GeoStabilization International®

Limit Equilibrium including Shear Capacity for Launched Soil Nails

Matthew Birchmier, P.E.

The Soil Nail Launcher

Declassified British Military Cannon modified to Launch Soil Nails – War on shallow landslides

The Soil Nail Launcher

The Soil Nail Launcher

Accelerates a 1.5” diameter, 20’ long, bar or tube
Into the ground in a single shot utilizing air pressure

The Soil Nail Launcher

Launching sequence is controlled by a microprocessor ensuring correct and safe operation

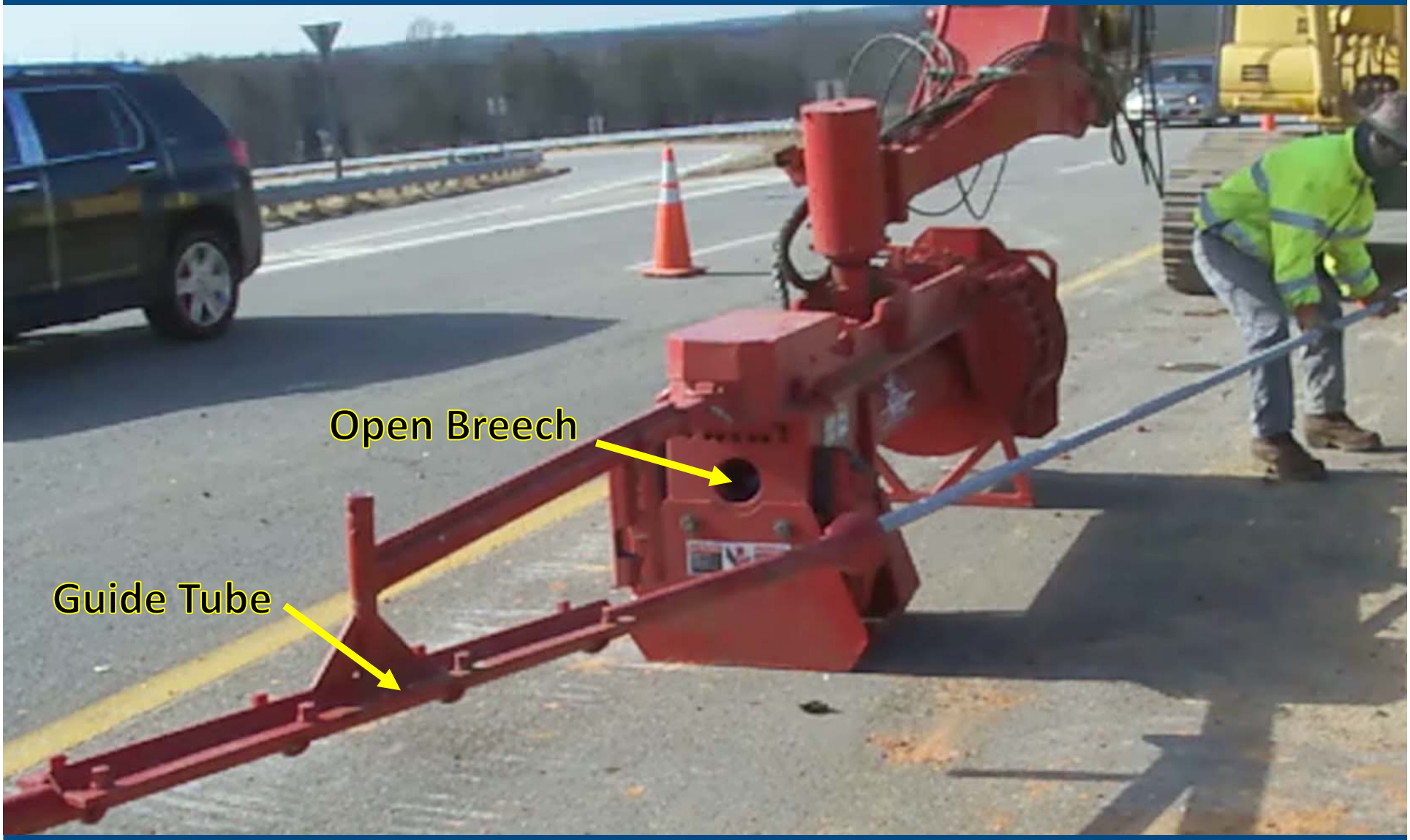
Building Launched Soil Nails

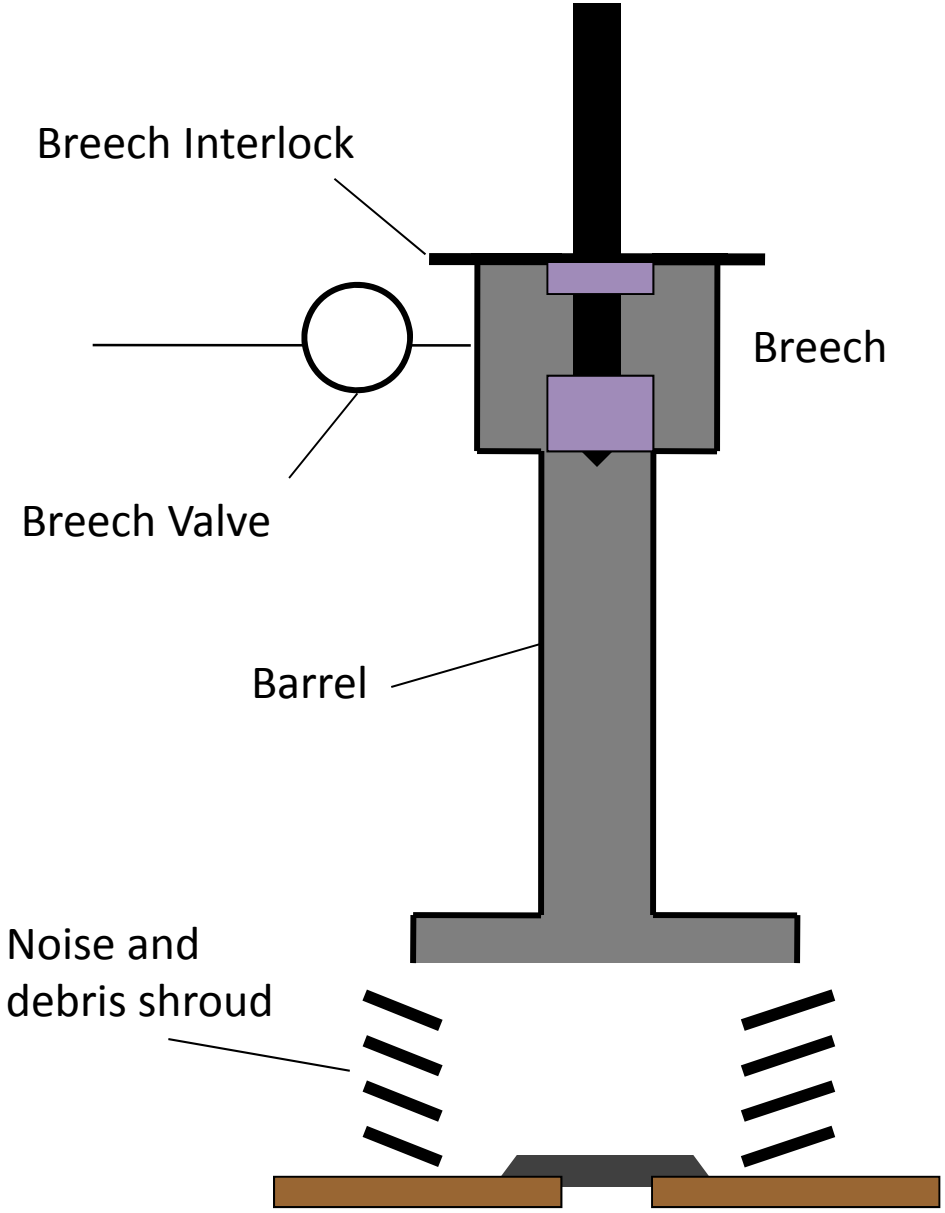
Barbed End

Collet

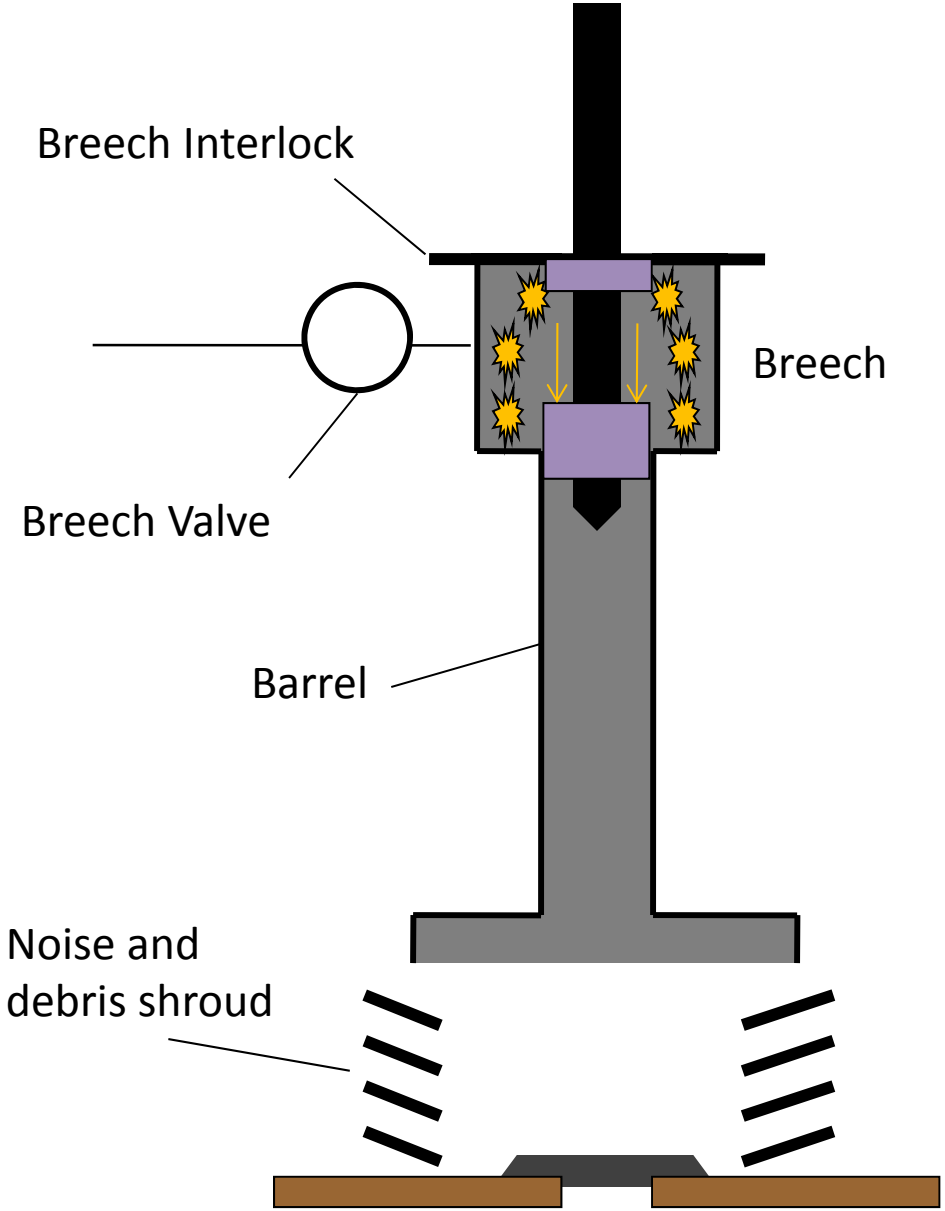
Assembled Nails

Loading Launcher

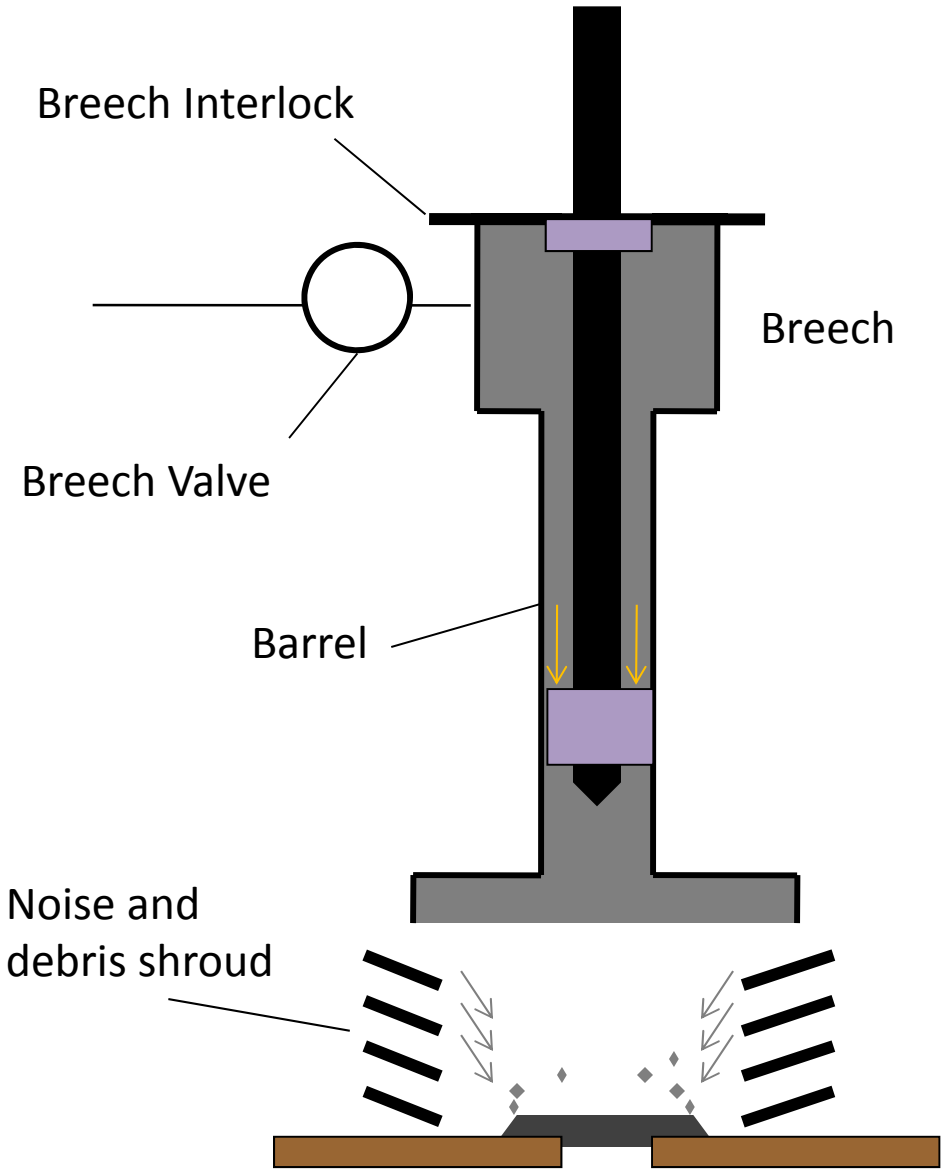




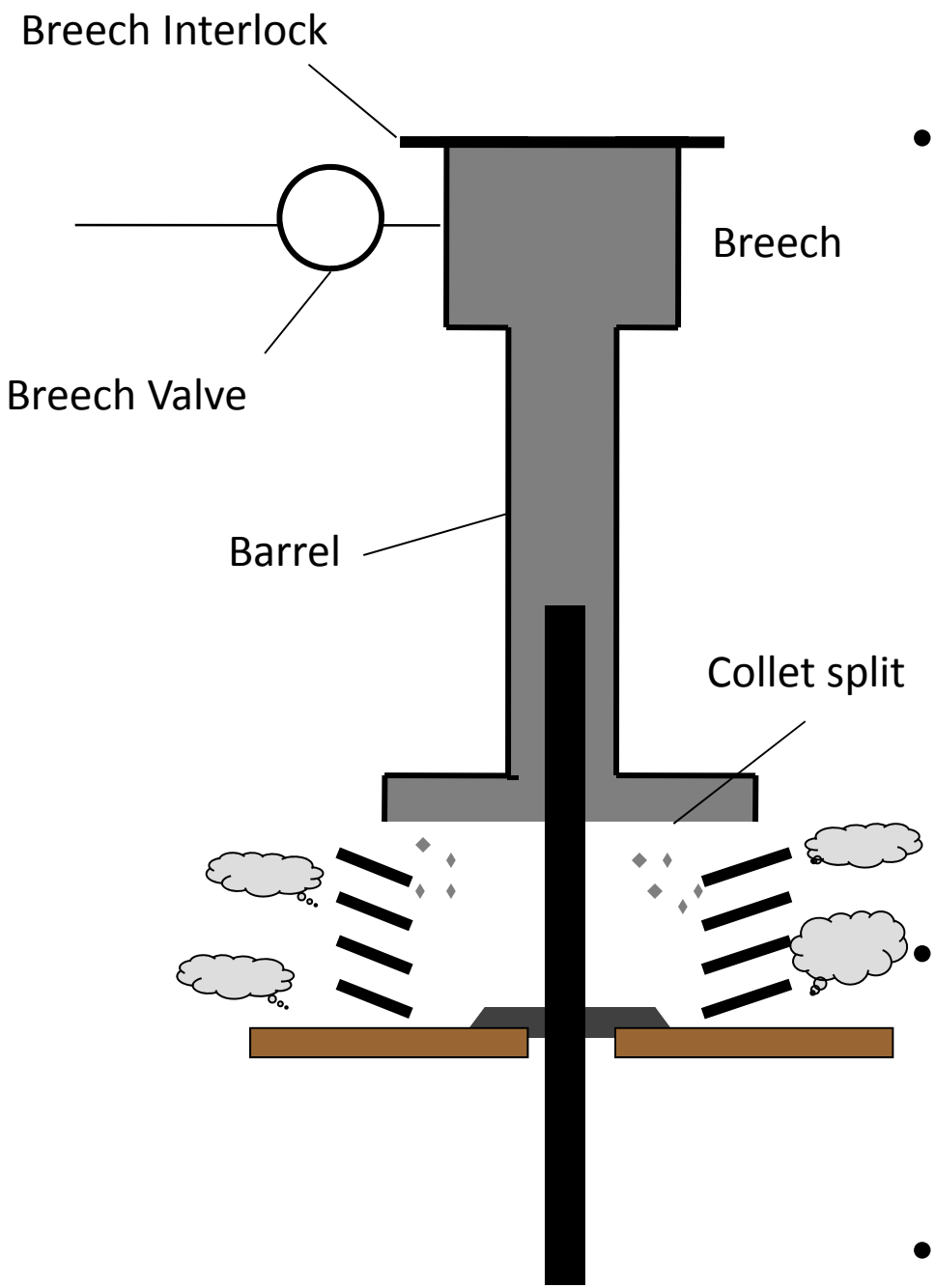
- Nail engaged within cylinder and breech closed.
- The onboard accumulator is charged to the desired air pressure.
- The maximum air pressure is ~4,000psi but can be varied depending on soil type and design requirements.



- Launched Nail is lifted into position and aligned in the desired direction.
- Baseplate must be in contact with ground to fire and personnel must be clear of the area.
- Following a sequence of auditory warning sirens, the nail is fired.

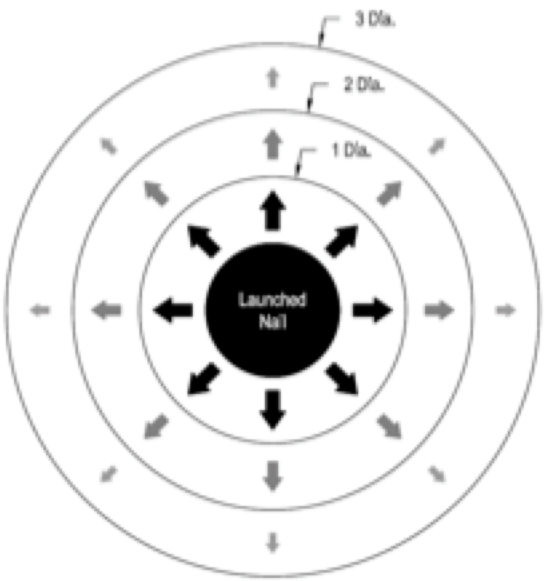


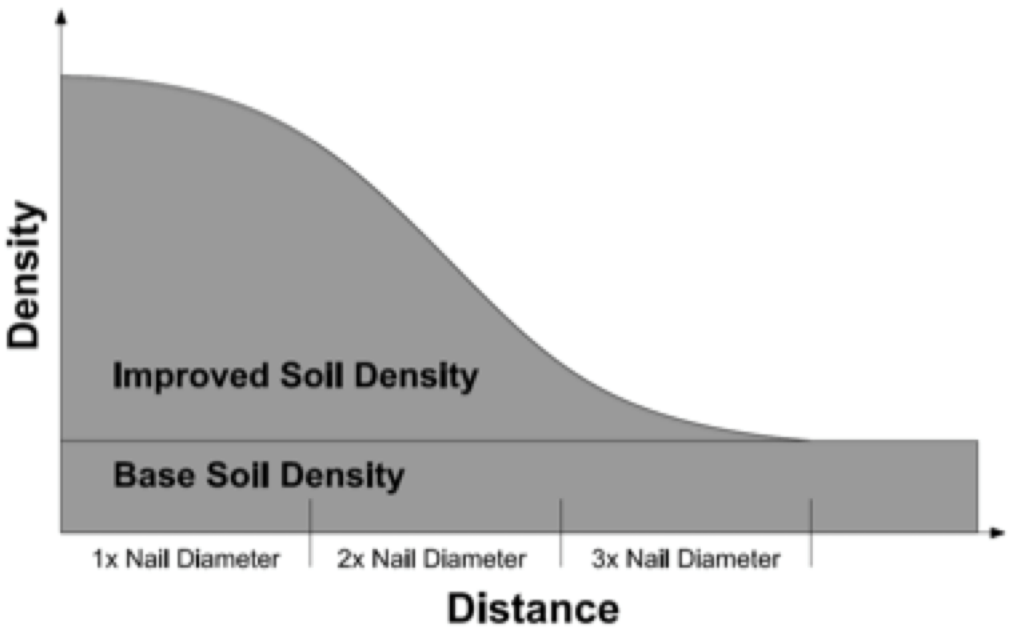
- The compressed air suddenly released against the collet forces the collet and nail through the barrel, much like a dart through a blowgun.
- The force acts upon the tip of the nail, placing the nail temporarily in tension, and preventing it from buckling.



- The collet breaks away as the nail enters the soil.
- The ground around the nail is displaced by compression at the tip, creating a shockwave in front of the nail tip that causes the soil particles to “jump away” from the main shaft of the nail. The nail subsequently enters the earth without significant abrasion or coating damage.
- The soil particles then collapse onto the nail providing a high pullout resistance.
- Nail is launched in 1/5 of a sec.

Improved Soil Density





Driven Nails

- Pounding, vibrating, or driving a nail into the ground disturbs the soil around the nail.
- Launched soil nails have a bond strength >10x that of driven nails.

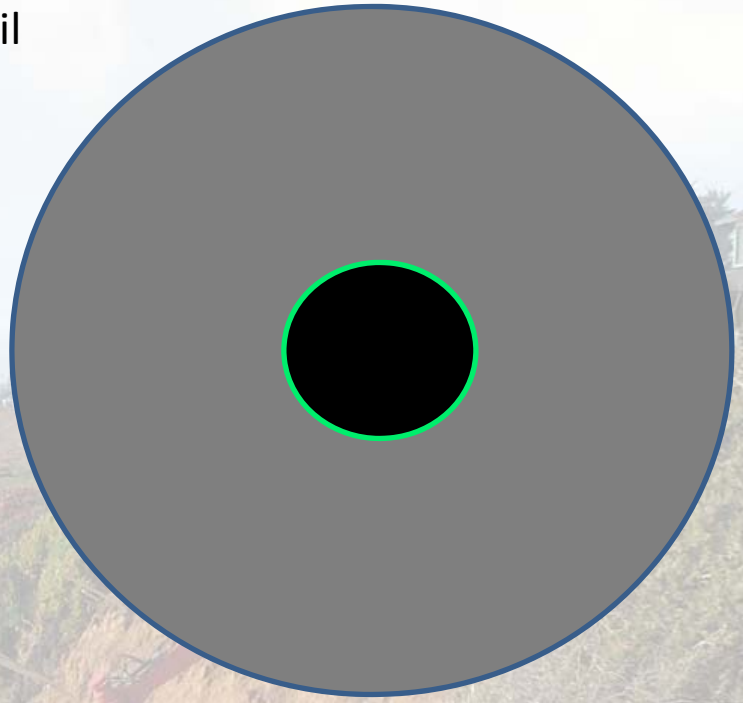
Grouting Launched Soil Nails

Inserting Inner Bar

Launched Soil Nails – Post Grouted

Post Grouted Launched Soil Nail
(SuperNail®)

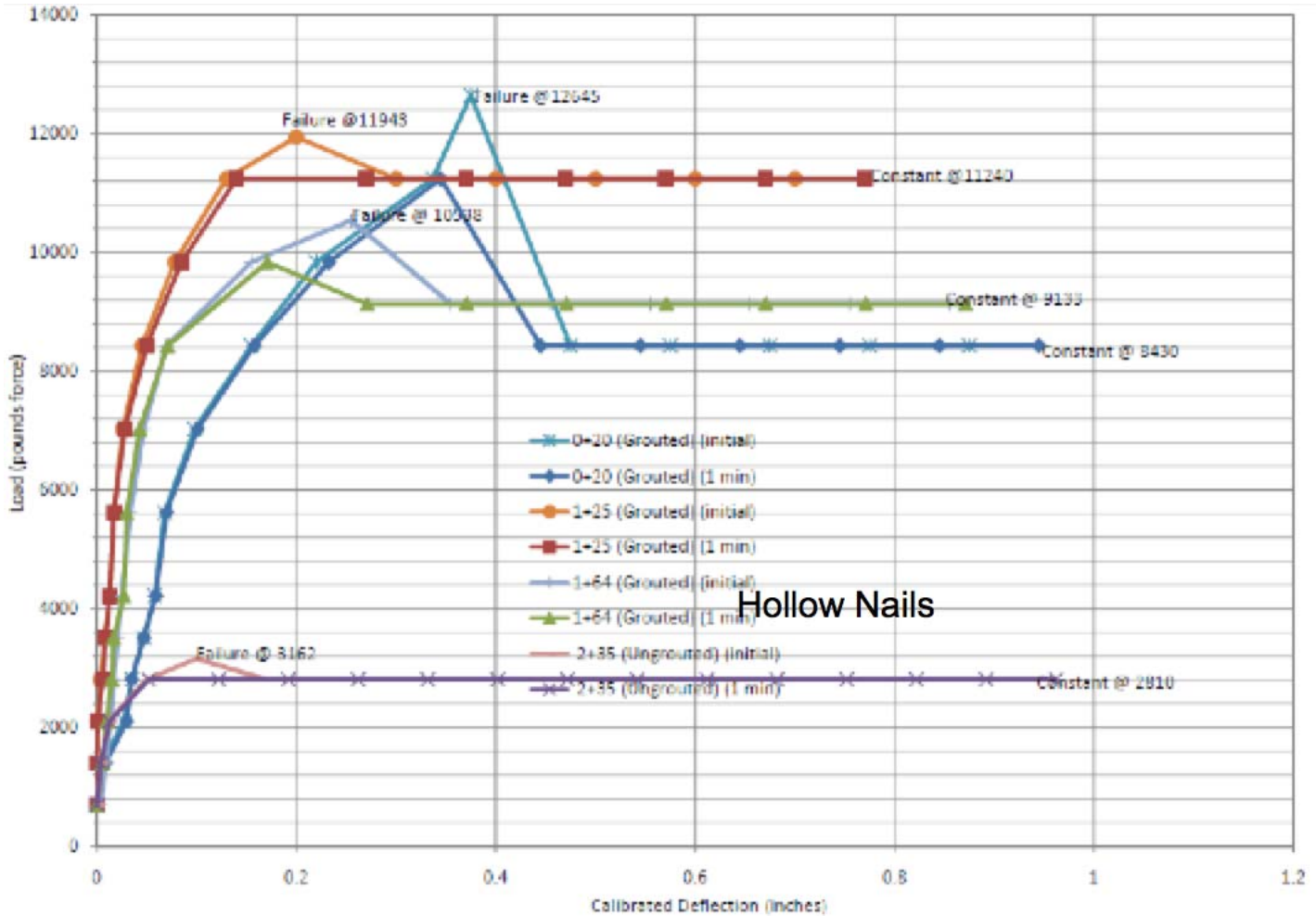
Traditional Soil Nail



Grout
Galvanization
Steel
Epoxy

Verification Testing

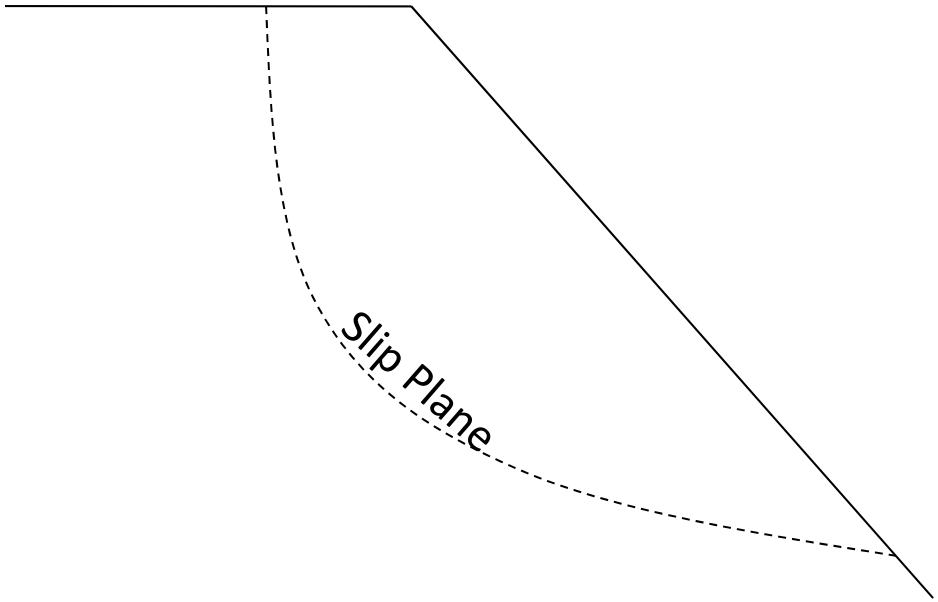
Pullout Results

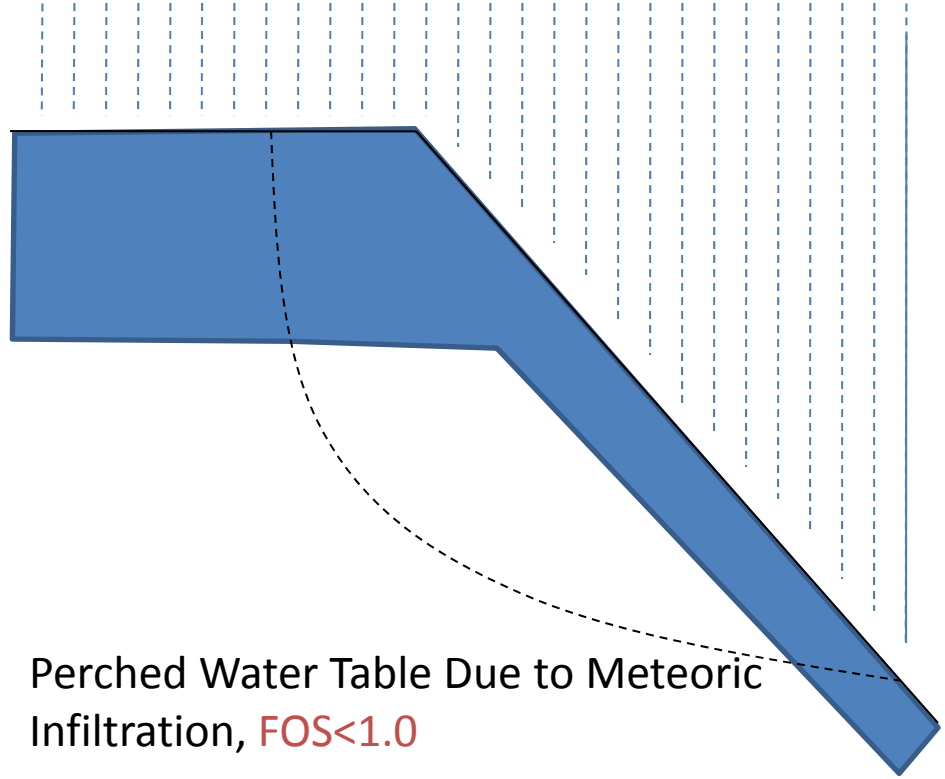


Average bond = 3.1 psi (ungrouted); 11.5 psi (grouted)

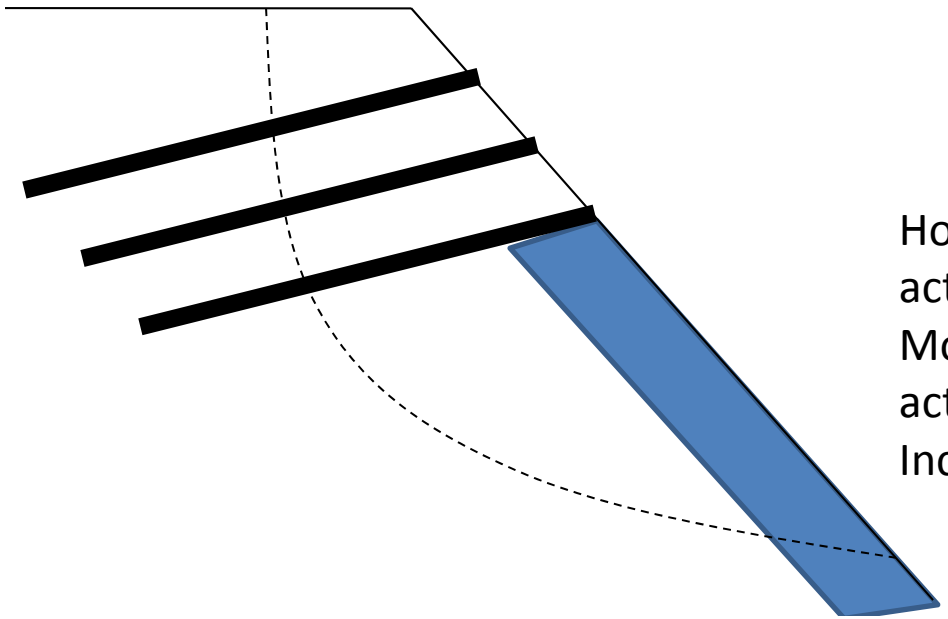
Launched Soil Nails - Drains

Landslide in dry conditions, FOS>1.0





Perched Water Table Due to Meteoric Infiltration, FOS<1.0



Hollow, Perforated Launched Soil Nails act as drains during high Moisture events, allowing drainage and acting as tensile Inclusions, FOS>>1.0

Material Types

- Any type of material can be utilized as long as it has the desired physical properties.
- Solid bar, threaded bar, or pipe. Steel bars can be left mill finish, galvanized, epoxy coated, plastic sheathing or a combination.

Site Analysis

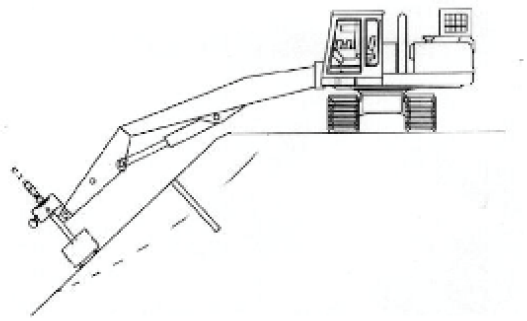
- Works well in sands, gravels, silts, and clays.
- Works well for shallow failures. Embedment depth limited to 20’.
- Sites with large cobbles, boulders, or bedrock are not suitable.

www.geotechtools.org

Technology Fact Sheet

SHOOT-IN SOIL NAILING

November 2012 http://www.GeoTechTools.org



Shoot-In Soil Installer Mounted on an Excavator
(Figure from Barrett et al. (2002))

Basic Function

Shoot in Soil Nailing uses a high pressure system to insert passive inclusions into the ground as a temporary or permanent earth retention system.

Advantages:

- More cost effective compared to alternate technologies
- Quick construction
- Can be constructed with limited headroom and limited right of way
- Can withstand large deformations
- Easily monitored and tested

General Description:

Soil nailing is an in-situ soil reinforcement technique wherein passive inclusions (soil nails) are placed into the natural ground at relatively close spacing (3 to 5 ft.) to increase the strength of the soil mass. In shoot-in soil nailing, the soil nails are inserted by a launcher that is typically mounted on a hydraulic excavator using high-pressure air.

The launcher typically launches plain or galvanized steel nails or fiberglass nails up to 1.5 inches in diameter and up to 20 feet in length. Shoot-in nails have seen much use in mountainous areas where rugged terrain limits construction options.

Geologic Applicability:

- Work well in sands, gravels, silts, and clays.
- Soils with large boulders or cobbles are not suitable.
- Dense gravels and stiff clays will reduce penetration and are not preferable.
- Soils that are corrosive or prone to liquefaction or collapse when water is present are not suitable for the technology.
- A high groundwater table should be drained if the forces are too great. Water will decrease slope stability.

Construction Methods:

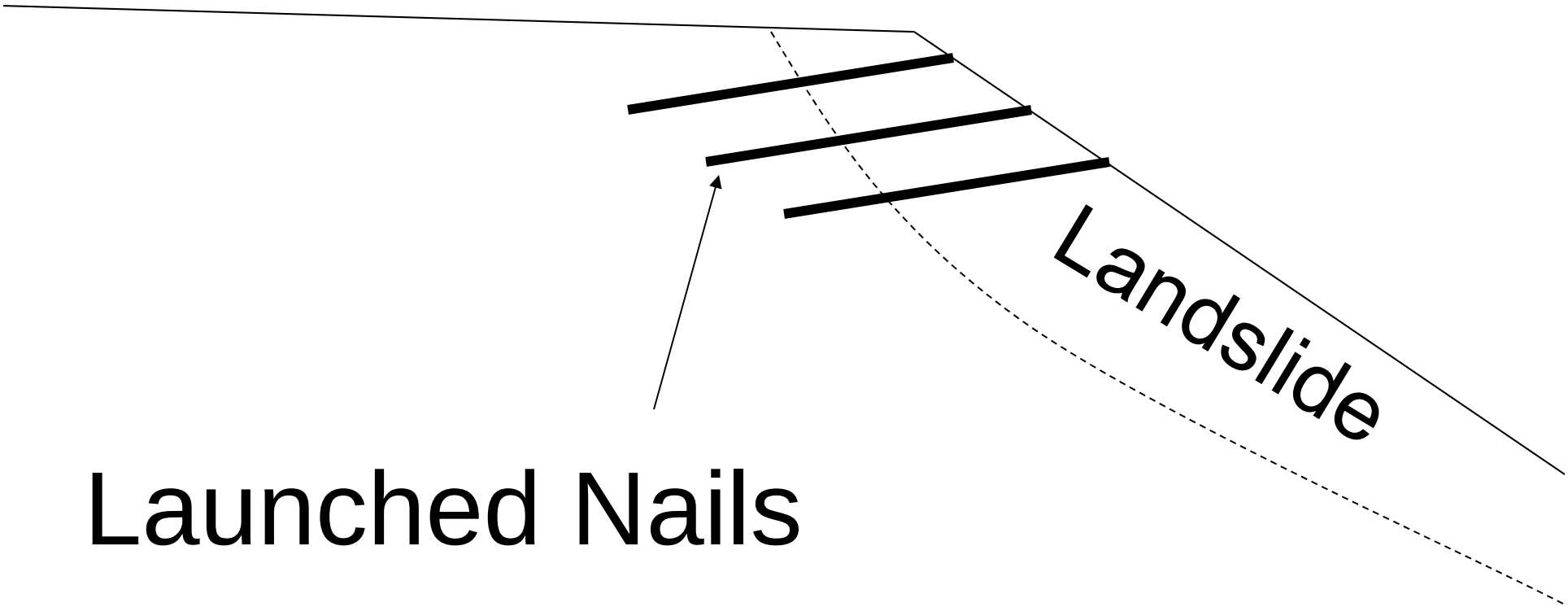
Soil nails are inserted by a launcher that is typically mounted on a hydraulic excavator and uses high-pressure air acting upon a collet (plastic collar) which is attached to the tip

R02 GEOTECHNICAL SOLUTIONS FOR SOIL IMPROVEMENT, RAPID EMBANKMENT CONSTRUCTION, AND STABILIZATION OF PAVEMENT WORKING PLATFORM

SHRP2

- More cost effective compared to alternative technologies
- Quick construction
- Can be constructed with limited headroom and limited ROW
- Can withstand large deformations
- Easily monitored and tested

Design Concept



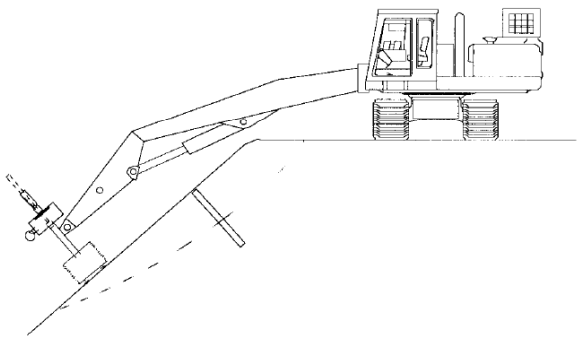
Launched Nails

Design Guidance

United States Department of Agriculture
Forest Service
Engineering Staff
EM 7170-12A
United States Department of Transportation
Federal Highway Administration
FHWA-FPL-93-003
July 1994

Application Guide For Launched Soil Nails

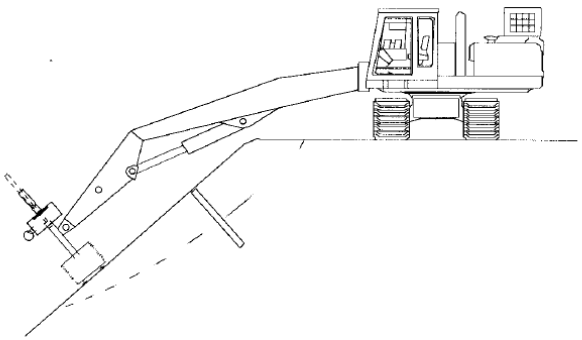
Volume I



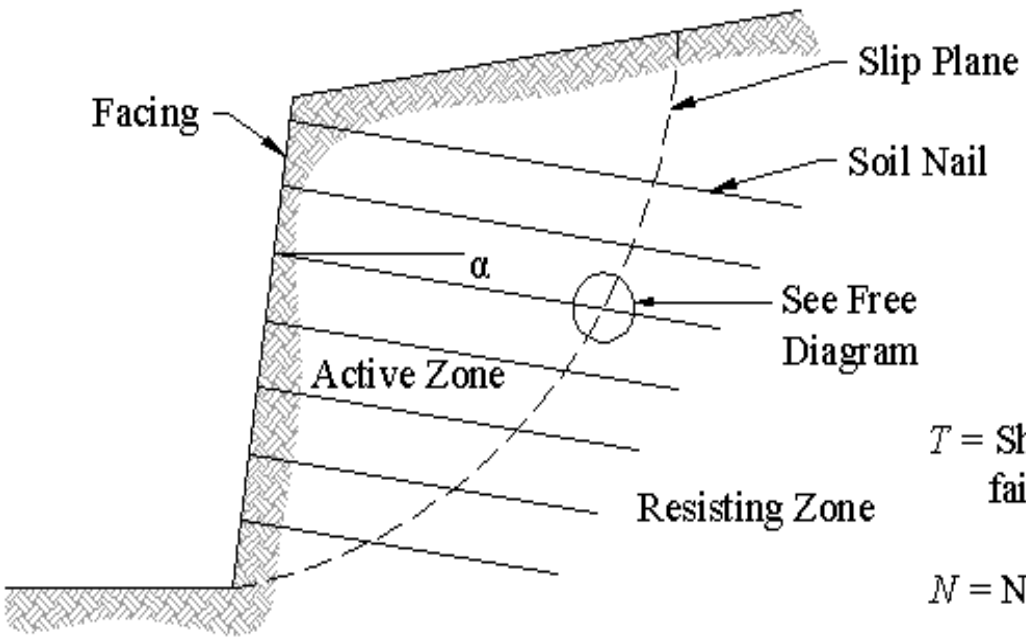
United States Department of Agriculture
Forest Service
Engineering Staff
EM 7170-12B
United States Department of Transportation
Federal Highway Administration
FHWA-FPL-93-004
July 1994

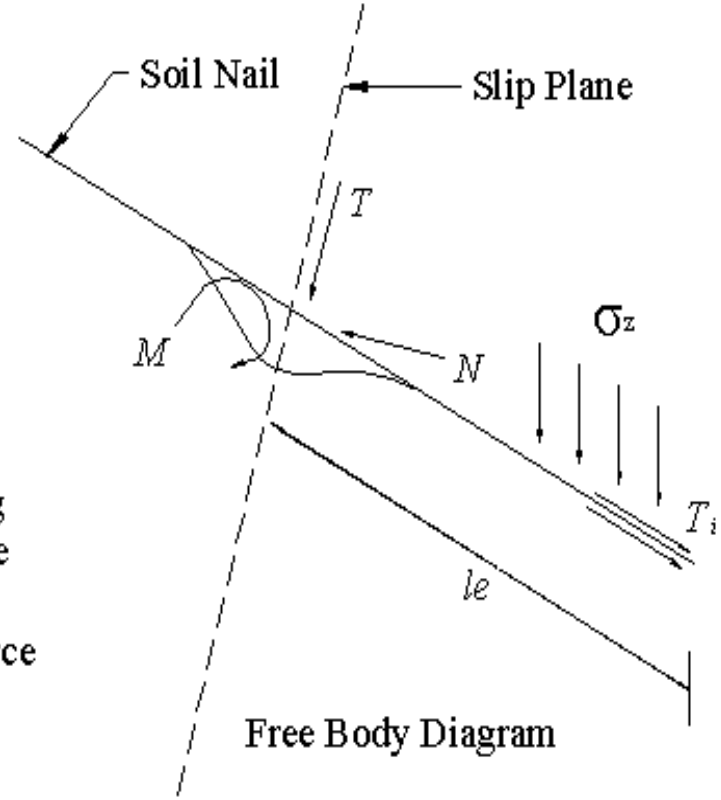
Project Report for Launched Soil Nails—1992 Demonstration Project

Volume 2



Soil Nail Failure Mechanism





T = Shear along failure plane

N = Normal force

M = Moment

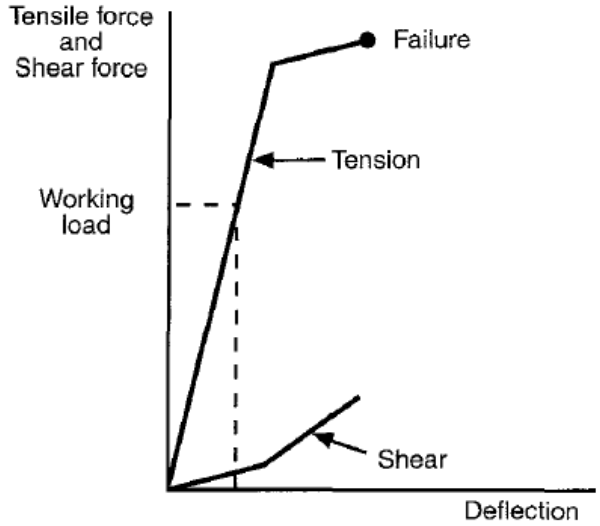
T_i = Interface Shear

le = Effective length

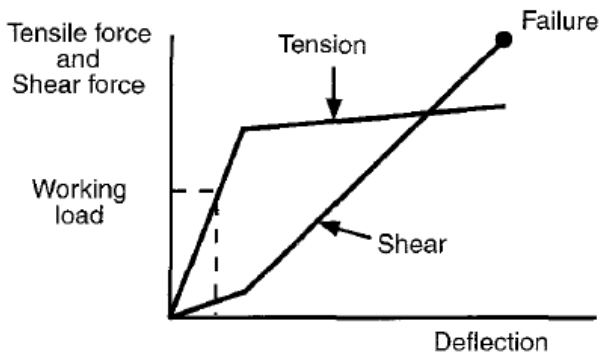
σ_z = Soil pressure

The nail is fired generally ungrouted and penetrates beyond the slip surface to a limited extent. In this case the tension is a small proportion of the fracture strength and the shear capacity requires to be exploited.

Development of Tensile & Shear

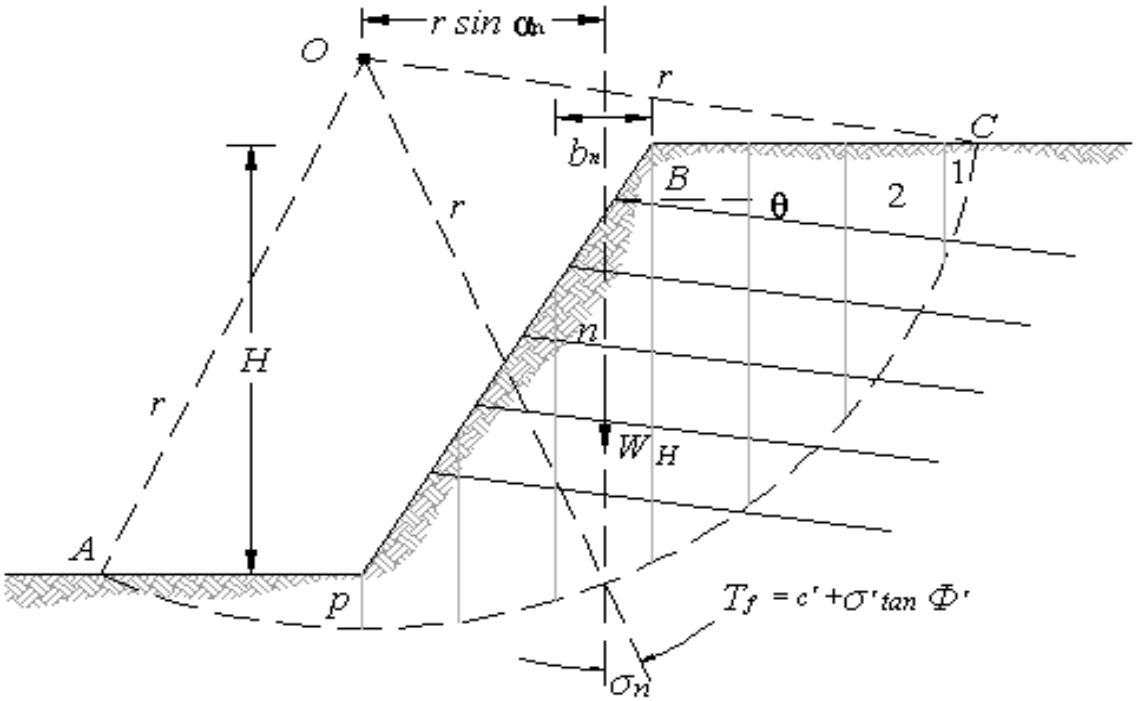


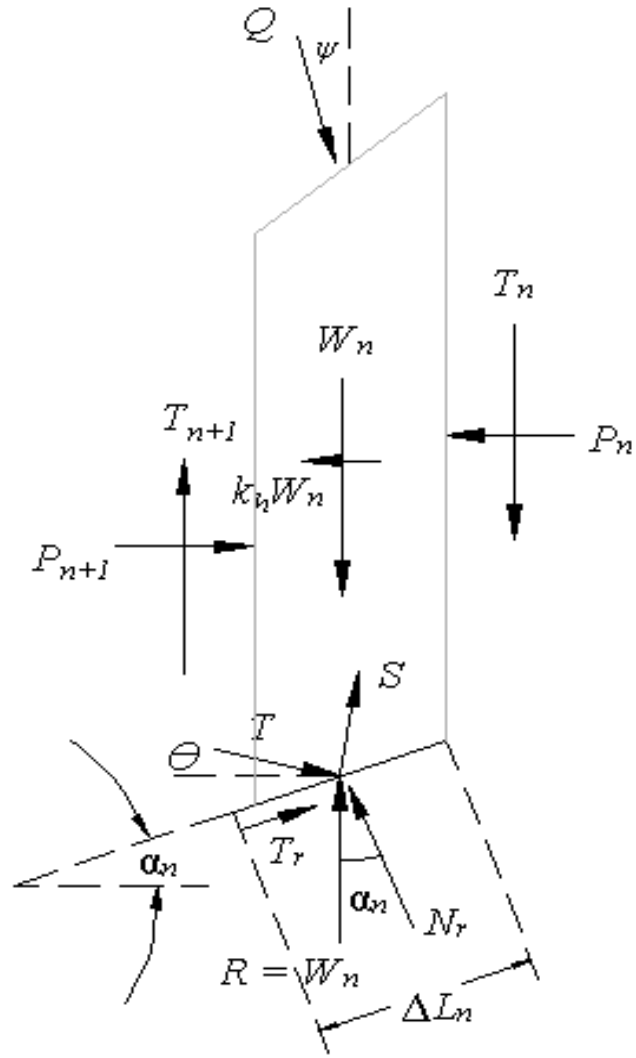
- Long grouted nail



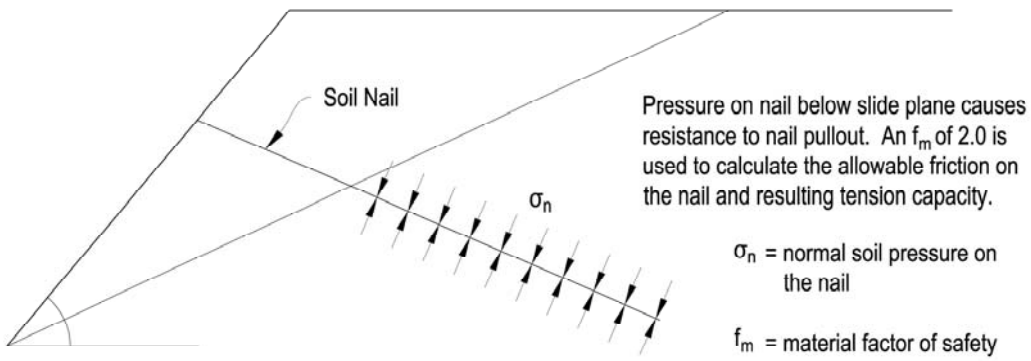
- Short ungrouted nail

Load & Stress Condition for Modified Bishop Analysis





Tension & Shear



$$T_{N_{allowable}} = \alpha_{N_{pullout}} \tau_{bond} \pi d L_B \qquad (3)$$

$\alpha_{N\_pullout}$ – pullout resistance factor
d – diameter of nail (typically 1.5 inches (38mm) for launched soil nails)
L_B – the bonding length of nails beyond the failure surface
τ_{bond} – bonding stress between nail and soil (lb/in^2)

For a nail of diameter of *d*, the ultimate shear resistance S_u is:

$$S_u = q_u L_o d$$

where

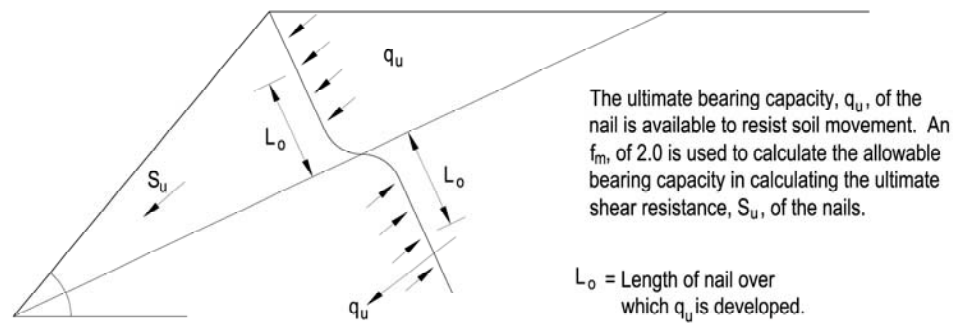
q_u – ultimate bearing capacity of the soil in the effective length of L
L_o – effective length of the nail over which q_u is developed

The ultimate bearing capacity of the soil is calculated by:

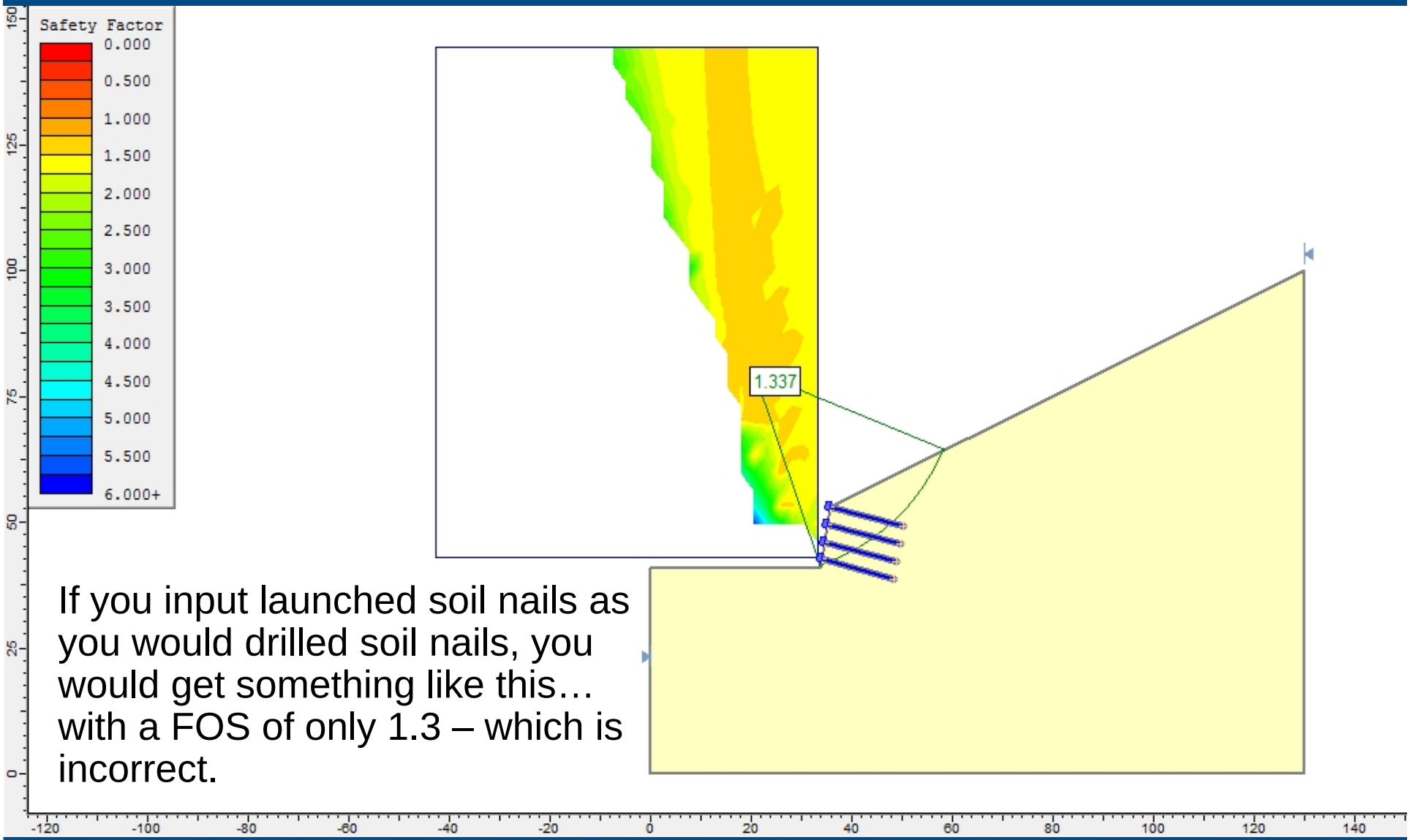
$$q_u = \sigma_n N_q^* \qquad (($$

where

σ_N – normal pressure on the nail at the intersection of the nail and tl failure surface
N^*_q – Terzaghi bearing capacity factor

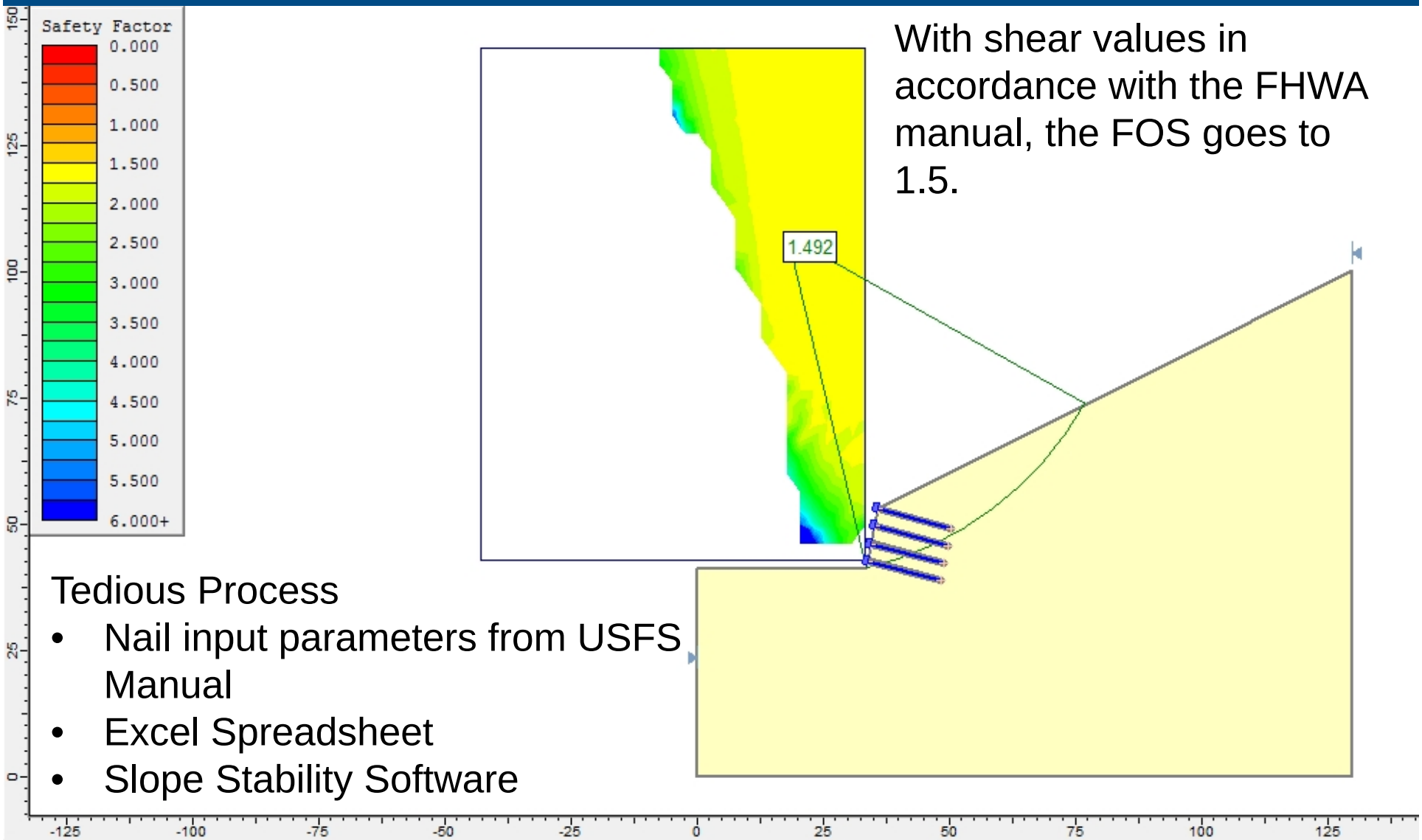


Slope Stability Modeling



If you input launched soil nails as you would drilled soil nails, you would get something like this… with a FOS of only 1.3 – which is incorrect.

Slope Stability Modeling

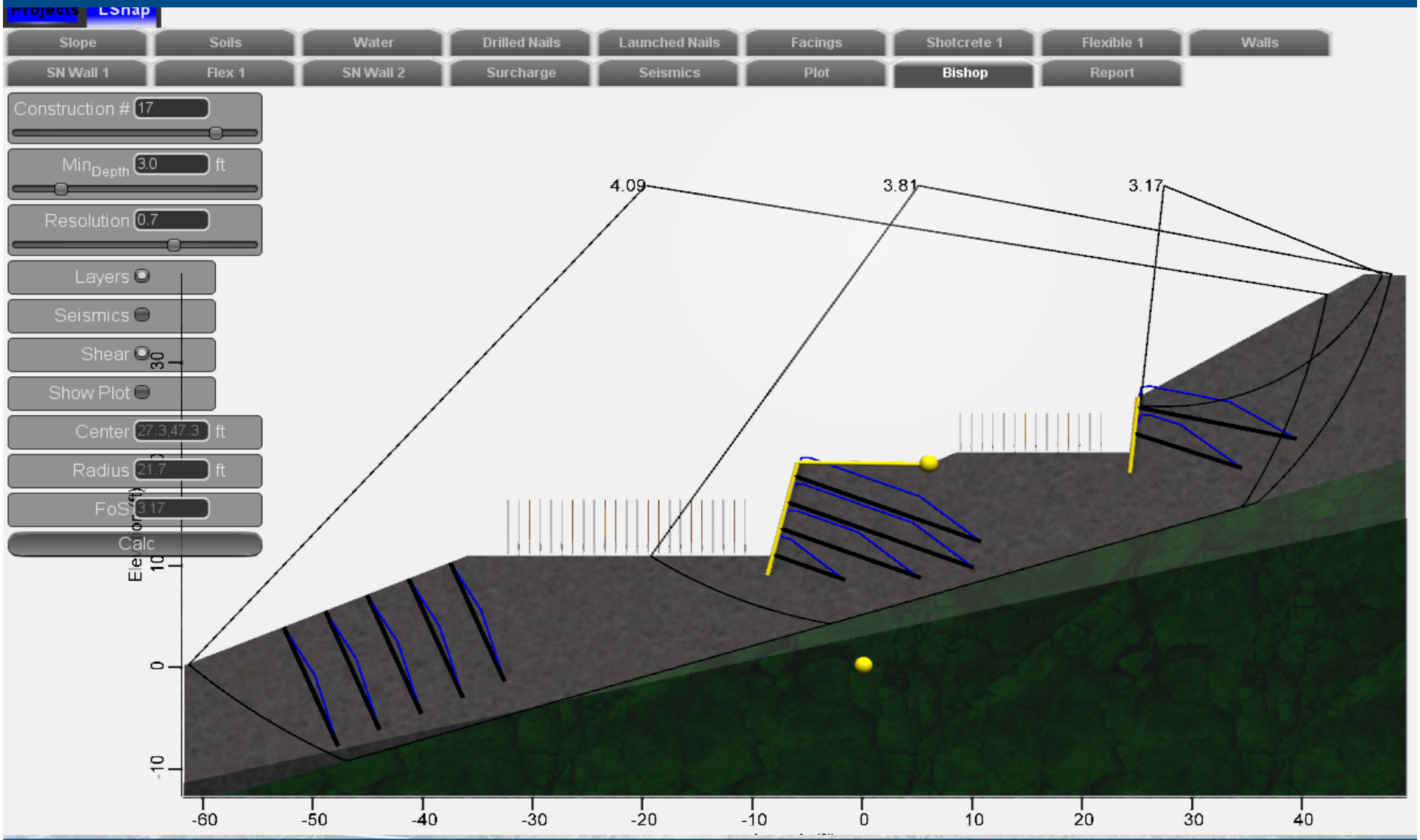


With shear values in accordance with the FHWA manual, the FOS goes to 1.5.

Tedious Process

- Nail input parameters from USFS Manual
- Excel Spreadsheet
- Slope Stability Software

LSNAP


Projects
LSnap
Slope
Soils
Water
Drilled Nails
Launched Nails
Facings
Shotcrete 1
Flexible 1
Walls
SN Wall 1
Flex 1
SN Wall 2
Surcharge
Seismics
Plot
Bishop
Report
Construction # 17
Min Depth 3.0 ft
Resolution 0.7
Layers
Seismics
Shear
Show Plot
Center 27.3,47.3 ft
Radius 21.7 ft
FoS 3.17
Calc
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-10
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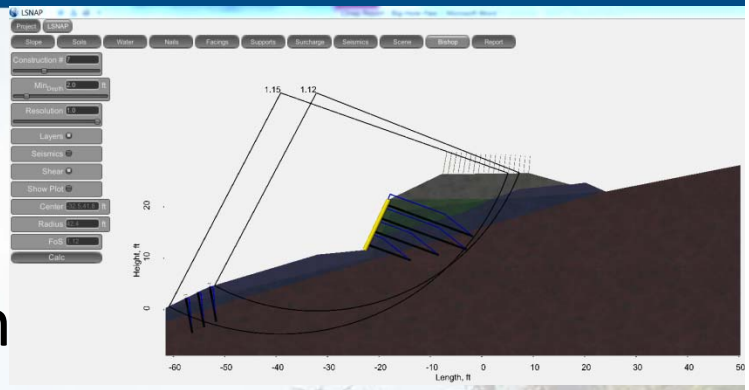
40

LSNAP

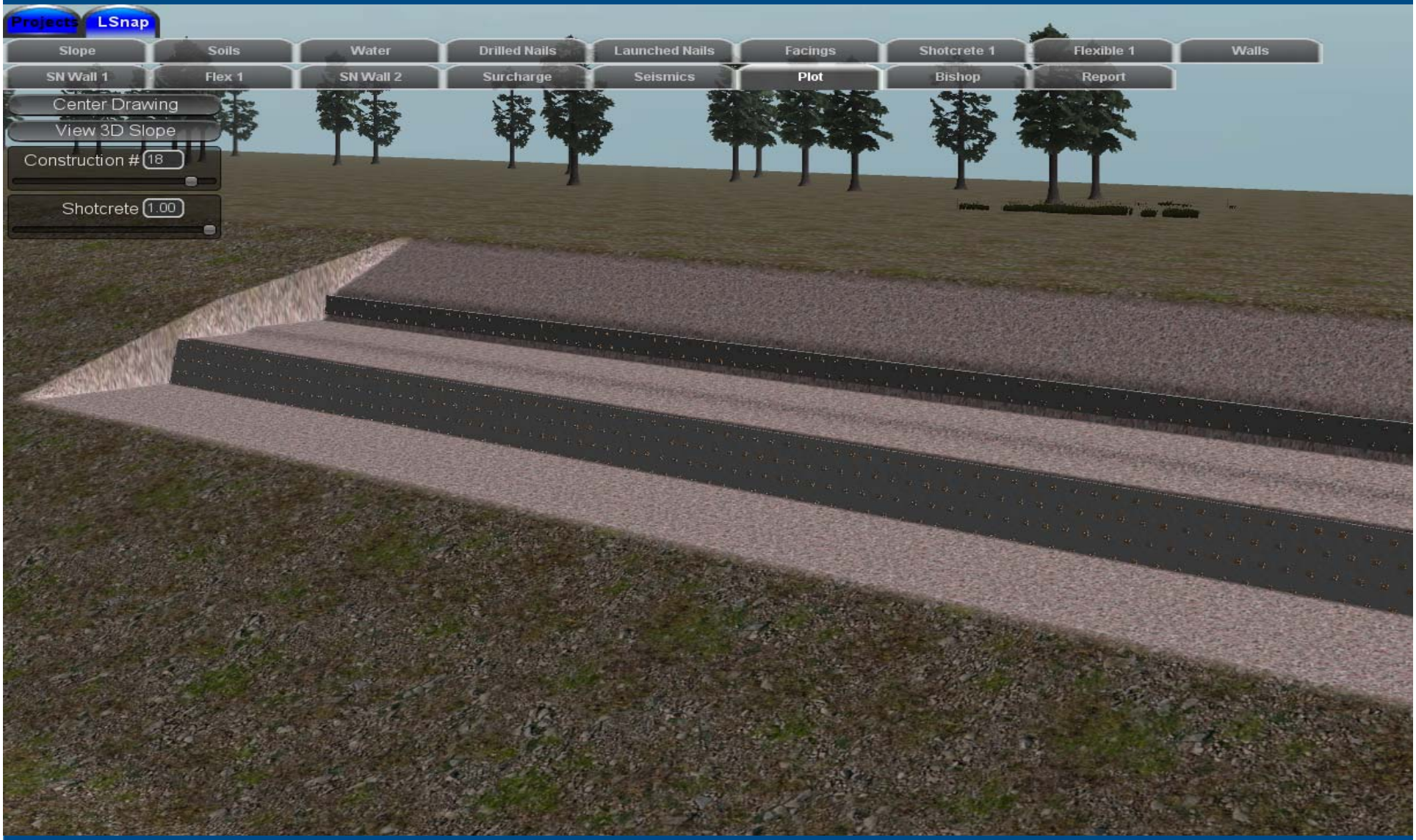


LSNAP Support:

- Traditional Soil Nail Wall Design
  - Shortcrete facing
  - Cast-in place facing
  - Flexible facing
- Launched Soil Nail Wall Design
- Multi-Tiered Walls Design
- Stage cut and Construction Sequence Analysis
- General Slope Stability Analysis

LSNAP

LSNAP


Projects
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Slope
Soils
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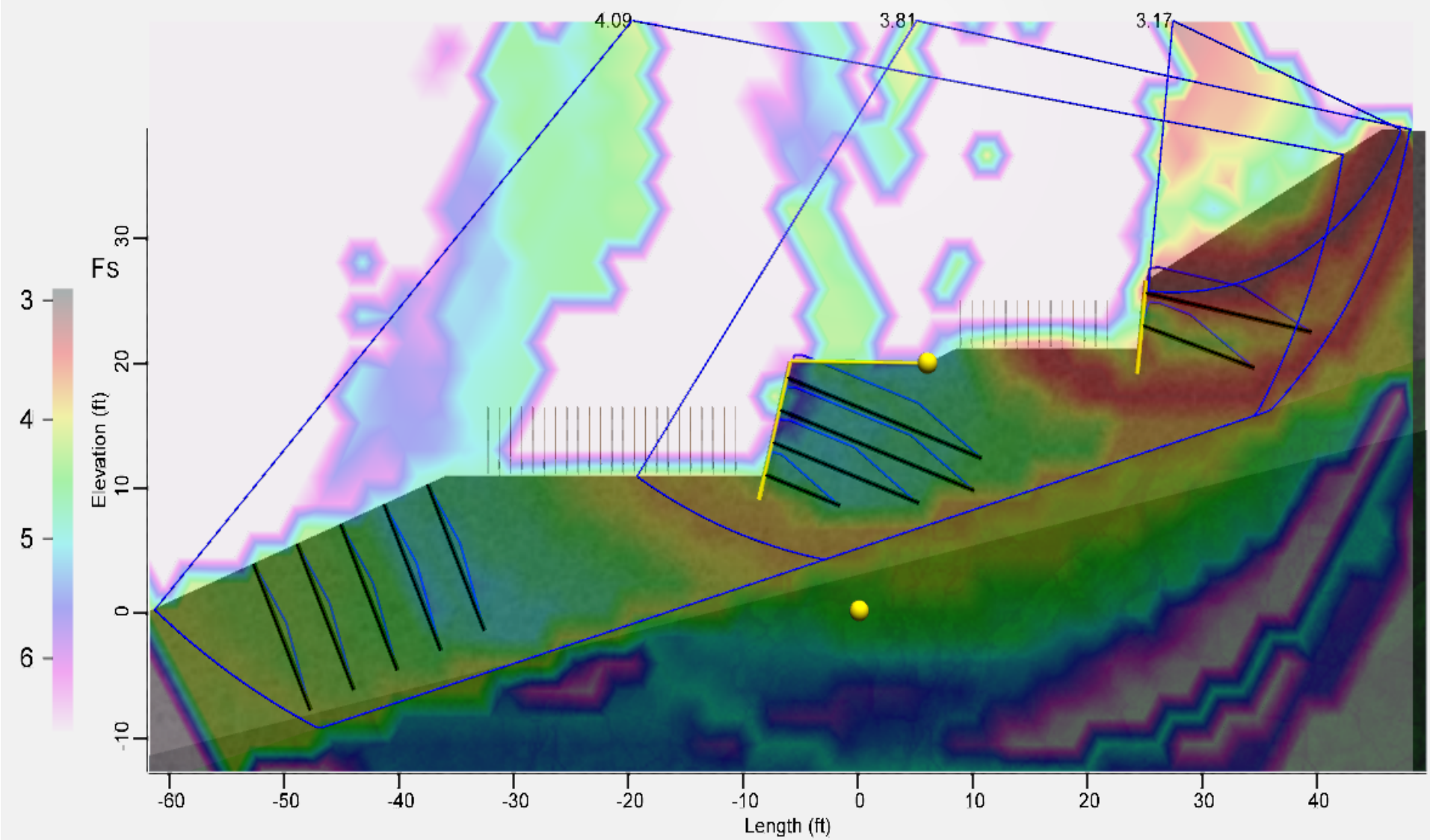
Launched Nails
Facings
Shotcrete 1
Flexible 1
Walls
SN Wall 1
Flex 1
SN Wall 2
Surcharge
Seismics
Plot
Bishop
Report
Center Drawing
View 3D Slope
Construction # 18
Shotcrete 1.00

LSNAP


4.09
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Elevation (ft)
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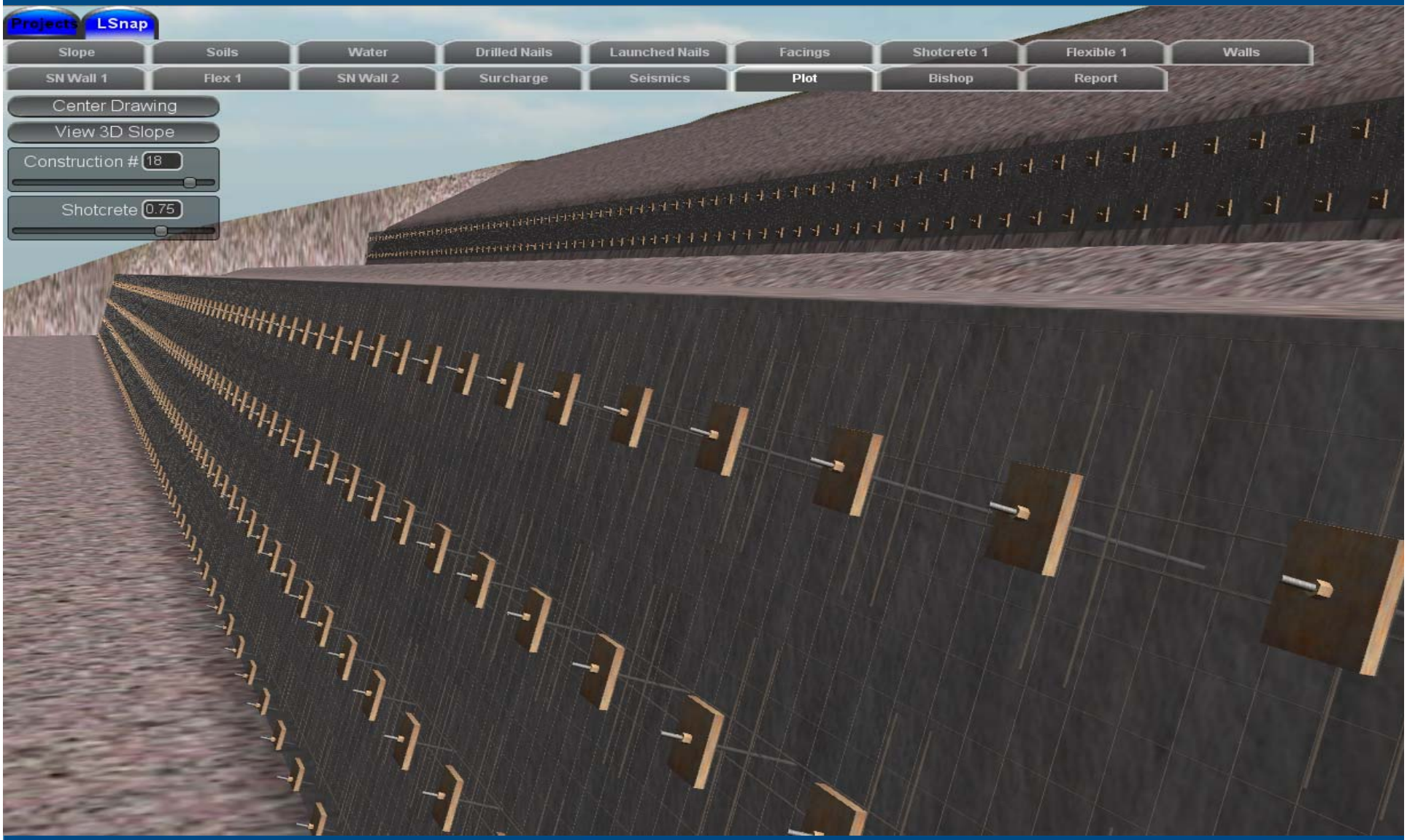
30
40
Length (ft)

LSNAP


Projects
LSnap
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Water
Drilled Nails
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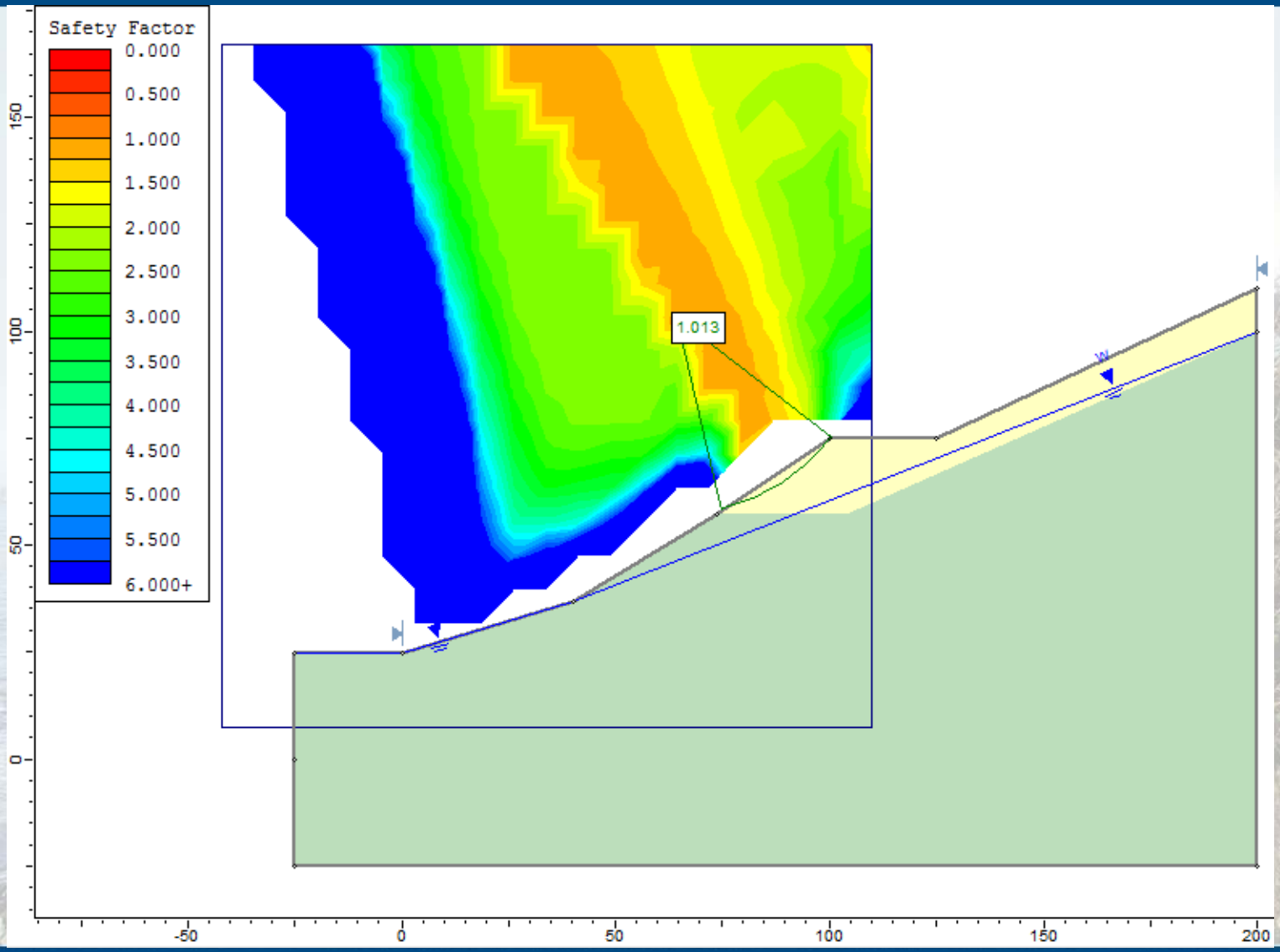
Facings
Shotcrete 1
Flexible 1
Walls
SN Wall 1
Flex 1
SN Wall 2
Surcharge
Seismics
Plot
Bishop
Report
Center Drawing
View 3D Slope
Construction # 18
Shotcrete 0.75

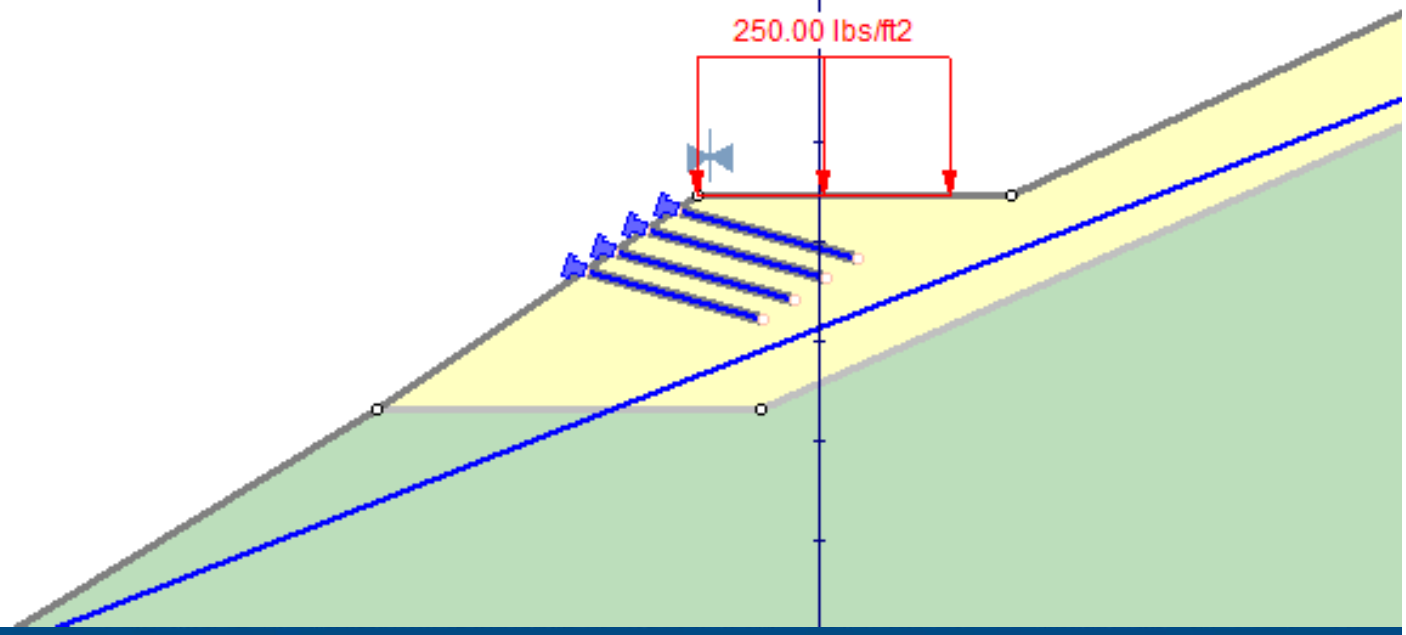
Back Analysis



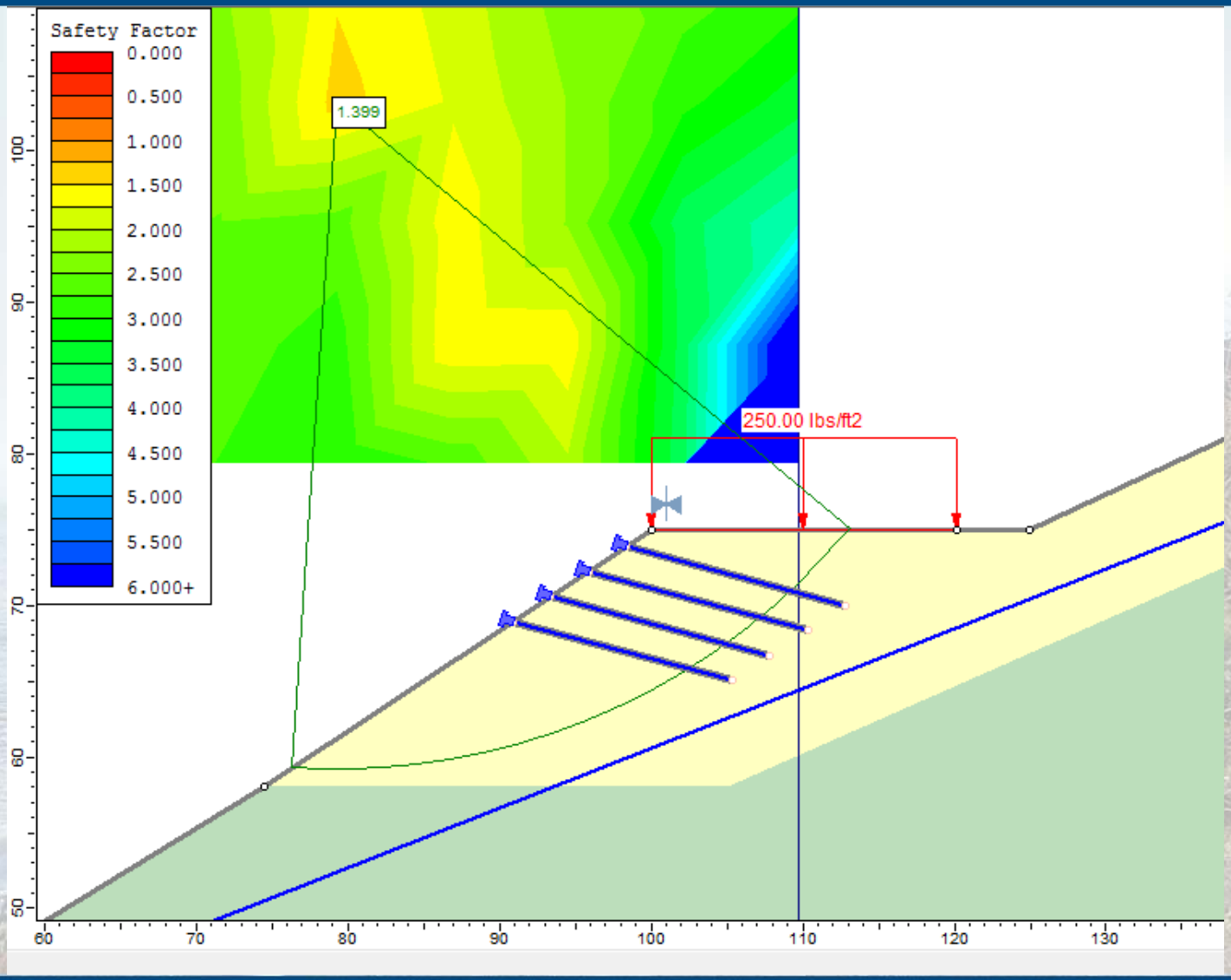
Designing with Slide

Support Name	Color	Type	Force Application	Out-Of-Plane Spacing (ft)	Tensile Capacity (lbs)	Plate Capacity (lbs)	Shear Capacity (lbs)	Bond Strength (lbs/ft)
Launched Nails		Soil Nail	Active (Method A)	3	20000	10000	0	250

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
Material 1		125	Mohr-Coulomb	20	28	Water Surface	Custom	1
Material 2		130	Mohr-Coulomb	1000	35	Water Surface	Custom	1



Designing with Slide



Determining Shear Capacity

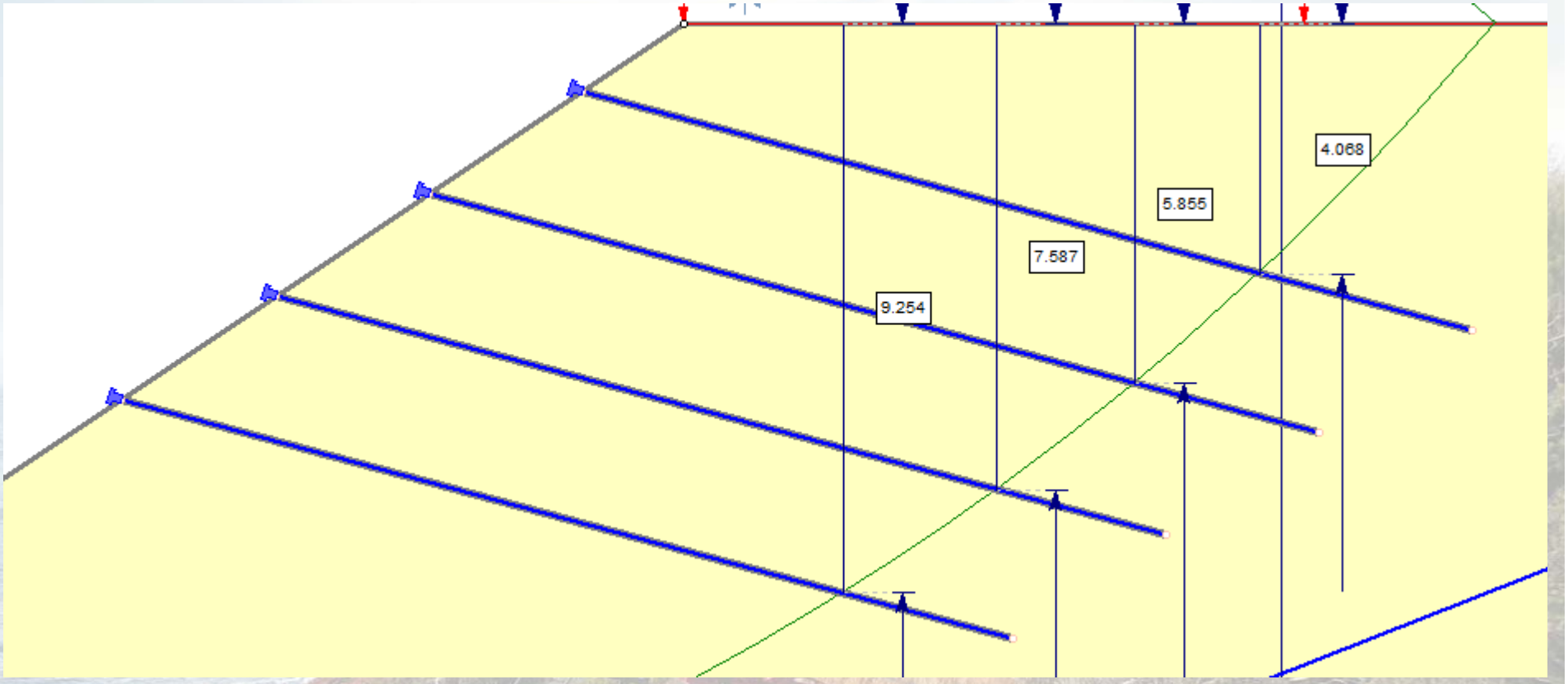
Soil Nail Wall Application		Cardiff Method		
Soil Properties				
Unit Weight (pcf)	γ'	125		
Friction Angle (°)	ϕ'	28		
Cohesion (psf)	c'	20		
Bearing Capacity Factor	N_q	14.72		
Allowable Bond (psi)	τ_{allow}	4.4	(250 lb/ft)	
Wall Geometry	Dimensions in feet unless noted otherwise			
	x_T	100.0		
Top of Wall Coordinates	y_T	75.0		
Angle of Backslope (°)	β	0.0		
Wall Batter (°)	θ	56.3		
Depth to First Nail Row (ft)	s_{v1}	1.1		
Vertical Nail Spacing (ft)	s_V	3.0		
Horizontal Nail Spacing (ft)	s_H	3.0		
Wall Height (ft)	H	12.5		

Nail Properties						
Tube				Inner Bar		
Outside Diameter (in)	$O.D._{tube}$	1.500		Diameter (in)	d_{bar}	0.500
Inside Diameter (in)	$I.D._{tube}$	1.260		Young's Modulus (psi)	E_{bar}	29000000
Young's Modulus (psi)	E_{tube}	29000000		Yield Stress (psi)	F_{ybar}	60000
Yield Stress (psi)	F_{ytube}	36000		Moment of Inertia (in^4)	I_{bar}	0.0031
Moment of Inertia (in^4)	I_{tube}	0.1248		Section Modulus (in^3)	S_{xbar}	0.0123
Section Modulus (in^3)	S_{xTube}	0.1664				

Determining Shear Capacity

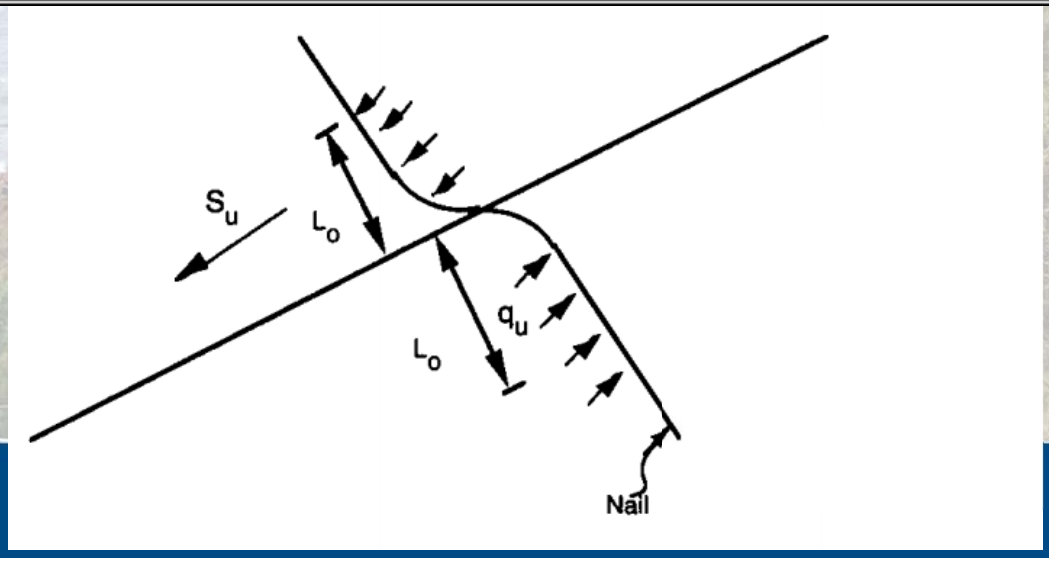
Composite Nail		
Moment Strength (lb·ft)	M_n	560.5
M_{nLF} per lineal foot (lb·ft/LF)	M_{nLF}	186.8
Nail Inclination (º)	α	15.0
Nail Length (ft)	L	15.0

Determining Shear Capacity

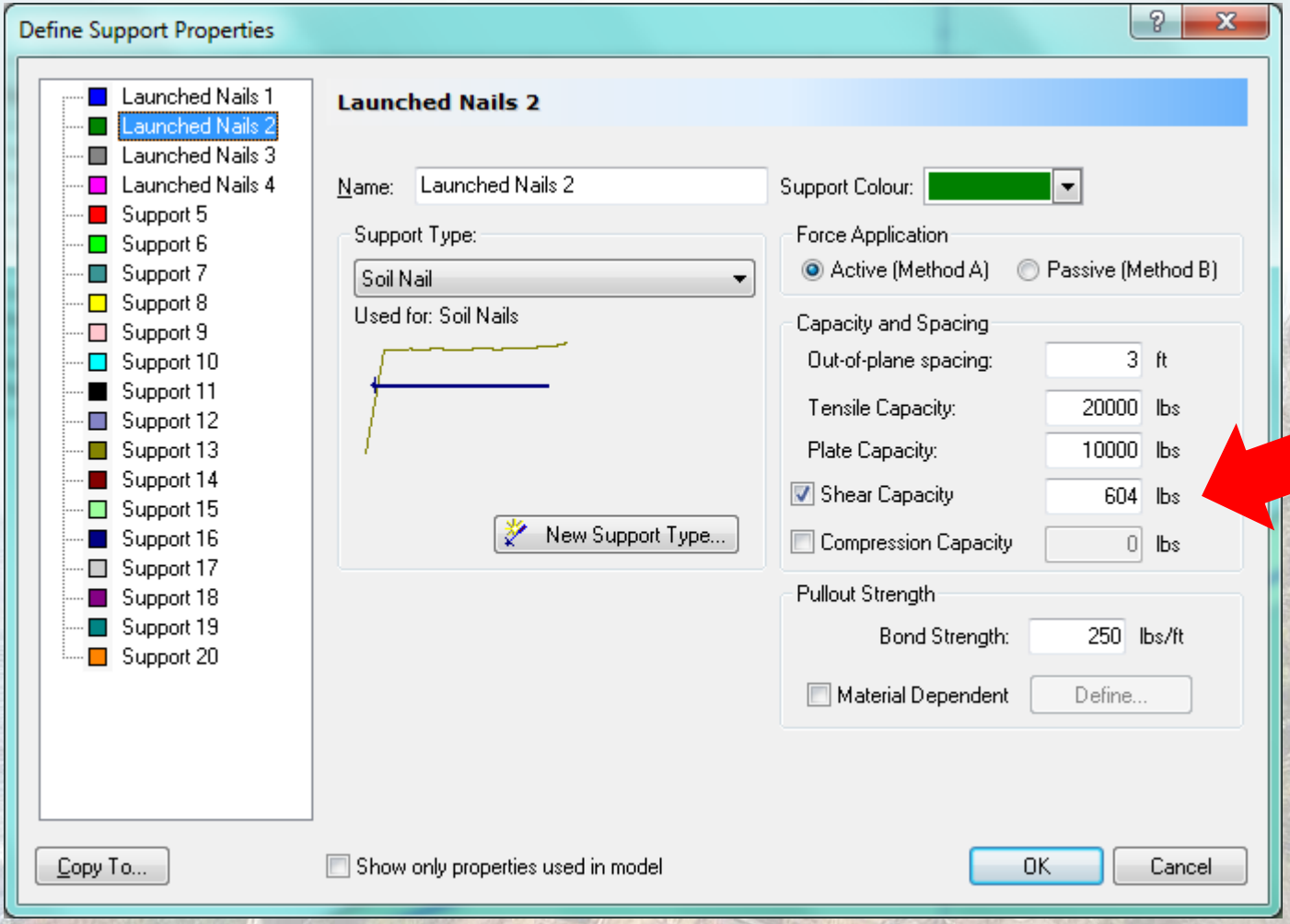


Determining Shear Capacity

Depth to Failure Plane / Nail Intersection	Normal Stress on Nail	Ultimate Lateral Soil Bearing	Allowable Shear in Nail	Allowable Shear in Nail per LF of Wall
z	σ_n (psf)	q_u (psf)	S_{nail} (lb)	S_{nail} (lb/LF)
4.1	491	7230	503	167.8
5.9	707	10406	604	201.3
7.6	916	13484	687	229.1
9.3	1117	16447	759	253.0
0.0	0	0	0	0.0

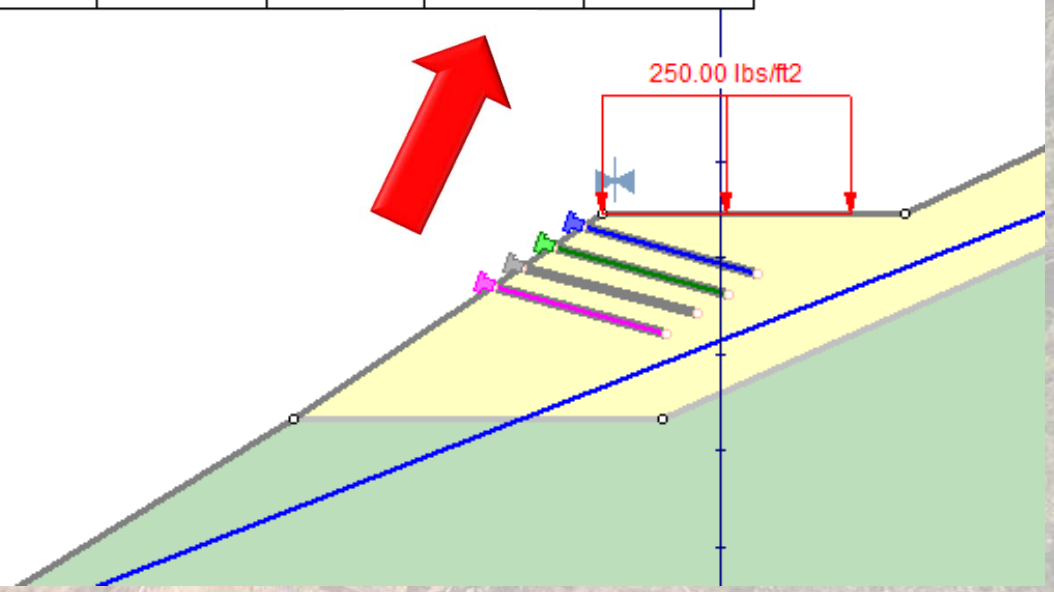


Re-Designing with Slide

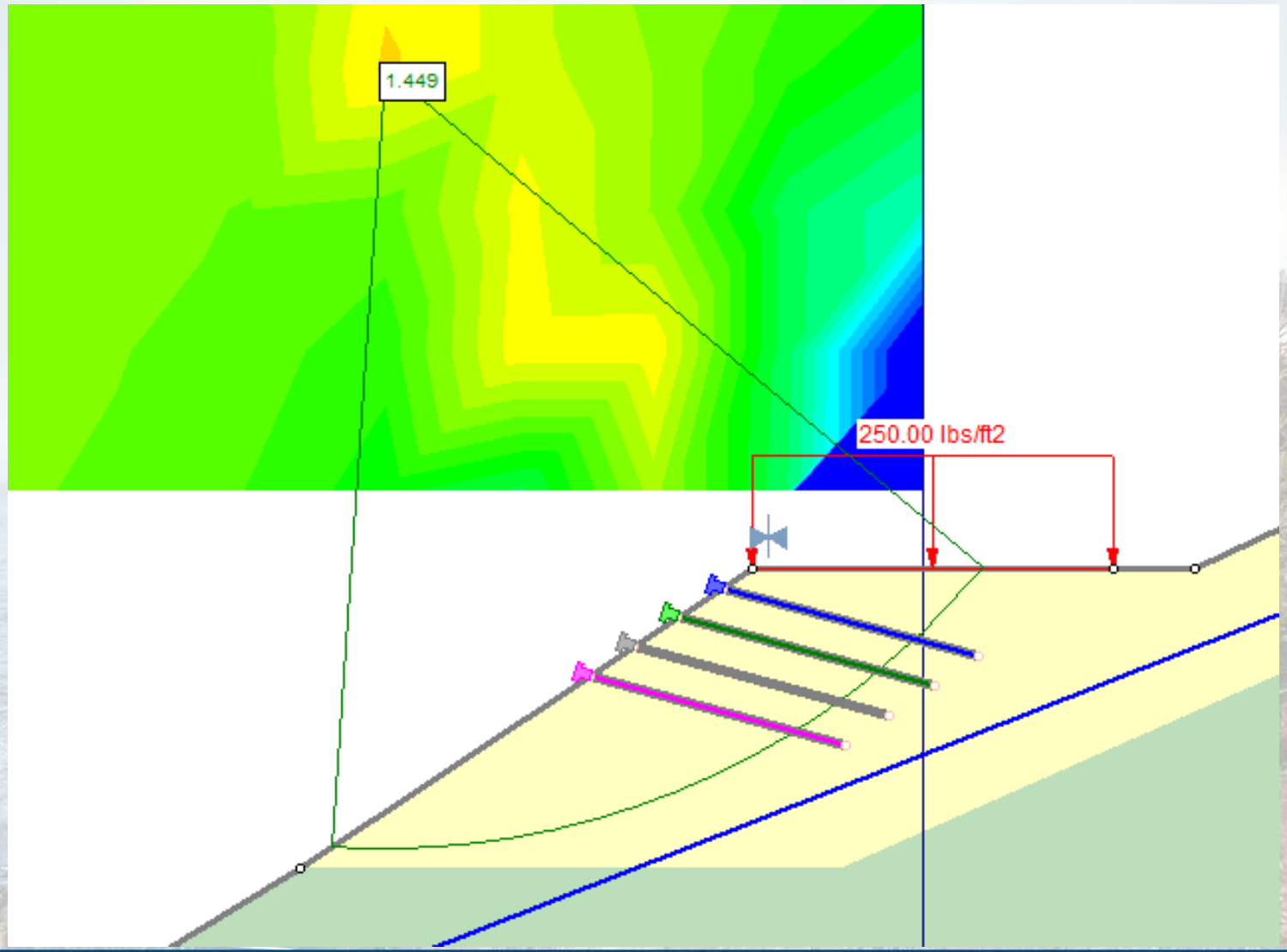


Re-Designing with Slide

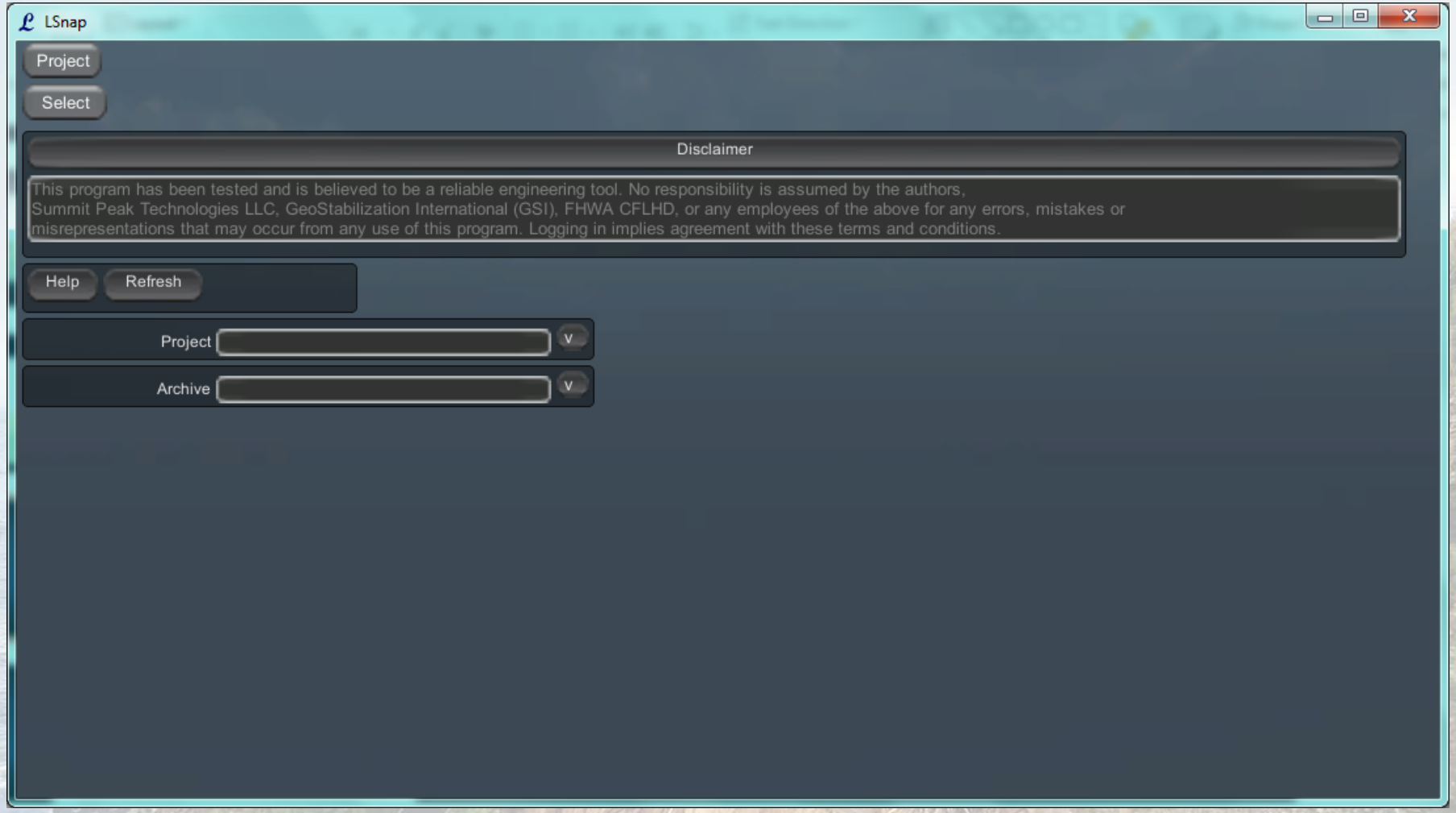
Support Name	Color	Type	Force Application	Out-Of-Plane Spacing (ft)	Tensile Capacity (lbs)	Plate Capacity (lbs)	Shear Capacity (lbs)	Bond Strength (lbs/ft)
Launched Nails 1		Soil Nail	Active (Method A)	3	20000	10000	503	250
Launched Nails 2		Soil Nail	Active (Method A)	3	20000	10000	604	250
Launched Nails 3		Soil Nail	Active (Method A)	3	20000	10000	687	250
Launched Nails 4		Soil Nail	Active (Method A)	3	20000	10000	759	250



Re-Designing with Slide

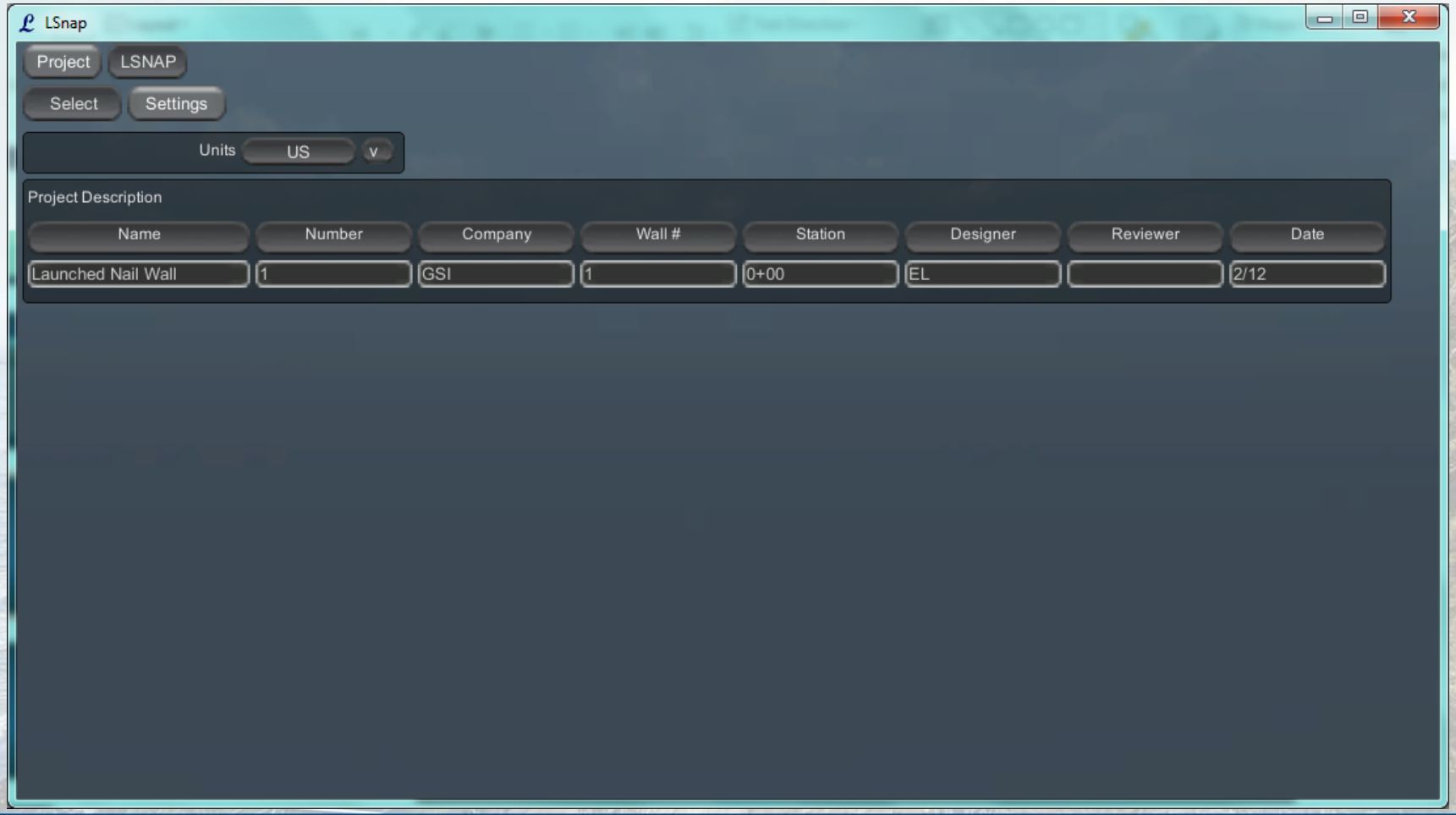


Introduction to LSNAP



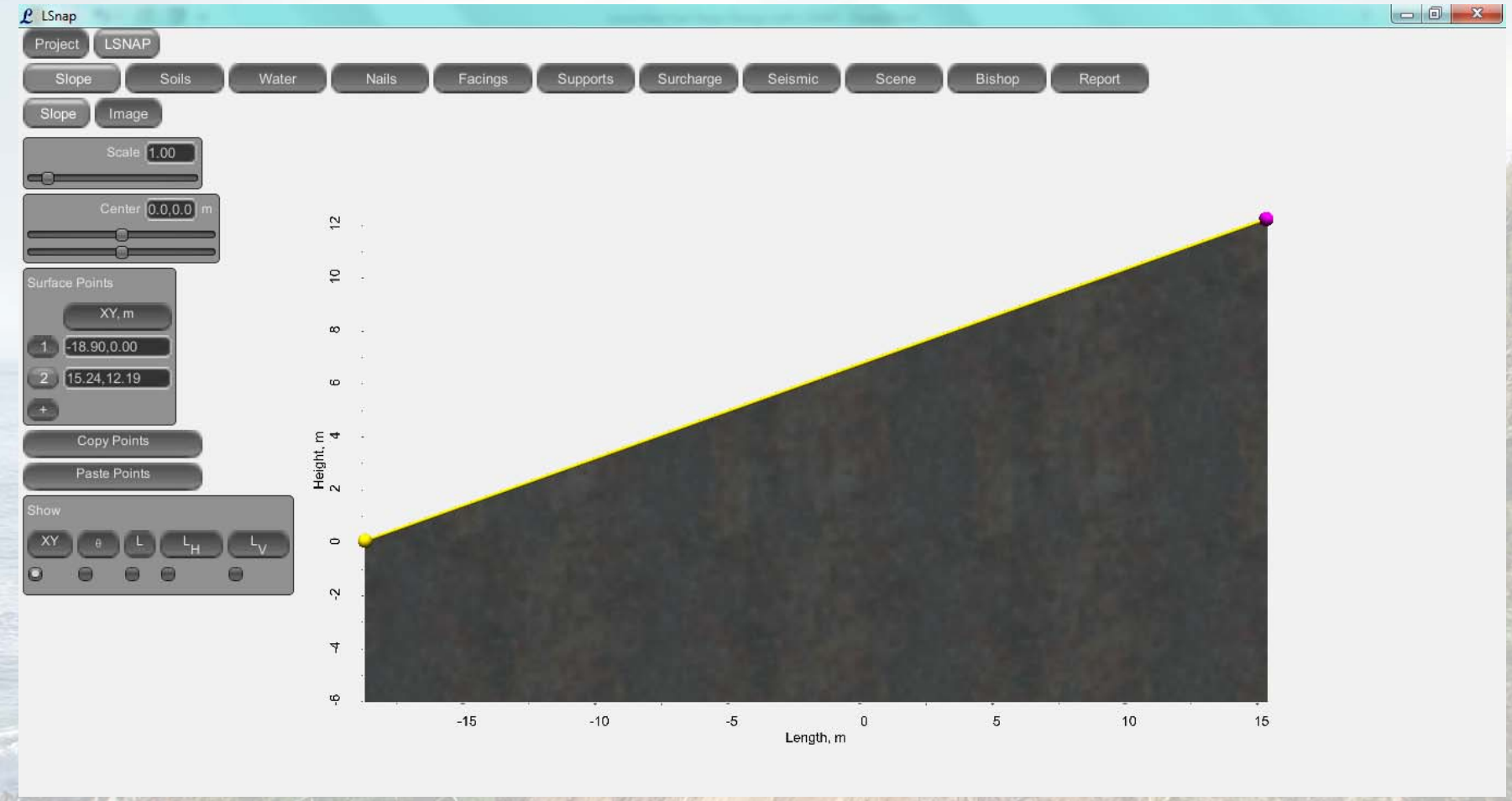
Introduction to LSNAP

Settings



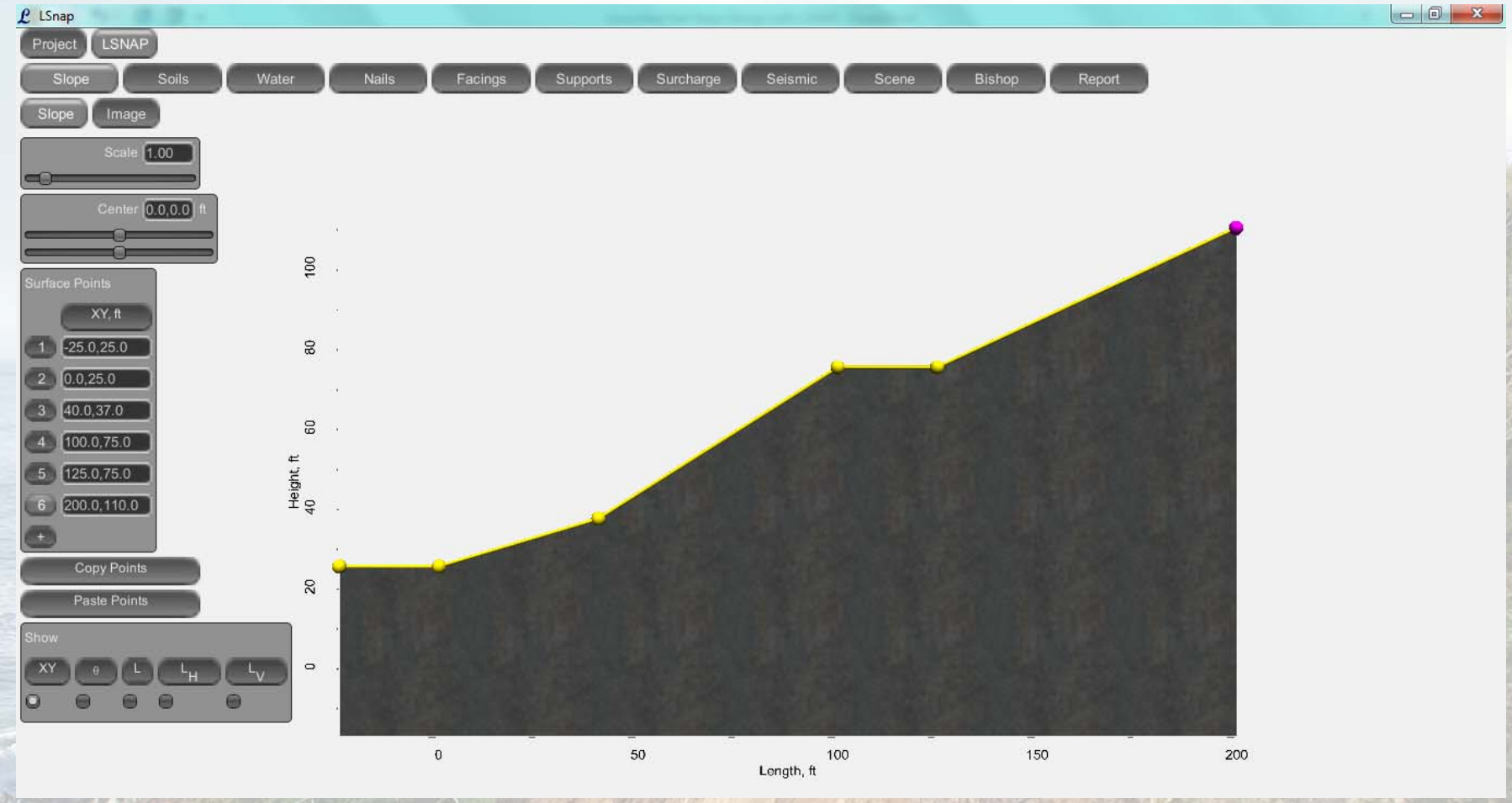
Introduction to LSNAP

Slope Construction



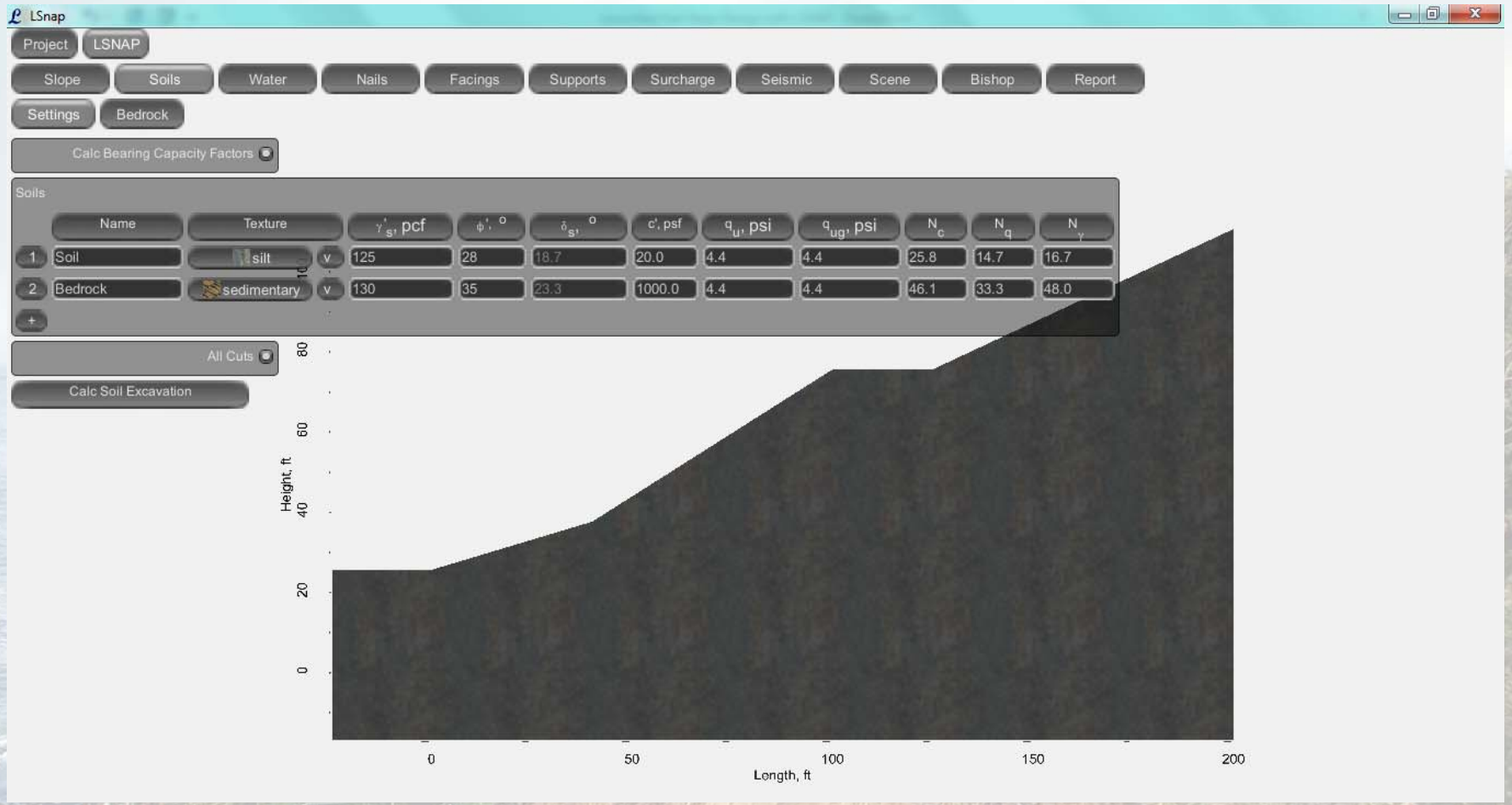
Introduction to LSNAP

Slope Construction



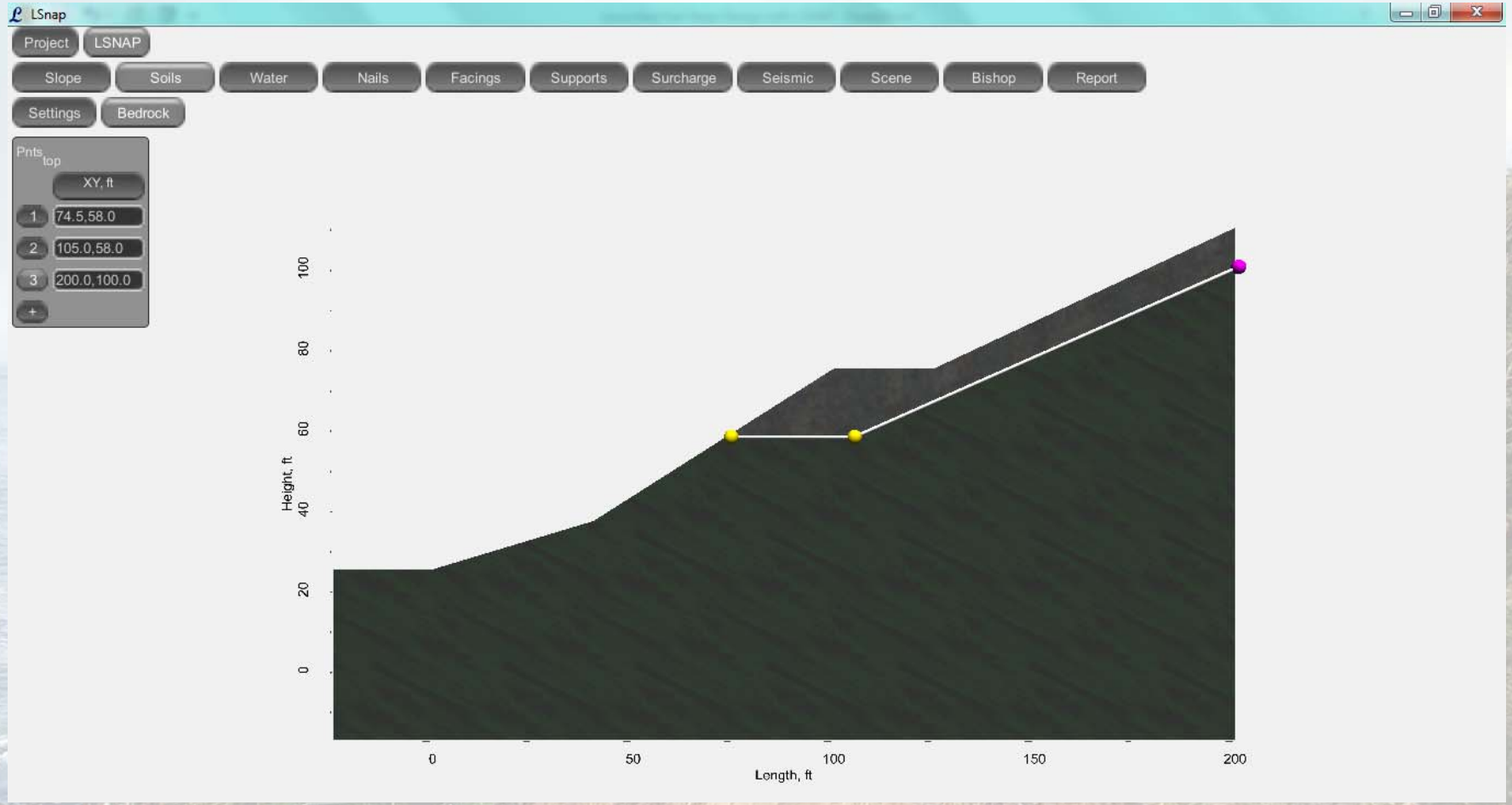
Introduction to LSNAP

Adding Material Layers



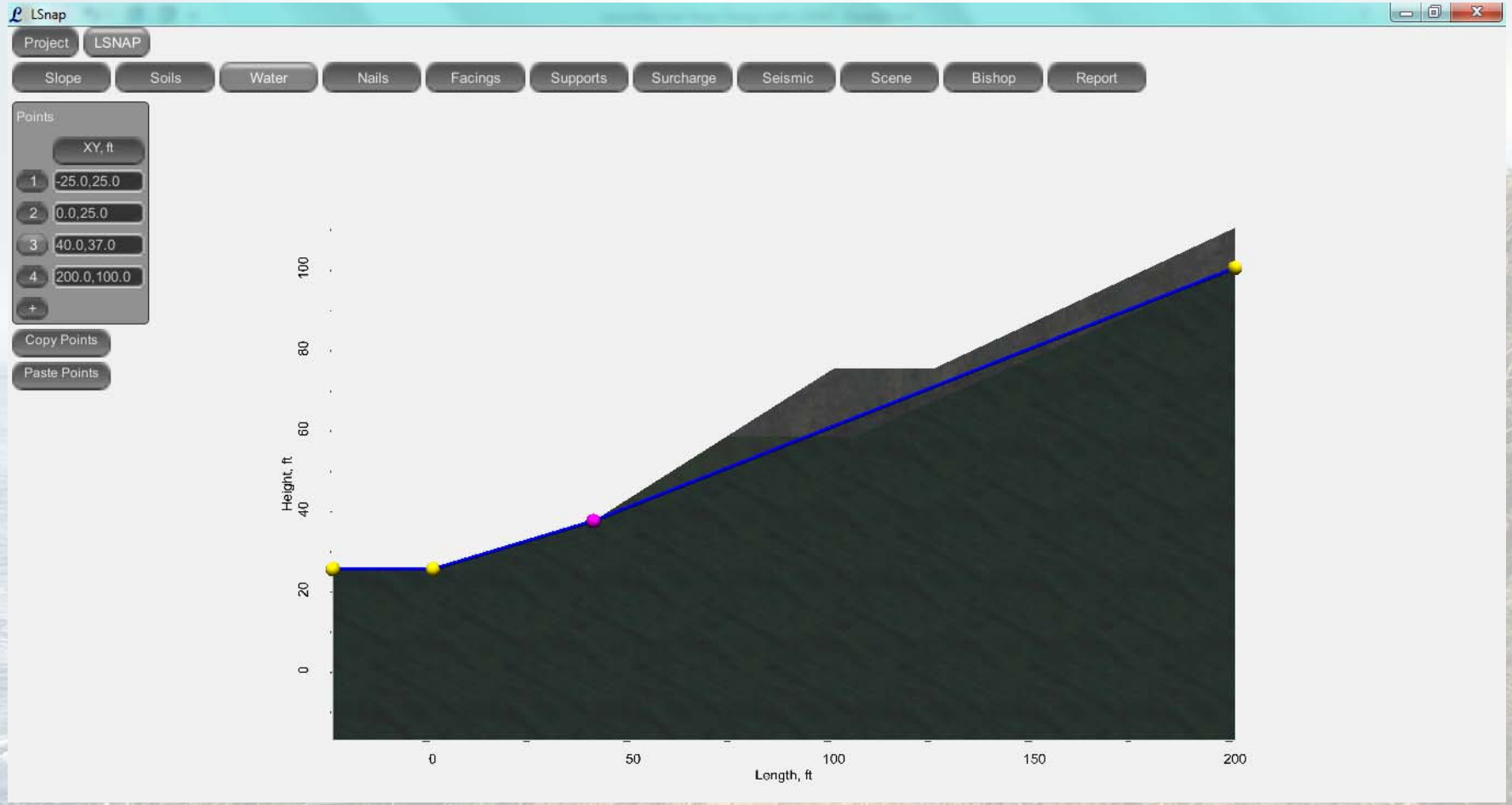
Introduction to LSNAP

Adding Material Boundary



Introduction to LSNAP

Adding Water Table

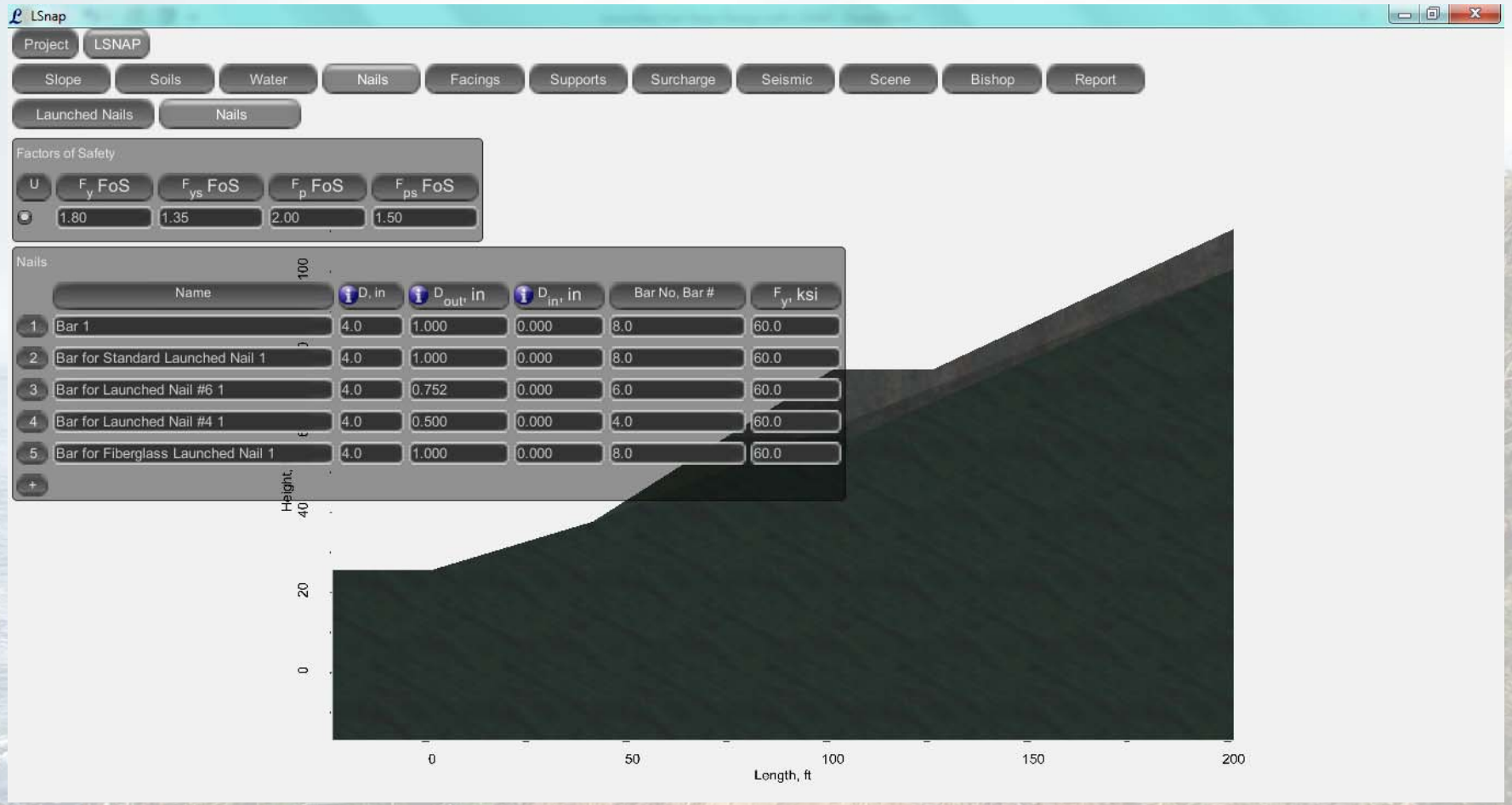


Introduction to LSNAP

Launched Nails

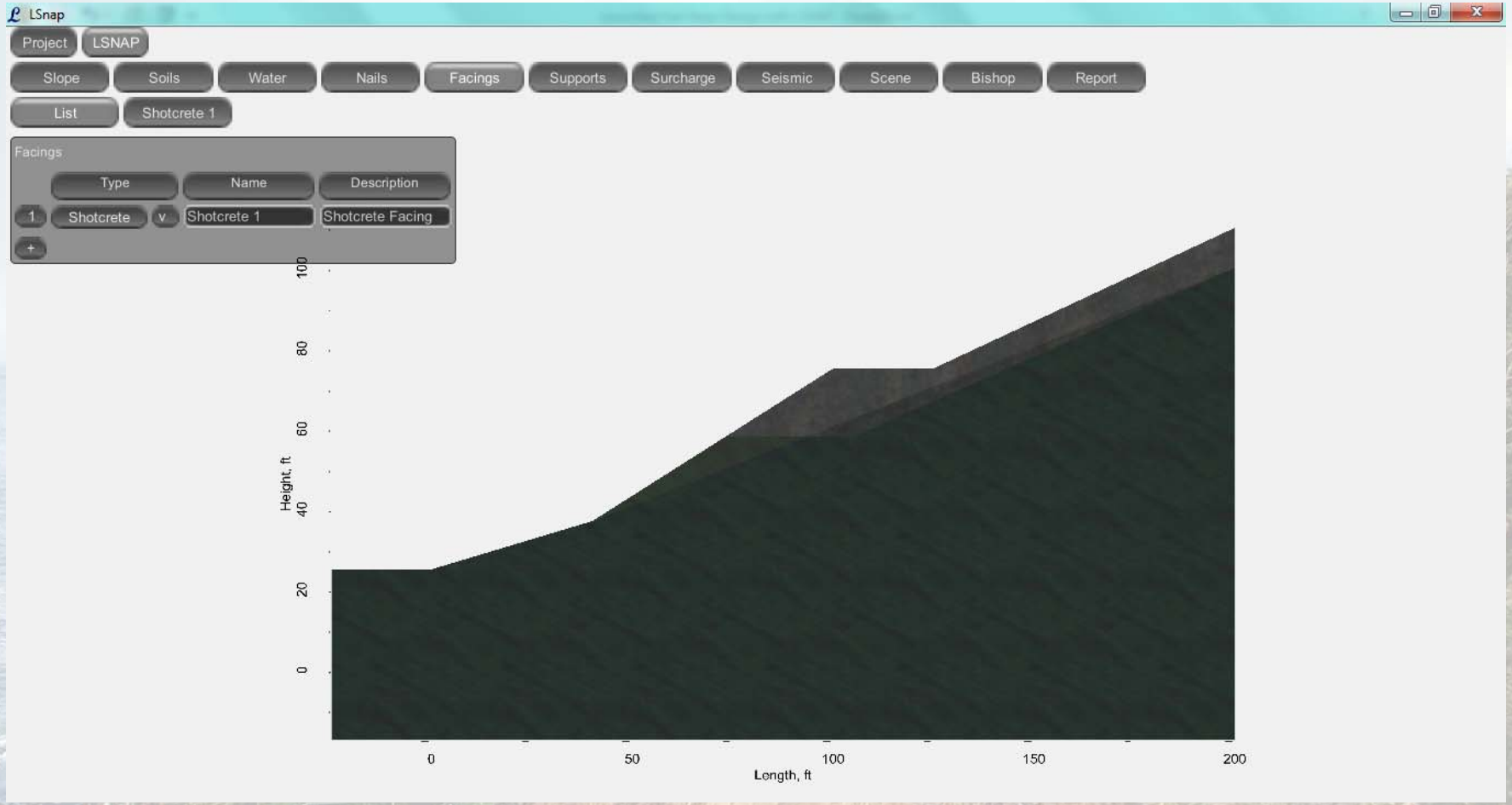
Introduction to LSNAP

Nails and Inner Bars



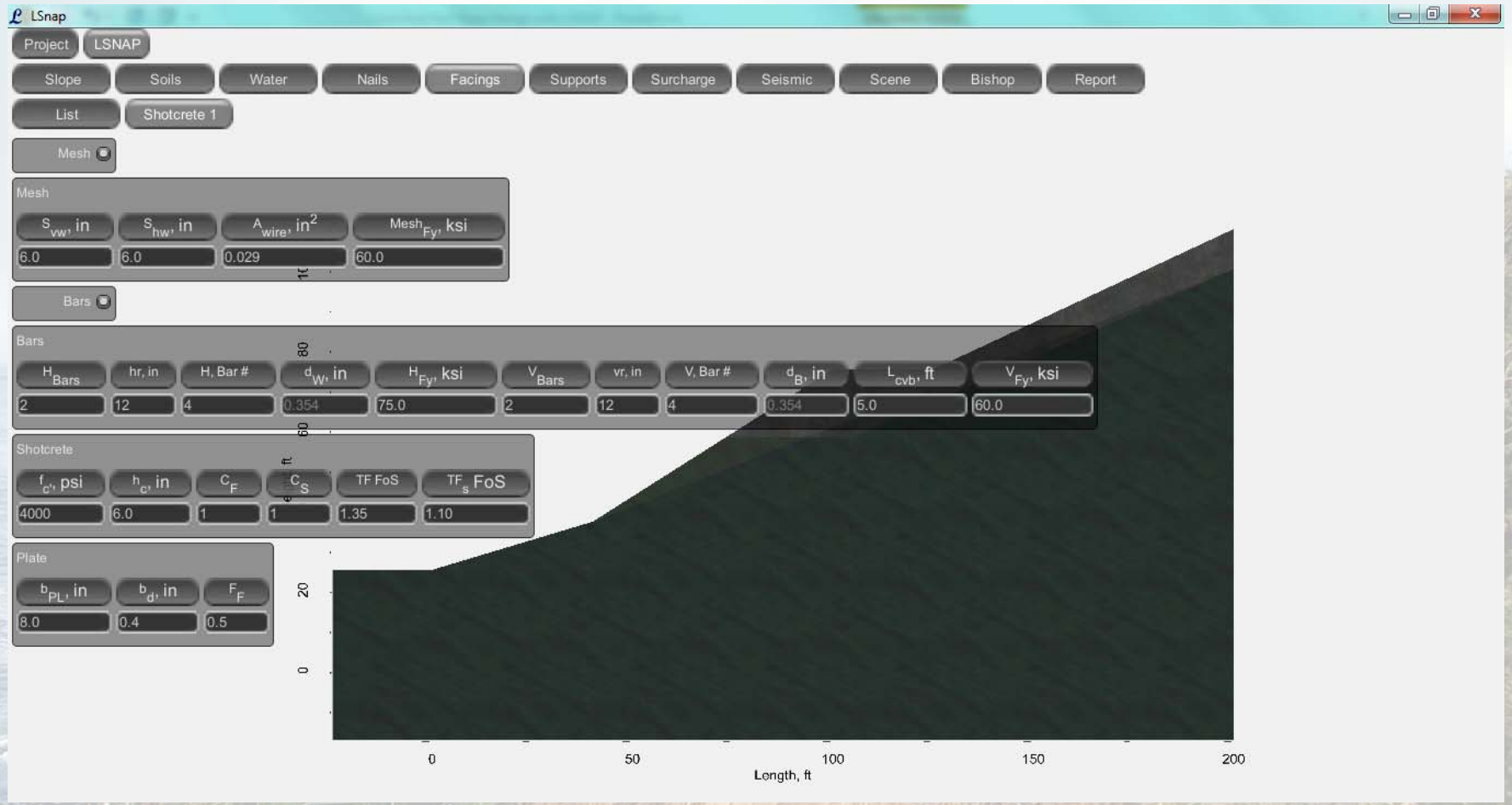
Introduction to LSNAP

Adding Facing Type



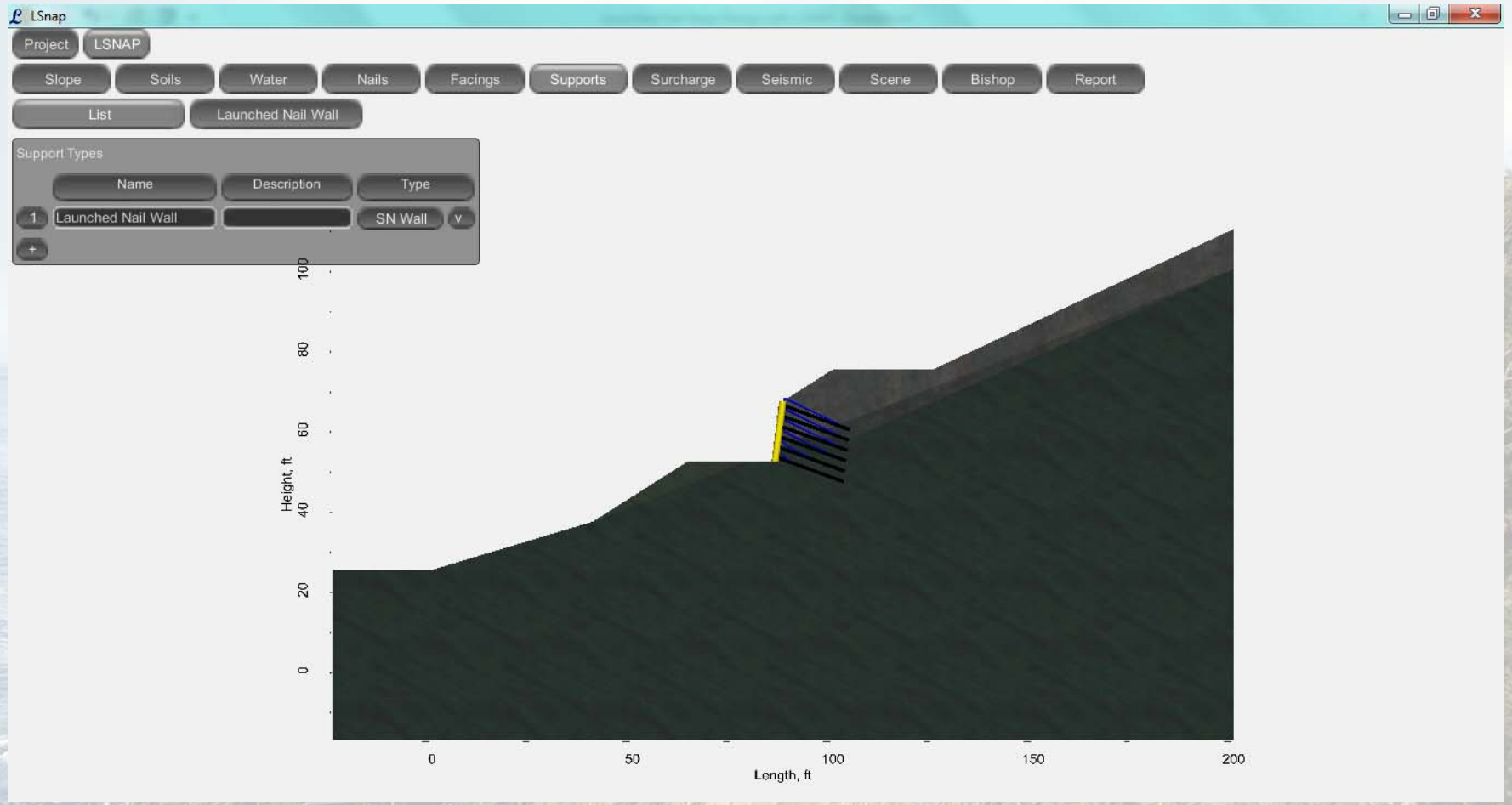
Introduction to LSNAP

Shotcrete Properties



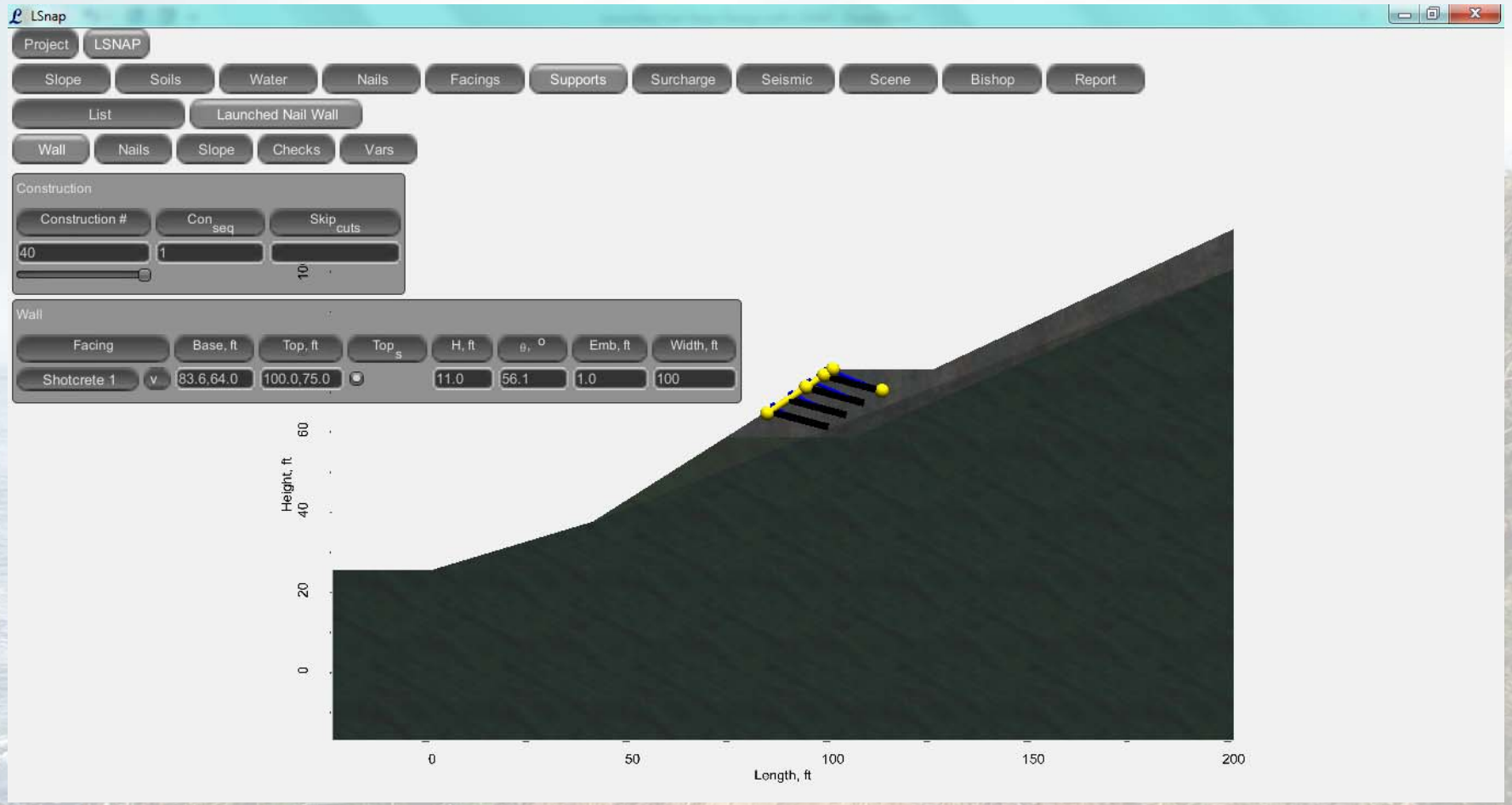
Introduction to LSNAP

Adding Support



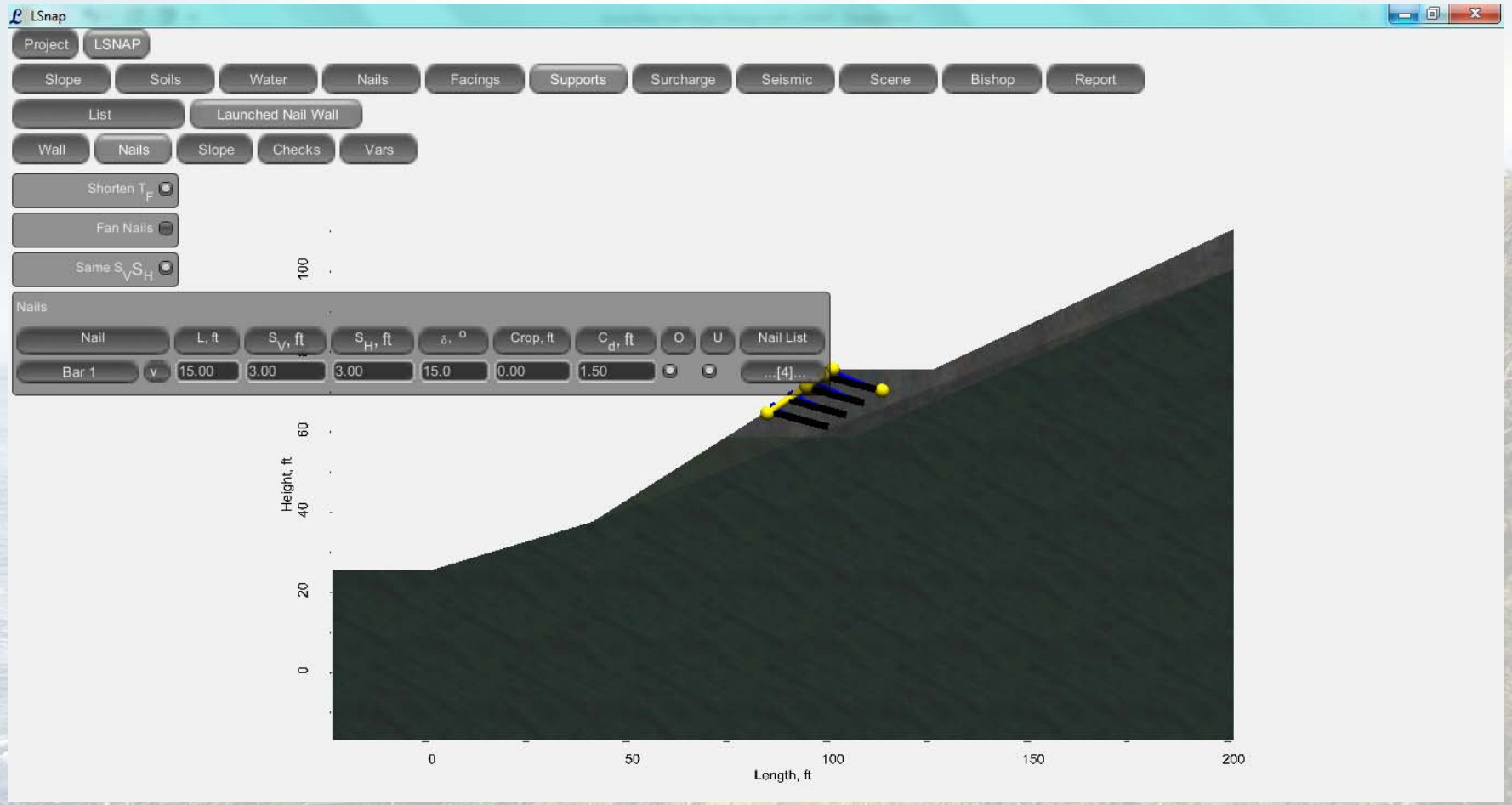
Introduction to LSNAP

Refining the Wall Location



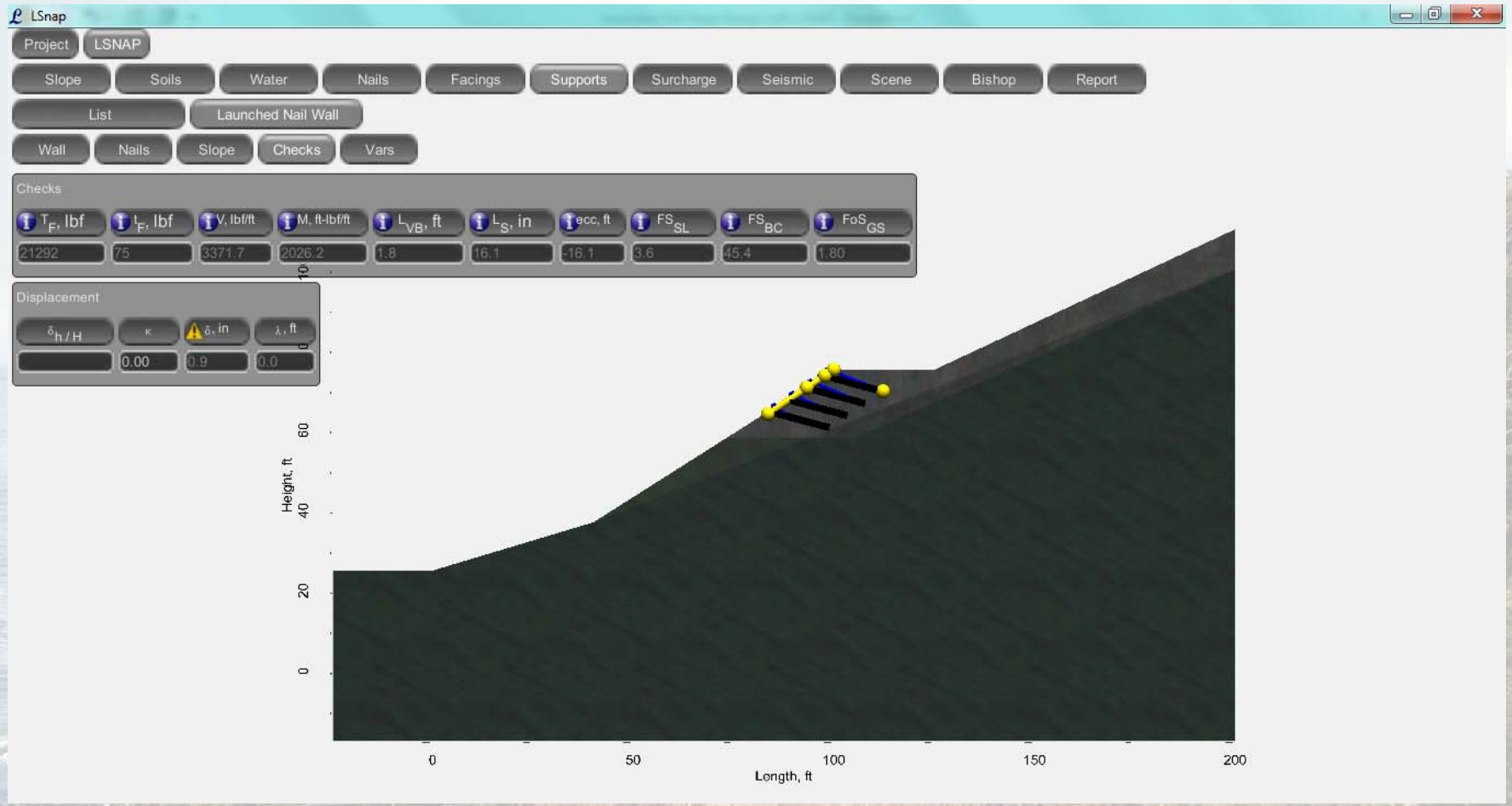
Introduction to LSNAP

Refining the Nail Properties



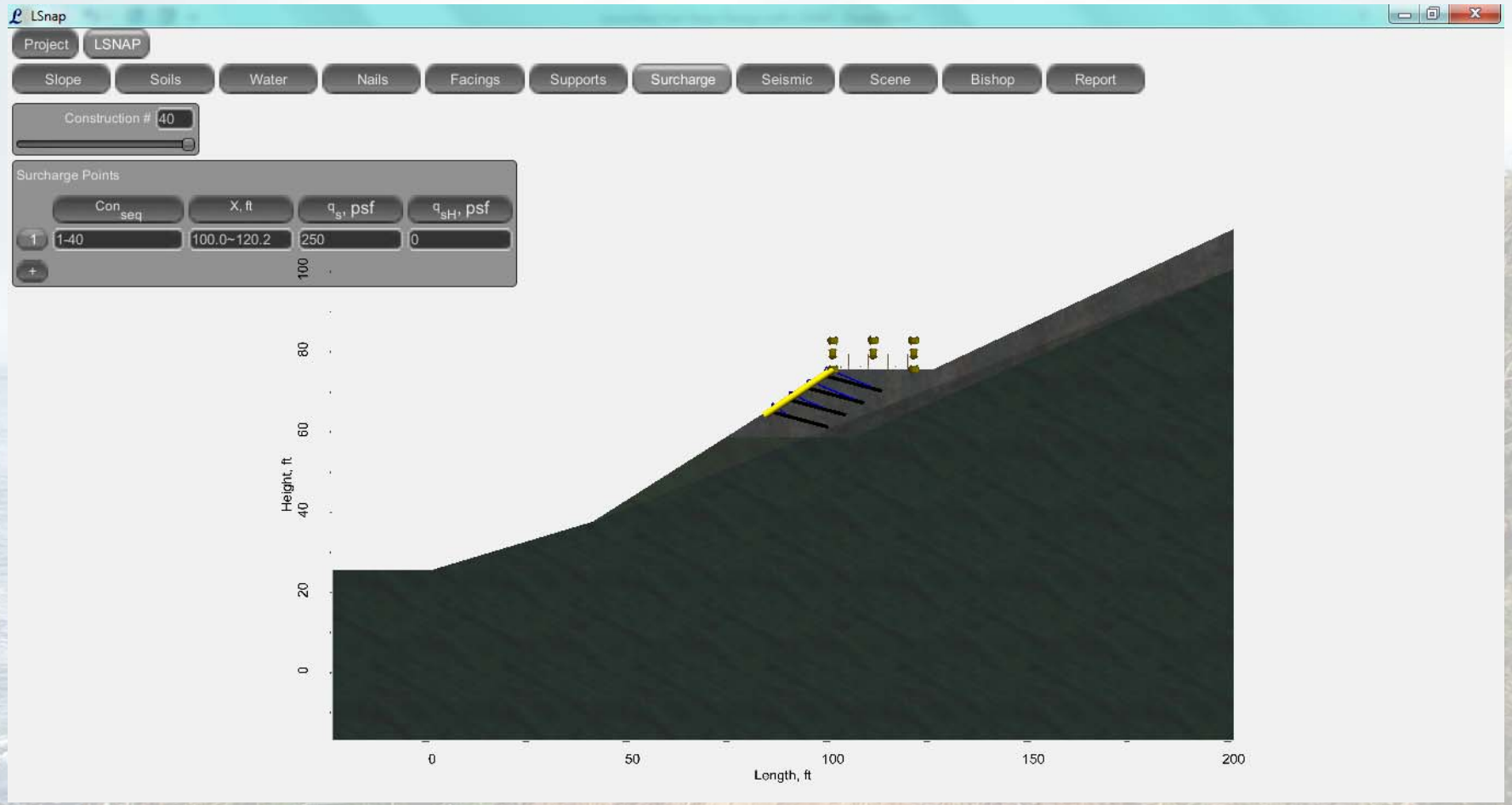
Introduction to LSNAP

Checks



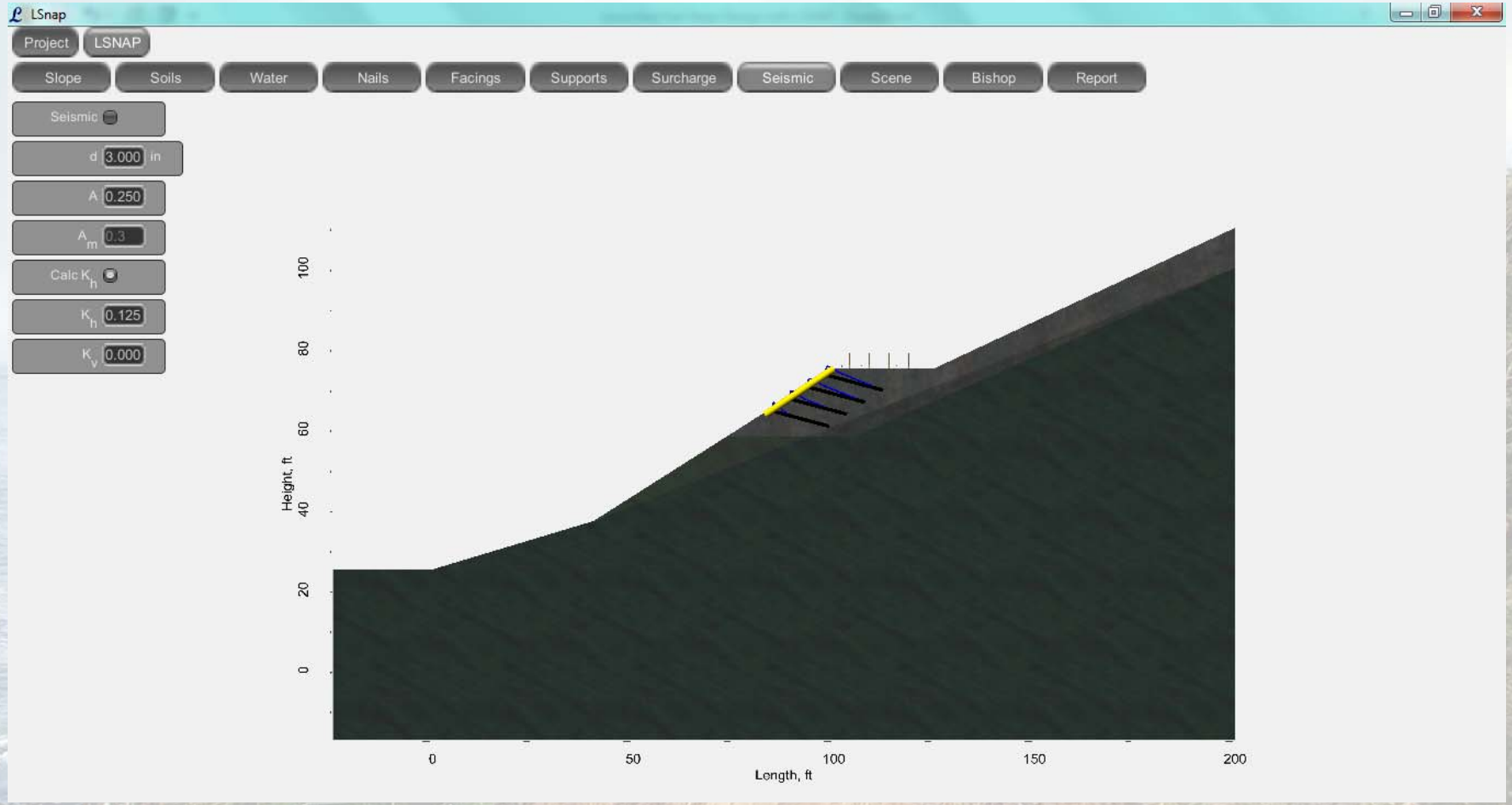
Introduction to LSNAP

Adding Surcharge



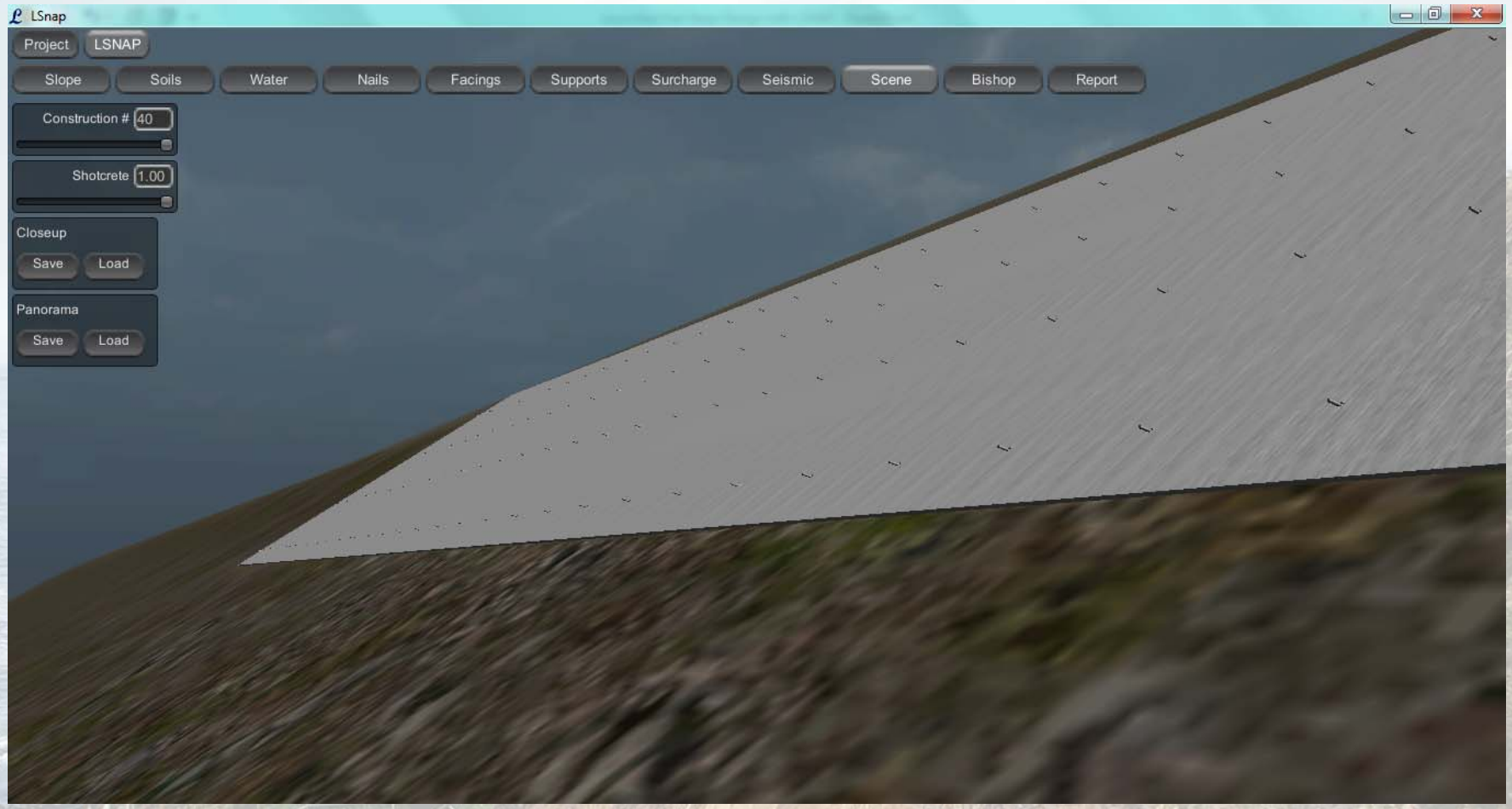
Introduction to LSNAP

Seismic Properties



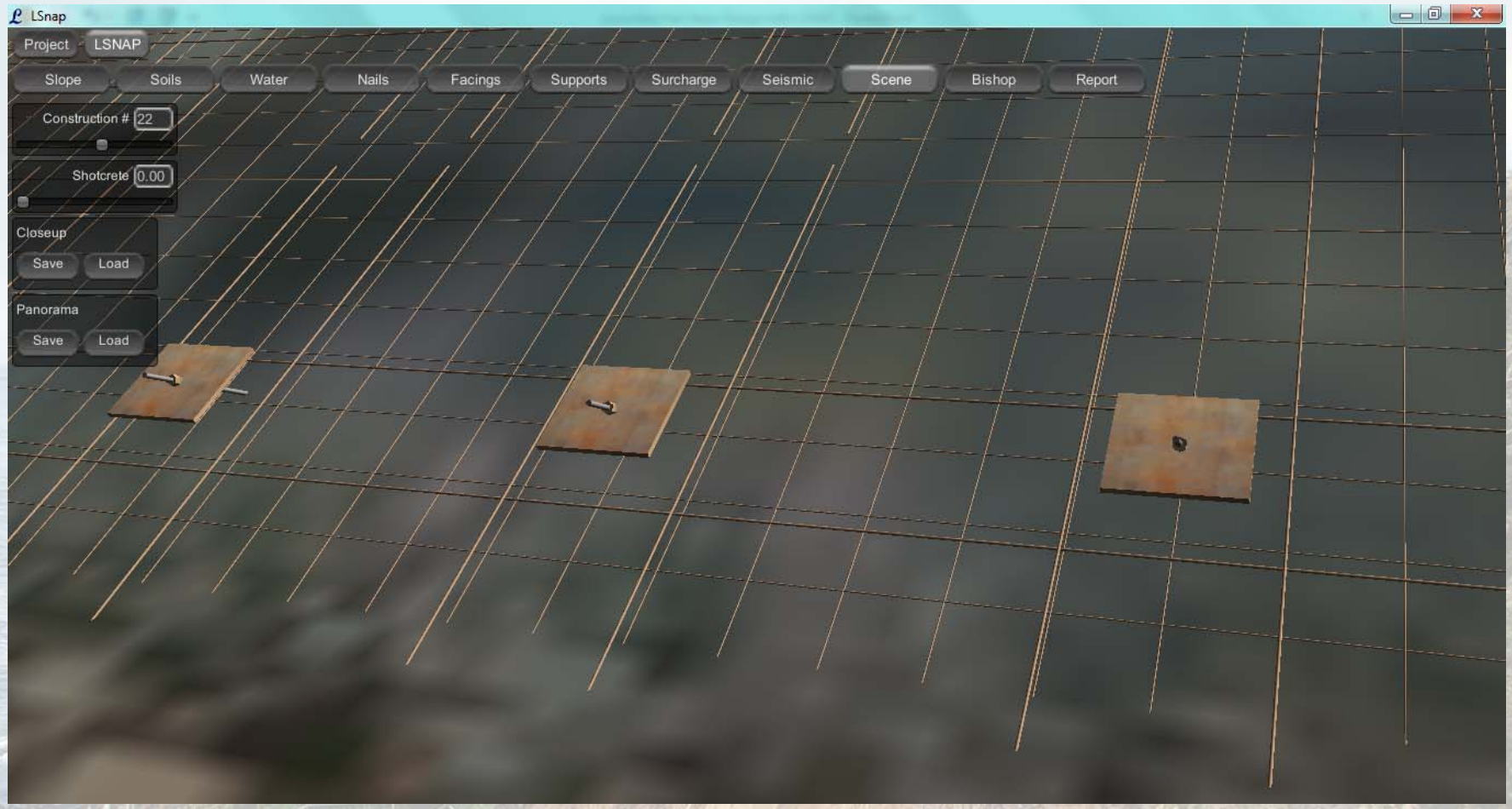
Introduction to LSNAP

Touring the Wall



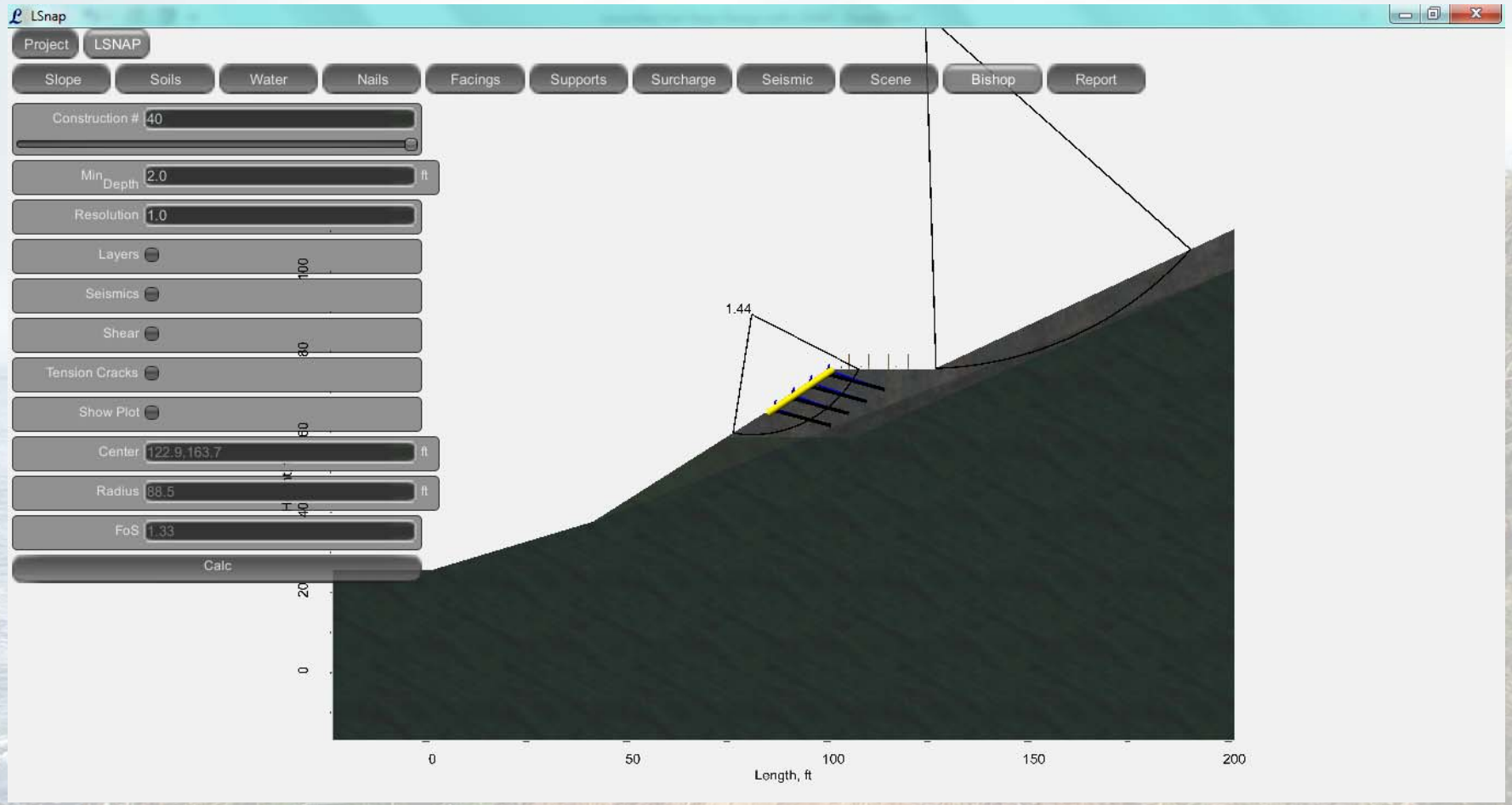
Introduction to LSNAP

Touring the Wall



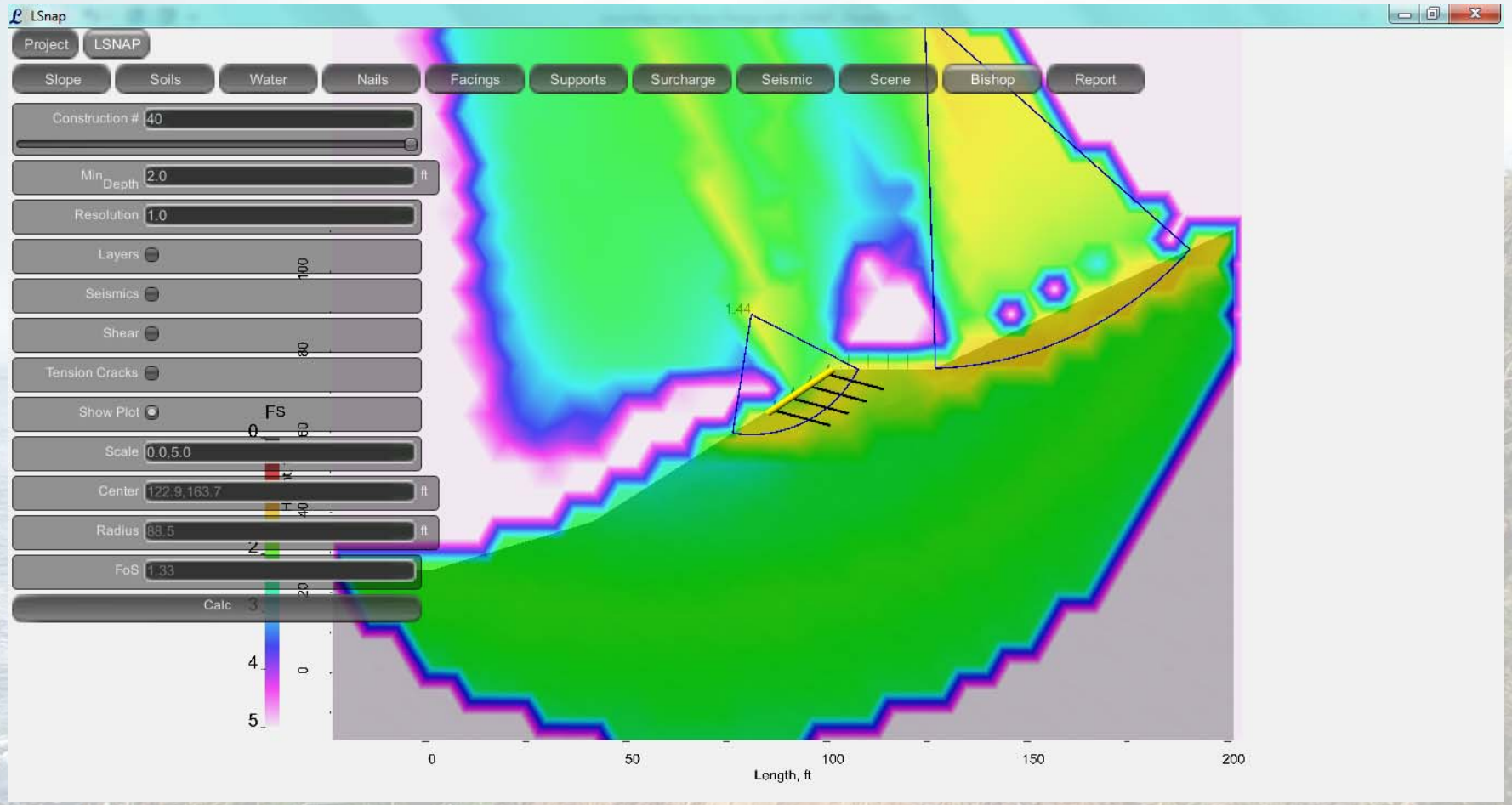
Introduction to LSNAP

Minimum FoS



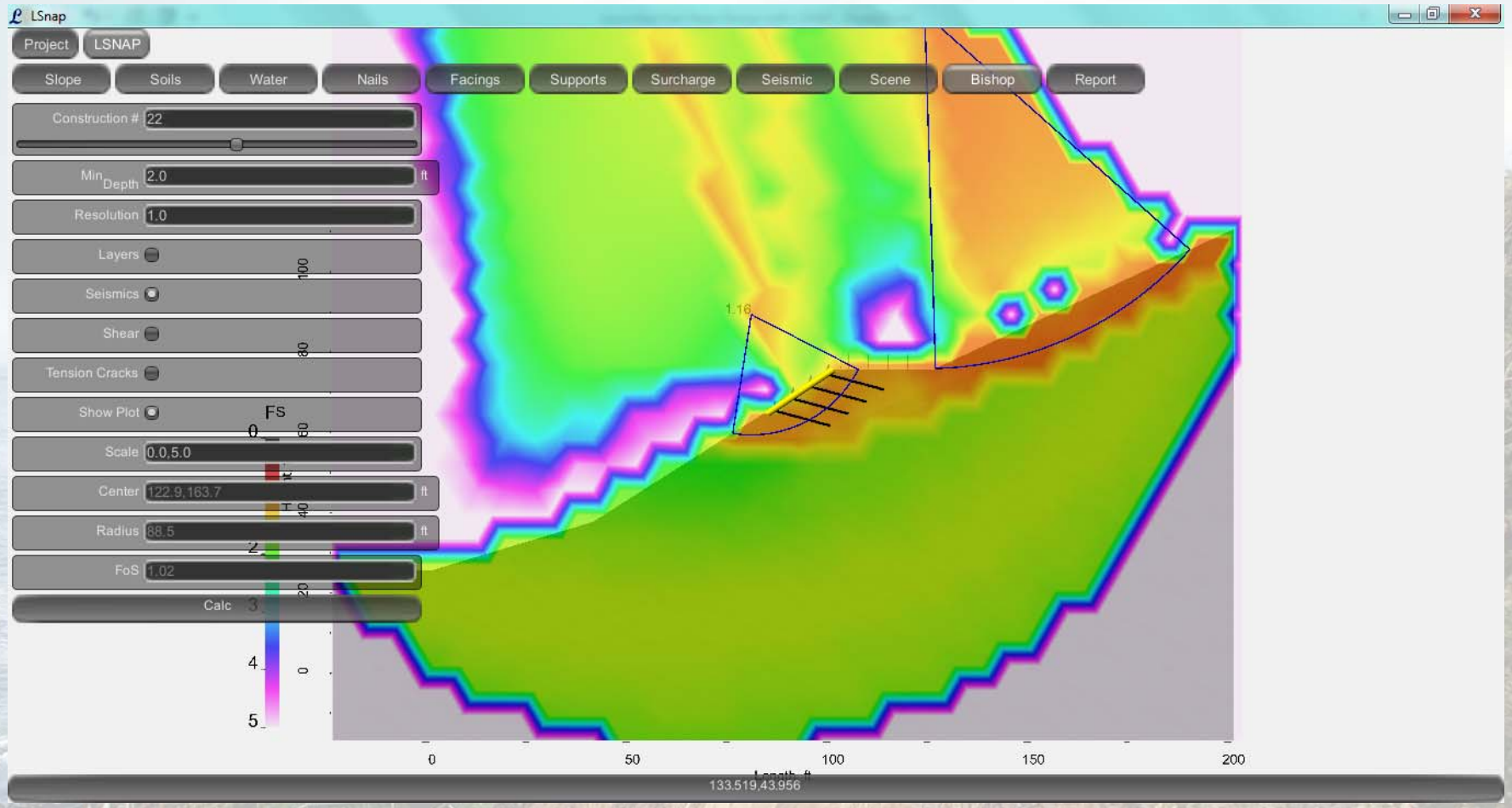
Introduction to LSNAP

FoS Plot



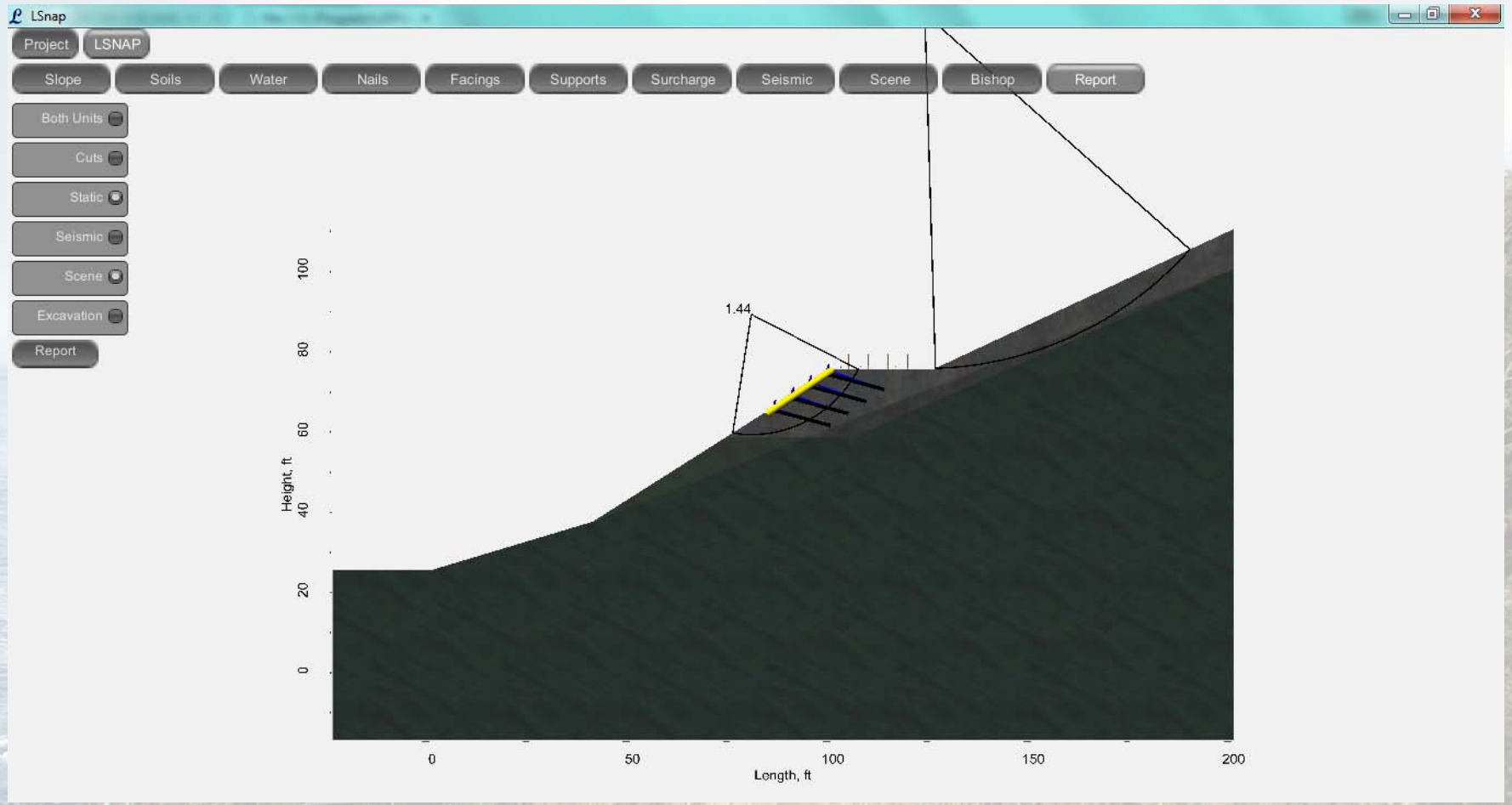
Introduction to LSNAP

Seismic FoS Plot



Introduction to LSNAP

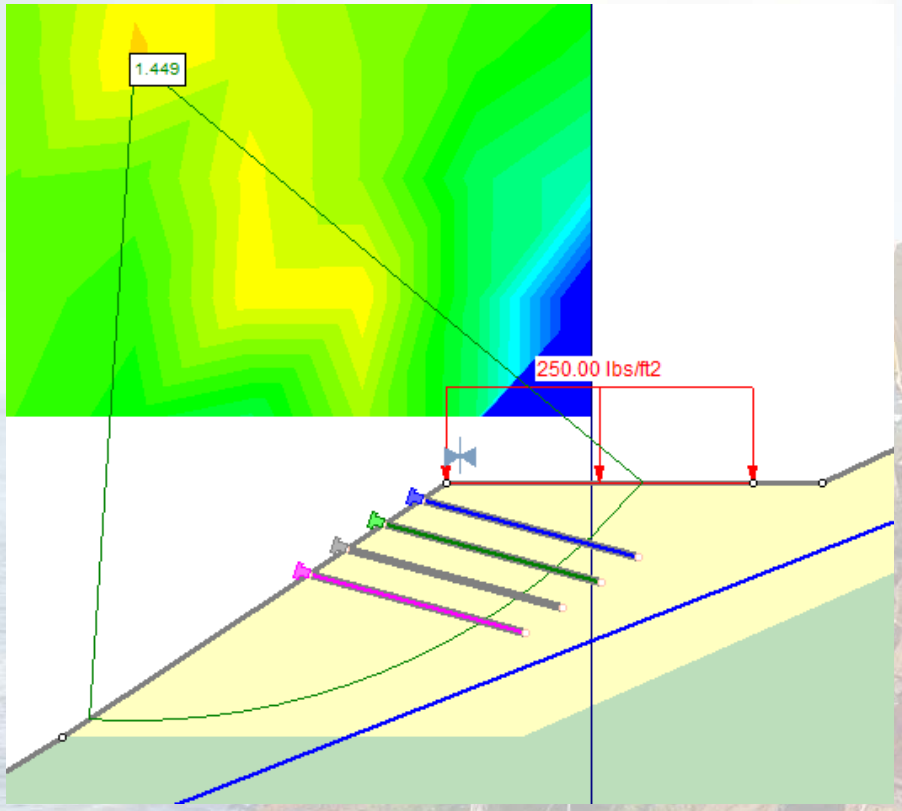
Creating a Report



Comparison

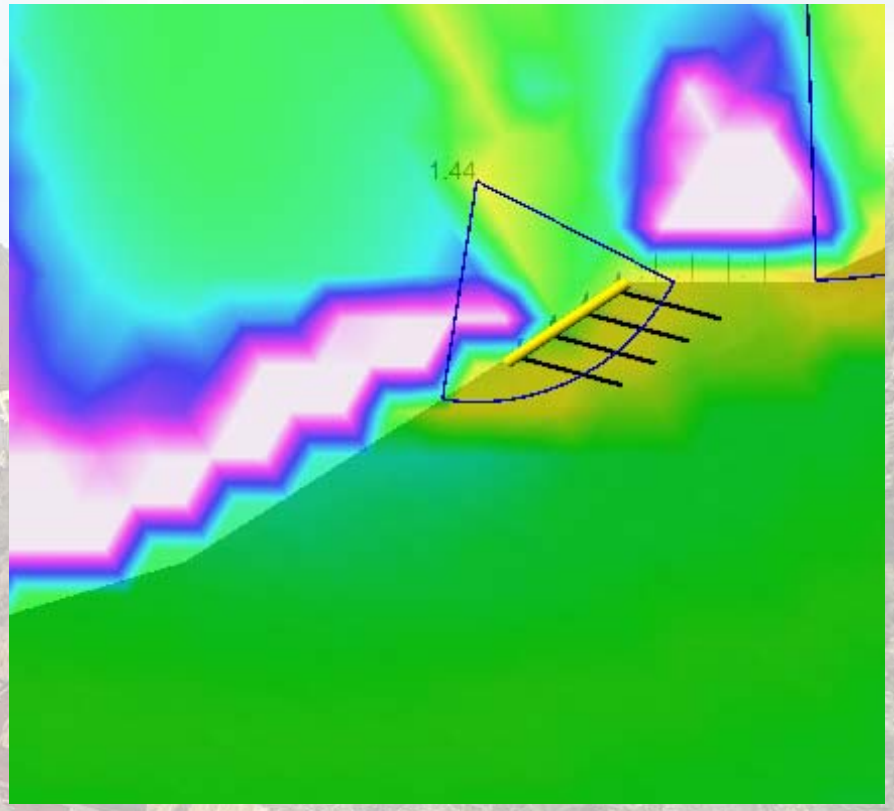
Slide:

FoS = 1.499



LSNAP:

FoS = 1.44




QUESTIONS?
KOMATSU
PC150LC