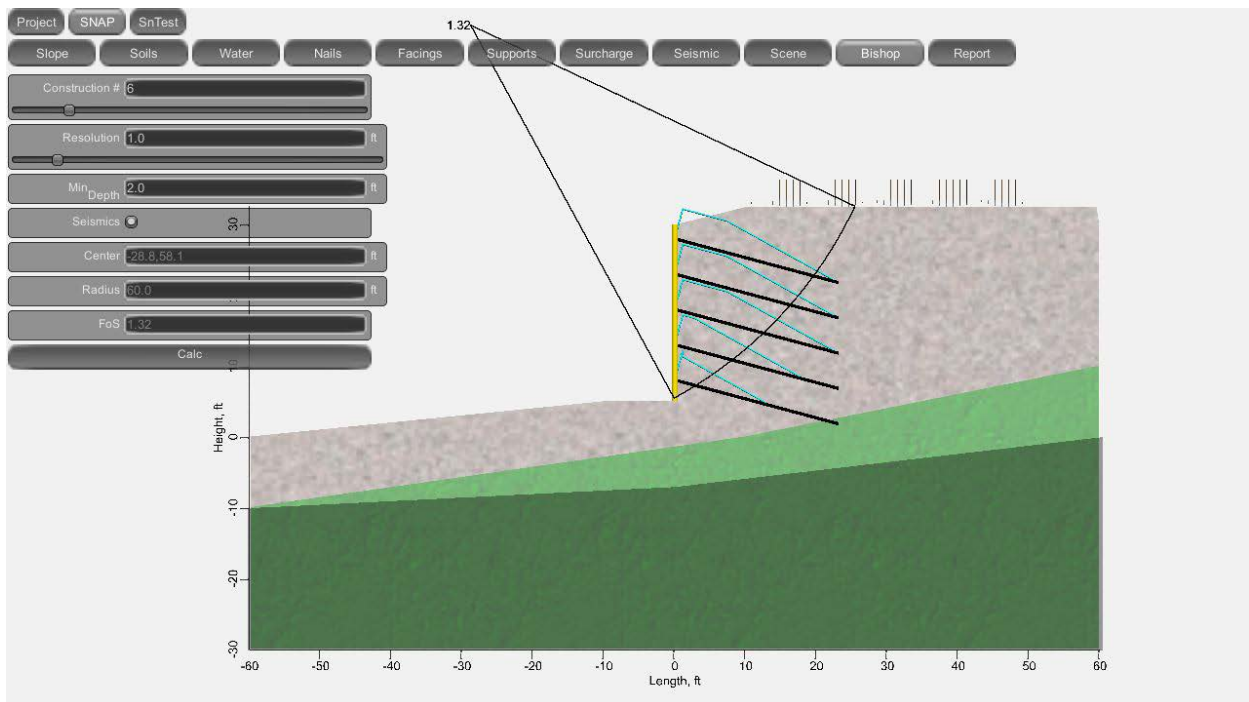**Figure 27. Screen Shot. SNAP – Bishop - Static**

Figure 28. Screen Shot. SNAP – Bishop - Seismic

SNAP – Report

Click on the Report tab when the SNAP_2 analysis is complete. Use the radio buttons to select what will be included in the report (Figure 29). Options include:

- Both Units – when this radio button is activated both US and SI units will be included in the report, otherwise only the units selected in the Projects – Settings screen will be included in the report;
- Cuts – when this radio button is activated the critical failure surface and global factor of safety (for the static condition) for each staged of construction will be included in the report;
- Static – when this radio button is activated the critical failure surface and global factor of safety for the static condition will be included in the report;
- Seismic - when this radio button is activated the critical failure surface and global factor of safety for the seismic condition will be included in the report;
- Scene – when this radio button is activated the Closeup and/or Panorama scenes that were saved in the SNAP – Scene screen will be included in the report.

Click on the Report tab below the radio buttons to create a report, this may take a few minutes depending on how many radio buttons are activated. This will create and open an .html document which can be saved as a text file or copied and saved to some other file format (e.g., .doc, .pdf, etc.).
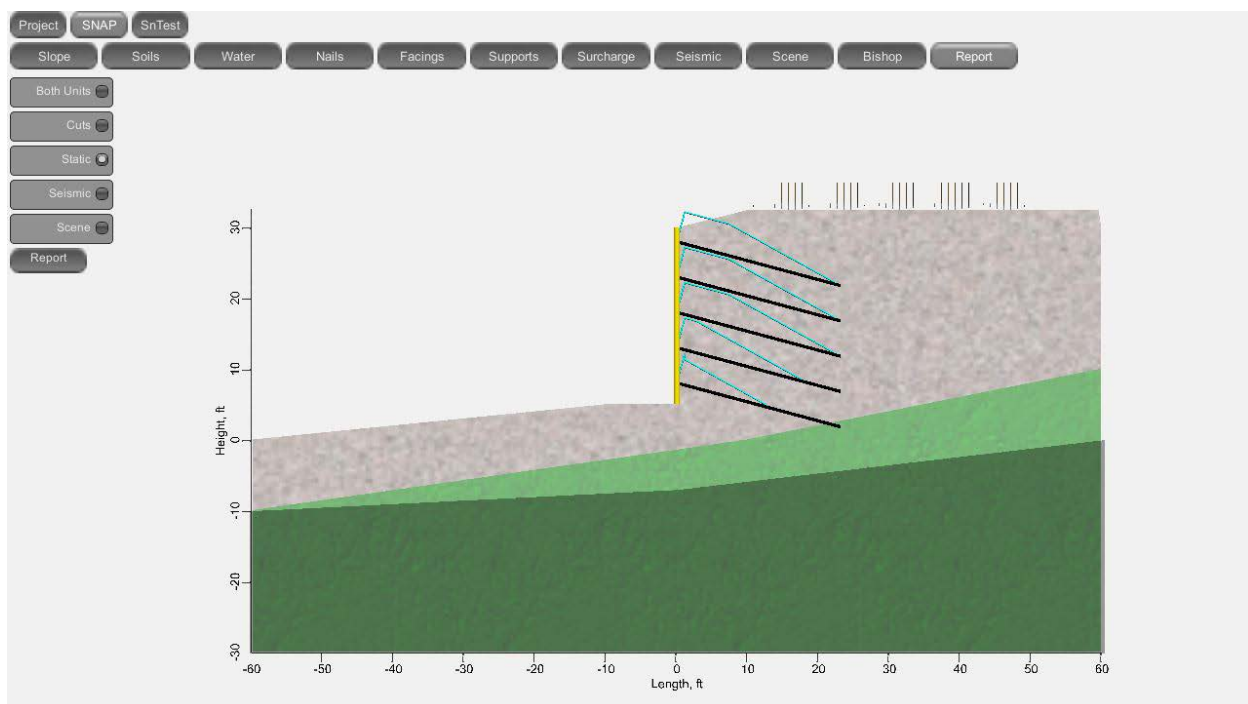

Figure 29. Screen Shot. SNAP – Report

A design example is shown in Chapter 3 and the report for the design example is shown in Appendix B.

SnTest – List

Specifications require a minimum of two verification load tests per soil nail wall. Proof tests are required on a minimum of 5% of production soil nails, with at least one proof test per row of soil nails. SNAP_2 includes a function that allows the user to record load test information and results for verification and proof tests performed on a project (Figure 30).

Click on the SnTest tab and then the List tab. Click on the plus sign (+) tab in the Test data box to add a load test. Click on the load test number in the Test data box and press the Delete key to delete a load test. Click on the Type down arrow and select a load test type (either Verification or Proof from the drop down menu. Tabs for each load test will appear to the right of the List tab. Type in a Name and Description for each load test.

Figure 30. Screen Shot. SnTest – List

SnTest – Verification/Proof - Design

Click on a Verification or Proof tab and a set of tabs will appear (Figure 31). First is the Data tab, which allows the input of test parameters in the Inputs data box. The Outputs data box shows values that are calculated from the values in the Inputs data box. Checks are made on the length of the bond zone, and for the verification test, to make sure that the length of the bond zone results in a maximum test load that does not exceed the maximum allowable test load.
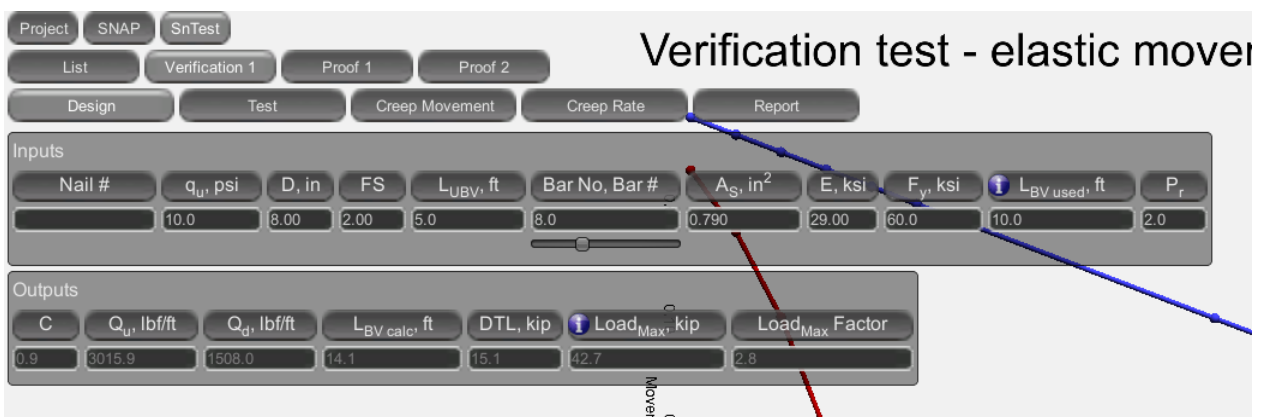

Figure 31. Screen Shot. SnTest – Verification – Design

SnTest – Verification/Proof – Test

Click on the Test tab to input actual test loads, jack gauge pressure, and dial gauge readings for each load increment and for the creep test at the 1.50 DTL load increment (Figure 32). This data can be typed or copied from an excel spreadsheet. For the verification test, additional dialog boxes are provided for test increments up to 3.0 DTL and creep test data for the 1.75 and 2.00 DTL load increments. A load-movement graph is developed showing the average dial gauge reading versus the actual test load in red and the minimum elastic movement criteria in blue.
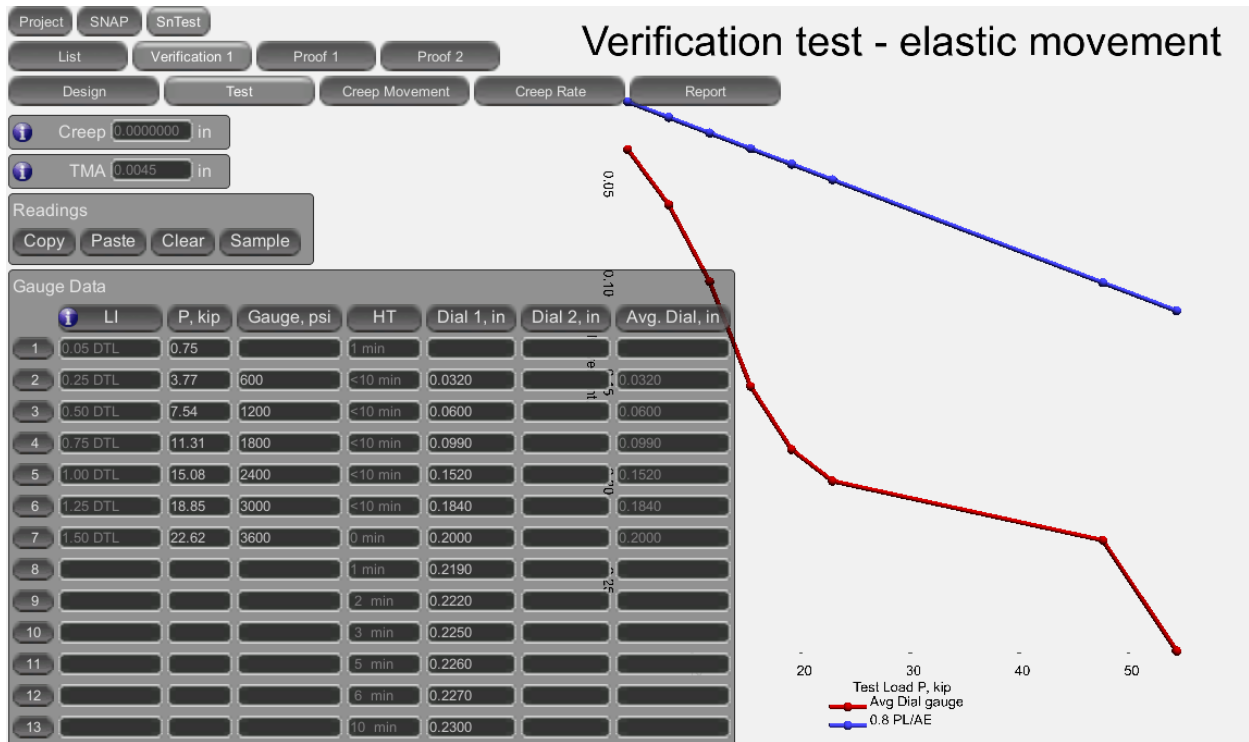
Figure 32. Screen Shot. SnTest – Verification – Test

SnTest – Verification/Proof – Creep Movement

Click on the Creep Movement tab to show a Creep Movement verses Time graph (Figure 33). For the verification test, the Creep Movement versus Time graph can be shown for any or all of the load increments by selecting the radio buttons on the appropriate data boxes.
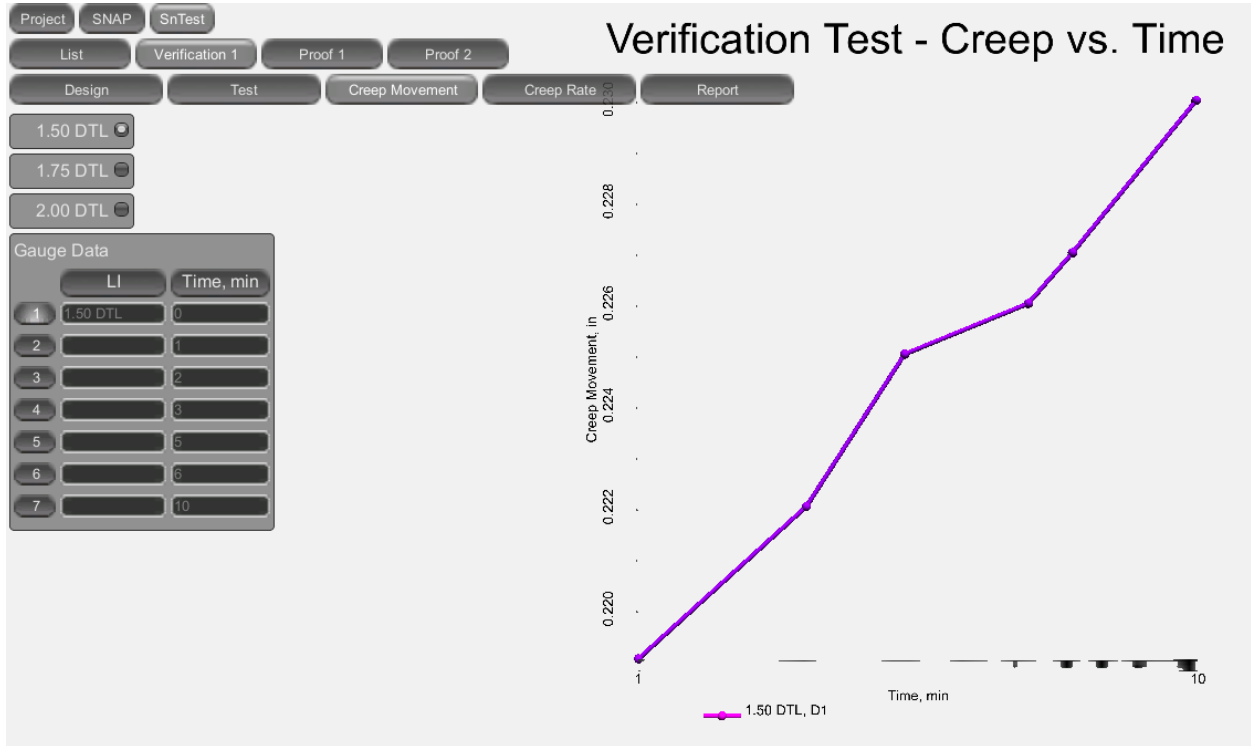

Figure 33. Screen Shot. SnTest – Verification – Creep Movement

SnTest – Verification/Proof – Creep Rate

Click on the Creep Rate tab to show a Creep Rate verses Time graph (Figure 34). For the verification test, the Creep Rate versus Time graph can be shown for any or all of the load increments by selecting the radio buttons on the appropriate data boxes.
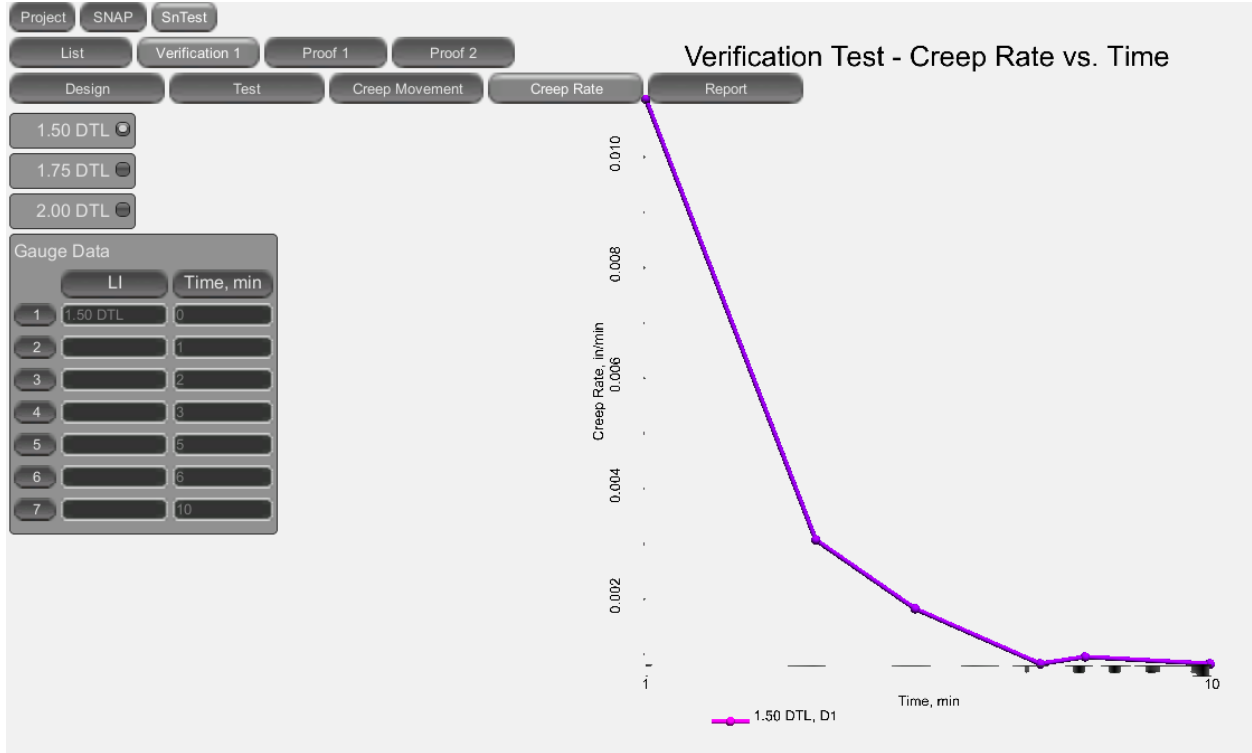

Figure 34. Screen Shot. SnTest – Verification – Creep Rate

SnTest – Verification/Proof – Report

Activate the Both Units radio button to have both US and SI units included in the report, otherwise only the units selected in the Projects – Settings screen will be included in the report (Figure 35). Click on the Report tab to create a load test report. This will create and open an .html document which can be saved as a text file or copied and saved to some other file format (e.g., .doc, .pdf, etc.).
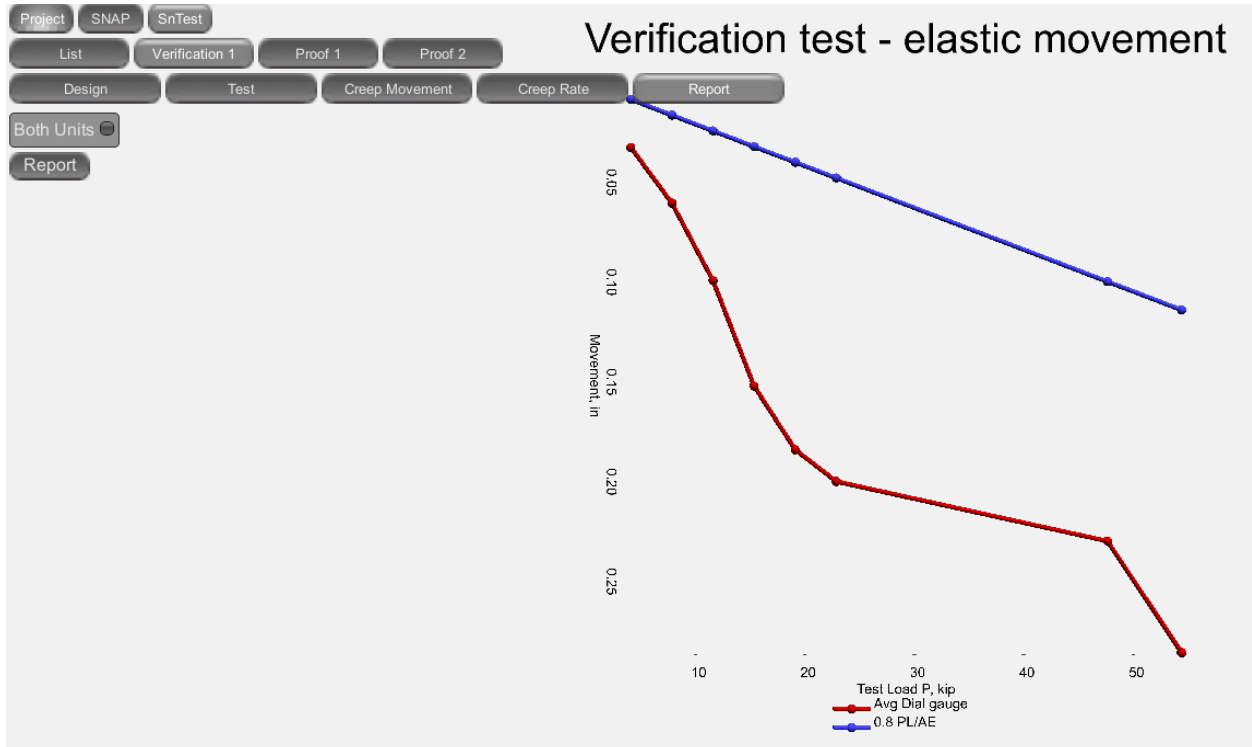

Figure 35. Screen Shot. SnTest – Verification – Report

CHAPTER 3 – DESIGN EXAMPLE

SNAP_2 APPLICATION

The following is a demonstration of the application of SNAP_2 for design of a soil nail wall support for a two-tiered wall (Figure 36). Each wall tier is 20 feet high for a total wall height of 40 feet, and the offset between wall tiers is 25 feet (horizontal distance between the tops of each wall). This example can be loaded in SNAP_2 by selecting Project > Example 1.
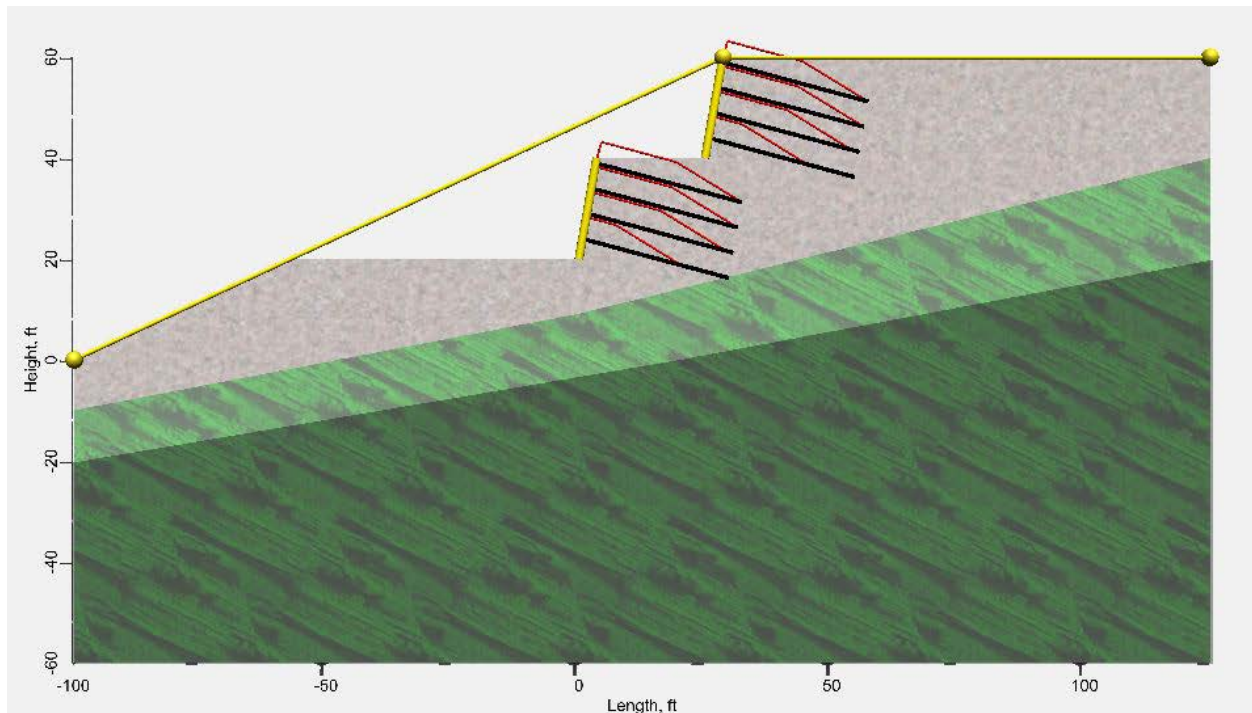

Figure 36. Screen Shot. Design Example 1

Geometry

The original ground is horizontal to the right of the top of the upper tier of the wall and slopes down to the left at an angle of 25 degrees from the horizontal (Figure 37). Each wall tier is 20 feet high with a batter of 10 degrees from the vertical. The top of the upper wall tier is located at the break in slope of the original ground, and the horizontal distance between the tops of the two tiers is 25 feet.

Figure 37. Screen Shot.
X and Y coordinates for original ground surface points

Soils Data

There are two soil types behind and below the wall (Figure 38). The upper soil is a medium dense Silty SAND with γ = 115 pcf, φ = 32°, c = 0, and q_u = 15.0 psi. The lower soil is a dense SAND with γ = 125 pcf, φ = 39°, c = 0, and q_u = 15.0 psi. The colors for soils 1 and 2 are selected to be white and green, respectively. The points that describe the top of the dense SAND are shown below (Figure 39).

	Name	Texture		Color		γ'_s, pcf	φ', °	δ_s', °	c', psf	q_u, psi	N_c	N_q	N_γ
1	MD Silty SAND	sand	v	white	v	115	32	21.3	0.0	15.0	35.5	23.2	30.2
2	Dense SAND	sedimentary	v	green	v	120	39	26	0.0	15.0	67.9	56.0	92.2

Figure 38. Screen Shot. Soil properties

Figure 39. Screen Shot.
X and Y coordinates for top of Dense SAND

Groundwater

The groundwater is well below the soil nail wall, but was encountered in the subsurface investigation and found in the Dense SAND. The points that describe the surface of the groundwater are shown below (Figure 40).

Figure 40. Screen Shot.
X and Y coordinates for top of groundwater

Nails

The color for the TForce line shown on the graphical display is selected to be red. The tendons for the soil nails are all the same so only one tendon is defined and named "Bar 1". The diameter of the drill holes, $D = 8$ in.; the diameter of the tendon, D_{out}, $= 1$ in. (or a #8 bar); and the yield strength of the tendon, F_y, $= 75$ ksi (Figure 41). The factors of safety for the tendon yield strength and for the pullout capacity (ground-grout bond) for both the static and seismic conditions (Figure 41) are those recommended by FHWA GEC 7.

Figure 41. Screen Shot. TForce color, Factors of safety for tendon rupture and pullout capacity, Tendon dimensions and yield strength

Facings

The temporary and permanent facings for the upper and lower tiers of the soil nail wall are the same so only one temporary and one permanent facing need to be defined (Figure 42).

Figure 42. Screen Shot. Names and descriptions of facings

The reinforcement for the temporary facing (Figure 43) consists of mesh, horizontal waler bars, and vertical bearing bars. The welded wire mesh is 6 inches by 6 inches with a wire cross-sectional area, $A_{wire} = 0.029$ in^2 and a yield strength, $Fy = 60$ ksi. Additional reinforcement is provided by 2 continuous horizontal waler bars and two vertical bearing bars that are 2 feet in length. All these reinforcing bars are #4 bars with a yield strength, $Fy = 60$ ksi. The shotcrete has a compressive strength, f'c $= 4000$ psi and a thickness, $h_c = 4$ in. The pressure factors are for flexure, $CF = 2.0$ and shear, $CS = 2.5$, based on recommendations in GEC 7. The factors of safety for flexure and punching for both the static and seismic conditions are those recommended by FHWA GEC 7. The bearing plate has a side length, $b_{PL} = 8$ in., and a thickness, $b_d = 1$ in. The nail head has a service load factor of $F_F = 0.5$.
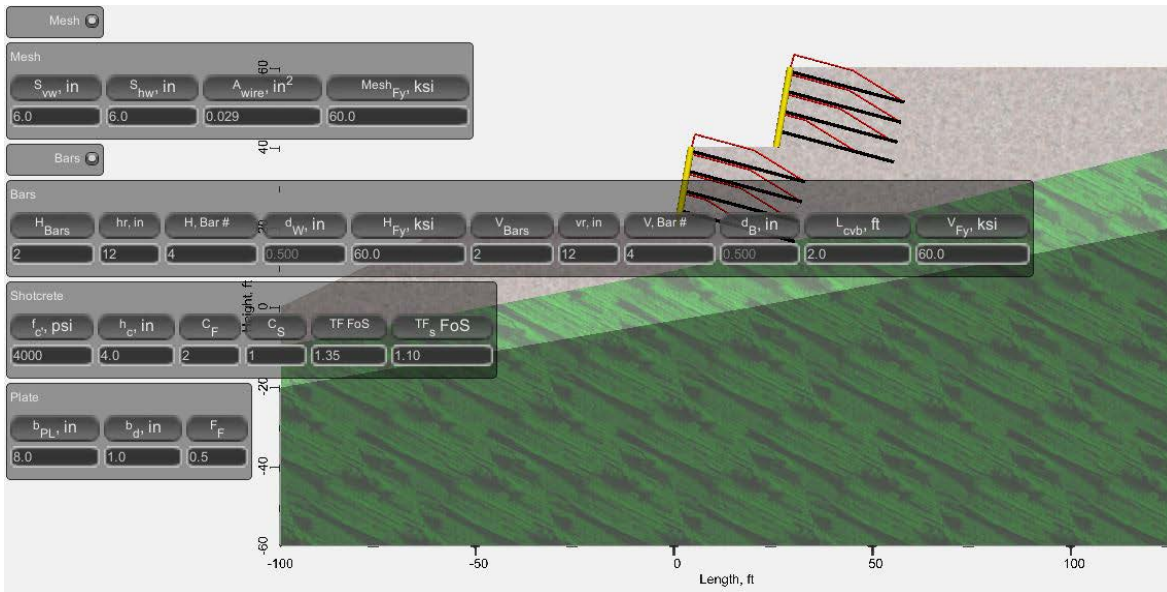
Figure 43. Screen Shot. Input for temporary facing

The reinforcement for the permanent facing (Figure 44) does not include mesh, but has continuous horizontal and vertical reinforcing bars that are both #4 bars with 12 in. spacings, and a yield strength, Fy = 60 ksi. The concrete has a compressive strength, f'c = 4000 psi and a thickness, h_c = 8 in. The pressure factors are for flexure, CF = 1.0, and shear, CS = 1.0, based on recommendations in GEC 7. The factors of safety for flexure and punching for both the static and seismic conditions are those recommended by FHWA GEC 7. The facing plates have headed studs with the following dimensions: body diameter, D_{HS} = 0.75 in.; head diameter, D_H = 1.25 in.; head thickness, t_H = 0.375 in.; overall length, L_S = 5.1875 in., and spacing S_{hs} = 5 in. The studs yield strength, Fy = 60 ksi with 4 studs per plate. The factors of safety for the tensile failure of the studs in both the static and seismic conditions are those recommended by FHWA GEC 7. Design checks are made on the stud dimensions to ensure that tensile failure of the stud body is the critical failure condition for the studs.
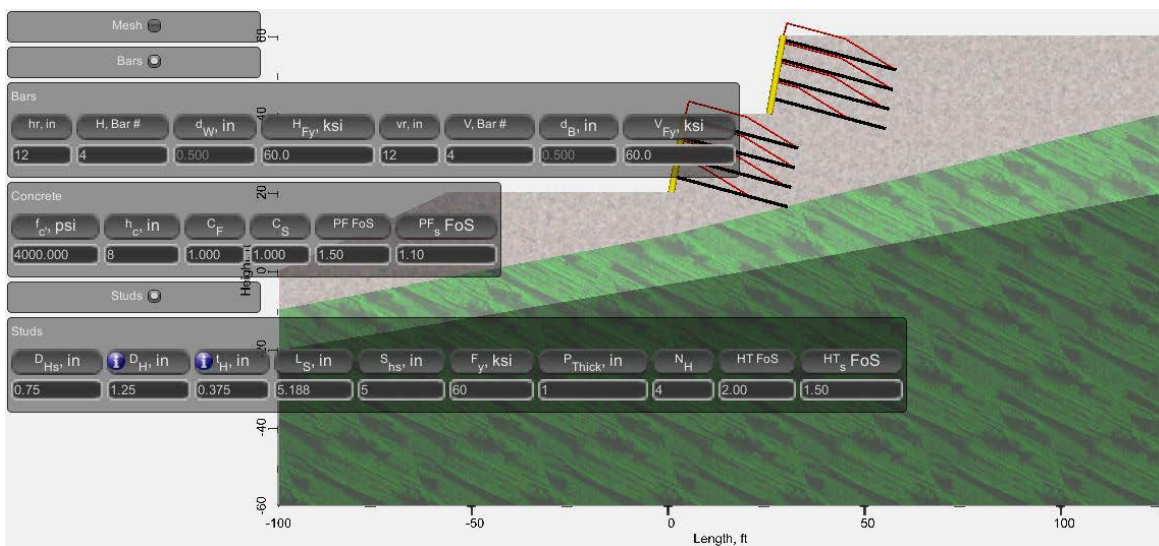

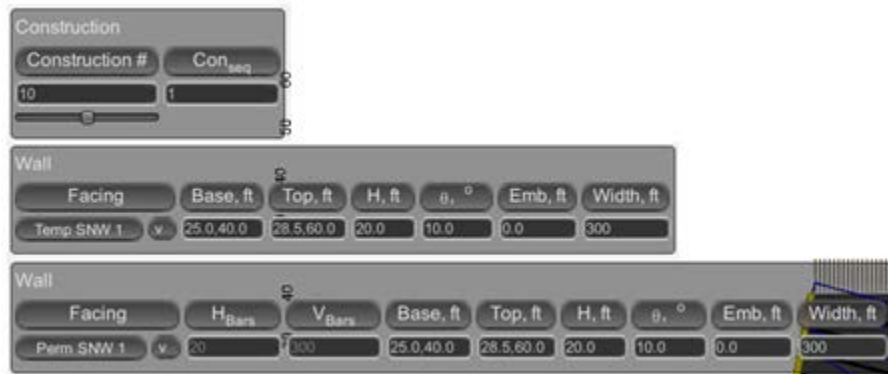**Figure 44. Screen Shot. Input for permanent facing**

38

Supports

Two wall tiers are named and described (Figure 45). The walls are described in the order of construction (top-down construction) so the first wall is the upper wall and the second wall is the lower wall.

Figure 45. Screen Shot. Names and descriptions for each wall tier

Since there are two wall tiers and four soil nails in each wall, ten (10) construction steps will be used. The construction of the upper wall begins with construction step one (1) (Figure 46). For the upper wall tier is at x,y coordinates are: base = 25.0,40.0; and top = 28.5,60.0. This gives a wall tier height of, H = 20.0 ft. and a wall tier batter angle of, $\theta = 10^o$. The wall embedment is 0.0 ft. and the wall width is 300 ft. The data is the same for the permanent facing for the upper wall tier.
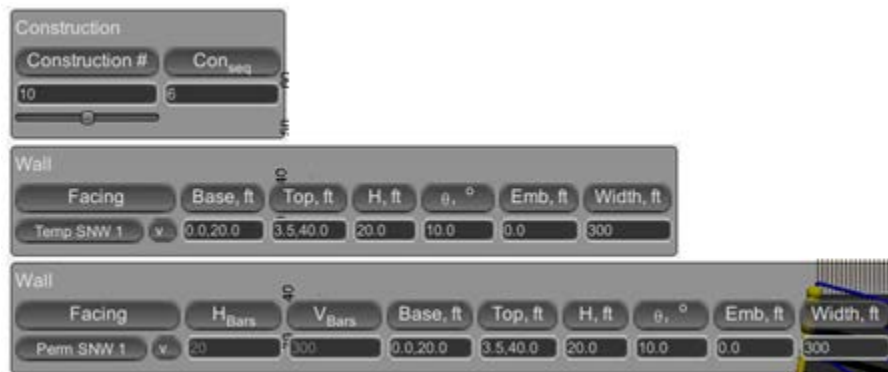
Figure 46. Screen Shot. Construction and wall dimensions for upper wall

The construction of the lower wall begins with construction step six (6) (Figure 47). For the lower wall tier is at x,y coordinates are: base = 0.0,20.0; and top = 3.5,40.0. This gives a wall tier height of, H = 20.0 ft. and a wall tier batter angle of, $\theta = 10^o$. The wall embedment is 0.0 ft. and the wall width is 300 ft. The data is the same for the permanent facing for the upper wall tier.

Figure 47. Screen Shot. Construction and wall dimensions for lower wall

The nails will use shortened nail forces, T_F, in the lower half of each wall tier in accordance with the procedure outlined in Appendix A. The tendons for the soil nails in both wall tiers are all the same, so only one tendon bar set will be defined and will be called "Bar 1". For Bar 1: the nail length is L = 30.0 ft.; the vertical nail spacing is S_V = 5.0 ft.; the horizontal nail spacing is S_H = 5.0 ft.; the nail inclination is δ = 15°; and the upper cantilever distance is C_d = 2.0 ft. The soil nails will be installed in an offset pattern and the soil nails all the same, or uniform (Figure 48).

Figure 48. Screen Shot. Nail parameters

The slopes below (downslope) and above (backslope) the soil nail wall are not modified from the original ground slope, so no input is required to further define the final downslope and backslope.

After clicking on the Checks tab, parameters are input for calculating the estimated displacement at the top of each wall tier and the horizontal distance behind each wall tier where ground deformation can be significant. These data are dependent on the general material type into which the soil nails are being installed. Since the soil nails for both wall tiers will be installed in a sandy soil, the displacement ratio is $\delta_{h/H}$ = 0.002 and the damping coefficient is, κ = 1.25 (Figure 49).

Figure 49. Screen Shot. Displacement parameters

Surcharge

For this project it is anticipated that the final CIP facing for the upper wall tier will be constructed during construction of the lower wall tier. Therefore, a surcharge will be placed on the bench between the upper wall tier and the lower wall tier for construction step six (6) through construction step nine (9). The surcharged will be removed for the long term static or seismic conditions. The magnitude of the surcharge load, q_s = 500 psf, to simulate construction equipment and material storage on the bench during the construction of the lower wall tier (Figure 50).

Figure 50. Screen Shot. Surcharge location and magnitude

Seismic

The tolerable seismically induced lateral wall movement, d = 12 in. and the peak ground acceleration coefficient, PGA = 0.25. The option to have the program calculate the horizontal seismic coefficient, K_h, is selected and the vertical horizontal seismic coefficient, K_v, is assumed to be zero (Figure 51).

Figure 51. Screen Shot. Seismic loading parameters

Bishop

The global factor of safety is checked for each stage of construction by selecting the construction stage of interest (1 through 10). The temporary facing is activated (in Supports – Wall) when checking the global factor of safety for construction stages. The permanent facing is activated when checking the global factor of safety for long term static and seismic conditions. A minimum height of failure circle arc is input to prevent unreasonably small failure circles (Figure 52).
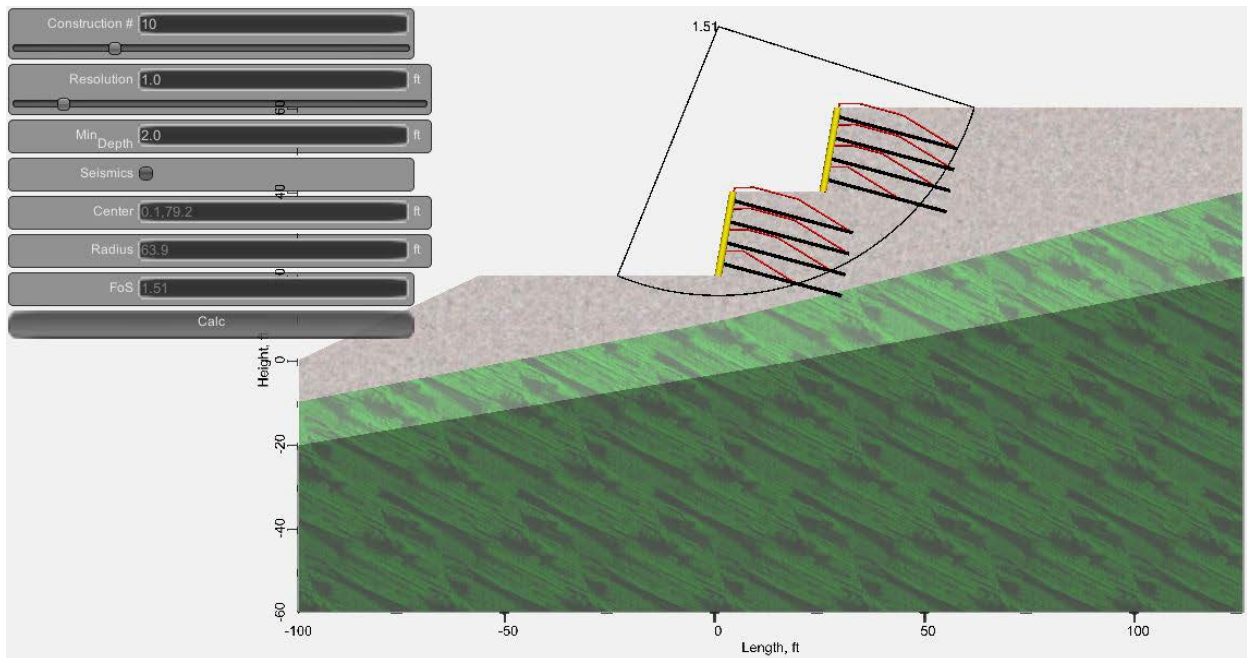

Figure 52. Screen Shot. Critical failure surface and global factor of safety

Design Checks

In the Supports - Checks screen, a check is made to ensure that the allowable nail head strength, T_F, is greater than the estimated nail head service load, t_F. Checks for external stability are calculated and reported eccentricity, sliding and bearing capacity for each wall tier and for both static and seismic conditions.

Scene

Three scenes are saved for the report: 1) a close up view of the temporary facing with the shotcrete faded out to show the temporary facing reinforcement; 2) a close up view of the permanent facing with the CIP concrete faded out to show the permanent facing reinforcement; and 3) a panorama view showing both wall tiers in their final configuration.

Report

The report for this example is shown in Appendix B. Options selected for this report include Cuts, Static, Seismic, and Scene.

APPENDIX A – SELECTION OF NAIL LENGTHS

The most significant benefits of the slip surface limiting equilibrium approach to soil nail wall design are: 1) the method considers all internal, external, and mixed potential slip surfaces for the wall (bearing capacity, sliding and overturning of the nailed mass are typically evaluated separately) and evaluates global stability for each; 2) the method does not require specification of a maximum tension line; and 3) the method is more convenient and accurate for heterogeneous geometries, soil types and surcharge loadings than the simplified earth pressure method.
A limitation of the slip surface method in the design of reinforced soil structures is the possibility to define a wide variety of reinforcement distributions that satisfy strength limit state requirements that are not satisfactory from a serviceability perspective (i.e., result in excessive deformations of the reinforced mass). Figure 53 and 54 show two fundamentally different nail layouts that result in calculated factors of safety that meet or exceed the minimum factor of safety requirements for any slip surface examined. Layout A in Figure 53, while satisfying the minimum factor of safety requirements for any potential slip surface, would constitute an unsuitable design because of the deformations likely associated with such an arrangement of nails.
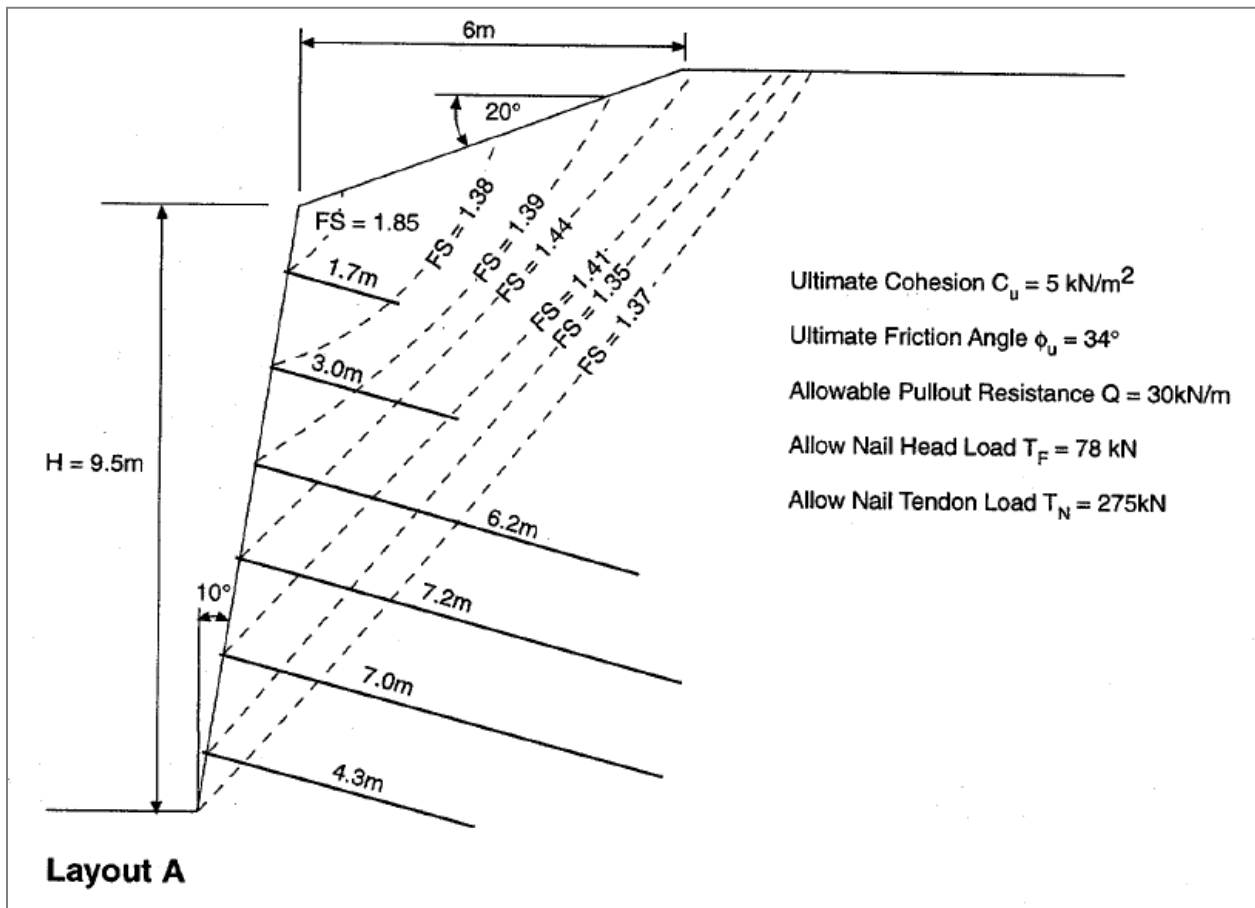

Figure 53. Schematic. Unsuitable nail layout that satisfies global stability requirements (FHWA SA-96-069R)

Layout B in Figure 54 represents a more typical design, with the same calculated minimum factor of safety. Clearly, it is not sufficient to simply specify strength limit state design criteria to ensure a satisfactory design. Other rules/constraints are therefore required to ensure a distribution of reinforcement that has been proven by experience to provide adequate performance of the wall under service conditions.
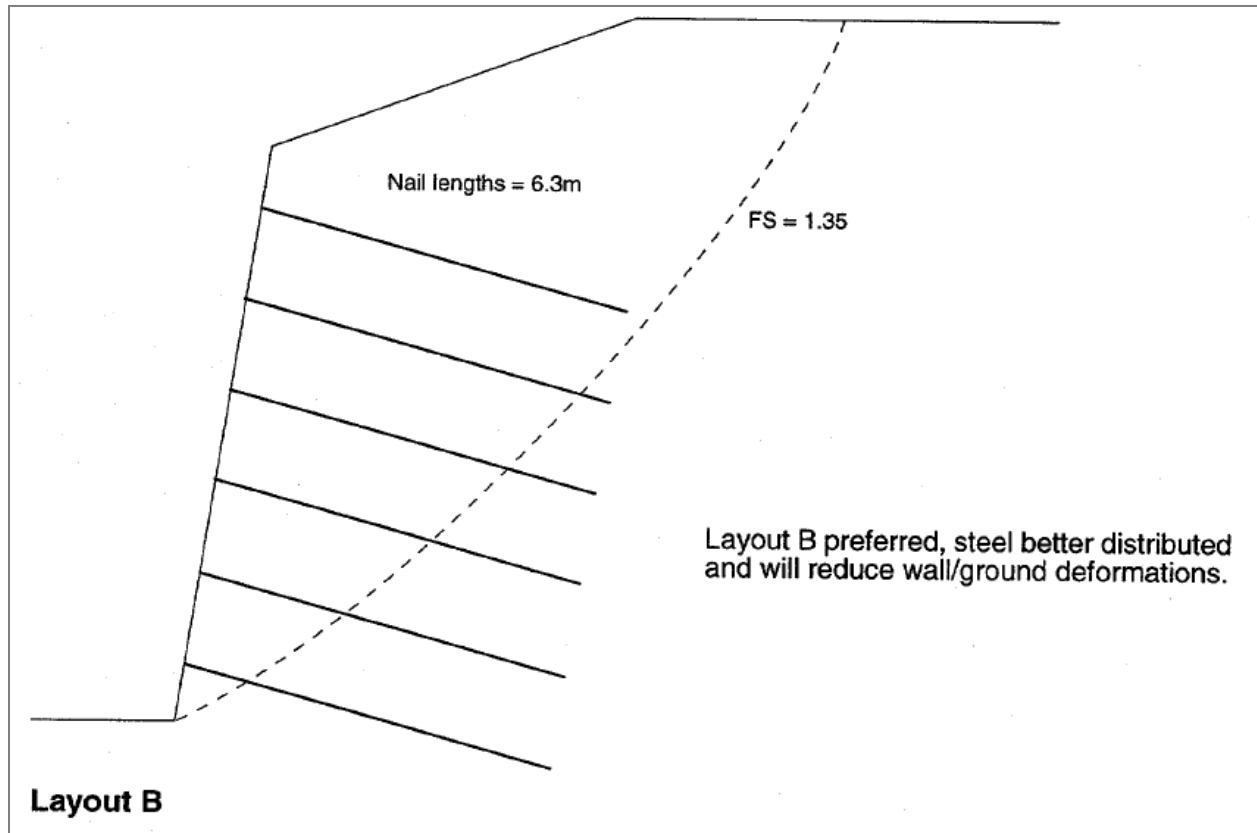

Figure 54. Schematic. Suitable nail layout that satisfies global stability requirements (FHWA SA-96-069R)

The following empirical constraints on the design analysis of nail length pattern are recommended for use when performing limiting equilibrium design calculations:

(a) Nails with heads located in the upper half of the wall height should be of uniform length.

(b) Nails with heads located in the lower half of the wall height should be considered to have a reduced length in accordance with the recommendations given in Figures 55 and 56.

The purpose of these recommendations is to ensure that adequate nail reinforcement (length and strength) is installed in the upper part of the wall. Performance monitoring of several instrumented soil nail walls, in which both nail loads and wall movements were measured, has demonstrated that the top-down method of construction of soil nail walls generally results in the nails in the upper part of the wall being more heavily loaded than the nails in the lower part of the wall and therefore more significant in developing resisting loads and controlling displacements.
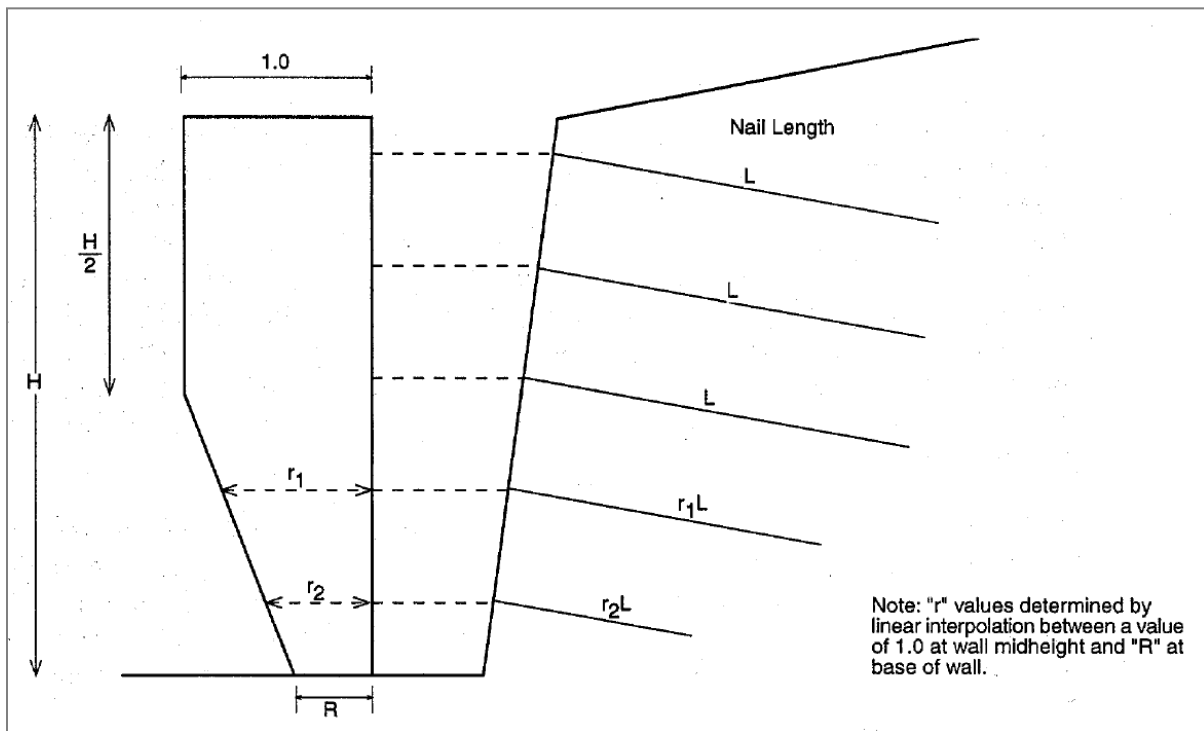

Figure 55. Schematic. Reduction of soil nail lengths in the lower part of the wall (FHWA SA-96-069R)
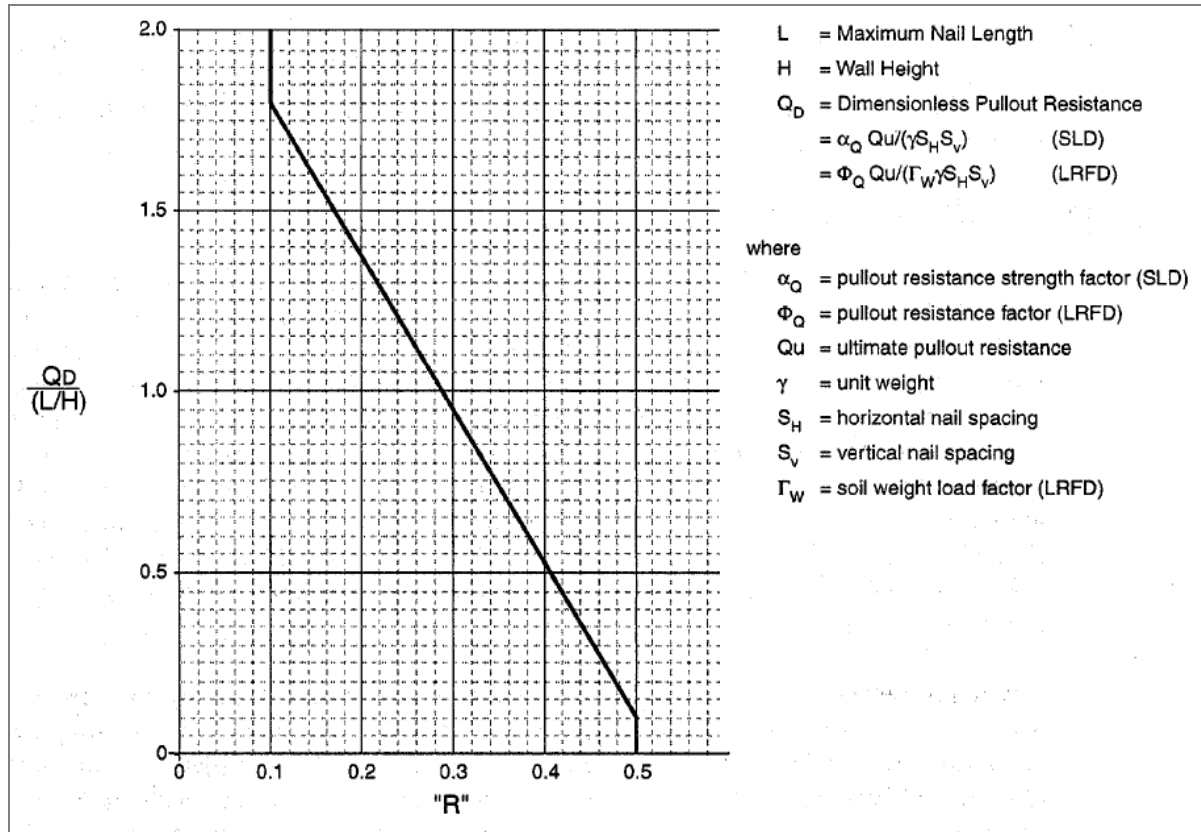
Figure 56. Schematic. Determination of the value "R" to be used in Figure 55 (FHWA SA-96-069R)

If the strength limit state calculation overstates the contribution from the lower nails, shorter nails and/or smaller tendon sizes in the upper part of the wall may be indicated, resulting in poorer in-service performance.

It should be noted that the above recommendation for the nail length pattern to be assumed for design calculation purposes does not imply that the installed nail pattern must correspond exactly to the design nail pattern. It is most common to install nails of uniform length, often to simplify construction. Provided the appropriate external stability checks are performed, it may be possible to install shorter nails in the lower part of the wall.

In SNAP_2 in the SNAP - Supports – Nails screen, the user has the option to have the computer shorten the nails in the lower part of the wall. When the Shorten T_F radio button is active the soil nails in the lower part of the wall will be shortened in accordance with the empirical method describe here in Appendix A. This shortening will be shown on the graphical display whereby the allowable nail load, depicted by the blue line above each soil nail, will be shortened accordingly for the soil nails in the lower part of the soil nail wall.
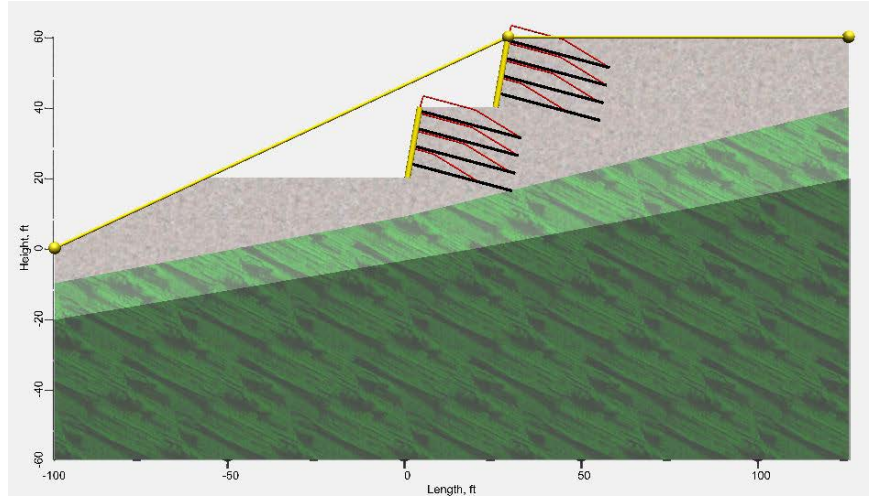
APPENDIX B DESIGN EXAMPLE REPORT

SNAP_2 REPORT

Name	Company	Wall #	Station	Designer	Reviewer	Date
Example 1	FHWA	RW -543	1000+00	R. Peck	K. Terzaghi	7/15/2013

Existing Slope

Existing Slope Points

#	X, ft	Y, ft
1	-100.0	0.0
2	28.5	60.0
3	125.0	60.0

Soils

Soil Properties

#	Name	Texture	γ'_s, pcf	ϕ', °	δ_s, °	c', psf	q_u, psi	N_c	N_q	N_γ
1	MD Silty SAND	sand	115	32	21.3	0.0	15.0	35.5	23.2	30.2
2	Dense SAND	sand	125	39	26	0.0	15.0	67.9	56.0	92.2

Dense SAND: Points at top of Dense SAND
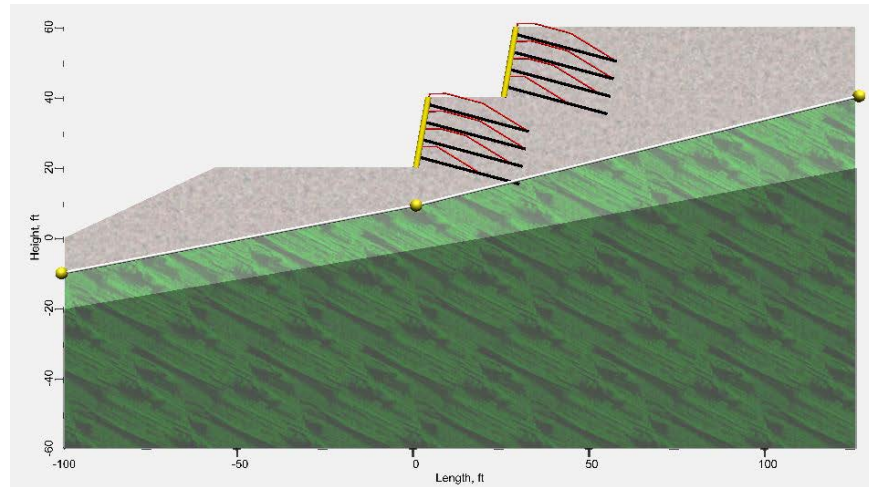
Points at top of Dense SAND

#	X, ft	Y, ft
1	-100.0	-10.0
2	0.0	9.1
3	125.0	40.0

Ground Water
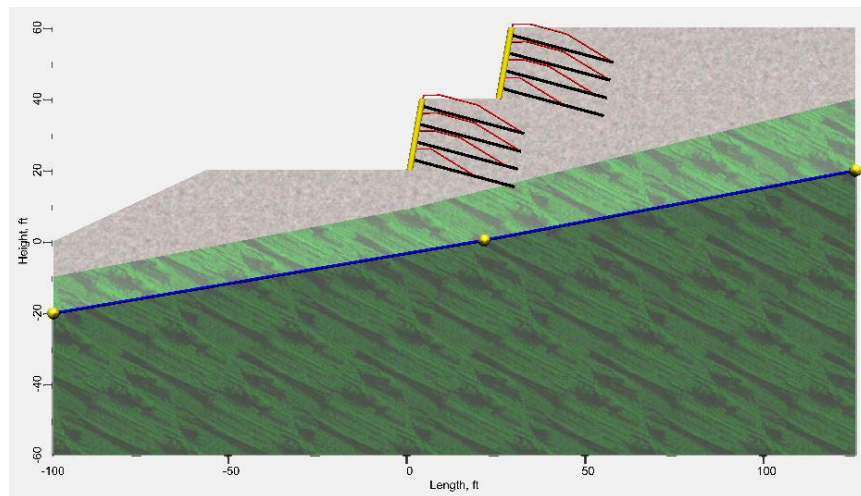
Points at top of water table

#	X, ft	Y, ft
1	-100.0	-20.3
2	20.9	0.2
3	125.0	19.8

Nails

Default Factors of Safety

U	F_y FoS	F_{ys} FoS	F_p FoS	F_{ps} FoS
true	1.80	1.35	2.00	1.50

Bar Properties

Name	D, in	D_{out}, in	D_{in}, in	Bar No, Bar #	F_y, ksi
Bar 1	8.0	1.000	0.000	8.0	75.0

Facings

Facing Properties

#	Type	Name	Description
1	Temp SNW	Temp SNW 1	Shotcrete
2	Perm SNW	Perm SNW 1	CIP

Temp SNW 1: Shotcrete

Mesh	Bars
true	true

Mesh: Temporary facing mesh

S_{vw}, in	S_{hw}, in	A_{wire}, in^2	Mesh$_{Fy}$, ksi
6.0	6.0	0.029	60.0

Bars: Temporary facing bars

H_{Bars}	hr, in	H, Bar #	d_W, in	H_{Fy}, ksi	V_{Bars}	vr, in	V, Bar #	d_B, in	L_{cvb}, ft	V_{Fy}, ksi
2	12	4	0.500	60.0	2	12	4	0.500	2.0	60.0

Shotcrete: Temporary shotcrete facing

$f_{c'}$, psi	h_c, in	C_F	C_S	TF FoS	TF$_s$ FoS
4000	4.0	2	2.5	1.35	1.10

Plate: Temporary facing plate

b_{PL}, in	b_d, in	F_F
8.0	1.0	0.5

Perm SNW 1: CIP

Temporary Facing	Mesh	Bars	Studs
Temp SNW 1	false	true	true

Bars: Permanent facing bars

hr, in	H, Bar #	d_W, in	H_{Fy}, ksi	vr, in	V, Bar #	d_B, in	V_{Fy}, ksi
12	4	0.500	60.0	12	4	0.500	60.0

Concrete: Permanent facing concrete

$f_{c'}$, psi	h_c, in	C_F	C_S	PF FoS	PF_s FoS
4000.000	8	1.000	1.000	1.50	1.10

Studs: Permanent facing studs

D_{Hs}, in	D_H, in	t_H, in	L_S, in	S_{hs}, in	F_y, ksi	P_{Thick}, in	N_H	HT FoS	HT_s FoS
0.75	1.25	0.375	5.188	5	60	1	4	2.00	1.50

Wall types

#	Name	Description
1	SN Wall 1	Upper Wall
2	SN Wall 2	Lower Wall

SN Wall 1: Upper Wall

Wall: Soil nail wall geometry
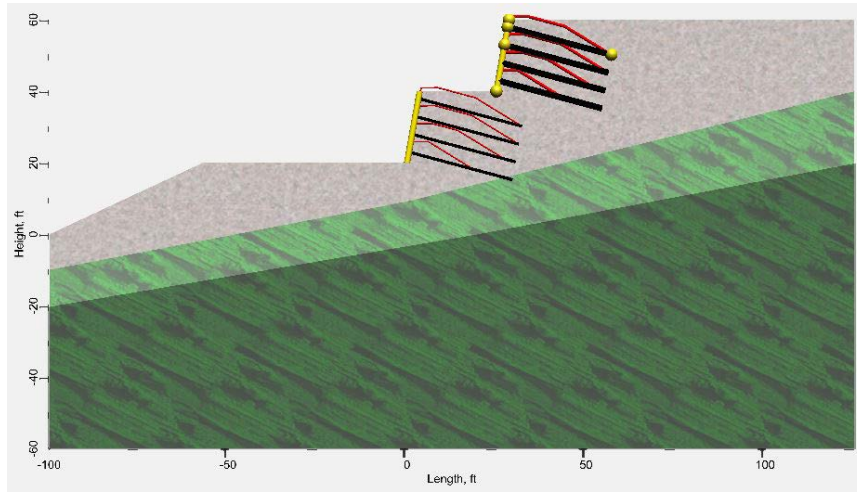
Construction: Construction specification

Construction #	Con$_{seq}$
10	1

Wall: Soil nail wall size and location

Facing	H$_{Bars}$	V$_{Bars}$	Base, ft	Top, ft	H, ft	θ, ^{o}	Emb, ft	Width, ft
Perm SNW 1	20	300	25.0,40.0	28.5,60.0	20.0	10.0	0.0	300

Nails: Soil nail wall nail geometry

Shorten T_F
true

Nails: Soil nail sizes and locations

Nail	L, ft	S_V, ft	S_H, ft	δ, º	C_d, ft	O	U
Bar 1	30.00	5.00	5.00	15.0	2.00	true	true

Checks: Soil nail wall design checks

Static Case

T_F, lbf	t_F, lbf	F_s, ksi	f_s, ksi	ecc, ft	FS_{SL}	FS_{BC}	FoS_{GS}
34942	6034	0.0	234.3	-2.9	3.5	27.6	1.50

Seismic Case

T_F, lbf	t_F, lbf	F_s, ksi	f_s, ksi	ecc, ft	FS_{SL}	FS_{BC}	FoS_{GS}
47648	6034	0.0	234.3	-1.3	2.6	25.2	1.24

Displacement: Long-term wall deformation and displacement parameters

$\delta_{h/H}$	κ	δ, in	λ, ft
0.002	1.25	0.5	20.6

SN Wall 2: Lower Wall

Wall: Soil nail wall geometry
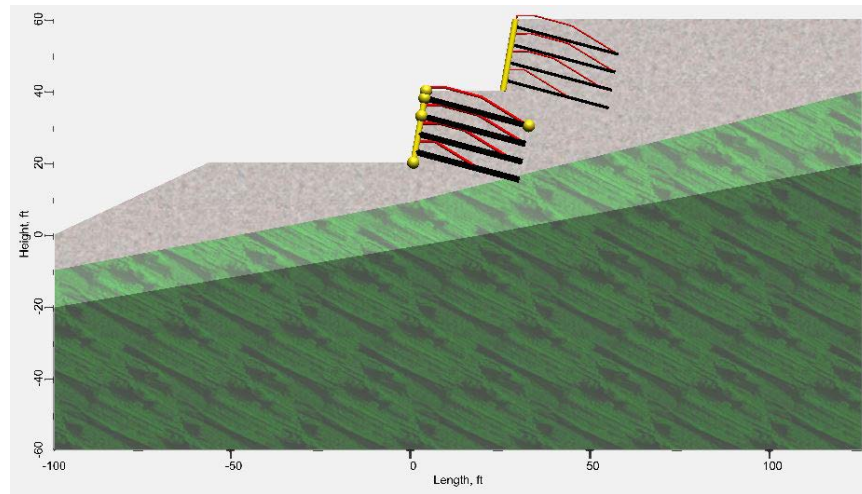
Construction: Construction specification

Construction #	Con$_{seq}$
10	6

Wall: Soil nail wall size and location

Facing	H$_{Bars}$	V$_{Bars}$	Base, ft	Top, ft	H, ft	θ, º	Emb, ft	Width, ft
Perm SNW 1	20	300	0.0,20.0	3.5,40.0	20.0	10.0	0.0	300

Nails: Soil nail wall nail geometry

Shorten T$_F$
true

Nails: Soil nail sizes and locations

Nail	L, ft	S$_V$, ft	S$_H$, ft	δ, º	C$_d$, ft	O	U
Bar 1	30.00	5.00	5.00	15.0	2.00	true	true

Checks: Soil nail wall design checks

Static Case

T_F, lbf	t_F, lbf	F_s, ksi	f_s, ksi	ecc, ft	FS_{SL}	FS_{BC}	FoS_{GS}
34942	9721	0.0	377.5	-3.9	1.8	18.3	1.50

Seismic Case

T_F, lbf	t_F, lbf	F_s, ksi	f_s, ksi	ecc, ft	FS_{SL}	FS_{BC}	FoS_{GS}
47648	9721	0.0	377.5	-0.1	1.3	13.7	1.24

Displacement: Long-term wall deformation and displacement parameters

$\delta_{h/H}$	κ	δ, in	λ, ft
0.002	1.25	0.5	20.6

Surcharge
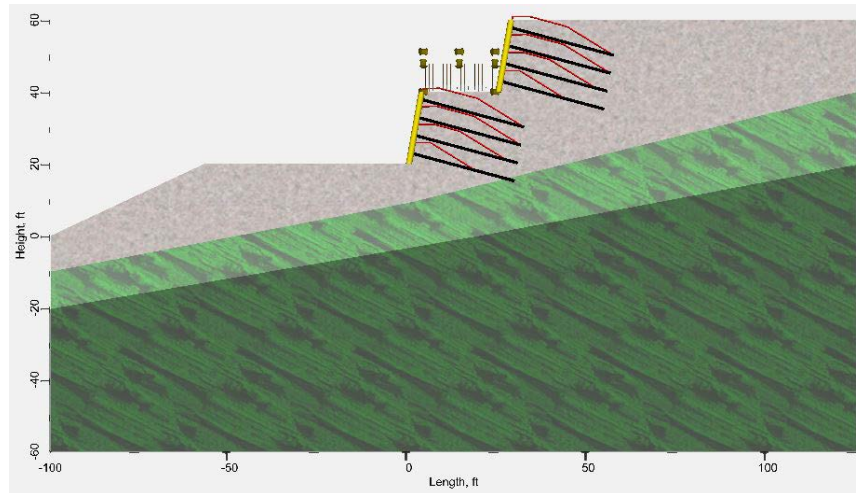
Con_{seq}	X1, ft	X2, ft	q_s, psf	q_{sH}, psf
6-9	4.0	24.0	500	0

Seismic

Seismic	d, in	A	A_m	Calc K_h	K_h	K_v
true	12.000	0.250	0.3	true	0.125	0.000

Static global stability for construction sequence 1
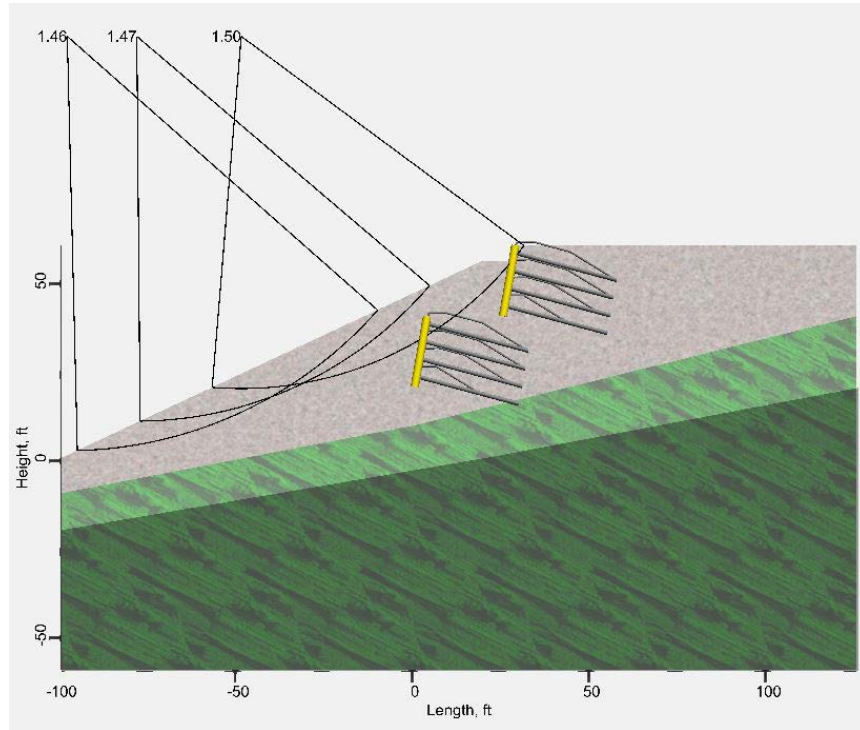
Construction #	Min$_{Depth}$, ft	Seismics	Center, ft	Radius, ft	FoS
1	5.0	false	-96.7,102.5	98.1	1.46

Scene Panorama for construction sequence 1
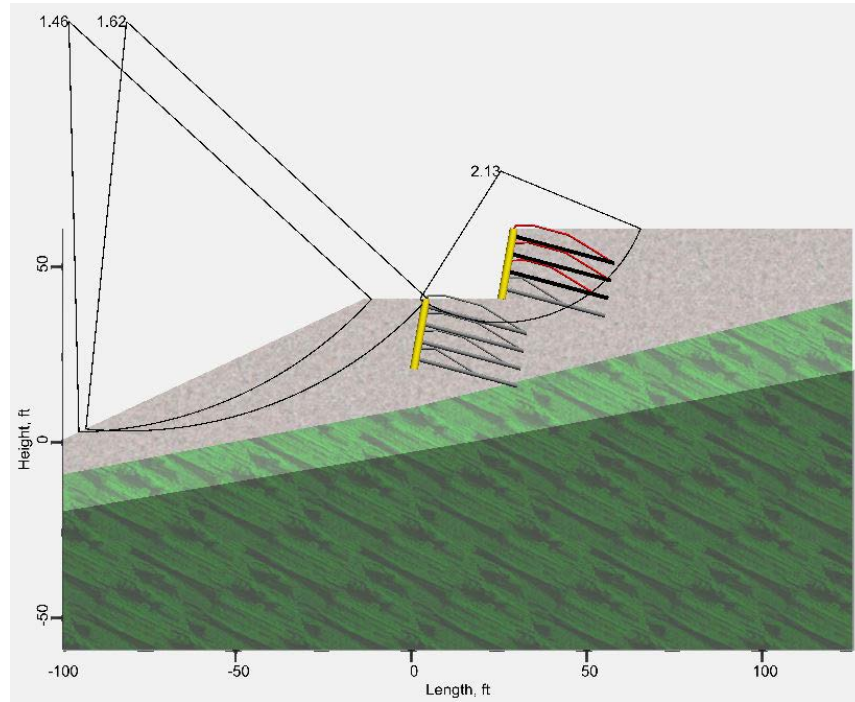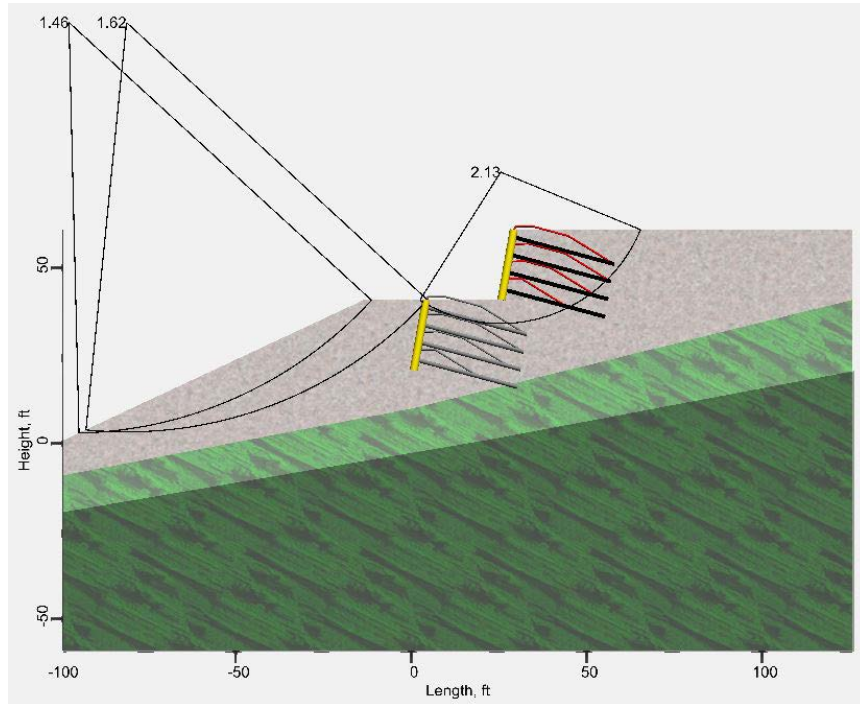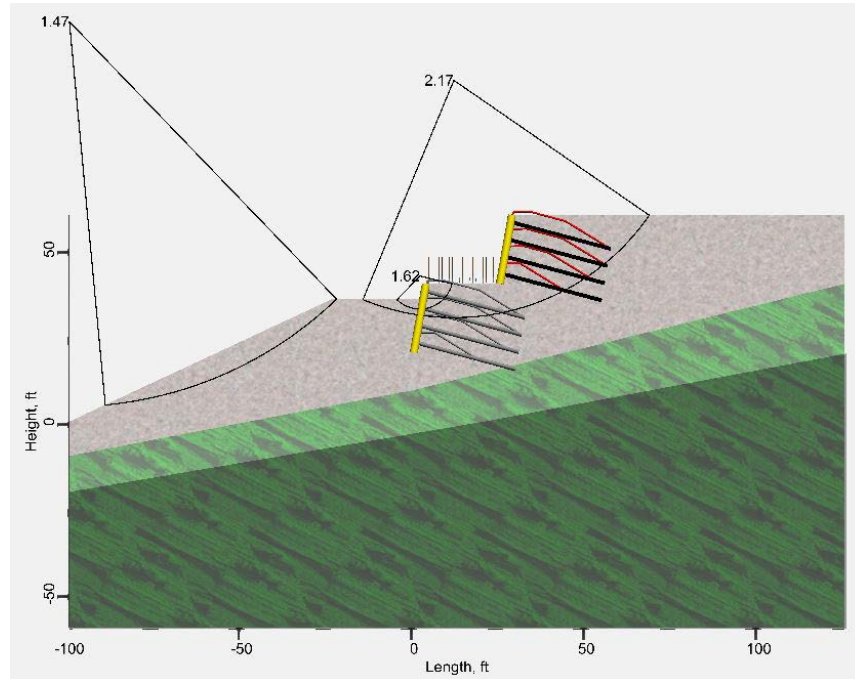
Static global stability for construction sequence 2
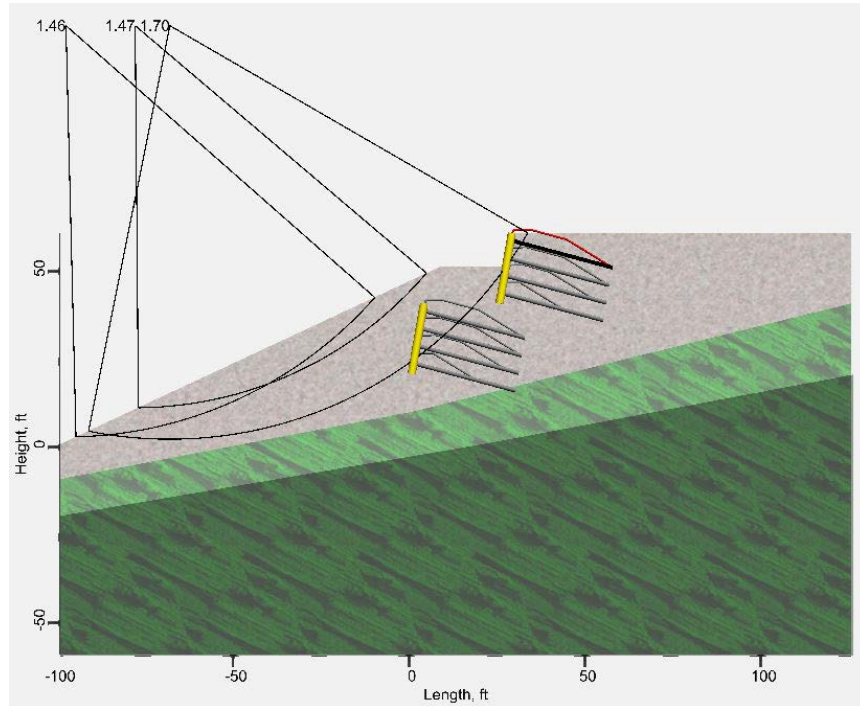
Construction #	Min$_{Depth}$, ft	Seismics	Center, ft	Radius, ft	FoS
2	5.0	false	-96.7,102.5	98.1	1.46

Scene Panorama for construction sequence 2
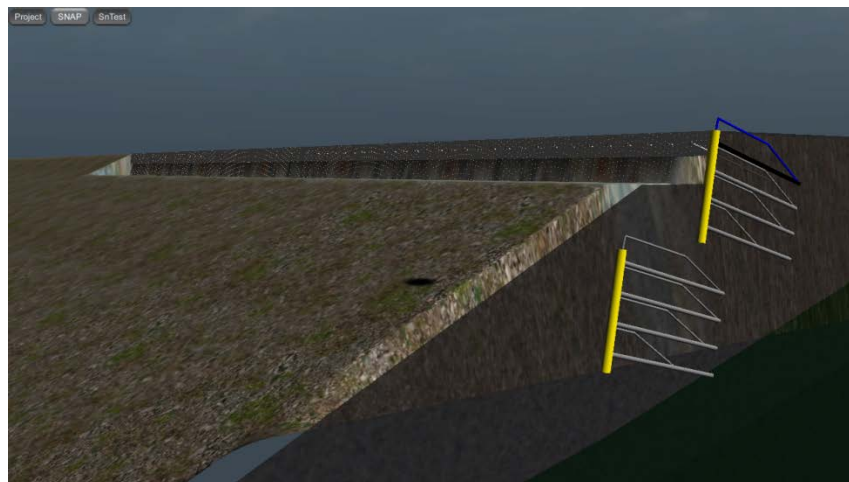
Static global stability for construction sequence 3
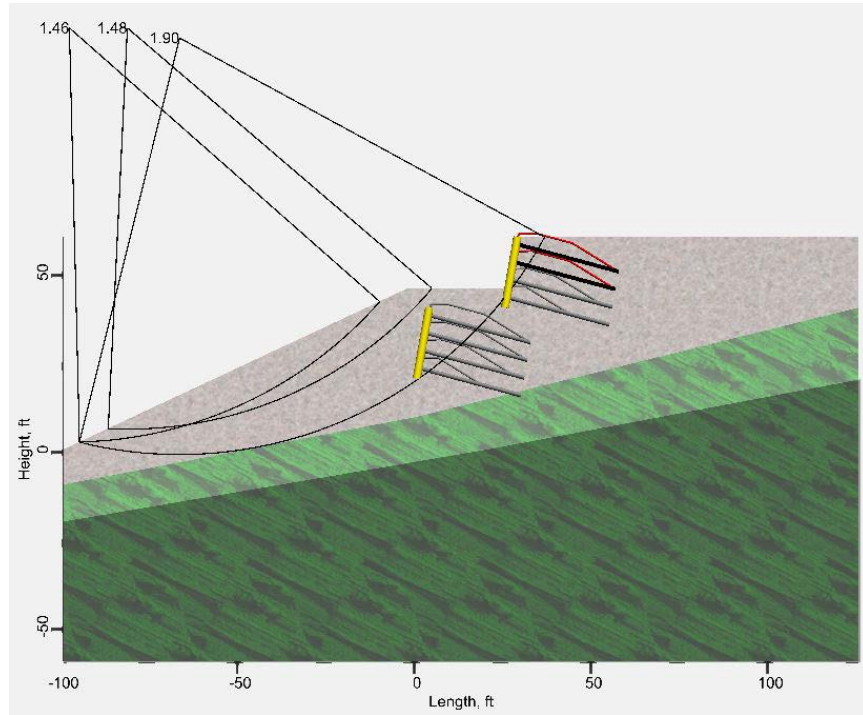
Construction #	Min$_{Depth}$, ft	Seismics	Center, ft	Radius, ft	FoS
3	5.0	false	-96.7,102.5	98.1	1.46

Scene Panorama for construction sequence 3
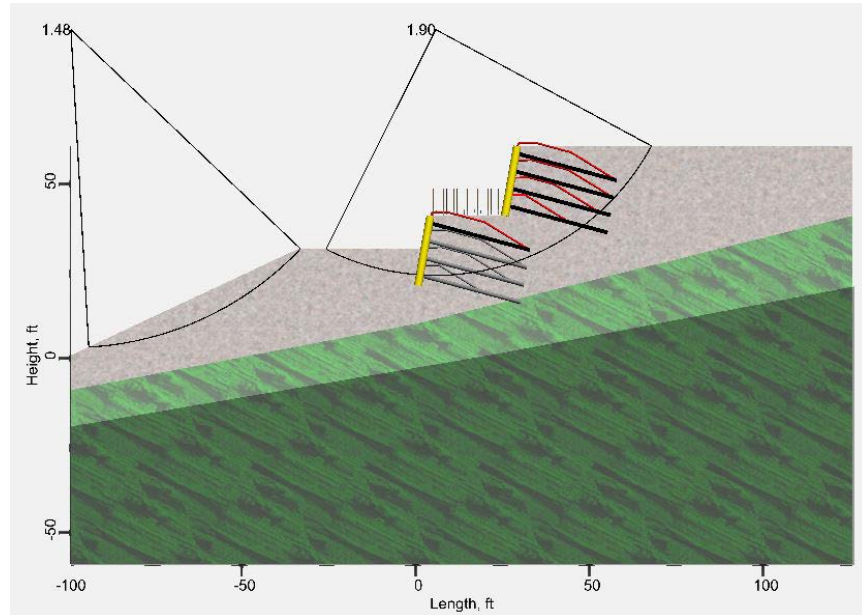
Static global stability for construction sequence 4

Construction #	Min$_{Depth}$, ft	Seismics	Center, ft	Radius, ft	FoS
4	5.0	false	-96.7,102.5	98.1	1.46

Scene Panorama for construction sequence 4
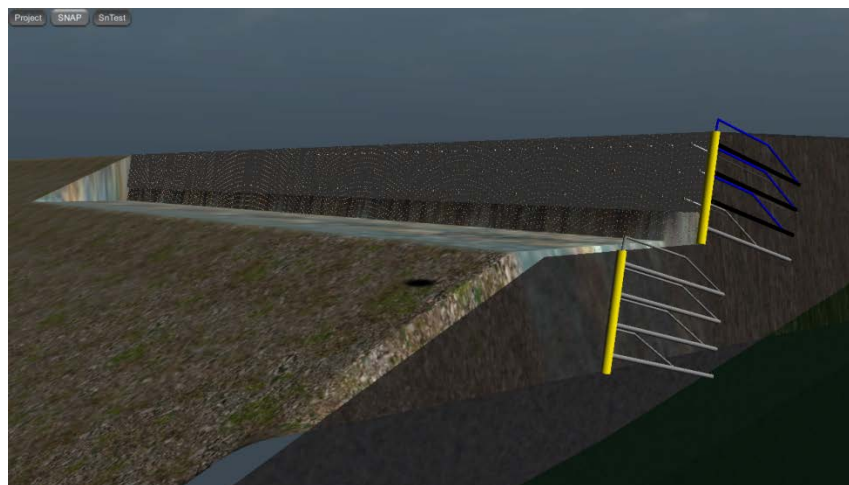
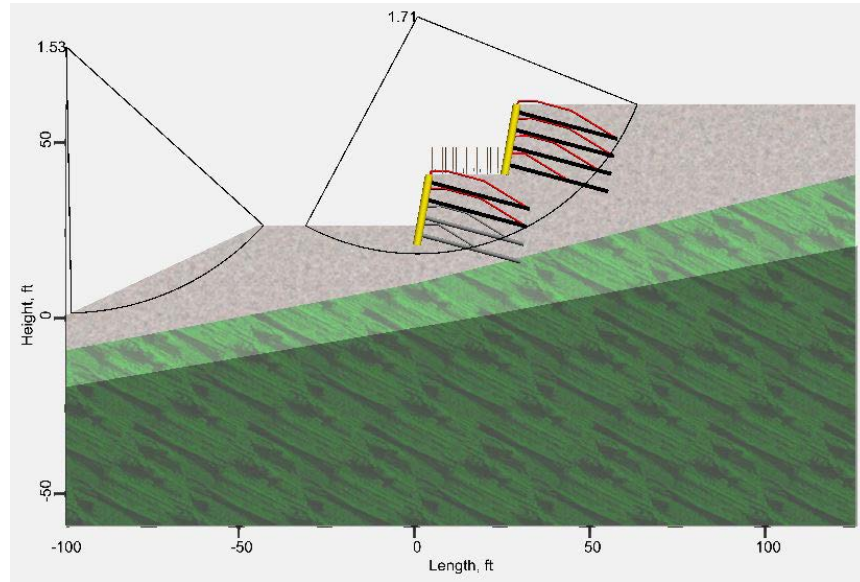## Static global stability for construction sequence 5

Construction #	Min$_{Depth}$, ft	Seismics	Center, ft	Radius, ft	FoS
5	5.0	false	-96.7,102.5	98.1	1.46

Scene Panorama for construction sequence 5
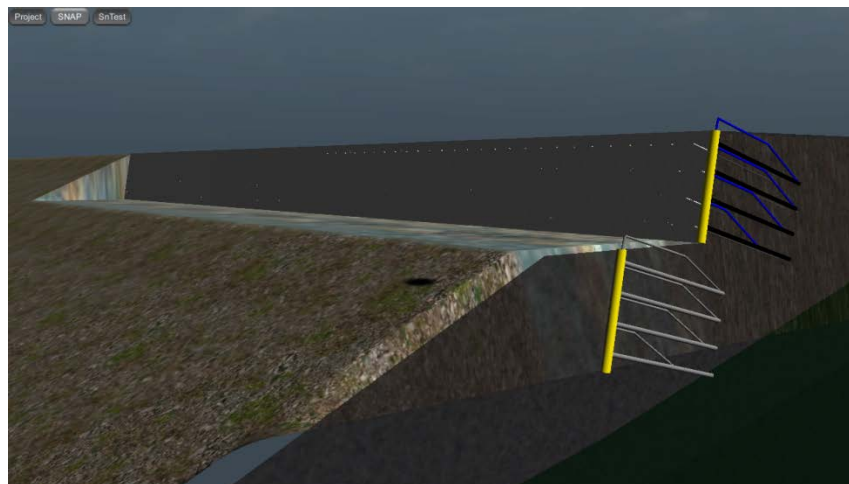
Static global stability for construction sequence 6

Construction #	Min$_{Depth}$, ft	Seismics	Center, ft	Radius, ft	FoS
6	5.0	false	-96.7,102.5	98.1	1.47

Scene Panorama for construction sequence 6
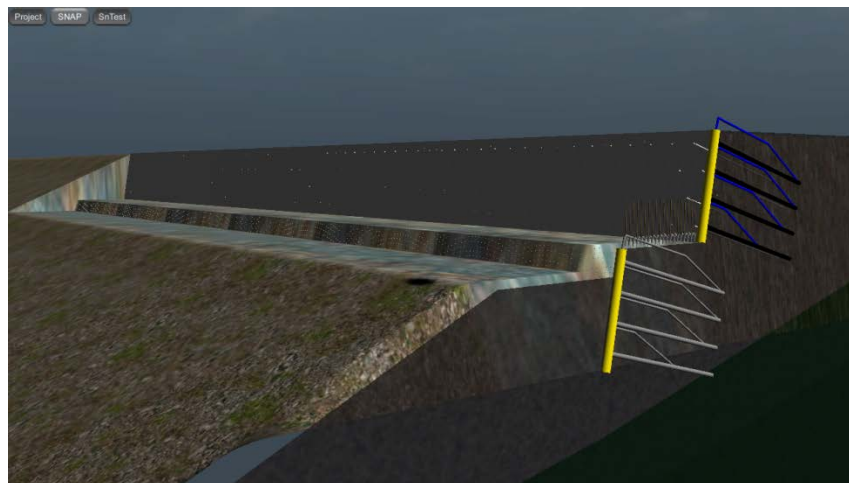
Static global stability for construction sequence 7

Construction #	Min$_{Depth}$, ft	Seismics	Center, ft	Radius, ft	FoS
7	5.0	false	-100.0,96.8	94.3	1.48

Scene Panorama for construction sequence 7
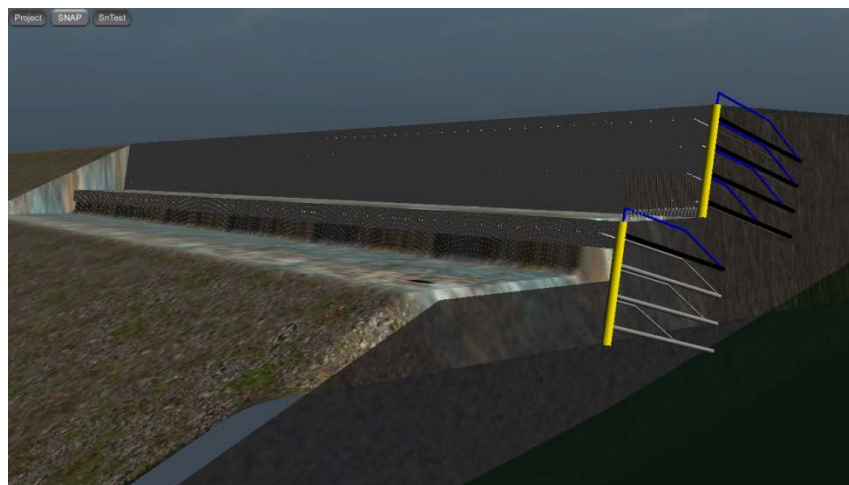
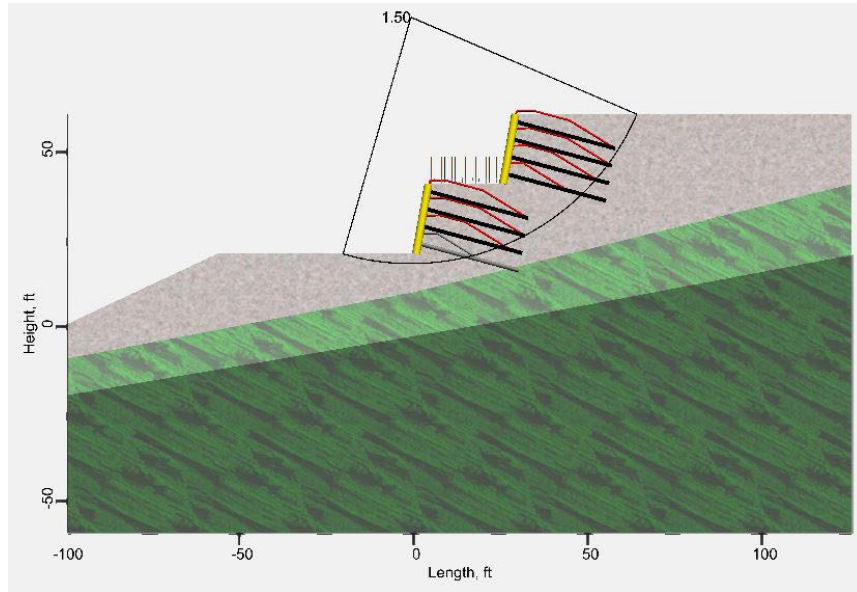## Static global stability for construction sequence 8

Construction #	Min$_{Depth}$, ft	Seismics	Center, ft	Radius, ft	FoS
8	5.0	false	-100.0,73.7	73.4	1.53

Scene Panorama for construction sequence 8
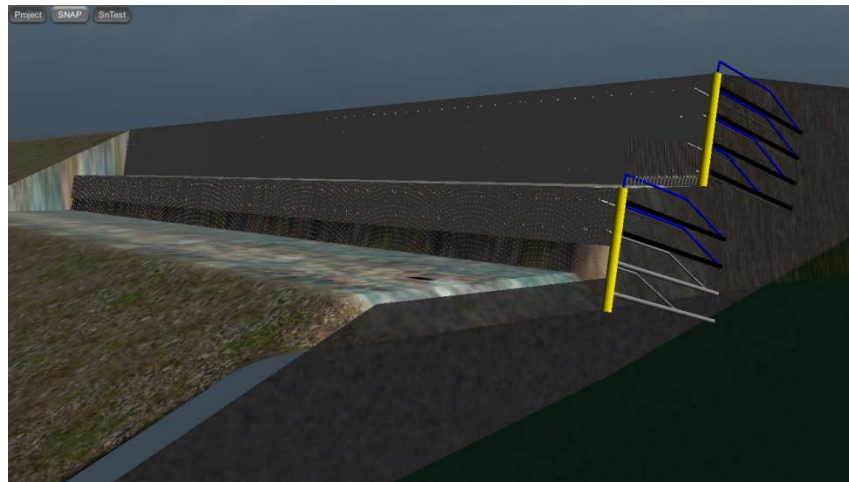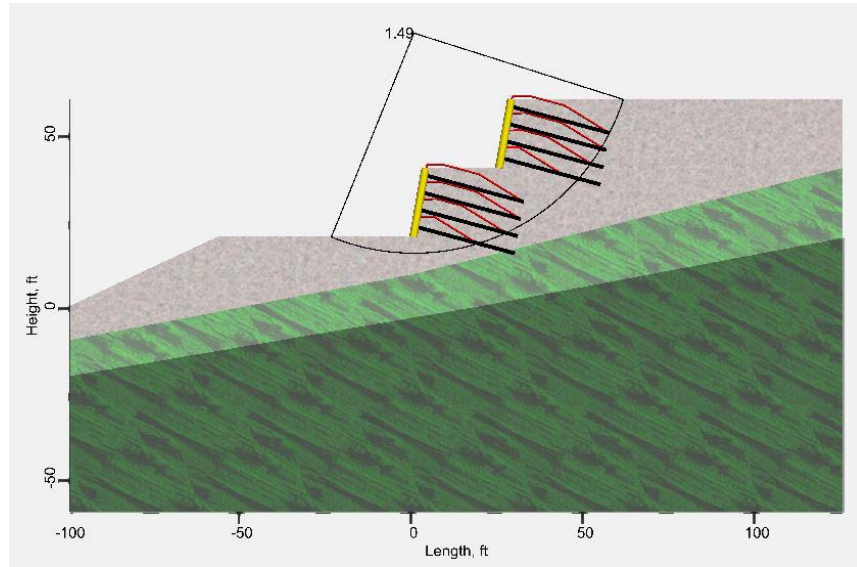
Static global stability for construction sequence 9

Construction #	Min_Depth, ft	Seismics	Center, ft	Radius, ft	FoS
9	5.0	false	-3.5,79.5	64.2	1.50

Scene Panorama for construction sequence 9
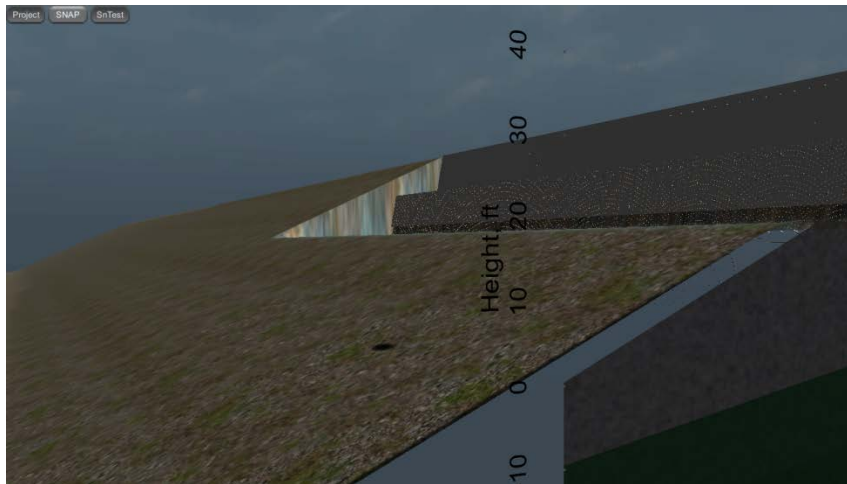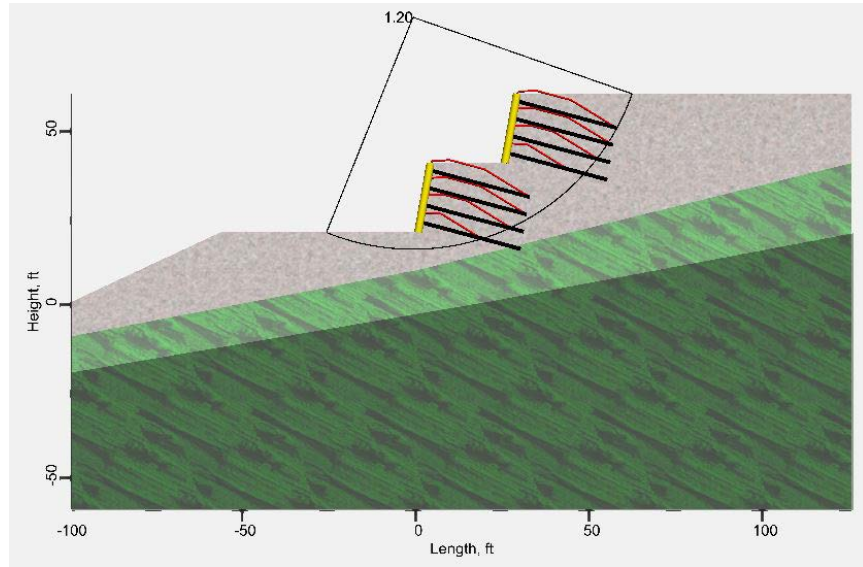
Static global stability for construction sequence 10

Construction #	Min$_{Depth}$, ft	Seismics	Center, ft	Radius, ft	FoS
10	5.0	false	-0.2,73.7	58.5	1.49

Scene Panorama for construction sequence 10
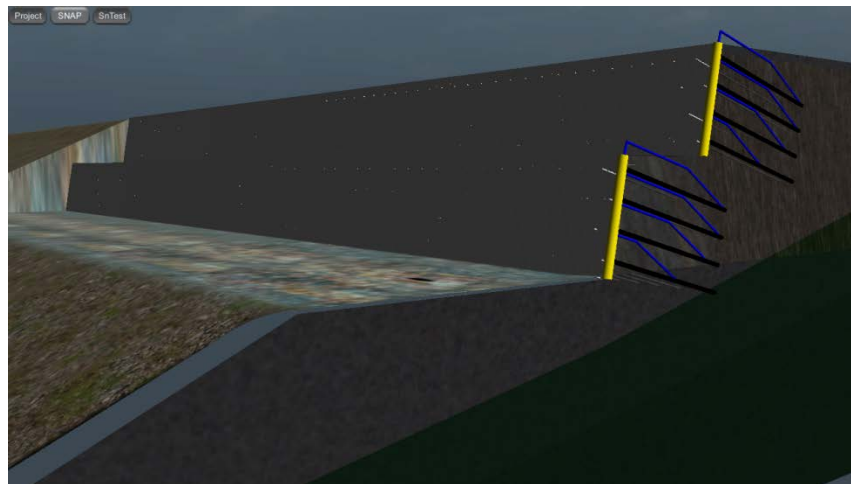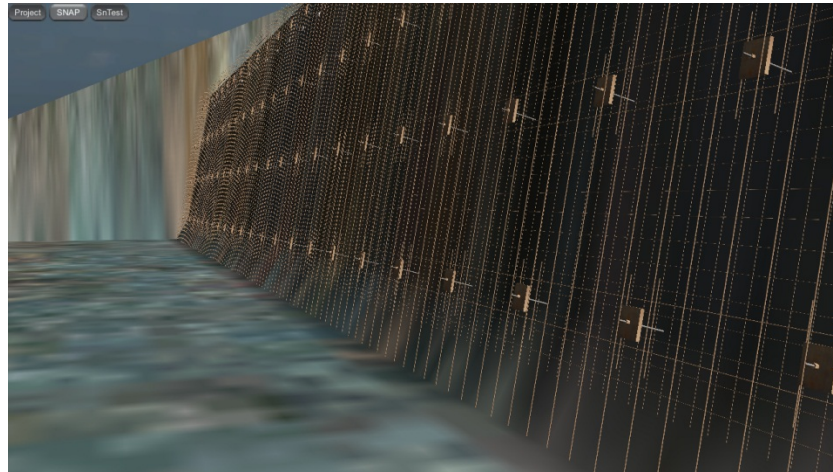
Seismic global stability for construction sequence 10

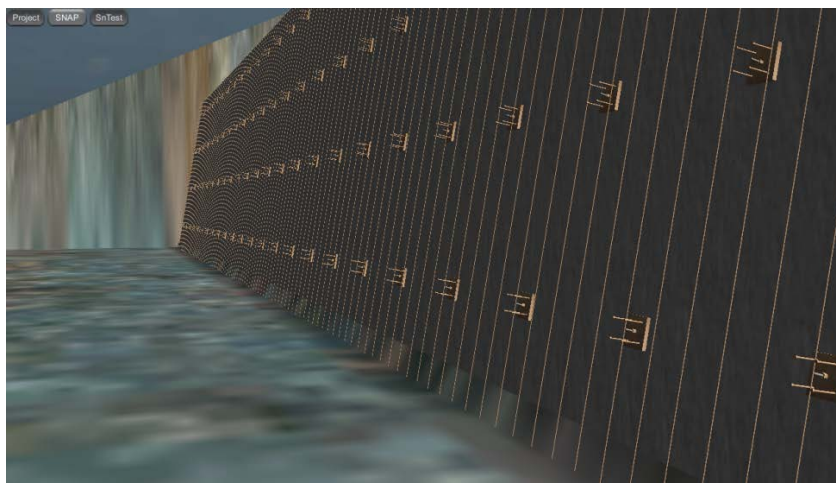| Construction #	Min$_{Depth}$, ft	Seismics	Center, ft	Radius, ft	FoS
10	5.0	true	-96.7,56.4	56.4	1.20

Scene Panorama for construction sequence 10
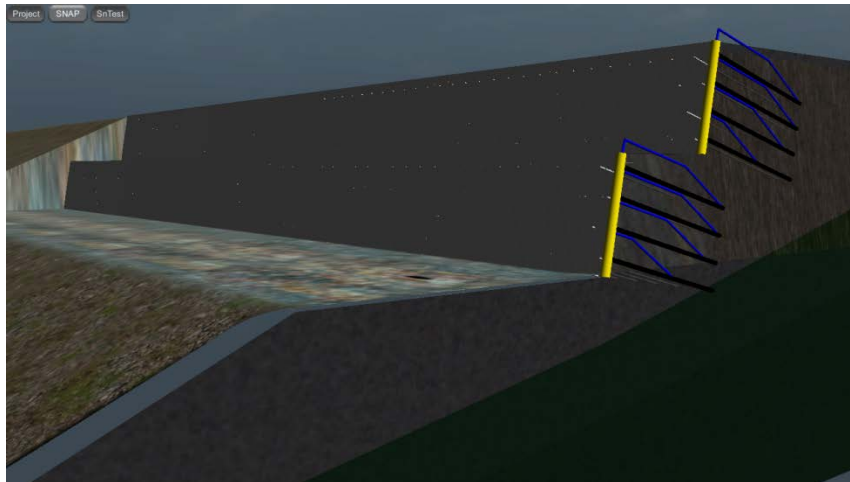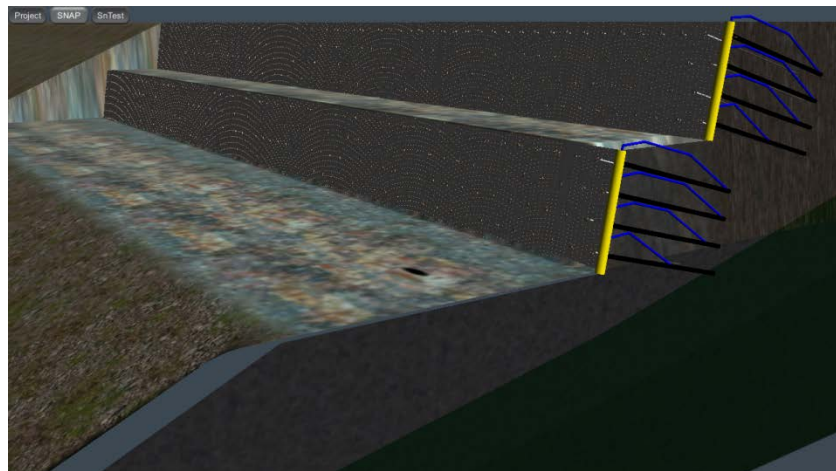
<u>Scene Closeup of Temporary Facing</u>

<u>Scene Closeup of Permanent Facing</u>

<u>Scene Panorama</u>

BIBLIOGRAPHY

Andrew, R., Hume, H., Hanson, S., Arndt, B. and Macklin, P. (2010). "SNAP (Soil Nail Analysis Program) User's Manual." Publication No. FHWA CFL/td-10-004. Federal Highway Administration, Central Federal Lands Highway Division, Lakewood, CO.

Byrne, R.J., Cotton, D., Porterfield, J., Wolschlag, C. and Ueblacker, G. (1998). "Manual for Design and Construction Monitoring of Soil Nail Walls," Report FHWA-SA-96-69R, Federal Highway Administration, Washington, D.C.

CALTRANS (1991). "A User's Manual for the SNAIL Program, Version 2.02 – Updated PC Version," California Department of Transportation, Division of New Technology, Material and Research, Office of Geotechnical Engineering, California Department of Transportation, Sacramento, California.

CALTRANS (2007). "A User's Manual for the SNAILZ Program, Version 2.02 – Updated PC Version," California Department of Transportation, Division of New Technology, Material and Research, Office of Geotechnical Engineering, California Department of Transportation, Sacramento, California. http://www.dot.ca.gov/hq/esc/geotech

Elias, V. and Juran, I. (1991). "Soil Nailing for Stabilization of Highway Slopes and Excavations," Publication FHWA-RD-89-198, Federal Highway Administration, Washington D.C.

FHWA (1993b). "French National Research Project Clouterre, 1991-Recomandations Clouterre 1991," (English Translation) Soil Nailing Recommendations, Publication FHWA-SA-93-026, Federal Highway Administration, Washington, D.C.

Golder (1993). "GOLDNAIL Soil Nailing Design Program," Golder Associates, Seattle, Washington.

Lazarte, C.A., V. Elias, R.D. Espinoza and P.J. Sabatini (2003). "Soil Nail Walls," Geotechnical Engineering Circular No. 7, FHWA-IF-03-017, Federal Highway Administration, Washington, D.C.

Lazarte. C.A., Robinson, H., Gómez, J. E., Baxter, A., Cadden, A, Berg, R. B., (2014) "Soil Nail Walls Reference Manual" Geotechnical Engineering Circular No. 7, FHWA-NHI-14-007, Federal Highway Administration, Washington, D. C.

Porterfield, J.A., Cotton, D.M. and Byrne, R.J. (1994). "Soil Nailing Field Inspectors Manual, Project Demonstration 103," Publication No. FHWA-SA-93-068, Federal Highway Administration, Washington, D.C.

PTI (1996). "Recommendations for Prestressed Rock and Soil Anchors," 3rd Ed., Post-Tensioning Institute, Phoenix, Arizona.

PTI (2005). "Recommendations for Prestressed Rock and Soil Anchors," 4th Ed., Post-Tensioning Institute, Phoenix, Arizona.