Launched Soil Nails: New Method for Rapid Low-Impact Slope Repairs

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A variety of methods have been used during the last 20 years to reinforce soils. One of these is soil nailing. Most often, soil nails are installed by inserting steel rods in drilled holes, then grouting them in place. Sometimes the nails are inserted using percussion methods. These methods generally require excavation of a working bench in order for the construction equipment to work below the slope being nailed. These methods are not suitable for repairing small slips of road fills and embankments where access is limited. Launched soil nailing, a new technique developed in the United Kingdom by Soil Nailing, Ltd., allows nails to be inserted into the slope using a launcher attached to the end of an excavator boom. With this method the nails can be installed into slopes up to 8 to 11 m (26 to 36 ft) above or below the road surface without excavation or ground disturbance. The launcher uses high-pressure compressed air to install the nail. The depth of penetration depends both on the compressed air pressure and on the in situ material. At a reproduction rate of 15 nails per hour, this method is rapid, yielding production results not experienced using conventional methods. In July and August 1992, the USDA Forest Service sponsored a demonstration project for launched soil nailing in the western United States. The project successfully demonstrated the feasibility of using launched soil nails to stabilize failing road slopes. Small slope failures [no deeper than about 4.5 m (15 ft)] can be stabilized for about $\$150/m^2$ ($\$14/ft^2$) of slope face. Low retaining walls and excavate-and-replace methods typically cost \$161 to $\$645+/m^2$ (\$15 to $\$60+/ft^2$) of face area. Equipment mobility, rapid placement, minimum site disturbance, and low costs indicate a strong future for launched soil nails for the repair of the road infrastructure.

In July and August 1992, the USDA Forest Service and Soil Nailing Limited from the United Kingdom sponsored a demonstration project for the launched soil nail method in the western United States. The demonstration involved installation of launched soil nails at eight sites in four states and three Forest Service regions. Demonstrations included soil nailing of road shoulders, retaining walls, a cut bank, and a sand bank. Financial assistance was provided by the FHWA Coordinated Technology Implementation Program (CTIP). Technical assistance was provided by the Washington and Colorado departments of transportation, and seven national forests that participated in the demonstration project.

The project was developed to demonstrate the use of launched soil nails to repair and reinforce unstable cut bank and embankment slopes. The demonstrations provided an opportunity for engineers, maintenance personnel, and contractors to view and explore the potential for using launched soil nails.

A video, *Application Guide for Launched Soil Nails* (*1*), and the project report (*2*) are products of the demonstration project. Demonstration site experiences, participant interviews and questionnaires, and a simplified wedge analysis for soil nailing provide the basis for this paper.

Demonstration Project Results

The soil nail launcher successfully installed galvanized steel nails with diameters of 38 mm (1.5 in.) (*3*) and lengths of 5.4 m (18 ft) into a wide variety of materials. Launcher air pressures of between 4.1 and 17.2 kPa (600 to 2500 psi) resulted in nail tip penetrations of 1.5 to 5.4 m (5 to 18+ ft).

A production rate of 15 nails per hour was achieved by a three-person work crew (launcher operator and two helpers).

Participants in the demonstrations indicated the following:

- For small road failures, equipment can be moved in, the failure repaired, and the equipment moved out in less than 1 day.
- The method has high potential for slope reinforcement, especially on road shoulders and backslopes.
- The method has medium potential for retaining wall reinforcement, horizontal drains, and anchor insertion.
- Either tracked or rubber-tired excavators are suitable, although tracked excavators may be more versatile.
- Using a self-propelled, rubber-tired excavator for road shoulder repairs could eliminate the excavator hauling unit.
- Minimum ground disturbance and mobility are important features of the technology.
- Potential limitations of the technology include the length of nails (limited to smaller slides), penetration in cobbly soil, and maintaining precise control over depth of nail penetration.
- Design concerns include nail pullout resistance; need for practical design guidance; need for more experience with the technology, including case histories; and corrosion of permanent installations.
- Facing systems would be appropriate for temporary walls and for very shallow slides or erodible soils.

Several actions have been initiated as a result of these demonstrations:

- Design charts for stabilizing road shoulders with launched soil nails were developed (see Figure 1).
- A longer-term (1- to 2-year) demonstration project is being planned to gain experience with completed projects and to develop case histories.
- More exposure is planned to increase awareness of this technology by engineers, contractors, and maintenance personnel.

Soil Nailing Using Launched Nails

Soil nailing is a reinforcement technique that inserts long steel rods into an unstable or potentially unstable existing soil mass. Soil nails installed into the soil act to reinforce the soil mass by transferring tensile and shear resistance of the nail to the soil. The nails maintain the restraint force because they are anchored beyond the slip surface. Figure 2 shows how these forces act to retain a small soil slip.

During the past 20 years, a variety of methods have been used to install soil nails. Most often they are inserted into drilled holes and then grouted in place. Sometimes they are driven into the soil using percussion methods. These methods generally require the excavation of a working bench (Figure 3) for the equipment and are not suitable for repair of small slips in road fills and embankments where access is limited. These methods also require the removal and replacement of soils, often resulting in large areas of disturbed and raw ground. Because the soils are moved twice and the drilling is slow, costs are generally as high as those for other retaining structures. Environmentally, the disturbed and raw ground requires time to heal, stabilize, and provide desirable ground cover.

Launched soil nailing, also called ballistic soil nailing, is a new technique developed in the United Kingdom. Soil nails are installed by means of a launcher mounted on a hydraulic excavator (Figures 4 and 5). The launcher uses high-pressure air acting upon a collet (plastic collar) attached at the tip (front end) of the nail (Figure 6). Compressed air suddenly released against the collet forces the collet and nail through the launcher barrel, much like a dart through a blow gun (Figure 3). Launched soil nails are installed rapidly with little soil disturbance.

The nails are launched at speeds of over 320 km/hr (200 mph) and at pressures approaching 17.2 MPa (2,500 psi). The collet breaks away as the nail enters the soil. As the launched nail passes into the soil, the ground around the nail is displaced by compression at the tip. This forms an annulus of compression as shown in Figure 7(*f*), reducing soil-drag on the nail and damage to the galvanized coating. Depth of nail penetration is normally controlled by air pressure and ground resistance. Optionally, the nail penetration can be arrested by fitting the end of the nail with a tapered screw-on coupling as shown in Figure 7(*e*). During launching, the force (air pressure) acts upon the tip of the nail, thus

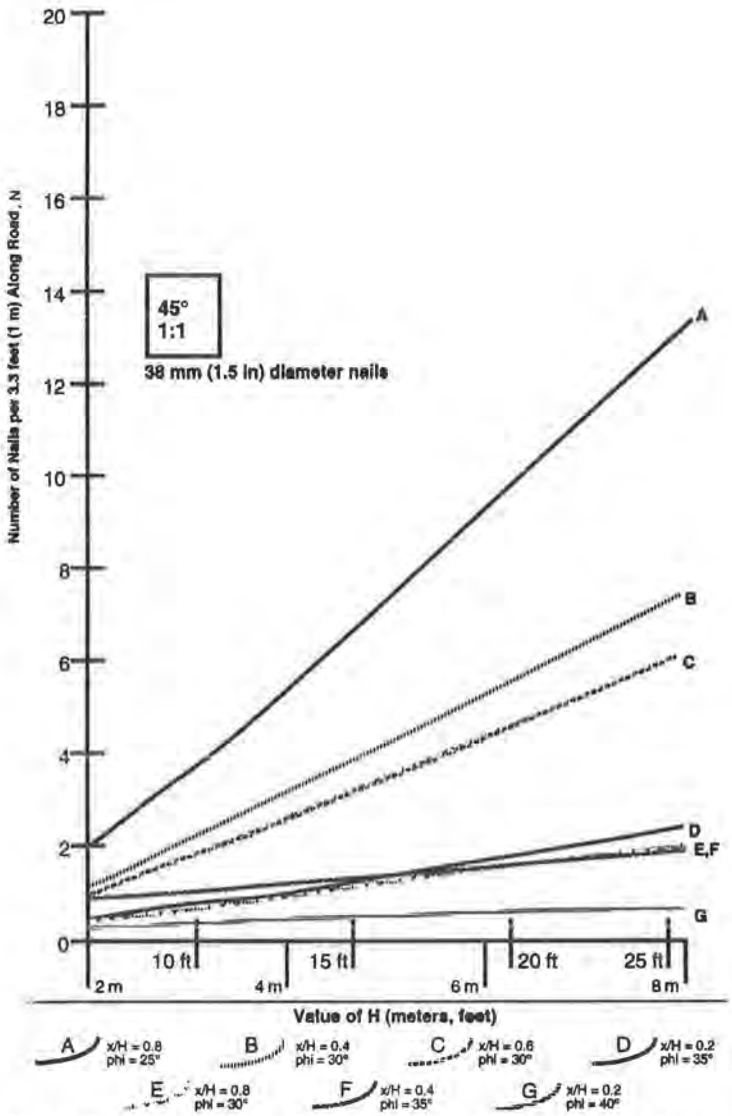


FIGURE 1 Number of nails required to stabilize road shoulder for 1:1 (45-degree) slope.

placing the nail temporarily in tension and preventing it from buckling.

The launcher typically launches plain or galvanized steel nails up to 38 mm (1.5 in.) in diameter and up to 6 m (20 ft) long (the 1992 demonstration used shorter nails—5.5 m (18 ft) long due to the length of the shipping container). The nail should be oriented normal to the potential slip plane to act primarily in shear and bending, with the tension being induced by movement.

Depending on the length of the boom, the launcher can be positioned 1.5 to 11 m (5 to 35 ft) above or below the excavator's platform. The launcher is attached to the boom by an articulated knuckle (Figure 4) that allows tilting of the launcher at almost any desired angle. Excavation for a working bench is usually not needed for road repairs using the launcher. The soil nail launcher has been used in the United Kingdom to successfully install nails in a variety of soil and slope conditions, primarily for reinforcement of road and railroad embankments and to strengthen retaining walls. Before this demonstration, the equipment had not been used in the United States.

Need for Launched Soil Nails

Roads constructed on steep slopes are susceptible to sliding and shoulder cracking (Figure 8). These cracks

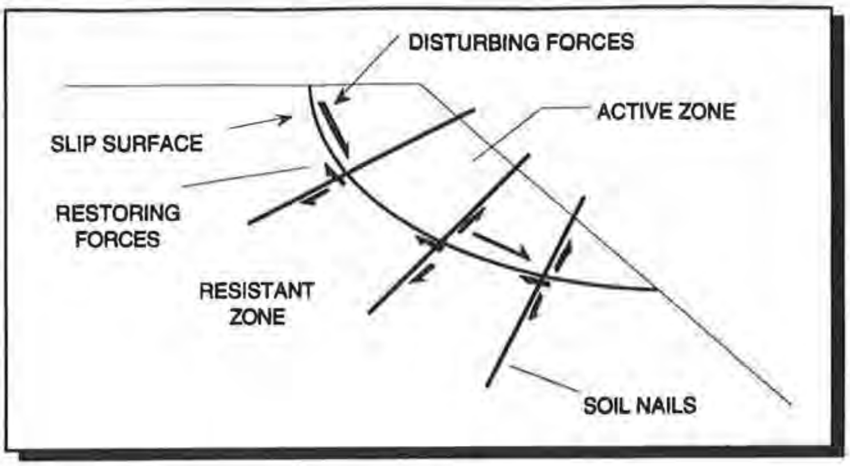


FIGURE 2 Forces acting on a road slope failure.

allow water from rain and snow melt to enter, adding excess moisture and water pressure directly to the slide mass. These areas are periodically filled and patched to smooth the road, adding weight to the sliding mass and further decreasing stability. Such fill failures are costly to repair, impair safe travel, and can cause extensive damage to the surrounding land and streams. Obviously, permanent repair methods are preferred over the annual crack-filling and patching of these unstable areas.

Launched soil nails offer a rapid economical alternative to recurring maintenance or other reconstruction solutions. Often several small fill failures can be fixed in one day without excavation. The launcher can be moved with ease between trees and shrubs, resulting in little or no vegetation removal and little need for environmental or visual mitigation (Figure 5).

The soil nail launcher, which weighs about 1250 kg (2,750 lb) mounted on a standard hydraulic excavator, is highly mobile and can respond quickly. Small slides can be quickly stabilized before they progress into larger slides. This quick response prevents more expensive repairs and further environmental damage.

Designing with Launched Soil Nails

A number of methods can be used to account for the reinforcement benefit to the slope using launched soil nails. Soil Nailing Limited developed a design method

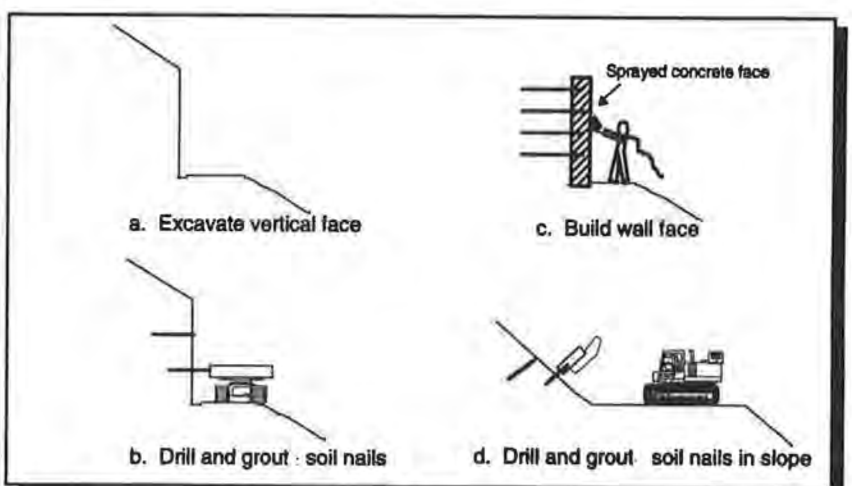


FIGURE 3 Conventional soil nailing.

FIGURE 4 Closeup of launcher, with numbers indicating (*1*) nail guide, (*2*) air chamber and valve, (*3*) barrel, (*4*) noise and debris shroud, (*5*) spring-loaded safety switch, (*6*) articulated knuckle, and (*7*) excavator boom.

FIGURE 5 Nails installed in road shoulder without disturbing vegetation. Nails were cut off at ground surface. Note pavement displacement in right foreground (*1*).

using a simplified wedge analysis (Figure 9) (*1*). The soil nails impart both tensile and shear resistance from the nail to the soil as shown in Figures 10(*a*) and 10(*b*).

The 1992 demonstration project provided a qualitative demonstration of the equipment capability. Sites were not designed to test the stabilization of moving slopes. However, areas of known movement were selected for most demonstration sites to judge potential performance.

As a result of the field demonstrations and work with technical advisors, the simplified wedge design methodology was developed to aid in selecting nail spacing to stabilize small road shoulder slides on low-volume roads. Typically these slides may require 15 to 50 nails for stabilization at a cost of $2,000 to $6,000 per site. Geotechnical drilling can cost $3,000 to $10,000 and is usually not warranted for these slides. The design method assumes that a site evaluation has been performed by experienced geotechnical personnel, usually without exploratory drilling.

Where a slope has failed or is near failure, it can be said that the soil profile has a factor of safety equal to 1. During the project, design charts were developed to calculate the number of nails needed per meter length of road for embankment slopes of 1:2 (26°), 1:1.5 (33°), and 1:1 (45°), respectively, to increase the slope factor of safety to 1.1. Like mechanically stabilized embankments (MSE), factors of safety are applied to the reinforcement. The design charts incorporate a material factor of safety (f_m) of 2 against pull-out and shear or tensile failure of reinforcement.

Additional assumptions for the design charts include the following:

- The slope has been in place for a number of years and can be represented by the consolidated-undrained condition during slope movement.
- The soil strength can be represented by an effective cohesion of zero ($C' = 0$) and an apparent angle of internal friction of ϕ estimated from site failure geometry, soil classification, and seepage conditions.
- Groundwater and seepage pressures are either minimal or controlled by installed drainage.
- Nails are installed nearly normal to the slide plane.
- The depth through the active zone into the resistant zone and in the active zone is at least 1 m (3.3 ft) to develop nail resistance.

FIGURE 6 Soil nail ready for insertion loading into launcher. Compressed air is introduced between locking washer (*1*) and collet (*2*). The collet separates from nail in noise and debris shroud.

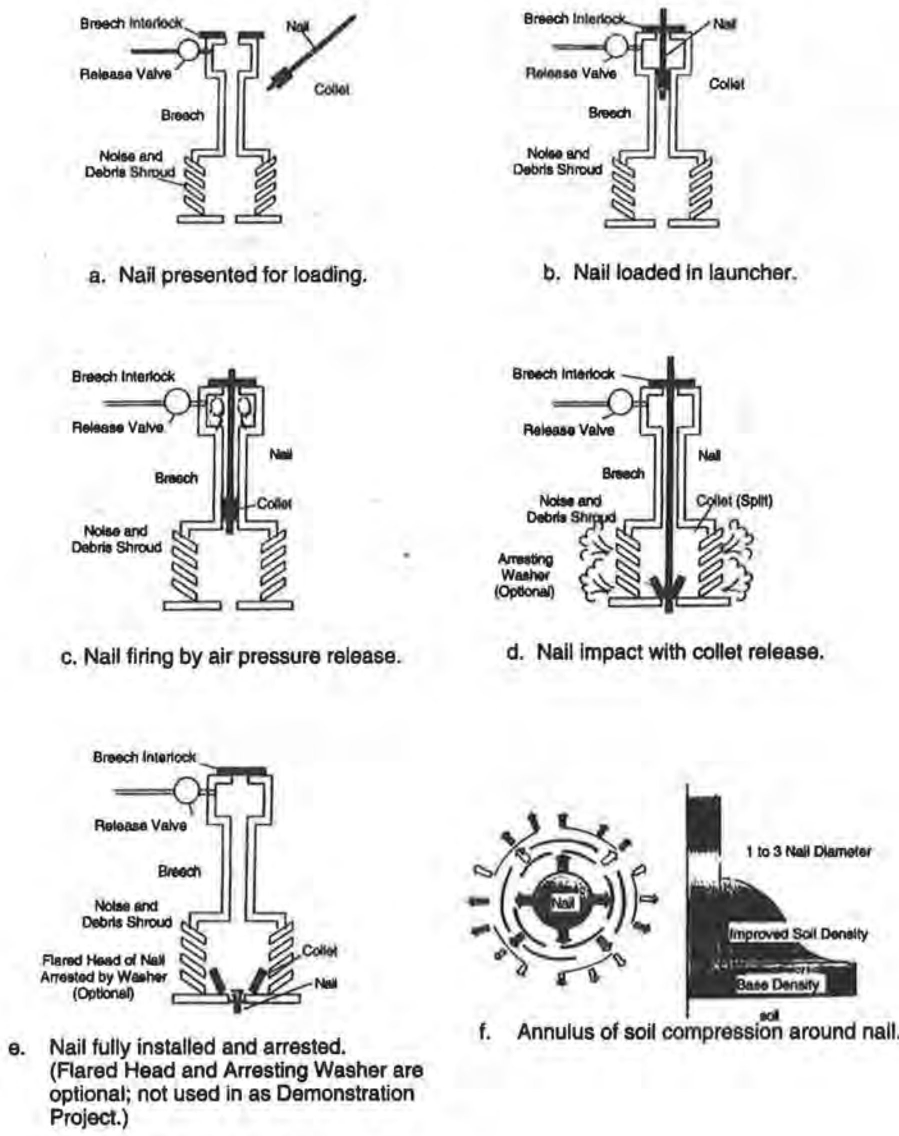


FIGURE 7 Soil nail launching sequence.

• The top row of nails is placed about 1 m from the road shoulder, the bottom row of nails is no closer than 1 m above the toe of the slide, and the remaining nails are evenly distributed throughout the slide mass.

Figure 1 shows the design chart for a 1:1 (45-degree) slope. The full design method and design charts for 1:2 (26-degree) and 1:1.5 (33-degree) slopes are contained in the application guide (*1*).

To ensure full penetration by the soil nails, the soil should not contain a high percentage of cobbles or boulders. Launching nails in ordinary sands, gravel, silts, and clays or mixtures of these is no problem. Penetration will be reduced in dense gravels and stiff clay. A few cobbles and boulders will not be a problem since penetration can still be achieved even if the nail is deflected into another portion of the soil. Nail locations can be adjusted around obstacles to install the correct number of nails. The launcher can easily be repositioned and a replacement nail installed for the nails blocked by subsurface objects.

A "best estimate" of subsurface conditions at the site is necessary to evaluate stability and conduct a preliminary design of nail spacing. The field data form shown in Figure 11(*a*) should be used to note the general soil, rock, vegetation, drainage, grade, and other physical

FIGURE 8 Failing road shoulder typical of those needing stabilization.

factors at the site. An estimate of the subsurface moisture condition at the time when slope movements occurred is essential in the overall evaluation of stability. Engineering geologists or geotechnical engineers should perform the field evaluation and design.

The site factor checklist shown in Figure 11(*b*) contains nail-spacing adjustments for local site conditions. The site factor evaluation is based on local conditions, the confidence in the site condition assessment (probability of sliding), and the consequence of continued slope movement. Generally the "high" site condition deserves a more critical design review (higher site factor of safety, f_s) than the "low" site condition. For high site conditions, it is recommended that a more in-depth site investigation, mathematical slope stability analysis, or both, be performed before a final repair alternative is selected. The site factor checklist is suggested for selecting an appropriate site factor of safety. An example of a completed field data form and site factor checklist is included in the design example discussed in this paper.

Since seepage pressures can have a major effect on the stability of the slope, it is best to install seepage control measures. Drilled horizontal drains and drainage trenches are commonly used to control groundwater and seepage pressures in slopes. Launched horizontal drains can also provide the needed drainage.

A high water table will affect the geometry of the slide, resulting in a larger slide and a lower apparent soil ϕ. Use of launched horizontal drains (Figure 12) and an appropriate apparent ϕ may counter the need to increase the number of nails to account for the

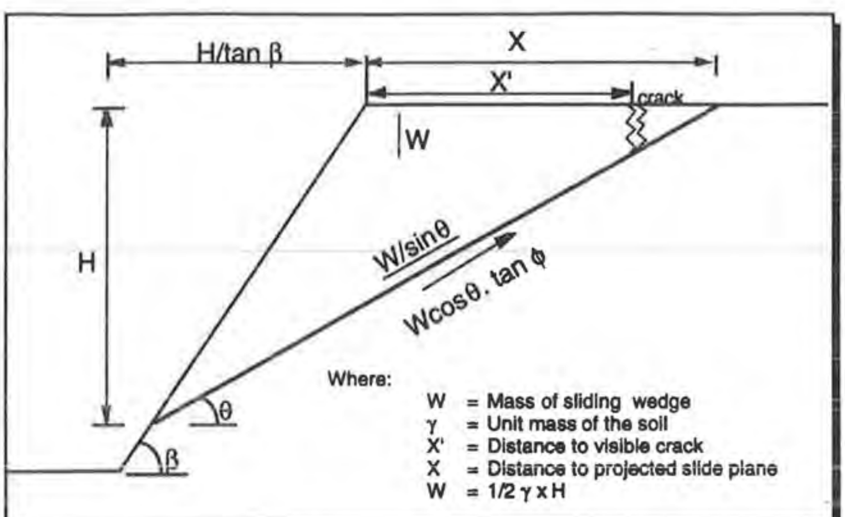


FIGURE 9 Simplified wedge forces.

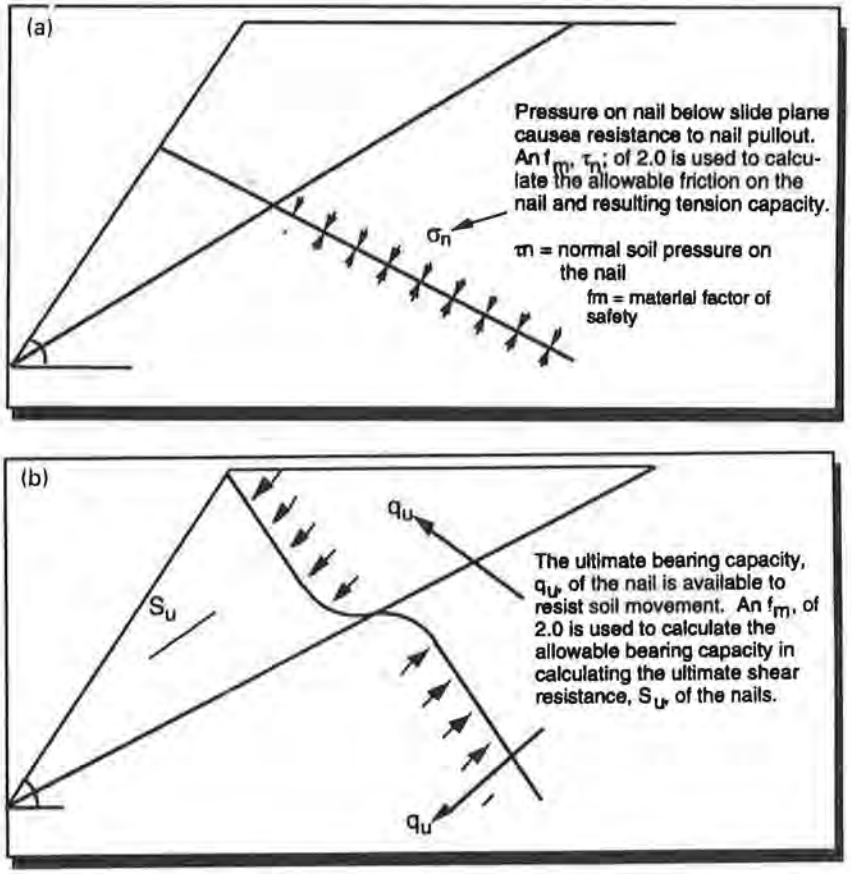


FIGURE 10 Tensile (a) and shear (b) resistance of nail.

groundwater table. This question will be answered as full-scale field installations are completed and monitored. Until then, it is recommended that either the number of nails be increased or the groundwater be controlled in areas with active seepage.

The number of nails, N, From Figure 1 can be adjusted to fit the condition. Although not mathematically exact, adjustments of $0.5N$ for low, $1.0N$ for medium, and $1.5N$ for high conditions will yield overall factors of safety ($f_m + f_n$) of about 1.1, 1.2, and 1.3, respectively. Figure 13(*a*) shows the preferred diagonal nail pattern.

Design Example

Figures 11(*a*) and 11(*b*) show the completed field data forms and site factor checklist for a typical road failure site on an older road in steep, mountainous terrain. The design of the launched soil nail stabilization for this site follows.

Design Information

$$x = 3 \text{ m } (9.9 \text{ ft}) \quad H = 5.5 \text{ m } (18 \text{ ft}) \quad \frac{x}{H} = 0.6 \qquad (1)$$

For $\theta = 32$ degrees, use $\phi = 30$ degrees; for $\beta = 42$ degrees, use $\beta = 45$ degrees.

Number of nails per 1 m (3.3 ft) along road shoulder, (from Figure 11): for Curve C, $N = 4$.

Site Factors

The steepness slope factor is contained in the design charts. Groundwater and seepage can be controlled by installing drainage. The other factors are not easily controlled after a road is constructed and must be accounted for during design of the repair. The low, medium, and high site evaluations are judgment calls at best.

(a)

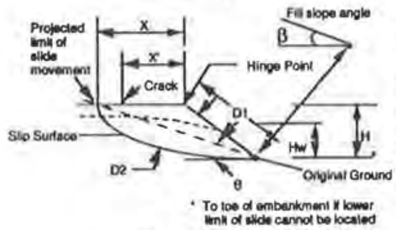
FIELD DATA FORM FOR LAUNCHED SOIL NAILS

Road Name *Example* Road No. *4671* Date *8/12/92*

Mile Post/Station *MP 3.8* Location T. *7S* R. *7E* Sec. ____

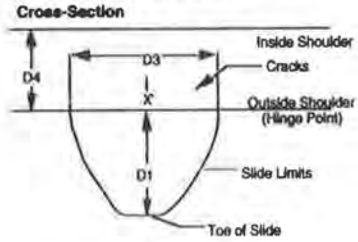
General Site Description: *Steep sidecast fill soil over colluvium (near 90% slope)*

Repair Priority *7* (1-10 High) Completed by: *S. Bear*



Cross-Section

	Dimensions (FT) or (m)	
X	*10 ft*	*3m*
x'	*5 ft*	*1.5 m*
D1	*33 ft*	*10 m*
D2	*5 ft*	*1.5 m*
D3	*40 ft*	*12.2 m*
D4	*20 ft*	*6.1 m*
H*	*18 ft*	*5.5 m*
Hw	*8 ft*	*2.4 m*
β	*42°*	
φ	*32°*	



Plan

(b)

SITE FACTOR CHECK LIST FOR LAUNCHED SOIL NAILS

SITE FACTORS	EVALUATION						
	Low		Medium		High		Remarks
Steepness of Slope (Slope Ratio)	2:1		1.5:1		1:1	X	
Depth to Failure Surface, D3	<5'	X	5'-10'		10'-15'		
Soil Moisture at Time of Slide	Moist		Wet	X	Seep		
Decayed Logs or Slash Within Fill	None		Some		Many	X	
Soil Type	Sand		Silt	X	Clay		
Consequence of Add'l Failure(s)	Low	X	Med		High		
Potential for Accident or Injury	Low	X	Med		High		

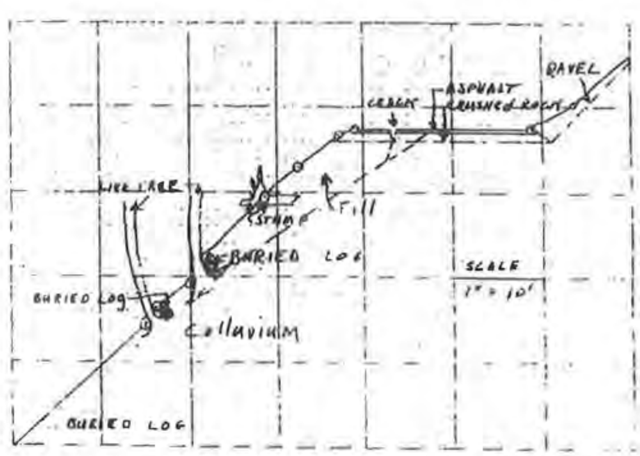


FIGURE 11 Design example field forms: (a) field data form, and (b) site factor checklist.

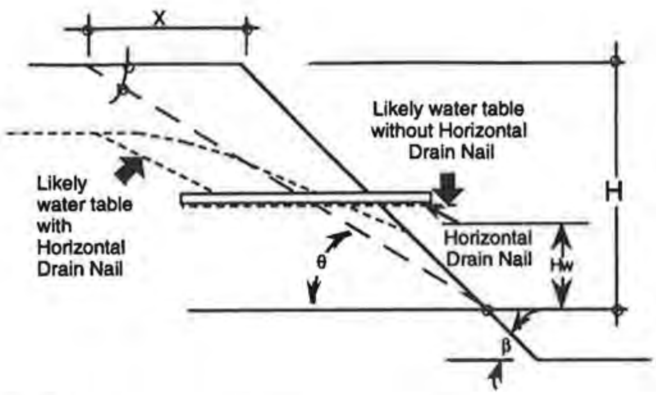


FIGURE 12 Water table consideration.

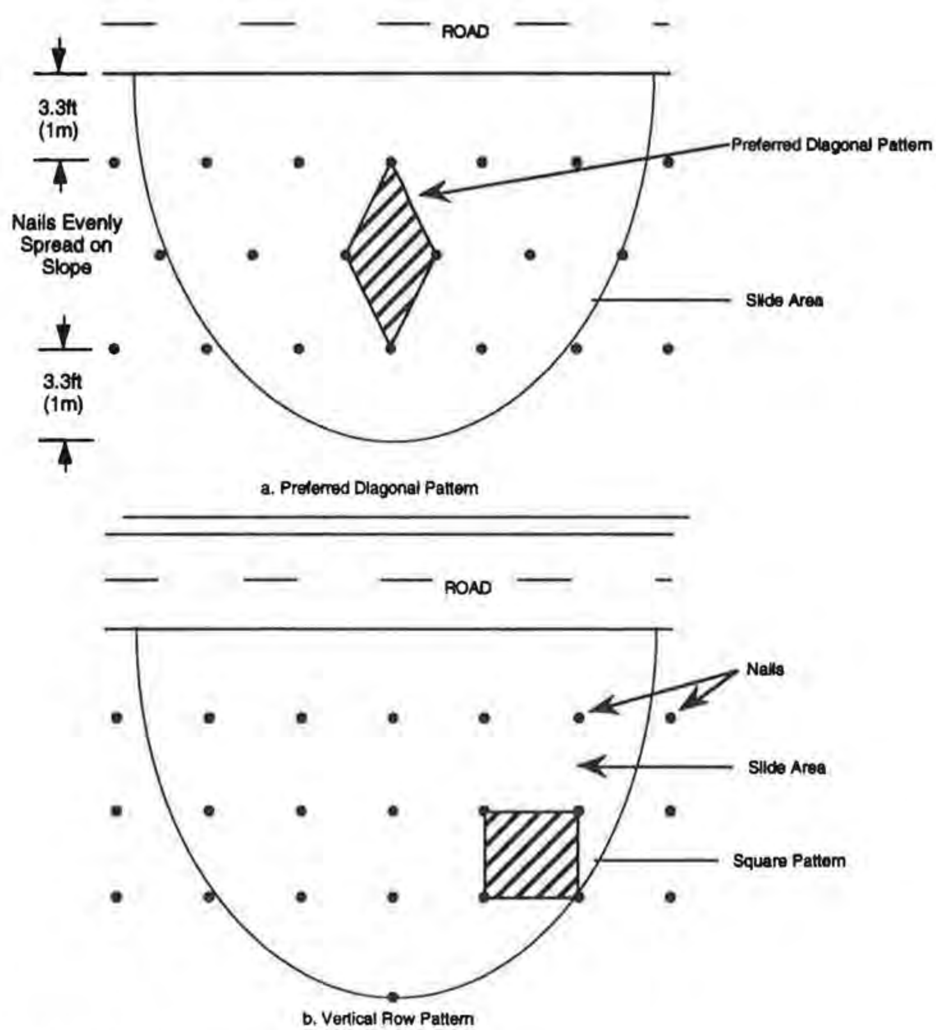


FIGURE 13 Nail pattern.

For this example, the evaluation is tending toward medium:

$$\text{medium} = 1.0N \text{ or } (1.0)\ 4 = 4 \text{ nails per meter (3.3 ft) of road} \quad (2)$$

Slope Area per Nail

$$\frac{1\text{ m }(D1)}{N} = \frac{1\text{ m }(10\text{ m})}{4\text{ nails}} = 2.5\text{ m}^2/\text{nail }(27\text{ ft}^2/\text{nail}) \quad (3)$$

Nail Spacing on Slope

$$\sqrt{2.5} = 1.6\text{ m }(5.2\text{ ft}) \quad (4)$$

Total Number of Nails

Assuming that the unstable area is within the limits on the sketch and is rectangular with two rows of nails outside the defined site area, the area to be nailed is as follows:

$$(D3 + 3.2)(D1) = (12.2 + 3.2)(10) = 154\text{ m}^2\ (1{,}656\text{ ft}^2)\ \frac{\text{Area}}{\text{Area/nail}} = \frac{154}{2.5} = 62\text{ nails} \quad (5)$$

Final selection of the number of nails and the nail spacing will depend on the following considerations:

1. The risk and consequence of failure assessed in terms of loss of life, property damage, environmental damage, and traffic disruption (low, medium, or high from Figure 11);
2. The existing stability of the slope and its ability to support the weight of the launcher and excavator (approximately 19 500 kg or 43,000 lb);
3. The sequence of nail installation to enhance the stability of the working area;
4. The maximum depth to the slip surface, perpendicular to the slope surface, not exceeding 4.5 m (15 ft) or 6-m (20-ft) nails;
5. The site factor of safety, f_n, applied relating to the level of confidence in and certainty that the factors will influence the slope's stability;
6. Evaluation of the influence of the groundwater and surface water in the worst-case seasonal condition; and
7. The durability of the nail. Factors that may accelerate corrosion must be appraised. High or low groundwater levels, pH conditions, and the presence of external contaminates such as road salt, organic debris, and leached wastes should be examined. Galvanized steel nails are expected to last as long as galvanized steel culverts under similar conditions.

Cost Estimating and Logistics

The design charts can be used in conjunction with the field data form to estimate the number of nails required. After setup on the site, the launcher is capable of installing 15 nails/hr. A cost range of \$80 to \$135/nail is appropriate for an initial cost estimate for the launched soil nail repair alternative, including mobilization.

Since the excavator normally works from the roadway, minimal site work is usually required for equipment access. On two-lane roads, traffic can usually proceed using traffic control, with full traffic stoppage only during actual launching. Single-lane roads may require longer delays in traffic. The excavator can be moved out of the way for traffic passage after several launches.

The support equipment needed for the soil nail launcher is minimal. The launcher can be moved to a site and set up, launch nails, and move off the site in one day. The launcher can be removed from the excavator's mounting within 30 min. A heavy-duty flatbed trailer or truck is needed to transport the launcher (750 kg or 1,652 lb), rods (54 kg each or 119 lb), and miscellaneous supplies.

Other Potential Applications

Launched soil nailing has many potential applications:

1. Horizontal Drains: Landslides are frequently associated with groundwater and groundwater seeps. Drilled horizontal drains have proven to be effective in reducing or controlling the effect of this groundwater. Launched perforated pipes up to 6 m (20 ft) long have been used to drain local areas.
2. Vertical Gas Vents: Vertical perforated plastic and metal pipes have been used to vent methane gas from landfills. This application has proved fast and safe for the installers.
3. Strengthened Walls: Soil nailing may be used for rapidly adding reinforcement to the materials behind retaining walls to replace deteriorating tiebacks, support increased external loading, support excavation at the toe, and compensate for aging components.
4. Ground Anchors and Tiebacks: With a typical pull-out resistance of 9 to 13.5 kN (2,000 to 3,000 lb), direct pull anchor uses may be limited.

5. Facings and Mesh Holdings: Soil nails may be used to support mesh on rocky slopes and erosion control materials on raveling slopes and fills.

6. Temporary Excavation Support: This method may be used to hold an excavated face until a permanent wall is constructed or while work is completed in the area and backfilled.

7. Widened Roads: The method may also be used to steepen a cut slope or build a small permanent wall at the toe of a cut slope instead of widening the fill, building a retaining structure, or moving into the cut slope.

8. Cut Slope Stabilization: The method may aid in the reinforcement and stabilization of cut slopes.

9. Vertical Drains: Finally, the method can aid in dewatering or consolidating loose materials such as dredge spoils and wet areas under roadways and bridge approaches.

Summary

Launched soil nails have been used to stabilize road- and railroad-related landslides in Europe and the United Kingdom since 1989. The technology was successfully demonstrated in the western United States in 1992.

Design charts for selecting the number of nails required to stabilize small landslides for road shoulders and embankments have been developed using the simplified wedge analysis method. The chart method of design is appropriate for low-volume roads where the cost of geotechnical drilling is generally not warranted. Other methods of design will certainly develop as case history projects are designed and constructed.

The launcher can be used without disturbing established vegetation. With the emphasis now placed on the environment, this method requires little or no vegetation or visual mitigation.

Launched soil nails appear to be an effective, rapid, and practical method for stabilizing small road shoulder landslides. Full-scale design and construction projects are needed to verify the design method proposed in this paper and generate commercial interest in the technology.

References

1. *Application Guide for Launched Soil Nails.* USDA Forest Service, Washington, D.C., July 1994.
2. *Project Report for Launched Soil Nails—1992 Demonstration Project.* USDA Forest Service, Washington, D.C., July 1994.