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

First Used in the UK in 1989 and then in the US in 1992
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

Open Breech

Guide Tube
• 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 (ungrounded); 11.5 psi (grouted)
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.
• 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
Launched Nails

Landslide
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

Pressure on nail below slide plane causes resistance to nail pullout. An \( f_m \) of 2.0 is used to calculate the allowable friction on the nail and resulting tension capacity.

\[ \sigma_n = \text{normal soil pressure on the nail} \]
\[ f_m = \text{material factor of safety} \]

For a nail of diameter of \( d \), the ultimate shear resistance \( S_u \) is:

\[ S_u = q_u L_o d \]

where

\[ q_u = \sigma_n N_q \]

\[ \sigma_n = \text{normal pressure on the nail at the intersection of the nail and the failure surface} \]
\[ N_q = \text{Terzaghi bearing capacity factor} \]

The ultimate bearing capacity of the soil is calculated by:

For a nail of diameter of \( d \), the ultimate shear resistance \( S_u \) is:

\[ T_{N_{\text{allowable}}} = \alpha_{N_{\text{pullout}}} \tau_{\text{bond}} \pi d L_B \]

\[ \alpha_{N_{\text{pullout}}} = \text{pullout resistance factor} \]
\[ d = \text{diameter of nail (typically 1.5 inches (38mm) for launched soil nails)} \]
\[ L_B = \text{the bonding length of nails beyond the failure surface} \]
\[ \tau_{\text{bond}} = \text{bonding stress between nail and soil (lb/ft\(^2\))} \]

\[ L_o = \text{Length of nail over which } q_u \text{ is developed} \]
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

Tedious Process
• Nail input parameters from USFS Manual
• Excel Spreadsheet
• Slope Stability Software

With shear values in accordance with the FHWA manual, the FOS goes to 1.5.
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
Back Analysis
## Designing with Slide

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

<table>
<thead>
<tr>
<th>Material Name</th>
<th>Color</th>
<th>Unit Weight (lbs/ft³)</th>
<th>Strength Type</th>
<th>Cohesion (psf)</th>
<th>Phi (deg)</th>
<th>Water Surface</th>
<th>Hu Type</th>
<th>Hu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material 1</td>
<td></td>
<td>125</td>
<td>Mohr-Coulomb</td>
<td>20</td>
<td>28</td>
<td>Water Surface</td>
<td>Custom</td>
<td>1</td>
</tr>
<tr>
<td>Material 2</td>
<td></td>
<td>130</td>
<td>Mohr-Coulomb</td>
<td>1000</td>
<td>35</td>
<td>Water Surface</td>
<td>Custom</td>
<td>1</td>
</tr>
</tbody>
</table>

250.00 lbs/ft²
Designing with Slide
## Determining Shear Capacity

<table>
<thead>
<tr>
<th>Soil Nail Wall Application</th>
<th>Cardiff Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Properties</td>
<td></td>
</tr>
<tr>
<td>Unit Weight (pcf)</td>
<td>γ</td>
</tr>
<tr>
<td>Friction Angle (°)</td>
<td>φ</td>
</tr>
<tr>
<td>Cohesion (psf)</td>
<td>C'</td>
</tr>
<tr>
<td>Bearing Capacity Factor</td>
<td>Nq</td>
</tr>
<tr>
<td>Allowable Bond (psi)</td>
<td>τallow</td>
</tr>
<tr>
<td>Wall Geometry</td>
<td>Dimensions in feet unless noted otherwise</td>
</tr>
<tr>
<td>Top of Wall Coordinates</td>
<td>Xr</td>
</tr>
<tr>
<td>Angle of Backslope (°)</td>
<td>β</td>
</tr>
<tr>
<td>Wall Batter (°)</td>
<td>θ</td>
</tr>
<tr>
<td>Depth to First Nail Row (ft)</td>
<td>s_v1</td>
</tr>
<tr>
<td>Vertical Nail Spacing (ft)</td>
<td>s_v</td>
</tr>
<tr>
<td>Horizontal Nail Spacing (ft)</td>
<td>s_h</td>
</tr>
<tr>
<td>Wall Height (ft)</td>
<td>H</td>
</tr>
</tbody>
</table>

### Nail Properties

<table>
<thead>
<tr>
<th>Tube</th>
<th>Inner Bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside Diameter (in)</td>
<td>O.D._tube</td>
</tr>
<tr>
<td>Inside Diameter (in)</td>
<td>I.D._tube</td>
</tr>
<tr>
<td>Young's Modulus (psi)</td>
<td>E_tube</td>
</tr>
<tr>
<td>Yield Stress (psi)</td>
<td>F_ytube</td>
</tr>
<tr>
<td>Moment of Inertia (in^4)</td>
<td>tube</td>
</tr>
<tr>
<td>Section Modulus (in^3)</td>
<td>S_xTube</td>
</tr>
</tbody>
</table>
### Composite Nail

<table>
<thead>
<tr>
<th>Description</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moment Strength (lb-ft)</td>
<td>$M_n$</td>
<td>560.5</td>
</tr>
<tr>
<td>$M_{nLF}$ per lineal foot (lb-ft/LF)</td>
<td>$M_{nLF}$</td>
<td>186.8</td>
</tr>
<tr>
<td>Nail Inclination (°)</td>
<td>$\alpha$</td>
<td>15.0</td>
</tr>
<tr>
<td>Nail Length (ft)</td>
<td>$L$</td>
<td>15.0</td>
</tr>
</tbody>
</table>
Determining Shear Capacity
## Determining Shear Capacity

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

![Diagram illustrating shear forces and nail intersection](image)
Re-Designing with Slide

Define Support Properties

Launched Nails 2

Name: Launched Nails 2
Support Colour: [Green]
Support Type: Soil Nail
Used for: Soil Nails

Capacity and Spacing:
Out-of-plane spacing: 3 ft
Tensile Capacity: 20,000 lbs
Plate Capacity: 10,000 lbs
Shear Capacity: 604 lbs

Pullout Strength:
Bond Strength: 250 lbs/ft

Material Dependent: Define...
Re-Designing with Slide

<table>
<thead>
<tr>
<th>Support Name</th>
<th>Color</th>
<th>Type</th>
<th>Force Application</th>
<th>Out-Of-Plane Spacing (ft)</th>
<th>Tensile Capacity (lbs)</th>
<th>Plate Capacity (lbs)</th>
<th>Shear Capacity (lbs)</th>
<th>Bond Strength (lbs/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launched Nails 1</td>
<td>Blue</td>
<td>Soil Nail</td>
<td>Active (Method A)</td>
<td>3</td>
<td>20000</td>
<td>10000</td>
<td>503</td>
<td>250</td>
</tr>
<tr>
<td>Launched Nails 2</td>
<td>Green</td>
<td>Soil Nail</td>
<td>Active (Method A)</td>
<td>3</td>
<td>20000</td>
<td>10000</td>
<td>604</td>
<td>250</td>
</tr>
<tr>
<td>Launched Nails 3</td>
<td>Gray</td>
<td>Soil Nail</td>
<td>Active (Method A)</td>
<td>3</td>
<td>20000</td>
<td>10000</td>
<td>687</td>
<td>250</td>
</tr>
<tr>
<td>Launched Nails 4</td>
<td>Pink</td>
<td>Soil Nail</td>
<td>Active (Method A)</td>
<td>3</td>
<td>20000</td>
<td>10000</td>
<td>759</td>
<td>250</td>
</tr>
</tbody>
</table>

250.00 lbs/ft²
Re-Designing with Slide
Introduction to LSNAP

Disclaimer

This program has been tested and is believed to be a reliable engineering tool. No responsibility is assumed by the authors, Summit Peak Technologies LLC, GeoStabilization International (GSI), FHWA, CFLHD, or any employees of the above for any errors, mistakes or misrepresentations that may occur from any use of this program. Logging in implies agreement with these terms and conditions.
Introduction to LSNAP
Introduction to LSNAP

Slope Construction
Introduction to LSNAP

Slope Construction
Introduction to LSNAP

Adding Material Layers

<table>
<thead>
<tr>
<th>Soil</th>
<th>Name</th>
<th>Texture</th>
<th>$\gamma'$,pcf</th>
<th>$\phi$, $\degree$</th>
<th>$\psi$, $\degree$</th>
<th>$c$, psi</th>
<th>$q_{uw}$,psi</th>
<th>$q_{uq}$,psi</th>
<th>$q_{uq}$,psi</th>
<th>$q_{uq}$,psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Soil</td>
<td>silt</td>
<td>125</td>
<td>28</td>
<td>18.7</td>
<td>20.0</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>2</td>
<td>Bedrock</td>
<td>sedimentary</td>
<td>130</td>
<td>35</td>
<td>21.5</td>
<td>1000</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
</tr>
</tbody>
</table>

[Graph showing material layers with height and length dimensions]
Introduction to LSNAP

Adding Material Boundary
Introduction to LSNAP

Adding Water Table

![Diagram of LSNAP software interface with points and graph showing height vs. length.]
Introduction to LSNAP

Launched Nails

Factors of Safety

Launched Nail

1. Standard Launched Nail 1
2. Launched Nail #6
3. Launched Nail #4
4. Fiberglass Launched Nail 1
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?