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SHRP 2 R02

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

**SHOOT-IN SOIL NAILING TECHNICAL
EVALUATION REPORT**

Prepared for
The Strategic Highway Research Program 2
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of
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TRANSPORTATION RESEARCH BOARD
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SHRP 2 R02

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EXECUTIVE SUMMARY

This evaluation was performed on shoot-in or “launched” soil nails based on information provided by the Federal Highway Administration (FHWA) and Soil Nail Launcher, Inc.

The soil nail launcher, typically mounted on an excavator, uses compressed air to launch 20-foot long, 1½-inch outside diameter steel or fiberglass tubes with closed steel tips into the ground in a single blast at speeds in excess of 200 miles per hour. The tubes can then be reinforced with a steel bar and grouted to achieve maximum strength. The tubes can also be perforated and pressure grouted to allow grout permeation into the soil, improving the adjacent soil properties and increasing the soil-nail bond.

Groups of launched nails can be used in both temporary and permanent applications including landslide remediation, bluff stabilization, micro-piling, ground anchoring, retaining wall applications, horizontal drainage, and excavation shoring. Corrosion protection is used on the launched tubes and on the inner reinforcing steel for permanent applications.

This system has seen limited but successful use in the United States since the mid-1990s with competitive costs and performance compared to competing technologies. Technology advantages include high nail installation rates and minimal environmental disturbance. Sites with high amounts of boulders and obstructions are not suitable for this technology.

1. INTRODUCTION

1.1. Scope and Purpose of Evaluation

This evaluation by the SHRP 2 R02 research team was conducted for the launched soil nailing system in use by Soil Nail Launcher, Inc., the proprietor of soil nail launching technology in the United States. This evaluation includes an overview of the technology and a review of the latest design methodology, quality control and quality assurance measures, and performance of launched soil nails. This evaluation was conducted using design and performance information provided by Soil Nail Launcher, Inc. and information from the Federal Highway Administration, particularly FHWA-FPL-93-003, “Application Guide for Launched Soil Nails” and FHWA-FPL-93-004, “Project Report for Launched Soil Nails – 1992 Demonstration Project.”

Launched soil nailing is an innovative soil nail installation method that has been shown to reduce construction time and costs in some situations. The technology has been included in the SHRP 2 R02 research for its applicability to roadway and embankment widening.

Lazarte et al. (2003) serves as the current FHWA standard for the design of soil nail structures. A new design methodology has been proposed for launched soil nails with consideration given to the nail installation method, nail dimensions, and nail composition with respect to traditional soil

nailing techniques. This design method, which includes the bending stiffness of the nail and a corresponding increase in the global factor of safety, is analyzed and discussed herein.

1.2. Methods and Documents Reviewed

The FHWA “Application Guide for Launched Soil Nails” was a major source of information for this evaluation. Published in 1994, the FHWA report was the culmination of negotiations and a demonstration project (FHWA-FPL-93-004) between the USDA Forest Service and Soil Nailing Limited of the United Kingdom. The document contains a “simplified design approach” to be used as an “interim design method.” The design approach uses the slope geometry, estimated soil properties, and information obtained through a visual site inspection to give appropriate nail spacing per linear distance along the slope through a series of charts.

The current soil nail design method given by the FHWA may be found in the “Geotechnical Engineering Circular No. 7 – Soil Nail Walls” (FHWA0-IF-03-017). This document is intended to provide “state-of-the-practice information for the selection, analysis, design, and construction of soil nail walls in highway applications” (Lazarte et al., 2003). This document was used extensively in the development of this report and the analysis of the design method proposed by Soil Nail Launcher, Inc.

Soil Nail Launcher, Inc. has developed a design methodology specifically for launched soil nails. The design involves the use of limit-equilibrium slope stability software, and, unlike Lazarte et al. (2003), includes the shear contribution of the soil nail. Supplemental design and performance information from Soil Nail Launcher, Inc. was also reviewed.

2. HISTORY AND SYSTEM CONCEPT

The soil nail launcher was developed from declassified British military technology. South African mining engineers first adapted the technology for launching soil nails to prevent mine tailings landslides. Use in the United Kingdom began in 1989, primarily for shallow road and rail embankment landslides (McIlveen, 2010).

The soil nail launcher made its first appearance in the United States in 1992 on a demonstration project funded by the USDA Forest Service, Federal Highway Administration, and several state DOT offices. Eight sites throughout California, Colorado, Oregon, and Washington were selected and launched soil nails were successfully installed in both soil slope and retaining wall applications (USFS, 1994). Currently, four soil nail launching rigs are in use: two in the United States owned by Soil Nail Launcher, Inc., one in Canada and one operating in Australia and New Zealand (McIlveen, 2010).

The launched soil nailing system is desirable for its speed and versatility. Once mobilized, nails can be installed at a rate of 15 nails per hour. The soil nail launcher is typically mounted as a fully articulating attachment on a traditional excavator. This gives the unit a high level of maneuverability, aiding the contractor on sites with limited right-of-way, awkward geometries, restrictions on traffic or environmental disturbance, and around obstacle such as trees, power lines, and guard rails. This system is viable in permanent and temporary-fix applications and can be a valuable tool in emergency response situations.

Due to the dynamic nature of the installation, soil particles elastically deform as the nail tip enters the ground. This shockwave effect reduces abrasion or loss of corrosion protection on the nail and allows for the soil to rebound and collapse on the nail in a relatively undisturbed state. Also, unlike alternative installation methods such as drilling or driving, which allow for relaxation of the soil, launched nails densify the surrounding soil. Both of these qualities add to the soil-nail bond and increase pullout capacity (Barrett & Devin, 2011).

Ground conditions must be suitable for the equipment to be roughly within 35 feet of the installation point and nails cannot be launched in soils with high amounts of boulders or large obstructions or in very dense soils.

3. EQUIPMENT AND MATERIALS

3.1. Soil Nail Launcher

The soil nail launcher consists of a barrel, shroud, and a high pressure breech valve that instantly allows compressed air to fill the firing chamber. Soil nails are loaded into the breech and the tip of the nail is fitted with a sacrificial plastic collet. Spring loaded safety switches are attached on the bottom plate of the soil nail launcher and must be compressed for the launcher to fire. Once the launcher is loaded and placed on the desired application point, compressed air at approximately 2,500 psi (adjustable for different site conditions) is instantly released into the firing chamber. The sacrificial collet is broken off as the nail exits the bottom plate of the launcher and is shot into the ground (FHWA, 1994).

3.2. Soil Nails

A typical launched soil nail is a galvanized steel tube, 20 feet long, with a 1½-inch outside diameter and a ⅛-inch wall thickness. Fiberglass nails and other steel alternatives have been used to some extent, especially when nail corrosion is a primary concern, but steel nails are most common. Because the launching force acts on the tip of the nail, the nail is placed in tension during installation, preventing buckling. After launching, steel reinforcement (steel bar) is often added to the launched tube and the annular spacing is grouted, providing a permanent nail. In

some cases, the tubes are left hollow and are perforated for use as horizontal drains in addition to their stabilizing effects (Barrett & Devin, 2011).

3.3. Reinforcement and Grout

Steel reinforcement and grout are often introduced to the nail to increase strength. No. 4 to No. 6 rebar is typically used for steel reinforcement in the tubes. The bars can be galvanized or epoxy coated to resist corrosion in permanent applications. The grout is used to transfer longitudinal shear stresses from the tube to the reinforcing steel. The grout and the outer steel tube also act as corrosion barriers for the center steel reinforcement. In some cases, the soil nail tubes are perforated to allow for pressure-injected grout to permeate into the surrounding soil and further increase the soil bond to the nail and improve the adjacent soil properties.

3.4. Slope Facing

In many temporary and permanent applications, a slope facing is required to cover the soil nail heads and further bond the soil plane. In these cases, the protruding nail passes through a plate on the soil slope surface and is secured with a nut. Typically, a four to eight inch layer of 3,000-psi shotcrete is sprayed onto a wire mesh, covering the soil slope. The shotcrete layer can be sculpted and painted to simulate a natural rock slope while protecting the soil nails and preventing future erosion of the slope (SNLI, 2010).

4. DESIGN METHOD EVALUATION

4.1. Performance Criteria

The reviewed methodology considers three categories of performance. The first category deals with the ultimate strength service limit and other characteristics of the reinforcement itself. Specified size, tolerances, and length must be met along with ultimate yield strength, designated galvanization thickness, and sacrificial steel thickness. Corrosion resistance test data and pullout coefficients for a range of backfill materials are also considered.

Long-term design strength should consider both the soil-nail interaction (i.e., pullout capacity), and the material degradation (i.e., corrosion). Creep test data should identify areas where the soil-nail bond will reduce with time. Nails in very soft to medium, saturated cohesive soils may be susceptible to pullout strength reduction, which may not always be indicated by creep tests.

Vertical and horizontal deflections are the final performance indicators. For soil nail walls, displacements for launched soil nail walls are assumed to be comparable to those of standard soil nail walls. Section 5.7 of the Lazarte et al. (2003) describes this analysis for cases where the nail shear capacity component is less than 15 percent of the tensile capacity component used for

design. For cases where the nail shear contribution is larger, larger deflections are expected. Longer, drilled nails may be recommended near the top of walls to reduce horizontal deflections.

For soil nail slopes, larger displacements are required to fully mobilize the shear contribution of the nail. These displacements may be acceptable for some embankment repair applications. Higher factors of safety may be used in situations where large displacements are not tolerable or when high surcharge loads are expected.

4.2. External Stability

The reviewed design method considered four categories for external stability: global stability, sliding potential, seismic loading, and settlement.

Global stability of walls and slopes are generally analyzed using industry standard methods and recommendations in the “Geotechnical Engineering Circular No. 7.” An overall factor of safety of 1.3 is used in the static case for temporary or less critical walls or slopes while a factor of safety of 1.5 is used for walls or slopes with low displacement tolerances or in highly critical areas. A factor of safety of 1.1 is typically used for all seismic analysis.

Sliding potential is analyzed using the methods prescribed in section 5.4.3 of Lazarte et al. (2003). Commercial slope stability limiting-equilibrium software may also be used for sliding analysis, which has the ability to analyze non-circular failure surfaces.

Seismic considerations are accounted for via a horizontal coefficient, k_h , within the slope stability software used in the global stability analysis mentioned above. Peak Ground Acceleration (PGA) is estimated from Section 3.10 of the AASHTO LRFD 2007 Bridge Design Specifications. Maximum wall acceleration, A_m , is then calculated as follows:

$$A_m = (1.45 - PGA) \cdot PGA$$

The horizontal seismic coefficient is then calculated as shown below:

$$\begin{aligned} k_h &= 0.67 \cdot A_m && \text{for low walls } H \leq 10 \text{ feet} \\ k_h &= (0.744 - 0.0074 \cdot H) \cdot A_m && \text{for walls } 10 < H \leq 33 \text{ feet} \\ k_h &= 0.50 \cdot A_m && \text{for high walls } H > 33 \text{ feet} \end{aligned}$$

Settlement is typically only an issue when weak soils are present at the foot of the slope or wall. These displacements are not typically measured, as they should be negligible provided an adequate factor of safety was used for the global stability analysis in both the drained and undrained cases.

4.3. Internal Stability

The reviewed design method assesses four potential failure modes in the evaluation of internal stability for soil nail slopes and walls: nail pullout failure, slippage between the reinforcement and grout, tensile failure of the nails, and bending/shear of the nails. The information in the subsequent paragraphs was developed after a review of Soil Nail Launcher, Inc. design documents.

Nail pullout resistance is evaluated using an empirical allowable bond stress between the soil and the nail. These values are tabulated for various soils, nail types, soil conditions, and nail installation methods.

Slippage between the reinforcement and the grout is generally not considered in the soil nail wall or slope design. Testing performed and documented by Soil Nail Launcher, Inc. shows that the ultimate bonding between the inner reinforcement and grout exceeds the ultimate bond stress between the soil and launched nails by a factor of 2.5 to more than 8.

Nail tensile failure is accounted for in the global stability analysis (using programs such as Slide or Slope/W). The long-term tensile strength of the reinforcement and the pullout capacity of the nail are input parameters required for the analysis. The capacity of the nail at the location where the failure surface being analyzed crosses the nail is considered as a resisting force in the limit equilibrium analysis.

Bending and shear failure of the nail is analyzed assuming nail deformations are elastic and that the shear resistance of each nail is controlled by the lateral soil bearing, calculated with a simplified bearing capacity approach using only the N_q term.

$$q_{uij} = N_q \cdot \sigma_{nij} \quad \text{ultimate lateral bearing capacity of nail } i, \text{ iteration } j$$

$$N_q = \left[\tan \left[45 + \left(\frac{\phi'}{2} \right) \right] \right]^2 \cdot e^{\pi \cdot \tan(\phi')} \quad \text{bearing capacity factor}$$

$$\sigma_{nij} = \gamma_{soil} \cdot z_{ij} \cdot \cos(\alpha) \quad \text{normal stress}$$

where,

$$z_{ij} = \text{depth to midpoint of the nail } i, \text{ iteration } j$$

$$\alpha = \text{installation angle below horizontal}$$

Additional consideration is given to slopes or walls with large surcharge loads or geometries (tiered structures, acute corners, obstructions, etc.). If applicable, wall facing and facing connections are designed in accordance with Lazarte et al. (2003).

4.4. Design Comments

Bending and shear resistance of the nails are included in the design method proposed by Soil Nail Launcher, Inc. This inclusion, which increases the global factor of safety, has been debated in soil mechanics for many years and has been the subject of several studies.

The addition of bending and shear resistance of the nail is based on the fact that the tubular cross section of the launched nail has a higher bending-stiffness-to-tensile-pullout-capacity ratio relative to a solid circular member of the same cross-sectional area (Barrett & Devin, 2011). Furthermore, the additional inner reinforcing steel and relatively short length of launched nails adds to the bending stiffness of the nail. The limited nail length reduces the bond length, which prevents the nails from developing their full tensile strength in pullout (Jewell & Pedley, 1992). Correspondingly, it may be assumed that the shear contribution from the shorter, stiffer, tubular launched nails plays a more significant role in the overall slope stability analysis.

However, several studies researching the tension and shear contribution of soil nails have shown that the shear contribution is negligible when compared to that of the tension contribution and is only mobilized at large deformations.

Research conducted by Pedley (1990), using a large-scale direct shear apparatus (1 m x 1 m x 1 m), analyzed soil reinforcement with respect to nail orientation, bending, and shear. Multiple nail types were used including tubular nails with a 1-inch outside diameter and a 1/8-inch wall thickness – very similar to a typical launched nail cross-section. Test results showed that as the measured bending moment neared the fully plastic moment, the maximum shear contribution of the nail was still less than 6% of the axial capacity. In the same study, an instrumented 6-meter high soil nail wall was loaded to failure. The highest nail shear force contribution was found to be less than 3% of the nail axial force contribution.

Bridle and Davies (1997) also analyzed the tension and shear contribution of soil nails using large-scale shear box tests, developing the computer program CRESOL, which incorporates the methods verified by their experiments. The research reviewed indicated an average mobilized-shear-force-to-pullout-resistance ratio of less than 3%.

Due to a lack of research indicating larger shear contributions in launched soil nail applications, it is recommended that the FHWA standard for the design of soil nailed structures found in Lazarte et al. (2003) be used for the design of launched soil nail structures.

5. EVALUATION OF THE LONG-TERM STRENGTH OF THE SOIL NAIL

Corrosion resistance is a primary concern in permanent applications. Launched tubes are typically galvanized for this reason. According to Soil Nail Launcher, Inc., the dynamic nature of the nail installation causes a shock wave around the nail head, causing soil particles to deform

elastically as the nail enters the ground. The temporary deformation of the surrounding soil reduces abrasion to the nail and corresponding loss of exterior corrosion protection (Barrett & Devin, 2011).

Nail design life is approximated using the method proposed by Elias in “Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes” (FHWA-NHI-00-044). The steel reinforcing bars can be galvanized or epoxy-coated. Protection from the surrounding annular grout is ignored and galvanization or epoxy-coating degradation is assumed to occur at a uniform rate (i.e., for both galvanized and epoxy coating the rate of loss is assumed to be equal). It is also assumed that uniform degradation of steel begins immediately following galvanization or epoxy depletion. The required sacrificial steel thickness is then defined as the difference between design life and the galvanization/epoxy depletion time divided by the steel uniform loss rate (Elias, 2000). The available sacrificial steel for No. 4 to No. 6 bars greatly exceeds the required sacrificial steel using a standard 12- or 16-mil epoxy coating for both 75 and 100 year design lives (SNLI, 2010). However, the corrosion rate for the galvanization and bare steel proposed by Elias et al. is based on a controlled electrochemical environment. This environment must be met for the corrosion rates by Elias to be valid.

6. CONSTRUCTION SPECIFICATIONS

Due to the proprietary nature of the launched soil nailing technology, a performance or end-result type specification is appropriate. This specification should define performance requirements and indicate the acceptable design methodology. In this case, the design method presented in Lazarte et al. (2003) “Geotechnical Engineering Circular No. 7 – Soil Nail Walls” (FHWA0-IF-03-017) is recommended. In addition to the specification, contractor pre-qualification requirements, any special provisions such as required submittals, and project drawings should be provided by the agency. Recommendations for information to be included in the plans furnished by the owner or agency can be found in Section 7.4 of Lazarte et al. (2003). The document also contains a performance guide-specification, which has been included in Appendix B of this report for reference.

7. QUALITY CONTROL AND QUALITY ASSURANCE PROCEDURES

The SHRP 2 R02 research team identified quality control and quality assurance (QC/QA) methods that should be included in launched soil nailing projects. A comprehensive QC/QA program should include proof, verification, and creep (in cohesive soils) testing of installed nails; surveying and visual inspection of the reinforced slope or wall; and material testing where applicable.

7.1. Proof, Verification, and Creep Testing

Proof and verification tests are performed on soil nails during construction. Verification tests load a sacrificial nail to failure or a set value much larger than the design load – typically 200%. Verification testing is performed prior to installation of production nails and the grout-to-ground bond values found in the test are used to produce final design values. One or two verification load tests should be completed prior to production-nail installation. Large projects may require more verification testing. Proof tests are performed on a small percent (typically 5%) of production nails during construction. Nails are typically loaded to 150% of the design value to ensure satisfactory pullout capacities. Creep testing is performed as a part of the proof or verification testing. Creep testing is only performed in cohesive soils and allows for long term movements of nails under a specified load to be monitored. Sacrificial nails are loaded with a sustained, constant load until failure (quantified by a designated displacement). All tests use a hydraulic jack to load the nails. The load is measured by a load cell or pressure gage and deflections are measured with a dial gage. An exact description is found in Lazarte et al. (2003).

7.2. Surveying and Visual Inspection

Surveying equipment should be used to record any slope or wall movements during and after construction. Surveying is used to identify areas where excessive movement is occurring – indicative of a slope failure. Like surveying, visual inspections help identify visible problems such as cracking, seepage, and heaving. A “walking inspection” should be conducted by the foreman and the engineer to observe any problem areas in the wall or slope during construction. In addition, inspection of construction materials verifies that samples from each batch of material conform to the design and construction specifications. Lazarte et al. (2003) provides a list of items an inspector should verify and record in the nail installation logs as part of the QC/QA program. Nail installation logs should be maintained throughout construction.

7.3. Materials Testing (Nail Tensile Strength and Shotcrete)

Tension testing of the soil nails may be performed in a laboratory to ensure a batch of nails meets the specified ultimate tensile strength. Nails typically come with a manufacturer’s certificate that states batch testing results. Soil nail walls and slopes utilizing shotcrete need to complete a full shotcrete inspection. For permanent walls, shotcrete core testing should be performed. Byrne et al. (1998) Appendix C 2.2.3 describes how to extract core samples from shotcrete walls to be tested for compressive strength. Cores from non-reinforced shotcrete test panels are tested for compressive strength while cores from reinforced test panels are inspected for air pockets and quality. According to Byrne et al. (1998), three cores should be tested at three days and three cores should be tested at 28 days to comply with AASHTO T24/ACI C 42.

8. PERFORMANCE REVIEW

Launched soil nails have been in use in the United Kingdom since 1989. The 1992 demonstration project (FHWA-FPL-93-004) sponsored by the USDA Forest Service and several state DOTs was deemed successful and had the following conclusions (quoted from USFS, 1994):

- The launcher equipment proved capable of installing 18-foot-long nails to depths of 5 to 18+ feet in a wide variety of materials and conditions.
- A small crew (operator and two helpers) can install 15 nails per hour.
- The equipment worked at elevations from sea level to 7,000 feet elevation.
- The equipment can be rapidly mobilized, requiring about 30 to 45 minutes to assemble and disassemble at the site.
- Relatively inexpensive, cost competitive with other alternatives.
- Requires little or no excavation and replacement of soil; minimum site disturbance.

To date, dozens of projects have been completed across the United States, especially along the East Coast and in the Midwest and Northwest, with thousands of nails installed.

No severe or unusual issues were found through this review. Some issues that have been found to occur include

- Nails launched too shallow or too deep. Adjustment of the air pressure can correct this.
- Steel tips being shot off the nail was observed in one case history.
- Aesthetic issues with nails protruding from the slope. This can be rectified by cutting nails flush with the slope and painting them to match the surrounding wall.

8.1. Cost

Costs for launched soil nails are competitive with and oftentimes considerably less than alternative technologies. The FHWA “Application Guide for Launched Soil Nails” (1994) gives a cost estimate of \$80 to \$135 per nail, including mobilization. The overall cost of a slope repair project near Lumsden, Saskatchewan in 2005 that consisted of 108 launched nails was normalized as \$400 per nail installed, including all project expenses (Antunes et al., 2005). Information reported in 2004 from several sites near Summit County, Ohio indicated total project costs between \$380 and \$450 per nail installed (Wendlandt, 2009).

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APPENDICES

Appendix A

Figures and Pictures

Appendix B

Performance Guide Specification from Lazarte et al. (2003)

Appendix C

Load Test Data

Appendix D

Case History Reference Project

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Appendix A

Figures and Pictures

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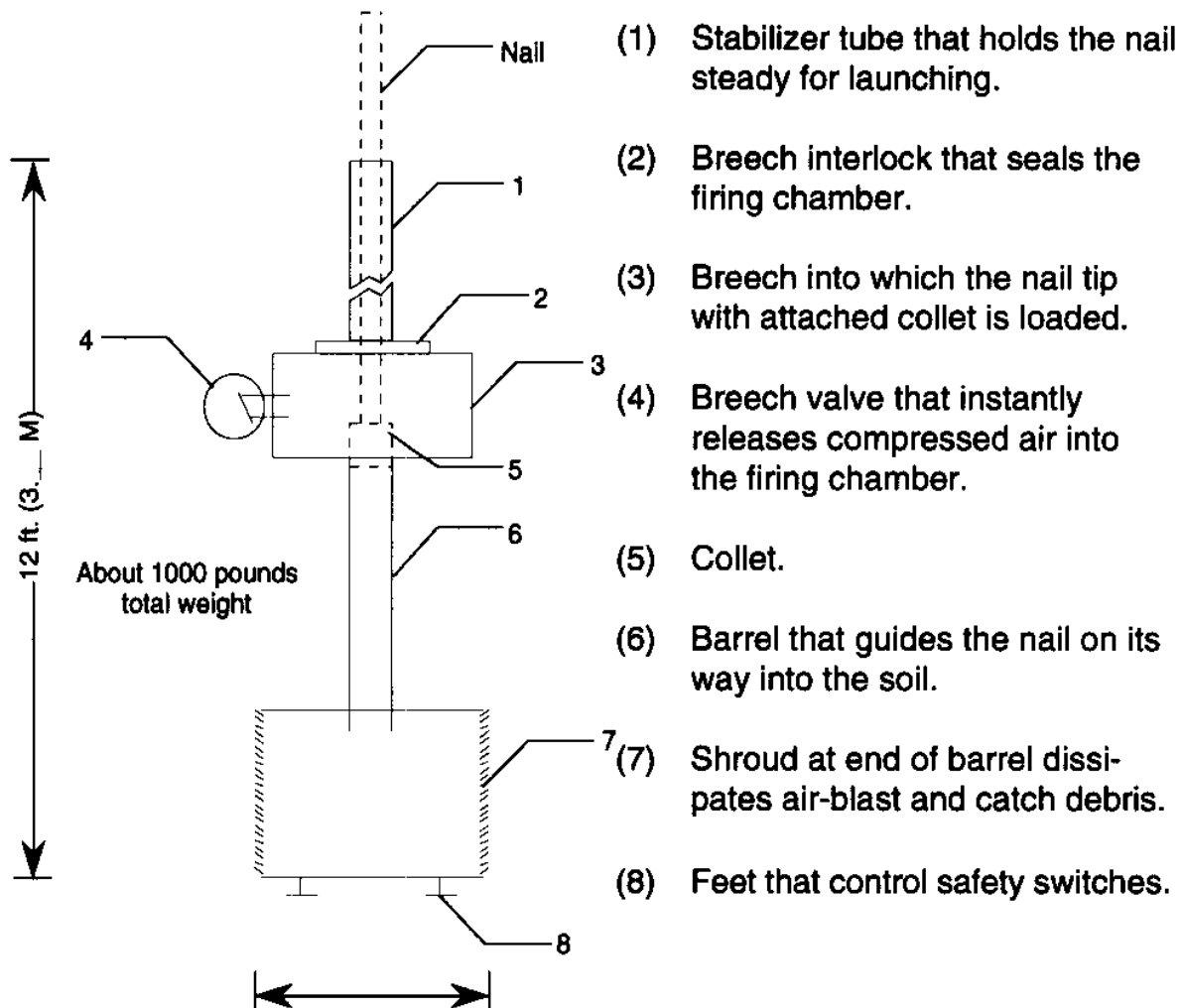


Figure 1. Schematic of the soil nail launcher (FHWA, 1994).

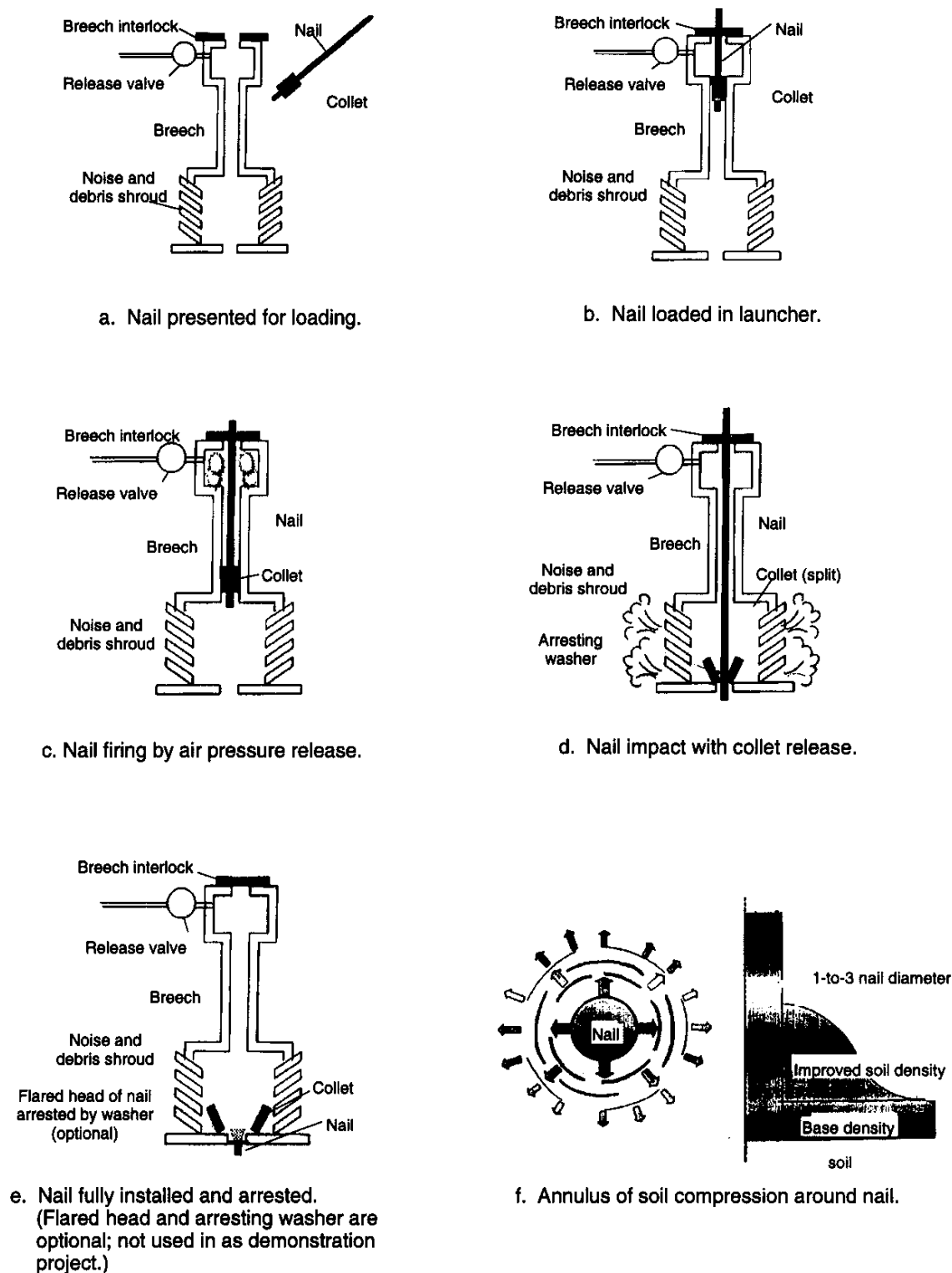


Figure 2. Illustration of the soil nail process (FHWA, 1994).



Photo 1. Soil nail launcher and nails ready for transport (USFS, 1994).



Photo 2. Excavator-mounted soil nail launcher reaching over guard rail to repair a failing slope (USFS, 1994).



Photo 3. Soil nail launcher operating on slope by Lake Tahoe in El Dorado County, CA (photo courtesy of Colby Barrett, Soil Nail Launcher, Inc.).



Photo 4. Soil nail slope in Wyoming with nail face plates and wire mesh in preparation for shotcrete application (photo courtesy of Colby Barrett, Soil Nail Launcher, Inc.).

Appendix B

Performance Guide Specification from Lazarte et al. (2003)

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SOIL NAIL WALL

PERFORMANCE SPECIFICATIONS

PART 1 GENERAL

1.01 SECTION INCLUDES

- A. 1.02 Scope of Work
- B. 1.03 Pre-Approved List
- C. 1.04 Available Information
- D. 1.05 Soil Nail Wall Design Requirements
- E. 1.06 Design Submittals

1.02 SCOPE OF WORK

- A. Specifications under a performance type contracting method are identical to the Procedural Specifications except for the first section.
- B. This work consists of designing and constructing permanent soil nail retaining wall(s) at the location shown on the drawings. The Contractor shall furnish all labor, plans, drawings, design calculations and all other material and equipment required to design and construct the soil nail wall(s) in accordance with this Specification.

1.03 PRE-APPROVED LIST

- A. The prime Contractor must select one of the specialty contractors listed below and shall identify the specialty contractor on his proposal at the bid opening. No substitution will be permitted without written approval of the Engineer. Substitution after the bid opening will not be grounds for changes in bid prices.
 - 1. Name and address of specialty contractor 1.
 - 2. Name and address of specialty contractor 2, etc.

1.04 AVAILABLE INFORMATION

- A. Available information developed by the (Agency) include the following items:
 - 1. Contract Drawings titled, _____, dated _____.
 - 2. Geotechnical Report (*Provide complete references for all available geotechnical data and reports*)

3. Other (*Agency-developed Inspector Information; Design Guidelines, etc.*).

(Note: These performance specifications must be completed by adding Subsections 1.03 to 1.21 and Section 2.0 from the Procedural Specifications.)

1.05 SOIL NAIL WALL DESIGN REQUIREMENTS

- A. Design the soil nail walls using the Allowable Stress Design (ASD) method, also known as Service Load Method (SLD), as outlined in FHWA Geotechnical Engineering Circular No. 7. "Soil Nail Walls." Soil/rock design shear strength parameters, slope and external surcharge loads, seismic design coefficient, type of wall facing, architectural treatment, corrosion protection requirements, easements, and right-of-ways will be as shown on the Drawings.

1.06 DESIGN SUBMITTALS

- A. At least 45 days before the planned start of the wall excavation, submit complete design calculations and working drawings to the Engineer for review and approval. Include all details, dimensions, quantities, ground profiles and cross-sections necessary to construct the wall. Verify the limits of the wall and ground survey data before preparing the drawings. The working drawings shall be prepared to the (*Agency*) standards. The drawings and calculations shall be signed and sealed by a Professional Engineer registered in *State of [Name of State/Commonwealth]* _____. The Engineer will approve or reject the Contractor's submittals within 30 calendar days after the receipt of the complete submission. The Contractor will not begin construction or incorporate materials into the work until the submittal requirements are satisfied and found acceptable to the Engineer.

Appendix C

Load Test Data (Soil Nail Launcher, Inc.)

The following pages are the results from pullout tests performed January 27 and 28, 2011 on three nails on the Route 58 embankment near Danville, VA.

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Soil Nail Launcher, Inc
955 Malachite
Fruita, CO 81521
303.909.6083
Web www.soilnaillauncher.com
Email Colby@SNL1.com

January 31, 2011

H. D. French Jr. P.E.
District Materials Engineer
VDOT - Lynchburg District
4219 Campbell Ave
Lynchburg Va. 24506
Office Phone 434-856-8104
Cell Phone 434-841-9250
Fax 434-947-2190

RE: Verification Testing, Route 58

Dear Mr. French:

Below are the test results from the three nails examined on January 27-28, 2011 at Route 58 near Danville, VA.

Testing Apparatus and Setup

A hydraulic jack and hand pump were used to examine the pullout capacities of four nails at the site. Excavation around the nails facilitated the installation of a timber crib reaction frame, and 2-ft of each nail was exhumed to facilitate loading. As the nails were loaded, cumulative deflection was measured from a stationary steel table founded on the ground in front of the nail in area independent of the loading. Movement was measured with a dial indicator read to 0.001 inch.

Test Dates: Began on January 27, 2010 (top row); terminated on January 28, 2010 (Bottom and Middle Row)

Test Personnel: Colby Barrett

Ram Type: Hydraulic 60 Ton (H0806000773)

Pump Type: BVA hand pump (R0810000037)

Gauge: 0 – 5,000 psi (0-4,500 psi verified load) (005)

Last Calibration: 09/09/2010, Conducted by Dan Downing and reviewed by Craig Burger, P.E. of CTL Thompson Inc., 234 Center Drive, Glenwood Springs, CO 81601 (970) 945-2809



Figure 1: Top Row Test Nail



Figure 2: Bottom Row Test Nail



Figure 3: Middle Row Test Nail

Test Results

Original test sheets are presented. Loading was performed in intervals. Design test load was 3,562 lbs and design Bond Stress was 3.5 psi. Maximum Safe Load for bar yield was 16,200 lbs. Readings were taken according to project specifications. No pullout or creep failure occurred during any of the tests.

Top Nail

Max 10 Minute Creep: 0.006 inches (at 5,344 lbs)

60 Minute Creep: 0.009 inches

Failure Load: 12,026 lbs

Calculated Ultimate Bond Stress: 11.82 psi

Middle Nail

Max 10 Minute Creep: 0.001 inches (at 5,344 lbs)

60 Minute Creep: 0.029 inches

Failure Load: 14,658 lbs

Calculated Ultimate Bond Stress: 14.40 psi

Bottom Nail

Max 10 Minute Creep: 0.000 inches (at 5,344 lbs)

60 Minute Creep: 0.000 inches
Failure Load: 10,316 lbs
Calculated Ultimate Bond Stress: 10.13 psi

Testing Procedure:

0.25 DTL for 10 minutes
0.50 DTL for 10 minutes
0.75 DTL for 10 minutes
1.00 DTL for 10 minutes
1.25 DTL for 10 minutes
1.50 DTL Creep Test
1.75 DTL for 10 minutes
2.00 DTL for 10 minutes

The creep period shall start as soon as the maximum test load (1.50 DTL) is applied and the nail movement shall be measured and recorded at 1 minute, 2, 3, 4, 5, 6, 10, 15, 25, 30, 45, and 60 minutes.

Discussion

Measured 10-minute and 60-minute creep in all nails was below the creep failure criteria. Observed pullout failure was between six and nine times design values. The tests indicate that any nail that penetrates more than 6-ft will satisfy the design loads.

Should you have any questions, please contact me.

Colby E. Barrett
President
Soil Nail Launcher, Inc.
303.909.6083

September 9, 2010

GeoSolutions International, LLC
955 Malachite Drive
Fruita, CO 81521

Attention: Mr. Nate Beard, P.E.

Subject: Hydraulic Ram Calibration
Hydraulic Ram System
Project No. GS05239-435

This report presents results of a load calibration performed on a hydraulic system delivered to our laboratory on September 7, 2010. The equipment consisted of one hydraulic ram, one hand-operated pump, and two gauges. The system was calibrated using our Forney compression-testing machine with a load capacity of 400,000 pounds. Calibration of our test machine is performed annually and is traceable to the N.I.S.T.

Gauge pressure and the corresponding load were measured three times over the load range for the hydraulic ram system. The other gauge was placed in the system and the calibration repeated. The results were averaged to determine a linear equation for the load in pounds versus gauge pressure in psi. The results of the calibration are presented numerically in Table I and Table II. Graphs presenting load versus gauge pressure are presented in Figures 1 and 2.

If you have any questions regarding this report, please feel free to contact us.

Very truly yours,

CTL | THOMPSON, INC.

Reviewed by:

Dan Downing
Laboratory/Field Manager

Craig A. Burger, P.E.
Project Manager

DD: CAB:cd

TABLE I
CALIBRATION DATA FOR HYDRAULIC RAM SYSTEM

Client: GeoSolutions International, LLC
 Calibration Date: September 8, 2010
 Ram I.D.: 60 Ton (H0806000773)
 Gauge I.D.: 5,000 psi (005)
 Pump I.D.: BVA (R0810000037)

<u>Gauge Pressure, psi</u>	<u>Average Load, lbs.</u>
500	6,000
1000	12,500
1500	19,000
2000	25,667
2500	32,667
3000	39,333
3500	45,500
4000	52,000
4500	58,000

Top row				Pillant: Pass Creep: Pass	
load	psi	deflection	time	reading notes	
890	104	3.000	0	2:48	
		3.000	10	2:58	
1781	171	3.000	0	2:58	
		3.006	10	3:08	
2672	239	3.006	0	3:08	
		3.007	10	3:18	
3562	307	3.008	0	3:18	
		3.008	10	3:28	
4453	374	3.013	0	3:28	
		3.016	10	3:38	
5344	442	3.026	0	3:39	
		3.028	1	3:39	
		3.028	2	3:40	
		3.028	3	3:41	
		3.029	4	3:42	
		3.029	5	3:43	
		3.029	6	3:44	
		3.032	10	3:48	
		3.033	15	3:53	
		3.034	25	4:03	
		3.034	30	4:08	
		3.035	45	4:23	
		3.035	60	4:38	
		3.040	0	4:39	
		3.042	10	4:48	
7125	577	3.050	0	4:48	
		3.051	10	4:58	
	600	3.054			
	700	3.070			
	800	3.093			
	900	4.040			
	1000	3.392	Final (950 psi)		
	1100				
	1200				
	1300				

Middle row					75
load	psi	deflection	time	clock	
890	104	2.200	0	12:00	
1254		2.200	10	12:10	Pullout: Pass
1781	171	2.201	0	12:10	Creep: Pass
		2.201	10	12:20	
2672	239	2.105	0	12:20	
		2.105	10	12:30	
3562	307	2.126	0	12:30	
		2.126	10	12:40	
4453	374	2.166	0	12:40	
		2.166	10	12:50	
5344	442	2.204	0	12:50	
		2.204	1	12:51	
		2.204	2	12:52	
		2.204	3	12:53	
		2.204	4	12:54	
		2.204	5	12:55	
		2.205	6	12:56	
		2.205	10	1:00	cribbing on R side pushing
		2.231	15	1:15	on causing nail bending
		2.231	25	1:25	jump to 2.231 due to
		2.231	30	1:30	plate roughness
		2.232	45	1:45	
		2.233	60	2:00	
6235	509	2.239	0	2:00	
		2.240	10	2:10	
7125	577	2.248	0	2:10	
		2.249	10	2:20	
	600	2.253			
	700	2.264			
	800	2.274			
	900	2.284			
	1000	2.296			
	1100	2.345			
	1200				
Failure 1150			Total: 3.450		

Bottom Row		Allant: Pass Creep: Pass			
load	ps	deflection	time	clock	notes
890	104	2.701	0	8:48	
		2.703	10	8:58	
1781	171	2.704	0	8:58	
		2.705	10	9:08	
2672	239	2.705	0	9:08	
		2.705	10	9:18	
3562	307	2.709	0	9:18	
		2.709	10	9:28	
4453	374	2.722	0	9:28	
		2.722	10	9:38	
5344	442	2.738	0	9:38	
		2.738	1	9:39	
		2.738	2	9:40	
		2.738	3	9:41	
		2.738	4	9:42	
		2.738	5	9:43	
		2.738	6	9:44	
		2.738	10	9:48	
		2.738	15	9:53	
		2.738	25	10:03	
		2.738	30	10:08	
		2.738	45	10:23	
		2.738	60	10:38	
6235	509	2.744	0	10:38	
		2.746	10	10:48	
7125	577	2.752	0	10:48	
		2.756	10	10:58	
	600	2.761			
	700	2.778			
	800	2.806			
	900				
	1000				
	1100				
	1200				
	1300				
		Total: 3.437			
Failure 820					

Appendix D
Case History Reference Project

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Shoot-In Soil Nailing

Del Norte Bluff – Project Case History –

Location: Pebble Beach Drive,
Crescent City, Del Norte County,
California

Owner: Del Norte County

Contractor: Soil Nail Launcher,
Inc.

Engineer: Steve Devin, P.E.,
G.E.

Year Constructed: 2009



Project Summary/Scope:

The bluffs on the coastline in Del Norte County were experiencing erosion. In the past, rip rap had been installed to help mitigate the receding slopes. Because of permitting and environmental issues, the project engineer decided launched soil nails were the best option.

Subsurface Conditions: Six exploratory borings were completed. A CPT test was also performed. These showed that the soil nails would be launched into an unconsolidated fat clay and sand.

The nails were installed in a triangular pattern. The type of nail used was a fiberglass nail with a steel tip. Over 350 launched soil nails were installed. The nail launcher was attached to the boom of an excavator. It was able to sit on the ledge of the bluff and extend down and over the slope to install the nails. Drainage galleries were installed in areas of the wall where excess pore pressure behind the shotcrete wall was anticipated.

There were issues with launched nails going too deep into the soil. To rectify this air pressure in the launcher was lowered. Another issue involved the steel tips getting shot off of the nails. An aesthetical issue was also presented with protruding drainage pipes. This was solved by cutting the pipes flush with the slope and painting them a color that matched the surrounding wall.

The project took place over a five week period from December 2008 to January 2009.



Project Technical Paper:
Barrett and Chinchio (2009) SHRP 2 R02 project communication.

Date Case History Prepared: 1 July 2011