United States
Department of
Agriculture

Forest Service

Engineering Staff

EM 7170-12B

United States
Department of
Transportation

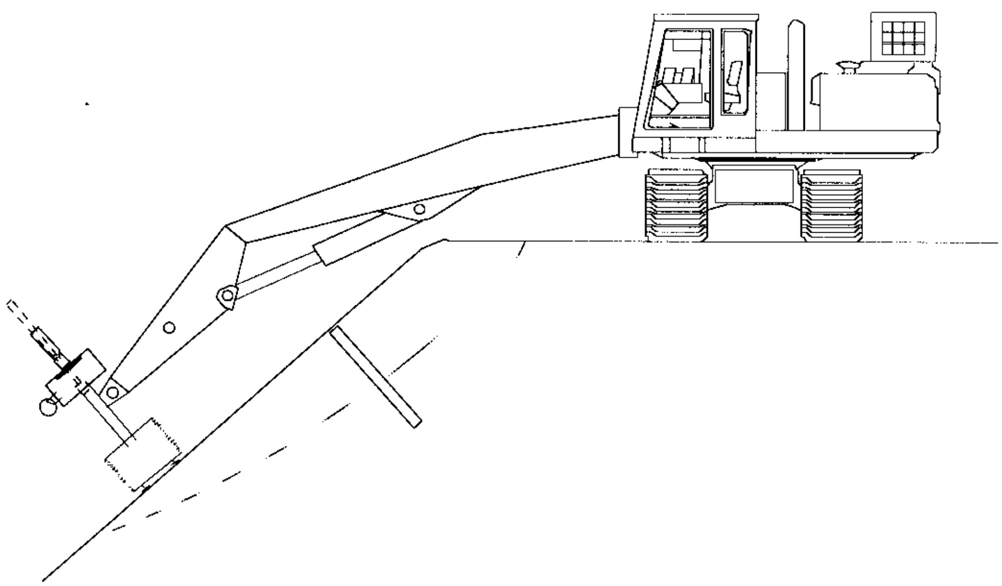
Federal Highway
Administration

FHWA-FPL-93-004

July 1994

Project Report for Launched Soil Nails—1992 Demonstration Project

Volume 2



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Metric Conversion

This publication uses soft metrics: English units followed by Systems International (SI) units in parentheses. Appendix A uses hard metrics: SI units only. The table below will aid in converting from one system to the other:

METRIC CONVERSION FACTORS

When You Know	Multiply By	To Find
	Length	
inches (in)	25.4	millimeters (mm)
feet (ft)	0.305	meters (m)
yards (yd)	0.914	meters (m)
miles (mi)	1.61	kilometers (km)
	Area	
square inches (in^2)	645.1	millimeters squared (mm^2)
square feet (ft^2)	0.093	meters squared (m^2)
square yards (yd^2)	0.836	meters squared (m^2)
acres	0.405	hectares (ha)
square miles (mi^2)	2.59	kilometers squared (km^2)
	Volume	
fluid ounces (fl oz)	29.57	milliliters (ml)
gallons (gal)	3.785	liters (L)
cubic feet (ft^3)	0.028	meters cubed (m^3)
cubic yards (yd^3)	0.765	meters cubed (m^3)
	Mass	
ounces (oz)	28.35	grams (g)
pounds (lb)	0.454	kilograms (kg)
short ton (2,000 lb) (T)	0.907	megagrams (mg)

Force and Pressure or Stress

poundforce (lbf)	4.45	newtons (N)
poundforce per sq inch (psi)	6.89	kilopascals (kPa)

Other

kips (1,000 lbf) per sq inch	6.89	N/mm^2
pounds force per cubic foot (pcf)	0.159	kilonewtons per meter squared kN/m^2

Foreword

This report is the result of negotiations that started in January 1989 between employees of the USDA Forest Service and the co-inventor of the soil nailing technology, Bernard Myles of Soil Nailing Limited in the United Kingdom. Forest Service employees in the Pacific Northwest Region (Oregon and Washington) determined that a significant portion of maintenance funds for paved roads was being used for shoulder repairs necessitated by slipping and cracking roadfills on steep side slopes. An informal request to explore alternate methods to permanently stabilize these slopes was made to the Regional Office in Portland, Oregon.

An informal field and office review in the fall of 1988 indicated that the soil could be reinforced to stop the slope movement. Discussions further indicated that drilling equipment used to install conventional soil nails was inappropriate and too costly for repair of small road shoulder failures. The need for a device that could sit on the road surface and reach over the side of the road to install the reinforcement elements was discussed.

Discussions with Bernard Myles at the annual Transportation Research Board (TRB) Meeting in January 1989 revealed that testing was in progress for the soil nail launcher. By January 1992, the technology had been used on several projects in the United Kingdom and Western Europe, indicating that it was ready for demonstration in the United States. Additional discussions resulted in a four-state cooperative demonstration effort supported by the Federal Highway Administration (FHWA), Coordinated Technology Implementation Program (CTIP), Washington Department of Transportation, Colorado Department of Transportation, Soil Nailing Limited, and the USDA Forest Service.

The cooperators used this demonstration as an opportunity to evaluate a promising technology for rapidly and economically reinforcing shallow road shoulder slippage so common for roads constructed on steep terrain. Cooperation in this project and the mention of commercial products and names is not an endorsement of these products or processes by the cooperators. This report shares the information learned in the demonstration project.

Information on the project can be obtained from:

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Project Report for Launched Soil Nails— 1992 Demonstration Project

Introduction

In July and August of 1992, the USDA Forest Service and Soil Nailing Limited sponsored a launched soil nail demonstration project. Financial assistance was provided by the Federal Highway Administration Coordinated Technology Implementation Program (CTIP). 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. Technical assistance was provided by the Washington and Colorado Departments of Transportation, and seven National forests that participated in the demonstration project.

The project demonstrated the use of launched soil nails for repair and reinforcement of unstable cut bank and embankment slopes. The demonstrations were an opportunity for engineers, maintenance personnel, and contractors to view and explore the potential for using launched soil nails.

A video, this documentation report and the *Application Guide for Launched Soil Nails* and are results of the demonstration project. Site experiences and participant questionnaire results are covered in this report. Guidance for determining the applicability of launched soil nails and nail spacing design are contained in the *Application Guide for Launched Soil Nails.*

The *Application Guide for Launched Soil Nails* is a stand-alone working document for designers and field personnel. The *Project Report for Launched Soil Nails* supports the application guide with additional information for recommendations contained in the application guide.

Goals of the Demonstration

The primary goals of the demonstration project were to:

(1) Demonstrate soil nail launching.
(2) Evaluate the potential use of launched soil nails.
(3) Encourage contractors to provide soil nail launching services.
(4) Develop an application guide and video about launched soil nails.

Stabilizing landslides was a secondary objective due to the lack of an accepted design method when the demonstration was planned and the lack of time and resources. Typically, a nail spacing of 3 to 4 feet (0.9 to 1.2 m) was used on most sites. This spacing was based on experience in Europe where there were detailed analyses for some road and railroad slope repairs.

The Demonstration Process

People made the demonstration project a success. Soil Nailing Limited provided the excavator, launcher, 20 nails per demonstration site (shipped from the United Kingdom), technical support, and local training. The FHWA funded the video, application guide, project report, project facilitation, and some of the transportation costs within the United States. Mauricio Ribera, Assistant Forest Engineer on the Siuslaw National Forest headquartered in Corvallis, OR invested 6 weeks of his time to facilitate the demonstrations and coordinate movement of equipment and personnel between demonstration sites.

A tentative agreement was reached in January 1992 for Soil Nailing Limited to import equipment and personnel into the country to demonstrate this new technology on roads in the western United States. Demonstration sites were identified by networking between Forest Service, Federal Agency, and State departments of transportation personnel. Units having a large workload for repairing road related slope movements and a demonstrated creativity in repairing failed areas were approached for participation in the project. These local sponsors provided the sites, local meeting facilities, support personnel, equipment and personnel for the demonstration, and equipment transport between local sites (generally within a Forest Service Region). Three Forest Service Regions (Pacific Northwest, Pacific Southwest, and Rocky Mountain), six National forests (NF's) (Mt. Hood NF, Siuslaw NF, Siskiyou NF, Klamath NF, Stanislaus NF, and San Juan NF) and the Washington and Colorado State departments of transportation provided demonstration sites and direct project support.

Each demonstration included classroom presentations and field demonstrations. The classroom demonstration included the history of the development of launched soil nail technology and an overview of previous projects in the United Kingdom and Europe by Bernard Myles of Soil Nailing Limited, followed by a description of the local site by the sponsor. Field demonstrations included close-up inspections of the launch equipment, nails, and collets; firing demonstrations; further discussions and questionnaire responses; and interviews for the project video.

Demonstration Sites

Selection

Sites were selected to:

- Show the range of potential uses for launched soil nails.
- Expose the technology to a wide geographic area.
- Expose the technology to potential users (Federal, State, and local government personnel and engineering consultants) and potential providers (contractors) of launched soil nails.

- Take advantage of local needs, interests, and support capabilities.
- Keep within the time and financial resources allocated to the project.

Sites with failures less than 15 feet (4.5 m) deep and within 30 feet (9 m) of the road edge were preferred. One project in Colorado, where movement extended to the toe of the slope about 60 feet below the road surface, caused considerable discussion about the effect of nailing only the top one-third of a slide mass. This discussion resulted in limiting the application guide to situations where the nails can be installed throughout the sliding mass.

Site Summaries

Eight sites in four States and three Forest Service Regions were included in the demonstration, as listed in figure 1 and shown in figure 2. The numbers on the sites indicate the sequence of the demonstrations (site 1, then 2, 3, etc.).

Project photos 1 through 23 in appendix A show the soil nail launching equipment and site conditions. Appendix B contains a listing of project and demonstration site contacts for those readers wanting more site information.

Site 1—Siuslaw National Forest, Waldport, OR
retaining wall

Site 2—Siskiyou National Forest, Gold Beach, OR
fill slope stabilization

Site 3—Klamath National Forest, Yreka, CA
cut slope stabilization

Site 4—Stanislaus National Forest, Sonora, CA
fill slope stabilization

Site 5—State Highway 133, Paonia, CO
fill slope stabilization

Site 6—San Juan National Forest, Dolores, CO
fill slope stabilization

Site 7—Washington DOT, Olympia, WA
sand pile test

Site 8—Mt. Hood National Forest, Ripple Brook, OR
fill slope stabilization

Figure 1.

Figure 2.–Demonstration Site Location Map.

Site 1	Siuslaw National Forest Tidewater Road (Road No. 52) Waldport, Oregon
Site Type	Retaining Wall

Site Description

The site was a driven sheet pile retaining wall on the outside shoulder of a single-lane, paved forest access road. The wall was about 15 feet high (exposed height) with driven H-piles on about 8-foot centers. Cable tiebacks, which were installed on the H-piles when the wall was constructed about 20 years ago, have failed due to corrosion. The road haul weight capacity has been reduced as a result of the corroded cable tiebacks.

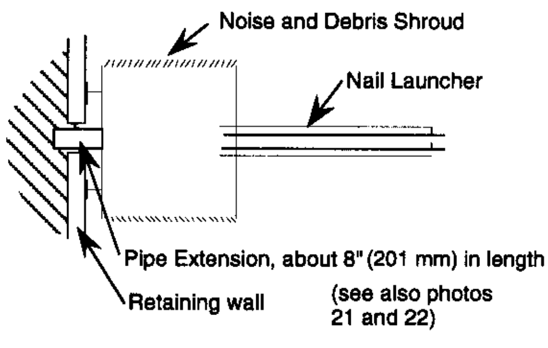
Demonstration Description

Nails were installed in the ditchline, fill slope, and through the retaining wall face. The nails in the ditchline and fill slope demonstrated the machine's versatility and ability to install nails at various angles from the horizontal. The nails in the retaining wall showed the ability to precisely locate and install the nails (photos 20–23).

Results

The first nail was launched through the retaining wall at about 2000 psi (13.8 Pa) launch pressure, penetrating about 16 feet (4.9 m) and leaving about 2 feet (0.6 m) exposed outside the wall. The second nail launched at the same pressure penetrated over 18 feet (5.5 m), completely disappearing inside the wall. Several more nails launched at successively lower pressures completely disappeared inside the wall. Finally, a nail launched at about 600 psi (4.1 MPa) resulted in a 16-foot (4.9 m) penetration. The retaining wall backfill appeared to be of low density. This demonstration illustrated:

- The ability to precisely install nails through holes in a retaining wall. A pipe extension (nail guide) attached to the bottom of the launcher helped guide the nail into the hole in the wall:



- The desirability of using a method of arresting penetration of the nail to prevent complete penetration and loss of the nail in the wall.

- The ability of the launcher to install nails at many angles, from horizontal in the retaining wall to vertical in the ditchline.

- Nail pullout tests using a rock bolt testing jack reading to the nearest 2000 pounds:

Number	Nail Location	Load (tons)	Nail L (ft)	Installation Presure (psi)
1	cutbank	19 (169.1 KN)	13 (4 m)	2500 (17.2 MPa)
2	cutbank	22 (195.8 KN)	13 (4 m)	2500 (17.2 MPa)
3	retaining wall	2 (17.8 KN)	18 (5.5 m)	600 (4.1 MPa)
4	retaining wall	3.5 (31.1 KN)	18 (5.5 m)	600 (4.1 MPa)
5	fill	0	18 (5.5 m)	2500 (17.1 MPa)

Site 2

Siskiyou National Forest
Bear Camp Road (Road No. 23)
Gold Beach, Oregon

Site Type

Fill Slope Stabiliztion

Site Description

This site was selected because it was representative of failures that are occurring along Forest Service roads that were built 20 to 30 years ago by using sidecast methods of construction.

This is a fill slope failure of sidecast, weathered mudstone located approximately 4 miles (6.4 km) above the intersection of paved roads 33 and 23 on road 23. The problem has been a re-occurring one that has been repaired with sealing and patching. The failure has progressed into the road 4 to 5 feet (1.2 to 1.5 m) from the outside top edge of the fill, resulting in a 1/2- to 1-1/2 inch (13 to 38 mm) vertical and horizontal displacement in the pavement and a 1-inch (25 mm) open crack. It extends approximately 35 feet (10.7 m) below the road and is 150 feet (45.8 m) long (see attached sketches). It is assumed that the failure is about 10 feet (3 m) deep at the center.

Demonstration Description

The plan was to nail one-third to one-half of the affected area and see if there was any recognizable difference in movements between the nailed and unnailed sections over the next few years. The nails were spaced approximately 5 feet (1.5 m) apart in a diamond pattern of three rows. Approximately 16 nails were installed, with the first row about 5 to 6 feet (1.5 to 1.8 m) below the road. This involved about 35 feet (10.7 m) of the 150-foot (45.8 m) movement (site 2, sketches 1–5).

Results

To monitor the movement, four sets of reference nails were installed to check lateral movement across the crack. Two sets of nails were installed immediately above the nailed section and two sets of nails above the unnailed area. Between the time they were installed on November 5, 1992 until June 15, 1993, *no measurable lateral movements were recorded at any of the reference sections.* However, comparing the initial photographs with the current visual observations, *there has been between 1/2 to 1 inch (13 to 25 mm) of settlement in the area that was not nailed and little or none in the area that was nailed.*

The monitoring system was practical and not very complicated or technical. Visual observations indicate that some stability has been achieved in the section that was nailed, and that the system can be applied to problems on Forest Service road systems.

The design charts in the applications guide were not available at the time of this installation. The 5-foot spacing of nails in three rows for a total of 16 nails was based on discussion with the nail launcher representative and experience in Europe and the United Kingdom. The table below compares the design charts in the application guide to the actual installation.

Design chart solution:

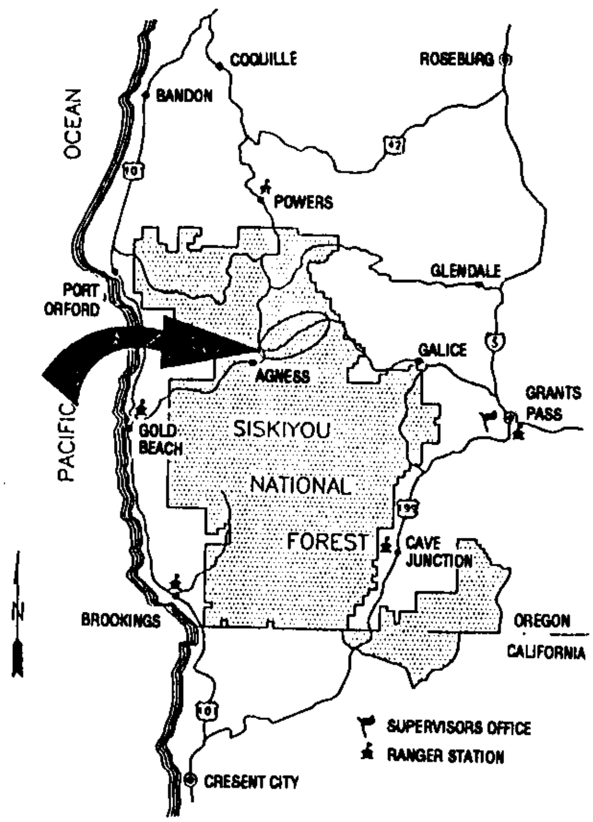
Trial	x, ft	H, ft	φ, degrees	β, degrees	N nail/3.28 ft	Total Nails
A	8 (2.4 m)	20 (6.1 m)	35°	45°	1.5	23
B	8 (2.4 m)	20 (6.1 m)	30°	45°	5.0	76
C	12 (3.7 m)	20 (6.1 m)	30°	45°	4.5	69
D	4 (1.2 m)	20 (6.1 m)	25°	33°	1.3	20
Installed	5+ (1.5 m)	20 (6.1 m)	30°+	40°	1.0	16

Design chart values for trials A and D correspond most closely to the actual installation.

Nail pullout tests using a rock bolt testing jack reading to the nearest 2000 pounds (8.9 KN) gave the following results:

Number	Nail Location	Load (tons)	Nail L (ft)	Installation Presure (psi)
1	top row	13 (115.7)	13 (4 m)	2500 (17.2 MPa)
2	middle row	10 (39 KN)	13 (4 m)	2500 (17.2 MPa)
3	bottom row	5 (4.4 KN)	13 (4 m)	2500 (17.2 MPa)
4	middle	6 (53.4 KN)	13 (4 m)	2500 (17.2 MPa)
5	cutank	0 (0)	13 (4 m)	2500 (17.2 MPa)
6	cutbank	12 (106.8 KN)	13 (4 m)	2500 (17.2 MPa)

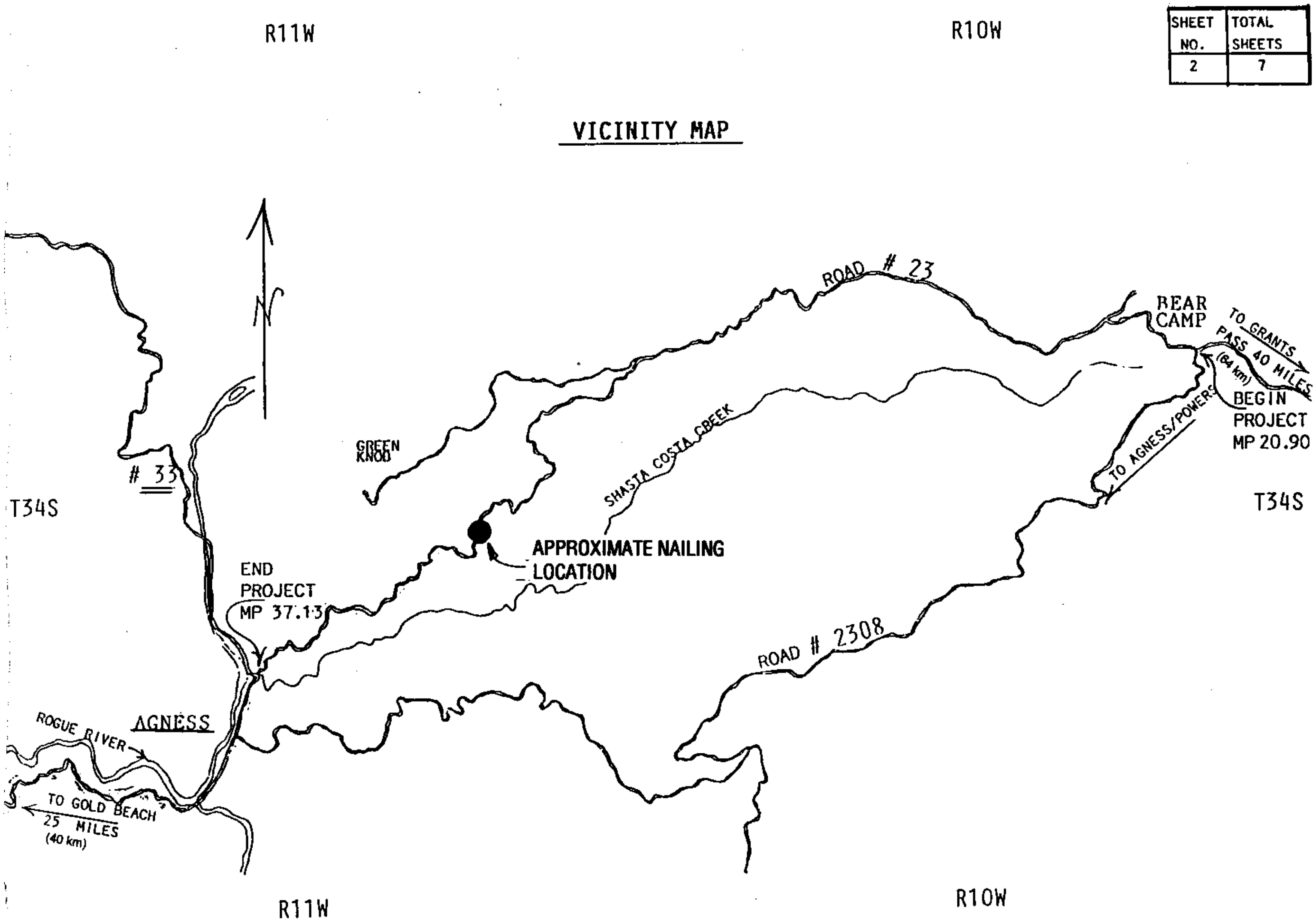
UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE – REGION SIX
SISKIYOU NATIONAL FOREST
GOLD BEACH RANGER DISTRICT
CURRY/JOSEPHINE COUNTY
OREGON, USA



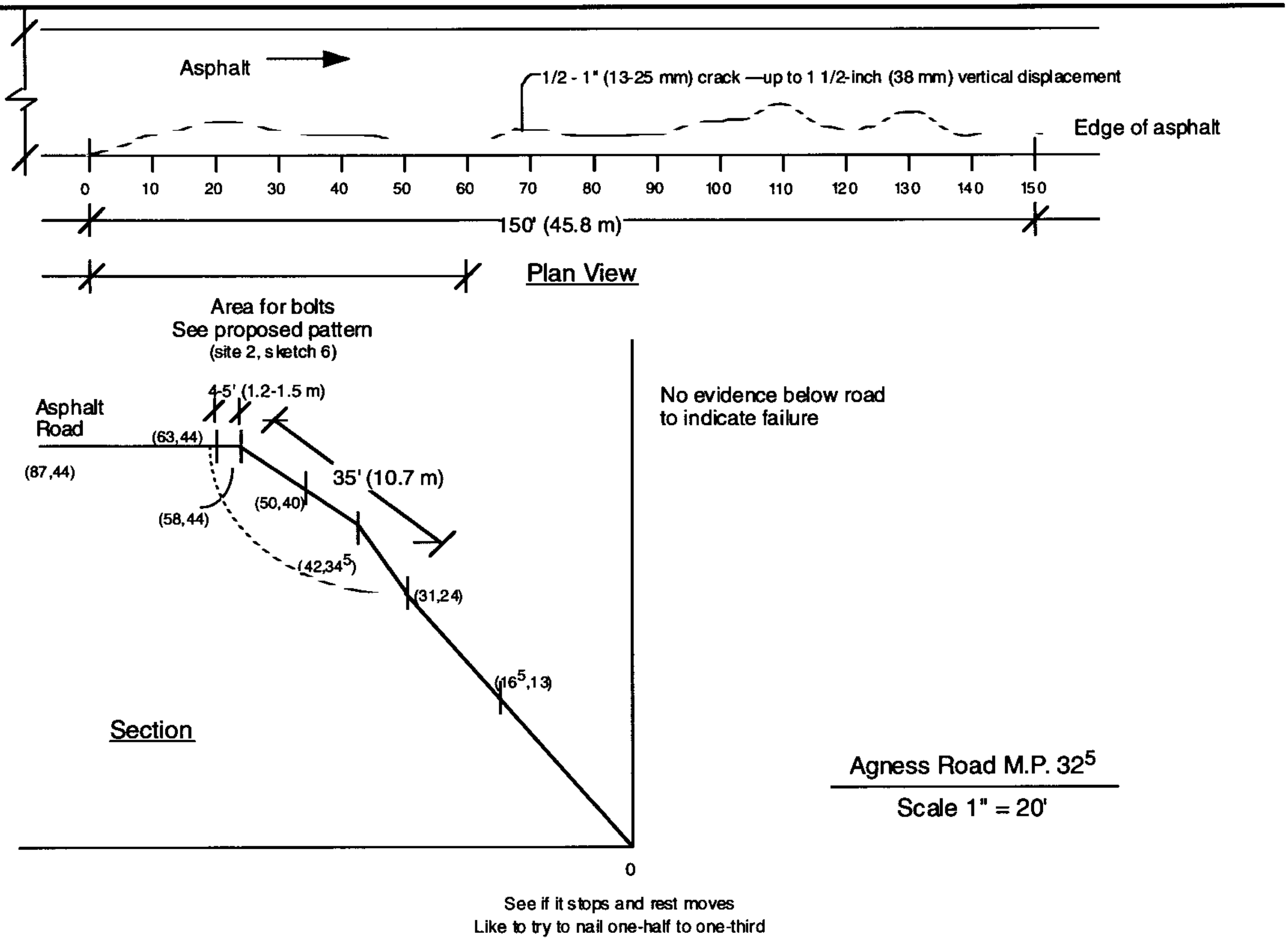
AREA LOCATION MAP
NO SCALE

Site 2, Sketch 1

SHEET NO.	TOTAL SHEETS
2	7



Site 2, Sketch 2



Site 2, Sketch 3

SOIL NAIL LAUNCHING FIELD DATA FOR DESIGN ESTIMATES

Road Name BEAR CAMP Road No. 23 Date 7/23/92

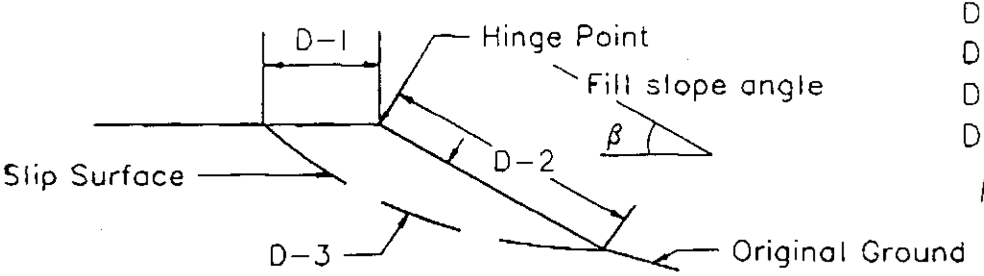
Mile Post / Station 32.5 Location T. 34S R. 11W Sec. 34

General Site Description: sidecast material is weathered mudstone over mudstone Bedrock.

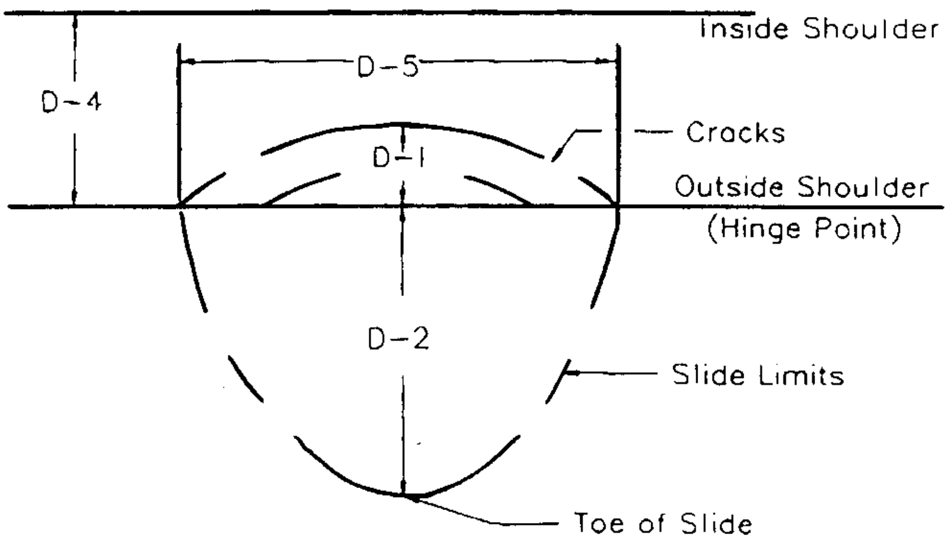
Repair Priority (1–10) 8
(10 High)

Compleated By: R. VANDYKE

Dimensions(FT)	
D–1	5
D–2	35
D–3	7
D–4	26
D–5	150
β	40



Cross–Section



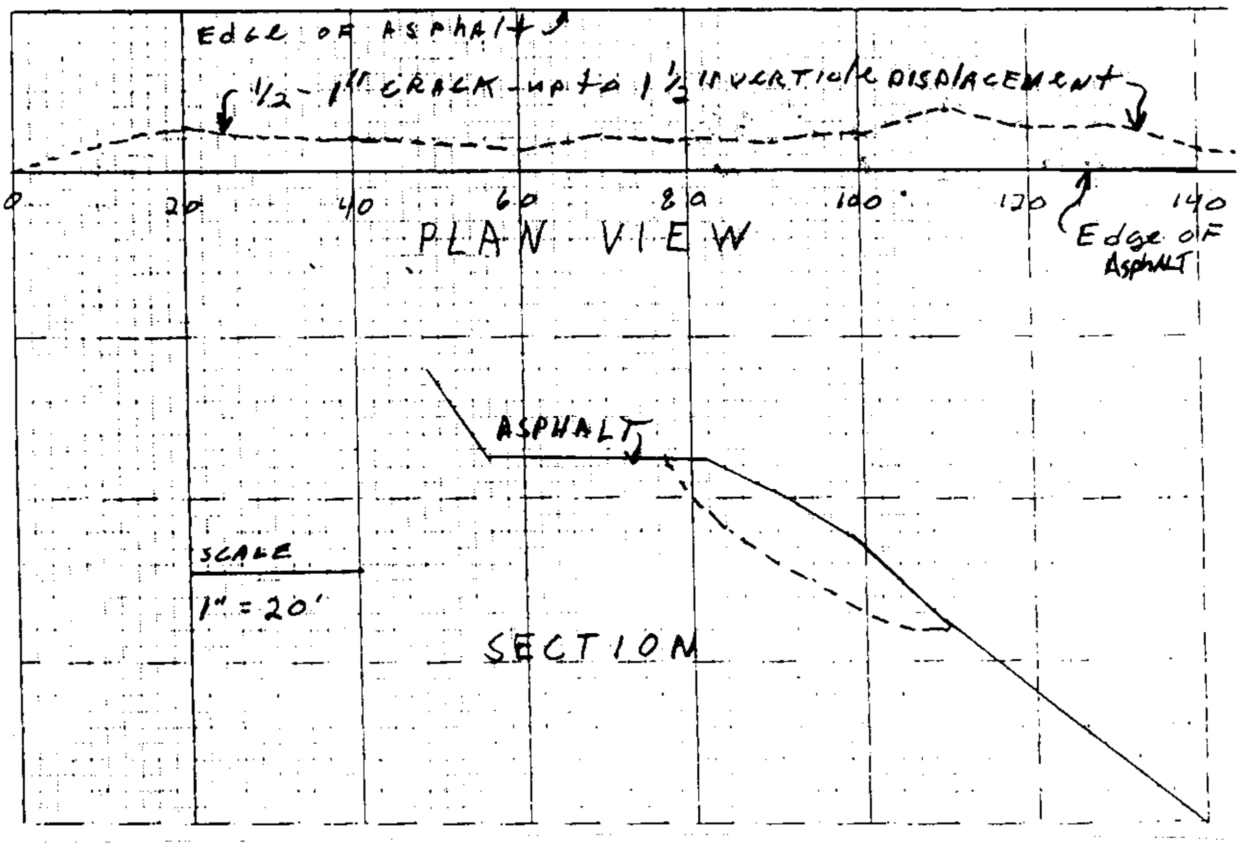
Plan

Site 2, Sketch 4

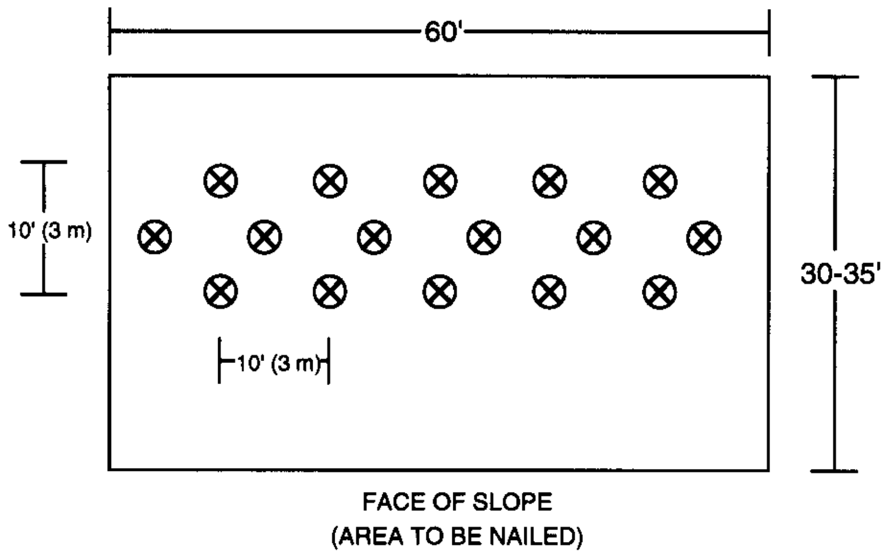
DESIGN CRITERIA CHECK LIST AND CONFIDENCE LEVEL

DESIGN CRITERIA	DESIGN CONFIDENCE LEVELS						
	High 0.2		Med 0.4		Low 0.6		Remarks
Steepness of Slope (Slope Ratio)	2:1		1.5:1		1:1	X	
Depth to Failure Surface, 0-3	< 5'		5'-10'	X	10'-15'		
Soil Moisture at Time of Slide	Moist		Wet	X	Seep		
Decayed Logs or Slash Within Fill	None		Some	X	Many		
Soil Type	Sand		Silt	X	Clay		
Consequence of Add'l Failure(s)	Low		Med		High	X	
Potential for Accident or Injury	Low		Med	X	High		

SITE SPECIFIC PLAN AND (OR) CROSS-SECTION



Site 2, Sketch 5



Site 2, Sketch 6.–Nailing Pattern.

Site 3

Klamath National Forest
Yreka, California

Site Type

Cut Slope Stabilization

Site Description

The Klamath demonstration site (photo 18) was a shallow rotational-translational cut slope failure. This site was picked because there were no small fill slope failures close enough to the supervisor's office morning meeting site to make it a 1-day, morning meeting–afternoon field trip. It appeared suitable since most of the other demonstration sites were fill slope stabilization projects. This showed the machine's use for various situations.

Demonstration Description

The material in the cut slope failure was a heterogeneous mixture of sandy-silt (SM) and weathered fractured rock with boulders up to 2 feet (0.6 m) in diameter. The depth to the slide plane appeared to be less than 10 feet (3 m). After driving a few nails to refusal at around 10 to 12 feet (3 to 3.6 m), it was postulated that competent bedrock was just below the slide plane in many places. Approximately 10 nails were installed in the lower one-third of the failed slope.

Results

There was normal to above normal precipitation at the site during the winter of 1992–93 with no further movement of the slide. The local Forest Service representative, Ed Rose, indicated this site is not the best one for which the soil nailer could be used to its maximum potential. However, he believes that there are many existing potential sites on the Klamath National Forest, where the soil nailer could be put to its best use.

DESIGN CRITERIA CHECKLIST AND RISK LEVELS FOR LAUNCHED SOIL NAILS

SITE FACTORS	EVALUATION**						
	Low		Med		High		Remarks
Steepness of Slope (Slope Ratio)[1]	2:1		1.5:1		1:1	✓	
Depth to Failure Surface, D1[1]	<5'		5'-10'		10'-15'		DRY
Soil Moisture at time of slide[1]	Moist		Wet		Seep		
Decayed Logs or Slash Within Fill[1]	None	✓	Some		Many		
Soil Type*[1]	Sand	✓	Silt	✓	Clay		SM**
Consequence of Add'l Failure(s)[2]	Low		Med	✓	High		
Potential for Accident or Injury[2]	Low		Med	✓	High		

* Unified or AASHTO Classification.
** Design charts were developed for Medium Site Condition (Site Factor of Safety, $f_n = 1.1$).
1 Relates to the probability of failure.
2 Relates to the consequence of failure.

SITE SPECIFIC PLAN AND (OR) CROSS-SECTION

Site 3, Sketch 1

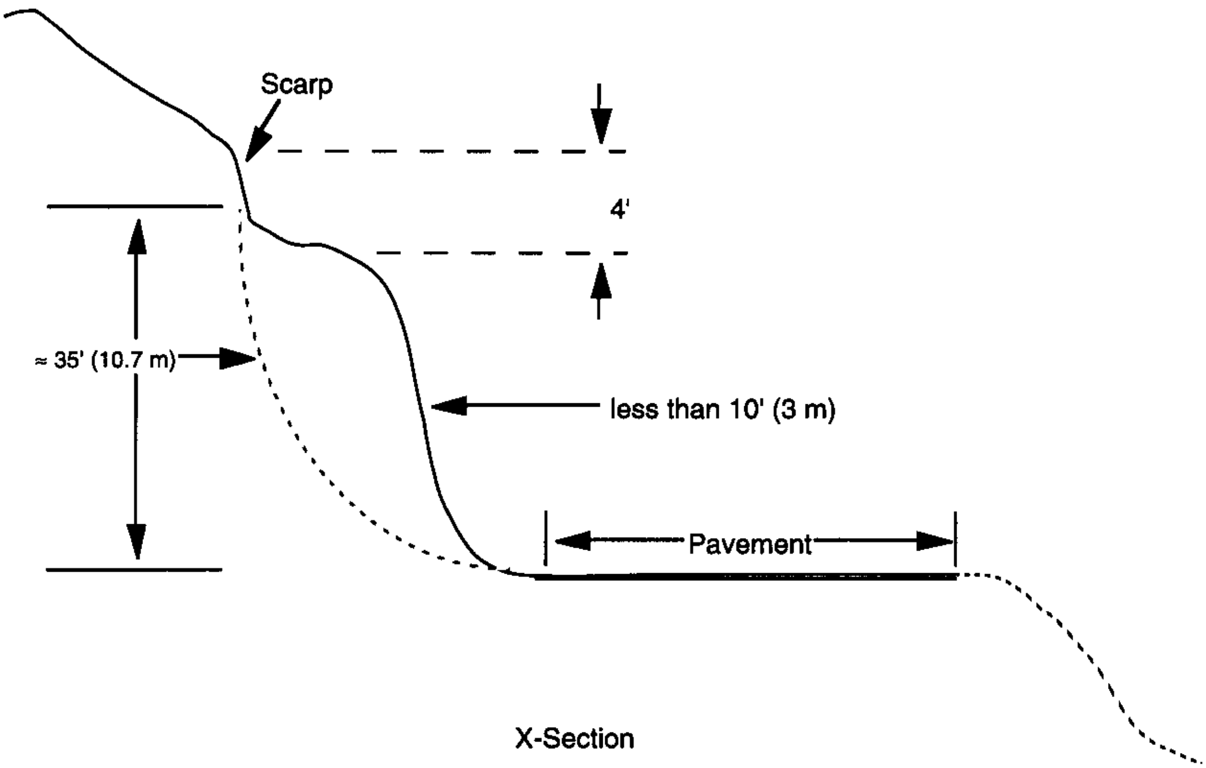
Klamath N.F. Soil Nailing Demo Site

Rotational-Translational Cut-Slope Failure

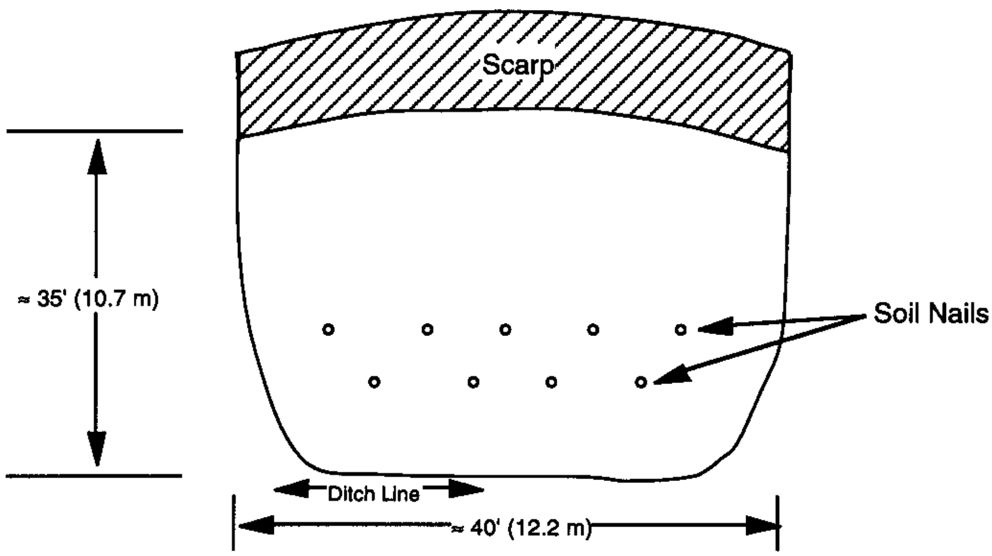
RF 48N01 M.P. 3.7 Oak Knoll Ranger District

Ed Rose
6/25/93

No scale



X-Section



— PLAN VIEW —

Site 3, Sketch 2

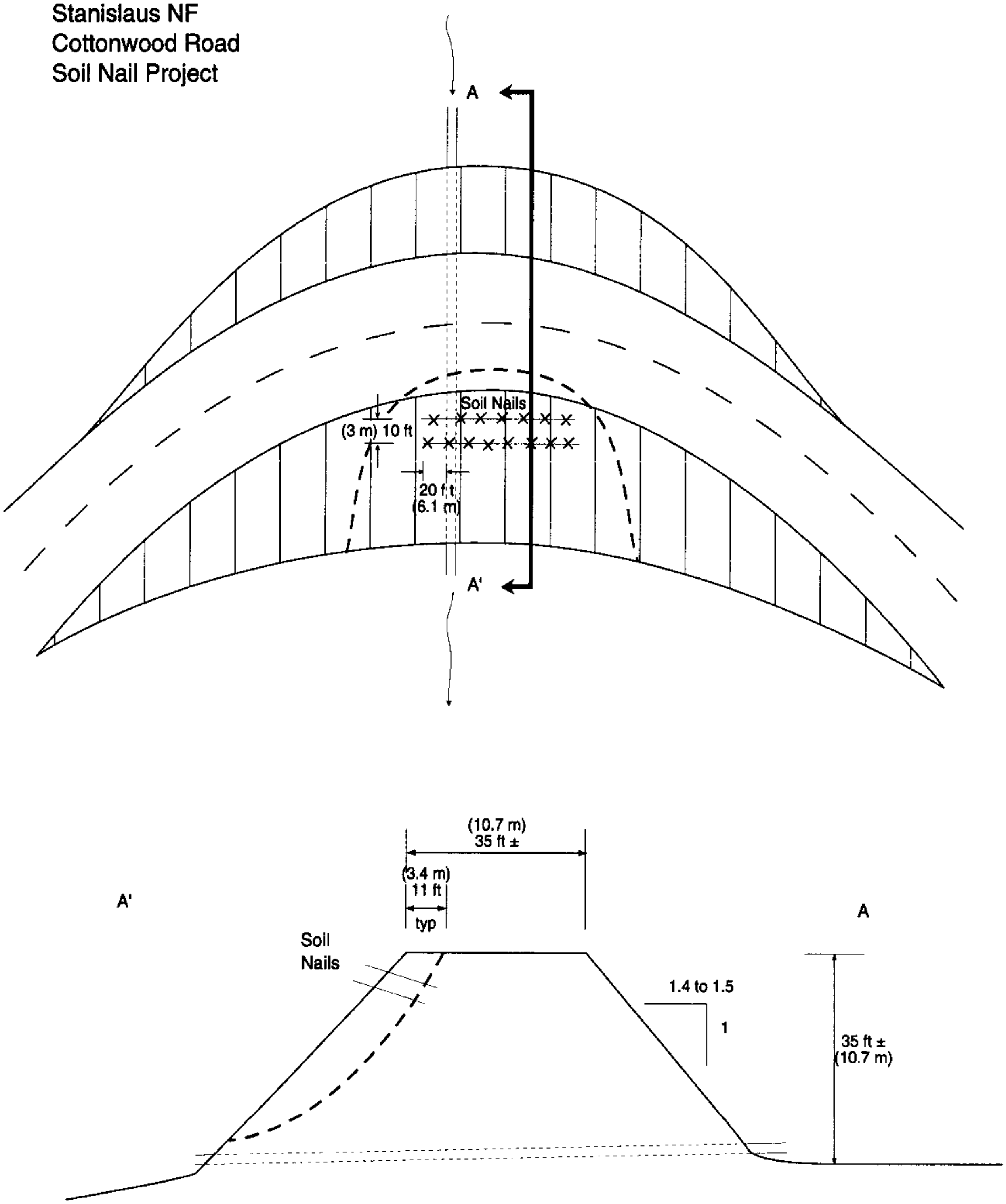
Site 4 | Stanislaus National Forest
Cottonwood Road
Sonora, California

Site Type | Fill Slope Stabilization

Site Description | This site is a through fill constructed of silty to clayey soil about 35 feet high on a double-lane paved road (site 4, sketch 1). The area had failed in previous years. In 1991, an underdrain costing about $30,000 was installed in the embankment to remove water seepage noted in an earlier failure. The area continued to slide after the drainage system was installed.

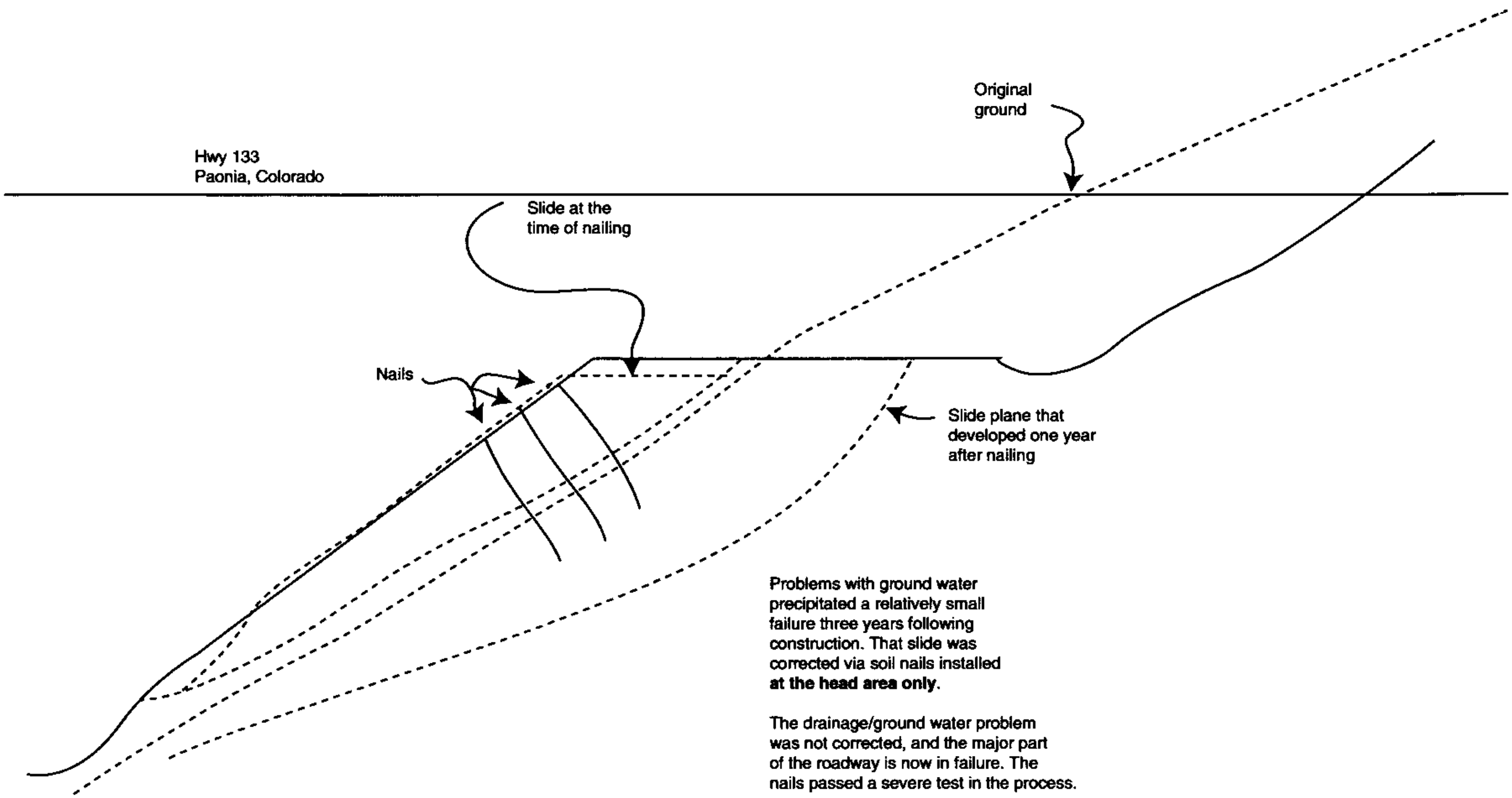
Demonstration Description | Two rows of soil nails on about 20 foot (6.1 m) centers along the road were installed in 100 foot (30.5 m) length of the embankment. About 15 nails were installed in two rows (see Site 4, sketch 1).

Results | There was no slippage of the nailed area during the 1992–93 winter and about a 1 inch (25 mm) drop during the 1993-1994 winter. The movement was much less than before nail installation. The launched soil nails appear to be a cost effective solution to this problem if movement is stopped over the long run. The Stanislaus NF representative, Richard Wisehart, indicated the nail solution would cost about one-third of the cost for the drainage attempt (at $135/nail).



Site 4, Sketch 1

Site 5	State Highway 133 Paonia, Colorado
Site Type	Fill Slope Stabilization
Site Description	The slide area is on a relocated section of double-lane State highway with the failure in a 60-foot (18.3 m) high side hill fill (site 5, sketch 1). The highway relocation, which was completed in 1991, began to show cracks in the pavement about 4 feet (1.2 m) from the fill shoulder during the winter of 1991–1992. The failure appeared to be 6 to 10 feet (1.8 to 3 m) deep, parallel to the slope face.
Demonstration Description	Three rows of nails were placed in the top 20 feet (6.1 m) of the slope in an area about 60 feet (18.3 m) long. The top row of nails was placed about 5 feet (1.5 m) below the road shoulder.
Results	The nailed and un-nailed sections of the fill moved during the winter of 1992–1993. The area with the launched nails appeared to fail further into the roadway, indicating the failure moved behind the nails. The area of nails moved downslope as a unit. Seepage was noted in the ditchline during the winters of 1991–1992 and 1992–1993, indicating a ground water condition in the area. Partially because of this demonstration area, the design charts in the application guide were developed for fill slopes where the nails can penetrate 3 feet (0.9 meter) behind the failure zone, ground water is controlled, and the nails can be installed equally throughout the slide mass. The slide at this site appears to be too deep, too high, and contains too much ground water for launched soil nails to be effective. No horizontal drain nails were installed.
Site 6	San Juan National Forest House Creek Slide (Dolores County Road 728) Dolores, Colorado
Site Type	Fill Slope Stabilization
Site Description	This slide is located on Dolores County Road 728 in the Dolores District of the San Juan National Forest in Colorado. The paved road is 26 feet (7.9 m) wide and accesses a developed recreation area. A maximum of 2 feet (0.6 m) of pavement (mainly shoulder) has been lost, with some damage to the pavement extending about 45 feet (13.7 m) along the shoulder. The slide, which has record of movement over 50 years, moved most recently in the spring of '92. The road was constructed about 8 years ago. A blanket drain was installed during construction in anticipation of possible trouble but it was probably installed in the wrong location. The area where there has been the most movement did not get any drainage.



Site 5, Sketch 1

The slide is approximately 120 feet long and 150 feet wide (see the attached cross-section, site 6, sketch 1, and photo 19). Movement is rotational with a very steep 5-foot headscarp near the top and probably translational towards the bottom. The soils exposed on the headscarp and most of the slide's surface is stiff, moist medium-plasticity clays with some silt near the toe. There has been seepage from the headscarp and from the base of the blanket drain.

Demonstration Description

Proposed repairs for the site included intercepting the failure surface with about 50 soil nails in two or three rows over approximately 90 feet (27.5 m). The concept was to stabilize the top of the slump block as a base for a lightweight sawdust fill.

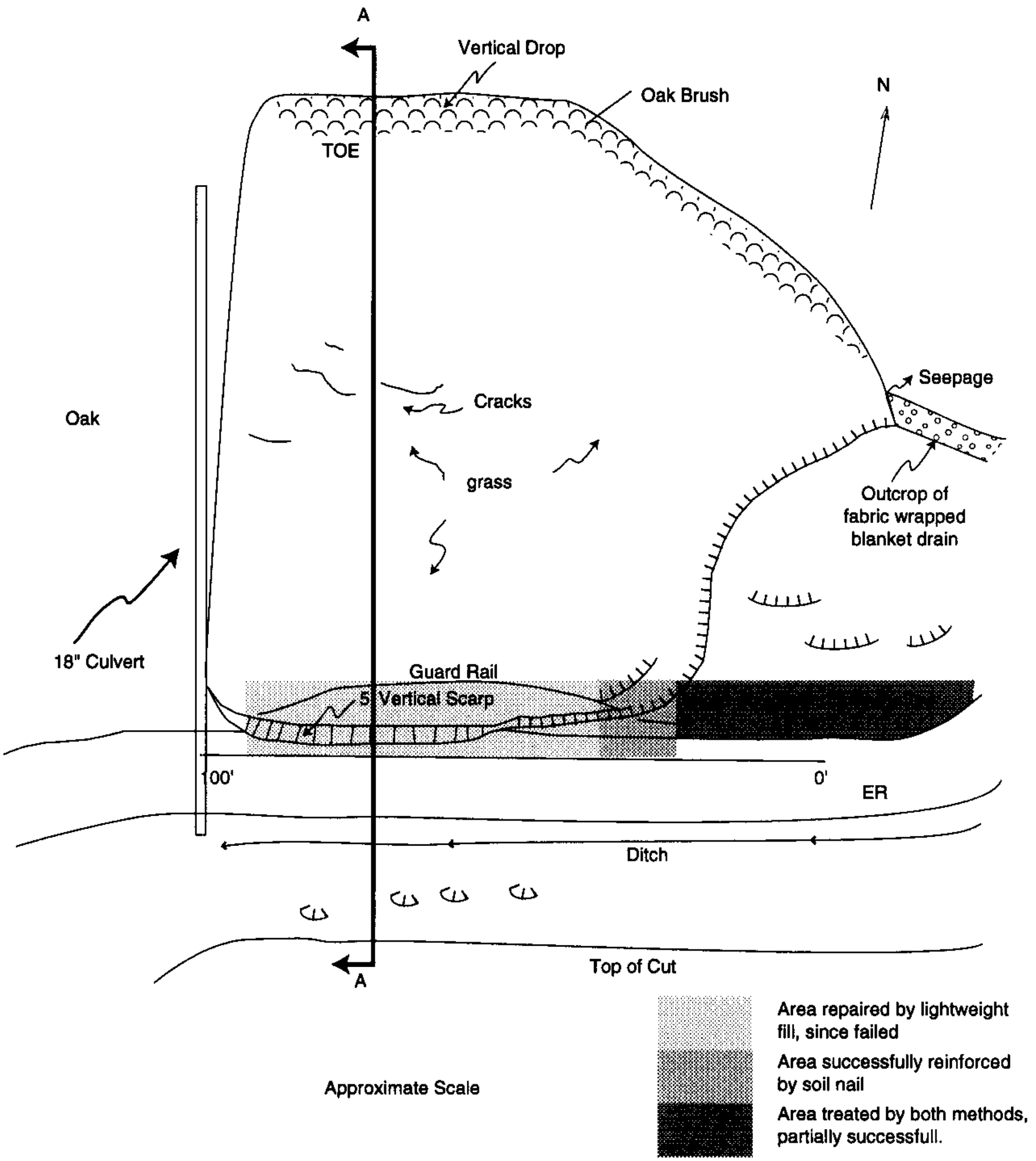
The San Juan National Forest representative, Mike Burke, was a little concerned that this project was too big to be appropriate as a demonstration site. Mike did not fully appreciate how much the slide had moved in the spring of 1992 until he was surveying for the field-generated cross-section. Also, the current slide geometry probably needs a better analysis than Mike was able to give it. The estimate given above for soil nails was based on typical spacings and intuition, not on true analysis.

Result

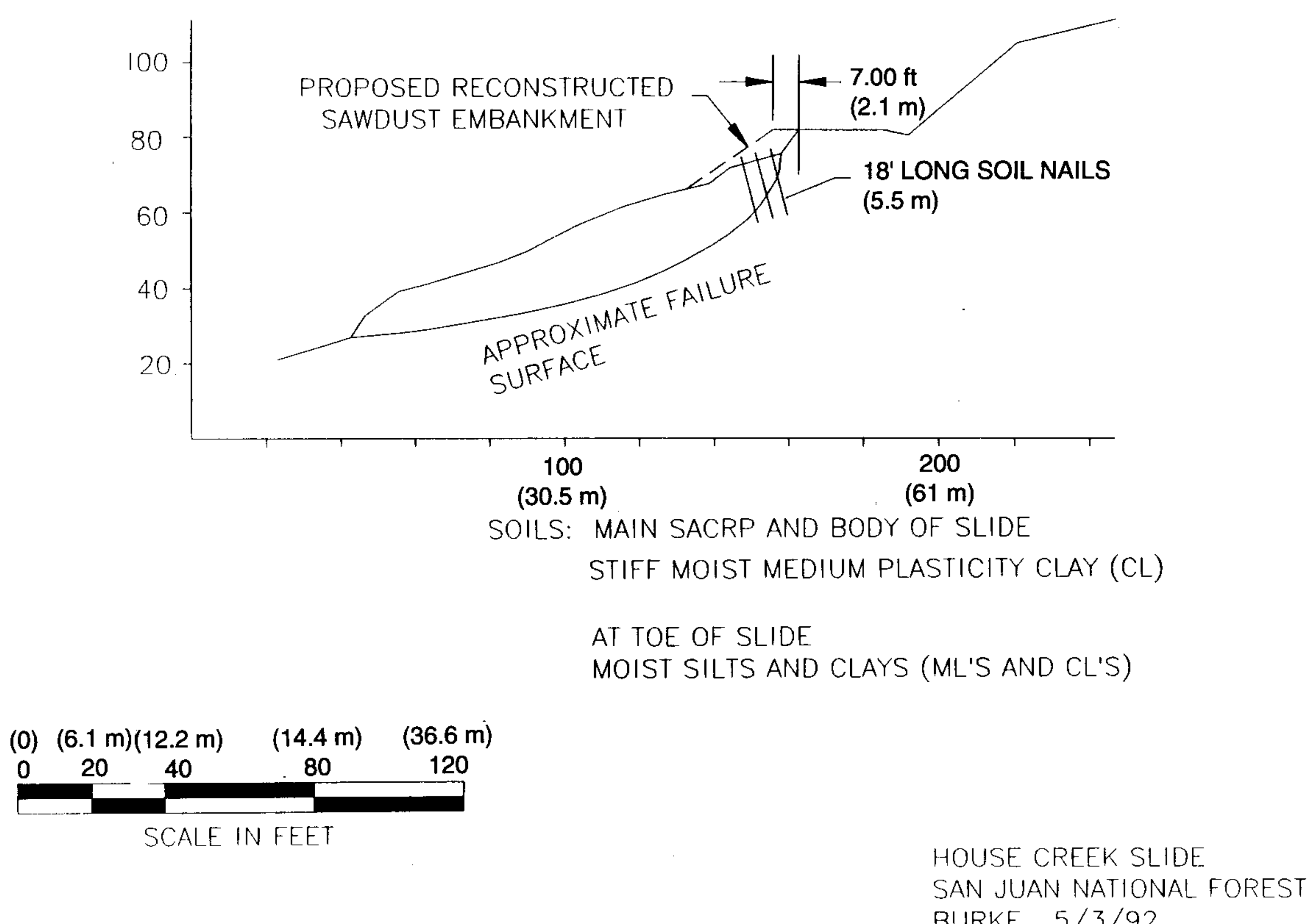
Three rows of nails were installed in the main fill area (about 20 feet (6.1 m) high) that had cracked and moved downslope less than 1 foot (0.3 m). Two rows of nails were installed in the lower fill area (less than 10 feet high) that had moved downslope about 0.5 feet (0.15 m). Two nails were installed vertically in the area that had failed completely and had been excavated for the lightweight fill (about 10 feet (3 m) vertical height at the road shoulder).

The lightweight fill was placed in the area that failed most extensively in 1992 and that failed again during the winter of 1992–1993.

The nailed areas where there has been small movement (about 0.5 to 1 foot (0.15 to 0.3 m) downslope) before nailing have had no apparent movement afterwards. It appears the smaller slide areas are suitable for stabilization with launched soil nails.



Site 6, Sketch 1



Site 6, Sketch 2

Site 7

Washington Department of Transportation
Olympia, Washington

Site Type

Sand Pile Test

Site Description

The test site was a materials stockpile. The nails were launched into a stockpile of sand.

Demonstration Description

Nails were launched into the sand pile at various angles and pressures to monitor control of location, nail inclination and penetration, effect of nail impact on the pile face stability, noise level, and nail capacity in tension.

Results

Pullout Tests

Anchor	Embedment (ft)	Total (kips*)	Capacity kips/ft	Capacity kips/ft²
Sand pile				
1	13.7 (4.2 m)	1.25 (568 kgf)	0.09 (134 kg/m)	0.23 (11 KPa)
2	13.8 (4.2 m)	1.96 (890 kgf)	0.14 (208 kg/m)	0.36 (17.2 KPa)
3	15.3 (4.7 m)	1.96 (890 kgf)	0.13 (194 kg/m)	0.33 (15.8 KPa)
Natural ground				
4	5.3 (1.6 m)	3.60 (1634 kgf)	0.68 (1012 kg/m)	1.73 (82.7 KPa)

* 1 kip = 1000 lbsf = 454 kgf

Objectives

Installation capabilities:

- Location control—Operator could position launcher within several inches of paint spots.
- Nail inclination control—Could be inclined at any angle, but operator has no way to measure angle from launcher.
- Penetration control—Penetration was controlled by varying air pressure and varied from 8 feet to over-penetration in the sand pile.
- Penetration vs. soil density—Nails could be over-penetrated in the sand pile. There was only 5 to 6 feet (1.5 to 1.8 m) of penetration in natural ground (over-consolidated soil).
- Effect of the impact on sand pile face—The existing face of the pile sloped at 65°. The slope stood during all 12 shots fired with only minor sloughing of the surface.

Work Area Impacts

Equipment safety (operation and collar throw):

- Collar ejection was not a problem. Some small debris flew out but was contained in a 10-foot radius. The bulk of the collar remained inside the shroud.

- Air pressure does not build up in the launcher until it is in place and ready to fire.

- The launcher cannot fire unless one of the three safety logs positioned around the shroud is depressed.

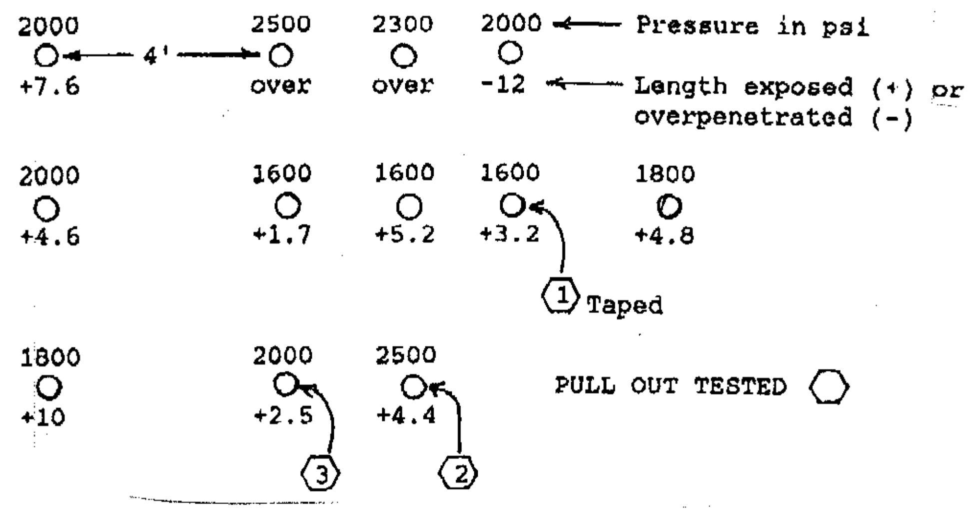
- Noise level:
  Average 114dB for launch
  Pile Driver 93dB

- Nail capacity in tension:
  Soil Properties—Density of sand pile γm = 115 pcf (18.3 KN/m^2)
  Graduation SW
  MC = 3.2%
  (-#4) = 70%
  (-#200) = 4%

SPT's and triaxial tests have not been run.

- Nail condition—No tape was found on the last 7 feet of the taped nail. One piece of tape was found when excavating the nail. No tape was on the nail when it was pulled out.

Nail Pattern



Site 8	Mt. Hood National Forest Clackamas River Road (Rd. 46) Ripple Brook, Oregon
Site Type	Fill Slope Stablization

Site Description

The site is located on the Mt. Hood National Forest about 1 mile south of the Clackamas Ranger Station (Ripple Brook) on Road 46, Section 2 R. 6E., T. 6S. Road 46 is a double-lane, asphalt-surfaced road and is a major north-south forest arterial.

Pavement cracking is on the fill slope side of the road extending back into the pavement 7–8 feet (2.1–2.6 m) in a circular arc fashion and running along the road surface and fill slope for 90–100 feet (27.5–30.5 m). Fill slopes are in the 45 to 50 percent range. The pavement drops an inch or more yearly and is routinely patched. Wet areas behind the road and along the ditch indicate a high ground water table.

Road 46 crosses an earthflow deposit with natural ground slopes in the 15 to 20 percent range. Soils are sandy, elastic silts. Ground water monitoring equipment on the earthflow within one-quarter mile of the site also shows a high ground water table during the wet time of the year.

Factors considered in selecting this site included:

- Yearly settlement and pavement cracking required annual maintenance to keep the roadway safe for traffic.
- Depth to the failure surface was estimated at 10 feet (3 m), which is within the 15-foot (4.5 m) limit noted in volume 1 of the application guide.
- The site was close to the Clackmas Ranger Station which for provided a convenient location for gathering and for a presentation of an overview of launched soil nail technology.

Demonstration Description

Traffic control was a key item for the demonstration's success because equipment blocked one lane of the roadway and 40 people were trying to watch the operations on August 13, 1992. Traffic delays during the firing of the nail launcher were generally less than 3 minutes.

Twenty-nine nails 1.5 inches (38 mm) in diameter and 18 feet (5.5 m) long were launched in three rows within the middle 40 feet (12.2 m) of the unstable fill. Rows were spaced generally at 3 feet (0.9 m) with the first row located 5 feet (1.5 m) below the pavement surface. Nail spacing laterally along the road averaged 4 feet (1.2 m).

All nails were fired at a pressure of 2500 psi. Nail penetration varied from 10 feet (3 m) to full penetration, with the bottom row consistently penetrating deeper than the top two rows. All nails were cut off as close as possible to the ground surface with a power saw.

Results

Winter, spring, and early summer weather since the demonstration can be classified as wet. Ground water monitoring on nearby earthflows indicated a ground water table near the ground surface. An examination of the demonstration site in early July 1993 revealed no visual evidence of pavement cracking or additional settlement. Nail locations were not immediately evident because a layer of vegetation covered the slope.

The design charts in the application guide were used after the installation to check its adequacy.

Design chart solution (without ground water):

	x, ft*	H, ft*	ϕ, degrees	β, degrees	N nails/3.28 ft*	Total Nails	N_W
A	5.2	13	20° est	26°	4	49	67
B	7.8	13	20° est	26°	3.8	46	63
C	10.4	13	20° est	26°	2.5	31	42
Installed	0.6	13	20°±	26°	2.4	29	—

* 1 ft = 3.28 m

Correcting for the ground water as described in the guide:

$$W_n = \frac{H}{H - 0.5H_w}$$

where Wn = multiplier for the number of nails and H and H_w are the height of the slide and ground water respectively as shown in site 8, sketch 1.

$$W_n = \frac{13}{13 - 0.5(7)} = 1.37$$

$$N_w = N(W_n)$$

The number of nails installed (29) is less than the number of nails required by the design charts (31 to 67). Since there was no visible movement of the slide during the 1992–1993 winter, the chart designs appear to be conservative.

Nail pullout tests using a rock bolt jack reading to the nearest ton (2000 pounds):

Number	Nail Location	Load (tons)	Nail L (ft) *	Installation Presure (psi)
1	middle row	1 (8.9 KN)	15 (4.6 m)	2500 (17.2 MPa)
2	bottom row	2 (17.8 KN)	16 (4.9 m)	2500 (17.2 MPa)
3	top row	1 (8.9 KN)	13 (4 m)	2500 (17.2 MPa)
4	top row	3 (26.7 KN)	13 (4 m)	2500 (17.2 MPa)
5	top row	4 (35.6 KN)	13 (4 m)	2500 (17.2 MPa)

FIELD DATA FORM FOR LAUNCHED SOIL NAILS

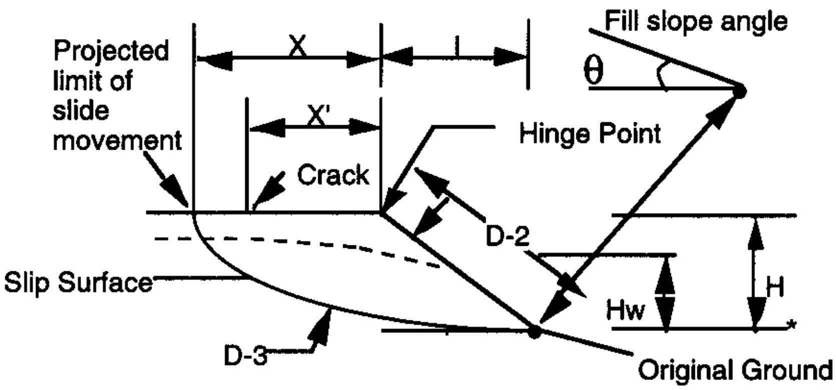
Road Name *Clackamas River Road* Road No. 46 Data ______

Mile Post/Station 0.3 Location T. *6S* R. *6E* Sec. *2*

General Site Description: *Pavement drops yearly an inch or more on fill slope side of road. Wet areas behind road and along ditch. Soils are sandy elastic silts.*

Repair Priority ____________ Completed by: ____________

(1-10 High)

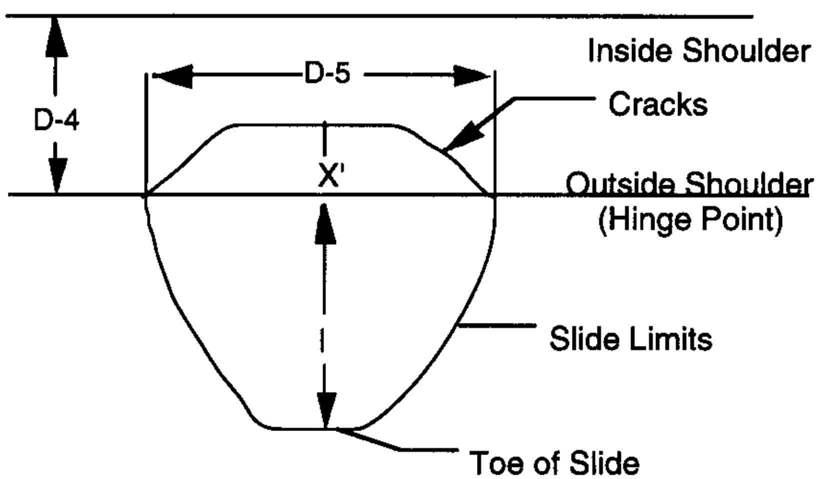


Dimensions (FT) *	
X	*7.5*
X'	*7.5*
D-2	*32*
D-3	*10*
D-4	*22*
D-5	*80*
H*	*13*
Hw	*7*
θ	*26° ≈ 50%*
I	*27*

* 1 ft = 3.28 m

* To toe of embankment if lower limit of slide cannot be located

Cross-Section



Plan

Site 8, Sketch 1

DESIGN CRITERIA CHECKLIST AND RISK LEVELS FOR LAUNCHED SOIL NAILS

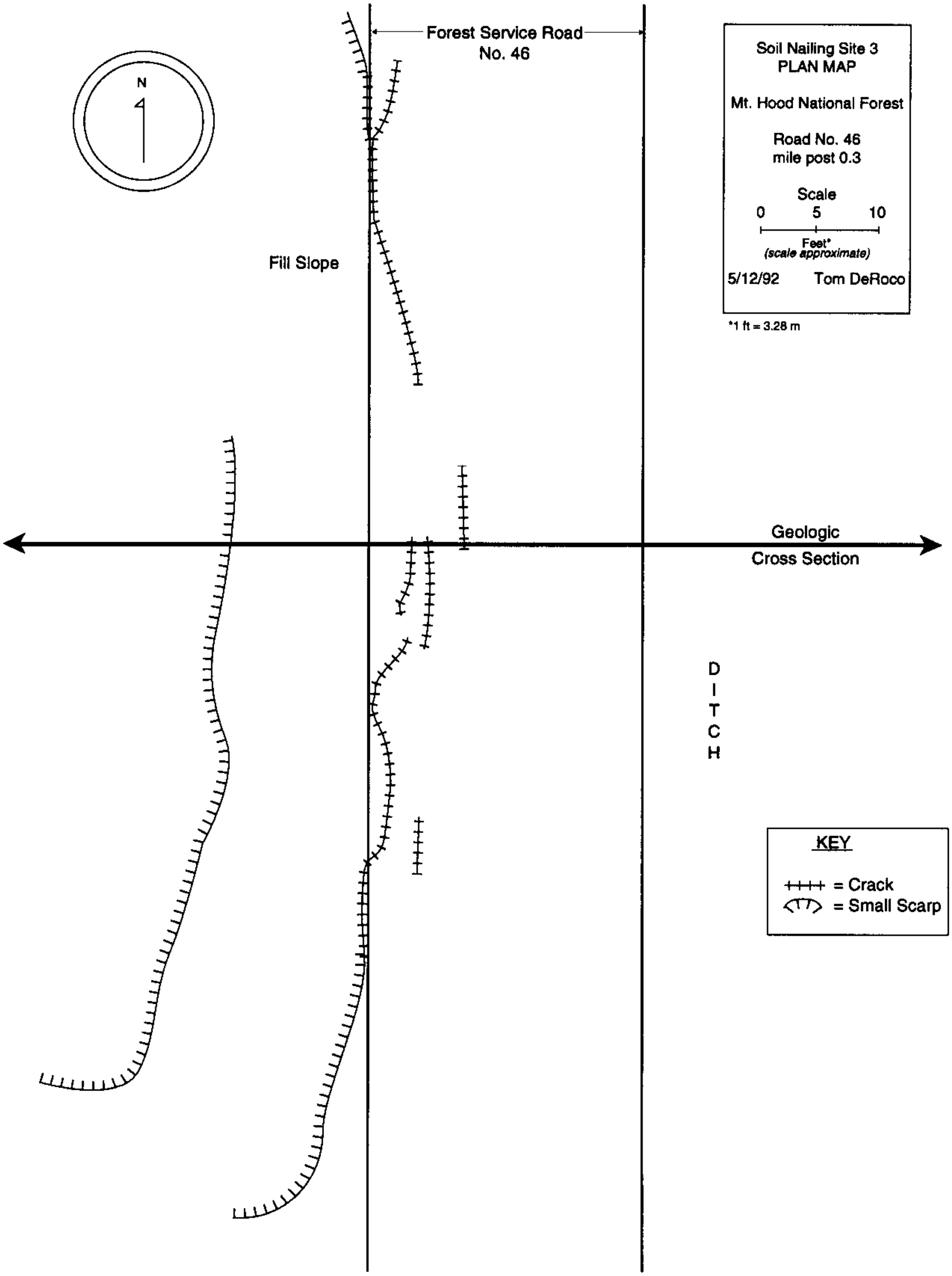
SITE FACTORS	EVALUATION**						
	Low 0.2		Med 0.4		High 0.6		Remarks
Steepness of Slope (Slope Ratio)	2:1	✓	1.5:1		1:1		Cut Slope
Depth to Failure Surface, D1	<5'		5'-10'	✓	10'-15'		
Soil Moisture at time of slide	Moist		Wet	✓	Seep		
Decayed Logs or Slash Within Fill	None		Some	✓	Many		
Soil Type*	Sand		Silt	✓	Clay		**
Consequence of Add'l Failure(s)	Low		Med	✓	High		
Potential for Accident or Injury	Low		Med	✓	High		

* Unified or AASHTO Classification.

** Design charts were developed for Medium Site Condition (Site Factor of Safety, $f_n = 1.1$).

SITE SPECIFIC PLAN AND (OR) CROSS-SECTION

Site 8, Sketch 2



Site 8, Sketch 3

Soil Nailing Site 3
Geologic Cross Section

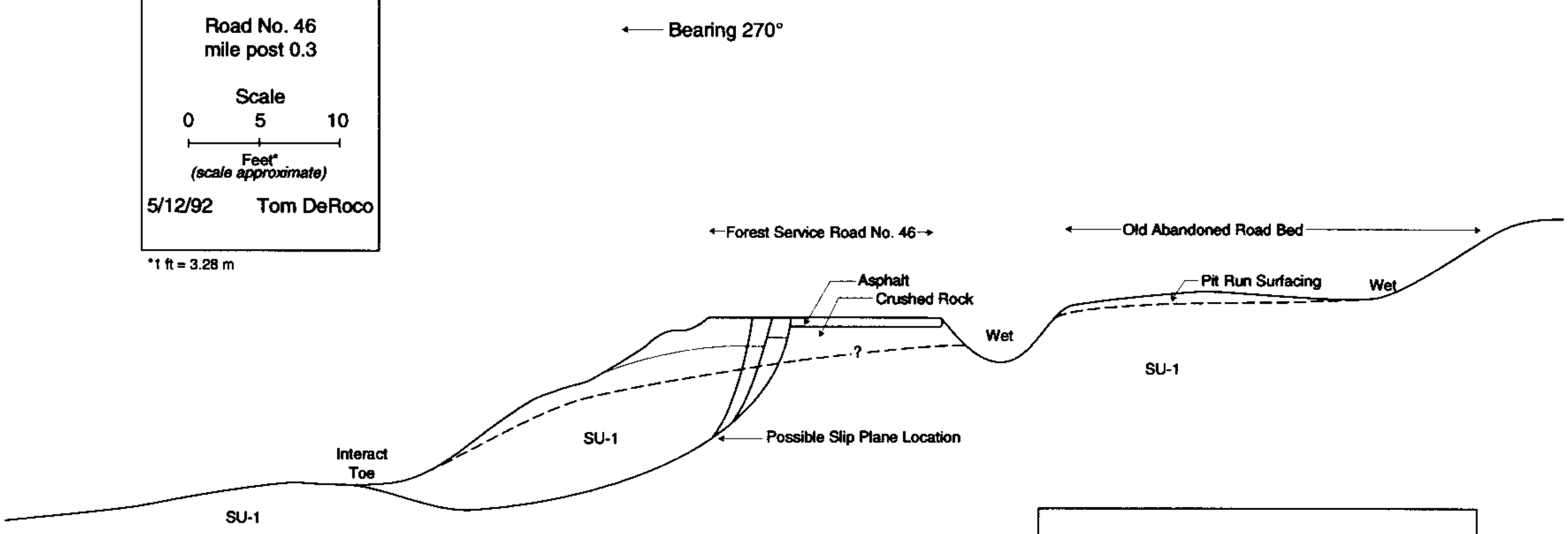
Mt. Hood National Forest

Road No. 46
mile post 0.3

Scale
0 5 10
Feet*
(scale approximate)

5/12/92 Tom DeRoco

*1 ft = 3.28 m



MATERIALS DESCRIPTION

SU-1 SOIL UNIT 1, EARTH FLOW DEPOSIT
yellow-brown, moist, firm, APL
75% fines, 24% sand 1% gravel
5% subangular to angular cobbels
and boulders from 3 inches to 3 feet
fines are silt
USCS sandy elastic silt (MH)

Site 8, Sketch 4

Key Findings

Three of the project goals were achieved:

1) Demonstrate soil nail launching technology;

2) Evaluate the potential use for launched soil nails; and

3) Develop an application guide and video about launched soil nails.

The fourth objective, to locate a contractor(s) willing to lease the equipment and provide launched soil nailing service, was not achieved. Several contractors attended the demonstrations. Comments over heard were, "it works . . . interesting . . . need to be out in front." However, no one indicated a willingness to risk their resources on an emerging technology. Contractors also asked questions about the volume of work (table 1).

Table 1. Workload Summary from Demonstration Project Questionnaires

Unit	Sites/Year	Nails/Site	Nail/Year/Unit	**Days/Year/Unit
*4 National Forests – High Workload	10 to 21	25 to 100	500 to 2,000 (per NF)	10 to 30
2 National Forests – Moderate Workload	4 to 12	30 to 100	120 to 1,200 (per NF)	3 to 20
1 National Forest – Low Workload	0.25 to 0.33	—	—	
1 DOT Bridge Unit	5 to 10	200 to 400	1,000 to 4,000	15 to 80
1 City Water Bureau	34	5	165	4+
1 Federal Lands Division, FHWA	8	3,505	28,040	375 to 560
1 Consultant	3	100 to 500	300 to 1,500	6 to 30
* One National Forest indicated the need with unlimited funding	288	209	60,130	750 to 1,200

** Assuming 50 to 70 nails/day

The auniversal comment from visitors was, "it works!" Many attended out of curiosity and left with ideas of where and how to use the technology. A detailed questionnaire was given to each visitor. Completed questionnaires were received from 46 visitors.

There were further findings:

- The launcher equipment proved capable of installing 18-foot-long ( ) nails to depths of 5 to 18+ (1.5 to 5.5 m) 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.

- Demonstration attendees indicated a need for full scale projects—design, construction, and monitoring—to establish hands-on experience and case histories.

The project financed 20 nails per demonstration. Several units purchased additional nails, which were installed before or after the demonstrations when permitted by the schedule. These additional nails showed the production capability of the equipment (15 nails per hour).

Questionnaire Results

Questionnaire responses were compiled for evaluation of the demonstration project and guiding future work with launched soil nails. Some taped interviews were reviewed also for additional information.

The questionnaires indicate:

1. Application of this technology
   - High potential use for slope, road shoulder, and backslope reinforcement.
   - Medium potential for retaining wall reinforcement and horizontal drain and anchor insertion.
   - Use will depend on cost and availability.
   - Corrosion is a concern for permanent installations.
   - Cost effectiveness is enhanced by adding to existing equipment.

2. Volume of work (one project every 3 or 4 years) to very large if funding was available (288 projects for 60,130 nails)

3. Equipment preference
   - Tracked excavation (as demonstrated) was judged to be most versatile
   - A rubber-tired excavator was suitable where most nails would be launched from existing road surface

4. Features
   - The most important features
     - Cost
     - Reinforce in situ
     - Rapid insertion
     - Minimum ground disturbance
     - Mobility

5. Comments on soil nail launcher technology
   a. Limitations include
     - Length of nails; limited to smaller slides
     - Penetration in cobbly soils
     - Reach of the machine (as demonstrated)
     - Availability
     - Controlling depth of nail penetration

   b. Advantages
     - Fast; speed
     - Mobility; access; deployment (ability to stabilize slide when it is small)
     - Relatively inexpensive, cost competitive with other alternatives
     - Requires little or no excavation and replacement of soil; minimum site disturbance

   c. Design information:
   What is needed?
     - Pullout resistance information on the nails
     - More experience with the technology: completed and documented projects
     - Basic design methods and information

   d. How well will current methods apply?
     - Need a practical design guide
     - Need case histories
     - Start with conventional soil nail design; current methods about okay; side by side with conventional soil nailing; should be independent of installation procedures

6. Facing needs and suggestions:
   a. What uses require a facing system?
     - Near vertical road fractures
     - Excavation shoring; temporary walls

- Right-of-way restrictions
- Steep slopes
- Excavation shoring; retaining walls
- Erodible soils
- Limited; most slide applications would not need facing. What facing type should be used?
- Vegetation for soil erosion; could use staked site mat or wire mesh independent of nails
- Walls/shotcrete; more conventional soil nailing may be more appropriate

b. Facing systems; attachment methods?
- Wide range of materials!
- Shotcrete over wire reinforcement
- Chont link over nails on slopes with loose materials
- Cost in place or precast panels with nails shot through holes
- Wood, metal, or wire baskets.

c. Other comments; ideas
- Methane problem was brilliant usage
- Saltwater applications with non-metal nails
- Consider recycling parts
- Great potential; would like to see someone get it and put it to work for about 6 to 12 months and try it on slow moving slopes, wells, etc. Instrument and compare before and after and compare with alternatives

Appendix A--
Project Photos

Appendix A – Project Photos

Photo 1. Excavator on transport vehicle. Note the straight boom, the bracket to retain the boom, and the compressor mounted behind the boom.

Photo 2. Utility trailer with soil nail launcher and nails ready for transport.

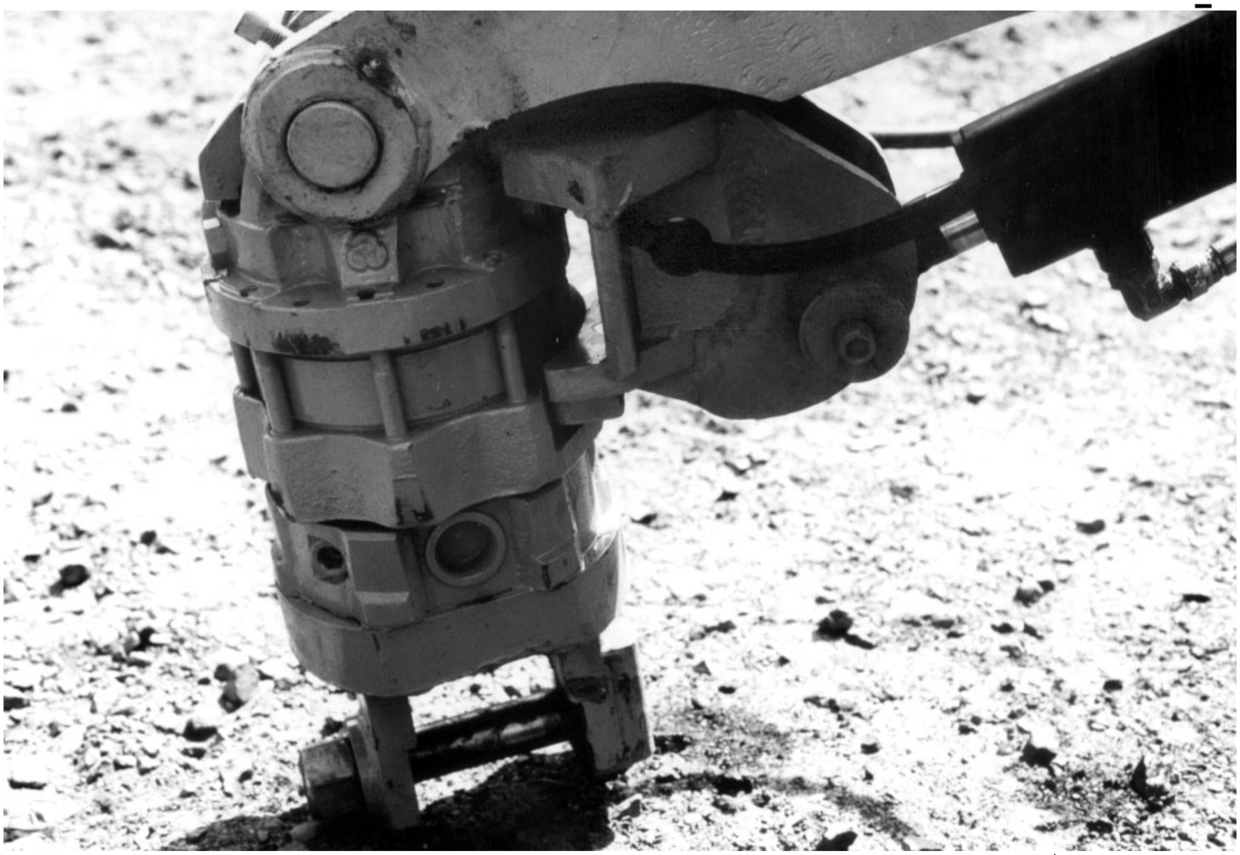


Photo 3. Multiposition hydraulic "knuckle" on the end of the boom for attaching and positioning the launcher.

Photo 4. The launcher attached to the hydraulic "knuckle" on the boom and loading a soil nail.

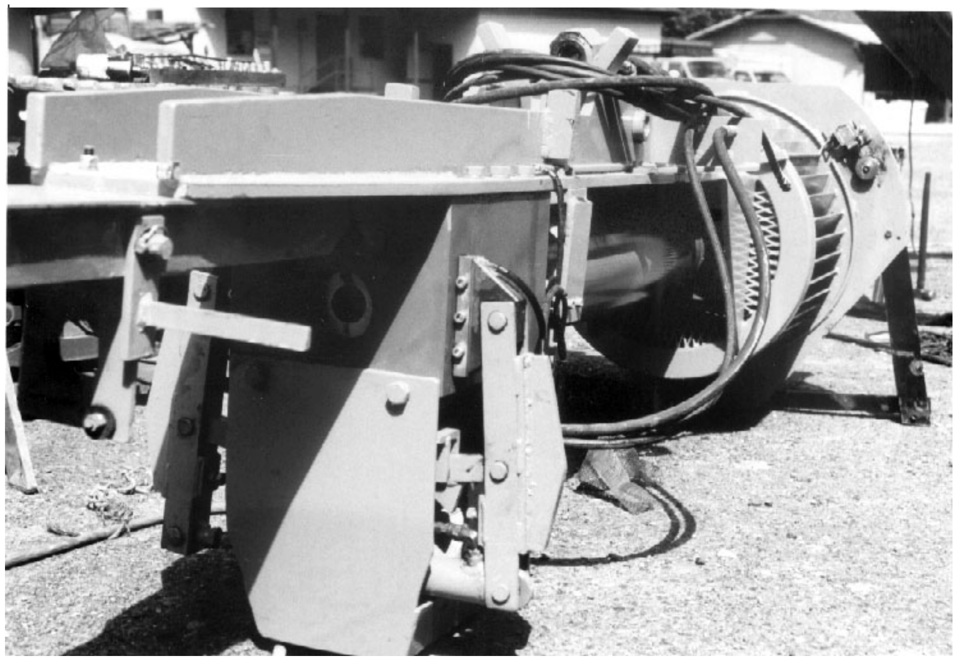


Photo 5. View of the top end of the launcher showing the hydraulic breech assembly for retaining the top end of the collet.

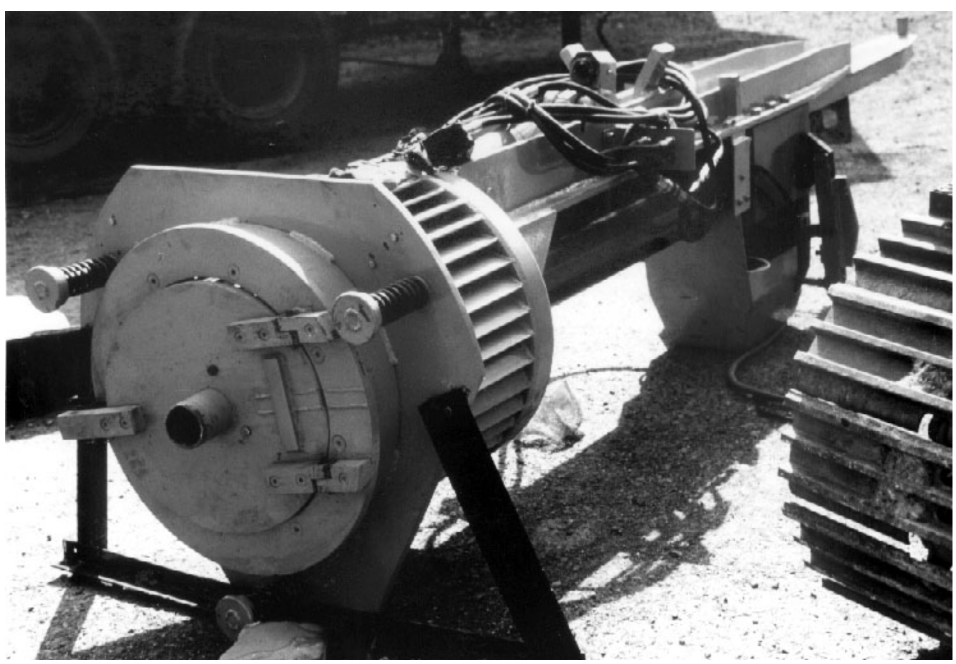


Photo 6. View of the lower end of the launcher showing the schroud for separating the collet from the launched nail and for retaining the collet pieces.

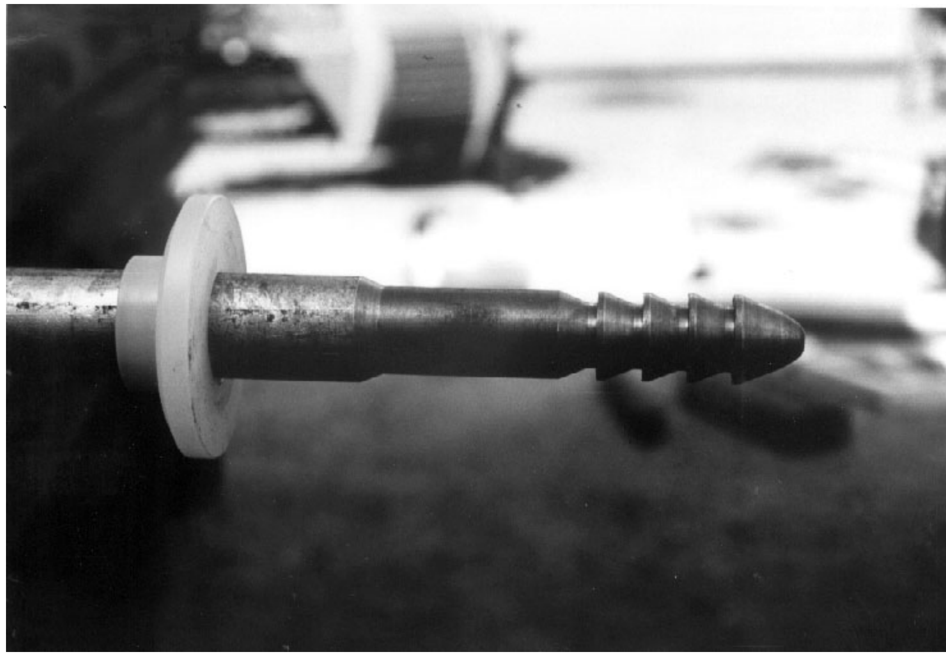


Photo 7. (above) Showing the barbed point of the soil nail for the lead transfer from the collet to the nail.

Photo 8. (left) Showing attachment of the collet to the nail.

Photo 9. Soil nails on support trailer with some collets installed in preparation for launching.

Photo 10. Soil nail in the support tube ready for placement of the collet and nail tip into the breech assembly.

Photo 11. Showing a forest road in steep terrain with a crack adjacent to the fill side of the road. Note the attempt to patch the crack.

Photo 12. Showing the launch of a soil nail to retain the road shoulder and halt further crack development. Note the retention of vegetation on the site.

Photo 13. Reaching over a temporary guardrail to nail a failing slope in Colorado.

Photo 14. Three rows of launched soil nails in the slope in photo 13 before cut-off of the nails.

Photo 15. Excavator, launcher, and transport vehicle adjacent to installed nails. Note three rows of nails installed without disturbing the vegetation.

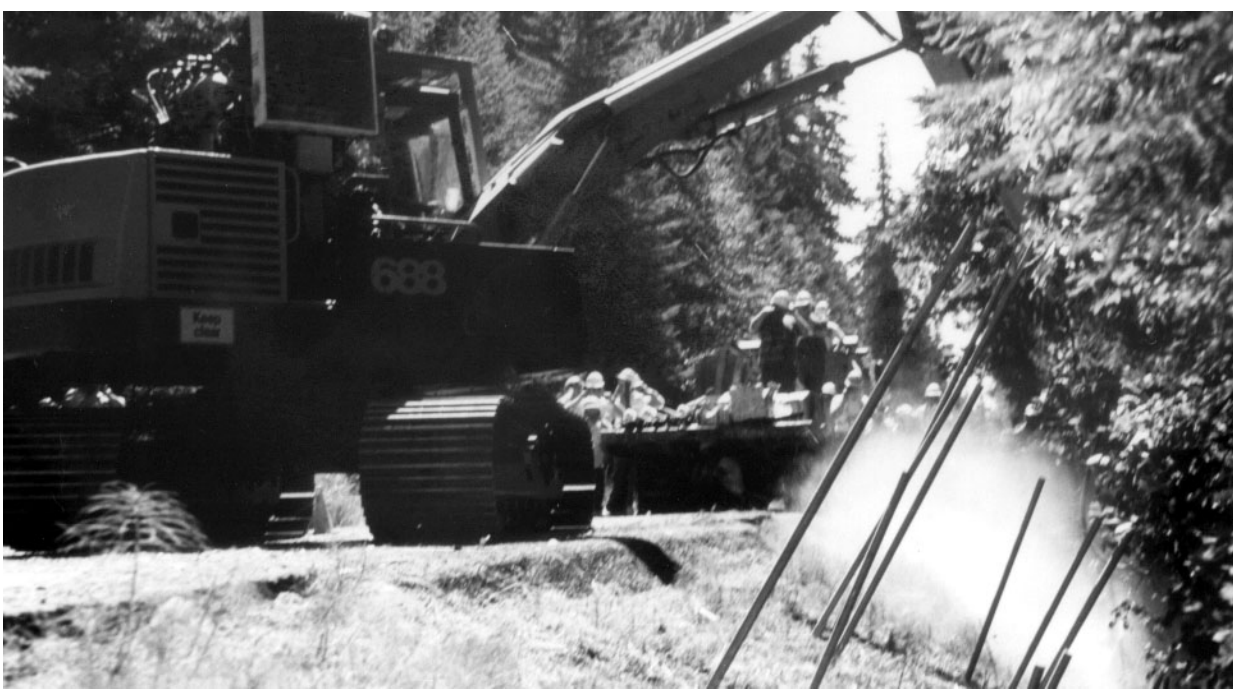


Photo 16. Launching a nail in the site in photo 15. Note the thickness of asphalt concrete pavement, indicating repeated patching of the pavement surface due to slope movement. Nails were cut off at the ground surface after the photo was taken.

Photo 17. Positioning the soil nail launcher without removing roadside vegetation.

Photo 18. Launching a soil nail into a cutslope on the Klamath NF in Northern California.

Photo 19. Ready to launch a soil nail into a failing slope in Colorado. The soil nails will prevent extensive downslope movement seen in the foreground.

Photo 20. A driven sheet pile 1H-pile retaining wall in Oregon. Note the holes burned into the sheet pile for the launched soil nails.

Photo 21. Positioning the launcher for installation of the soil nails.

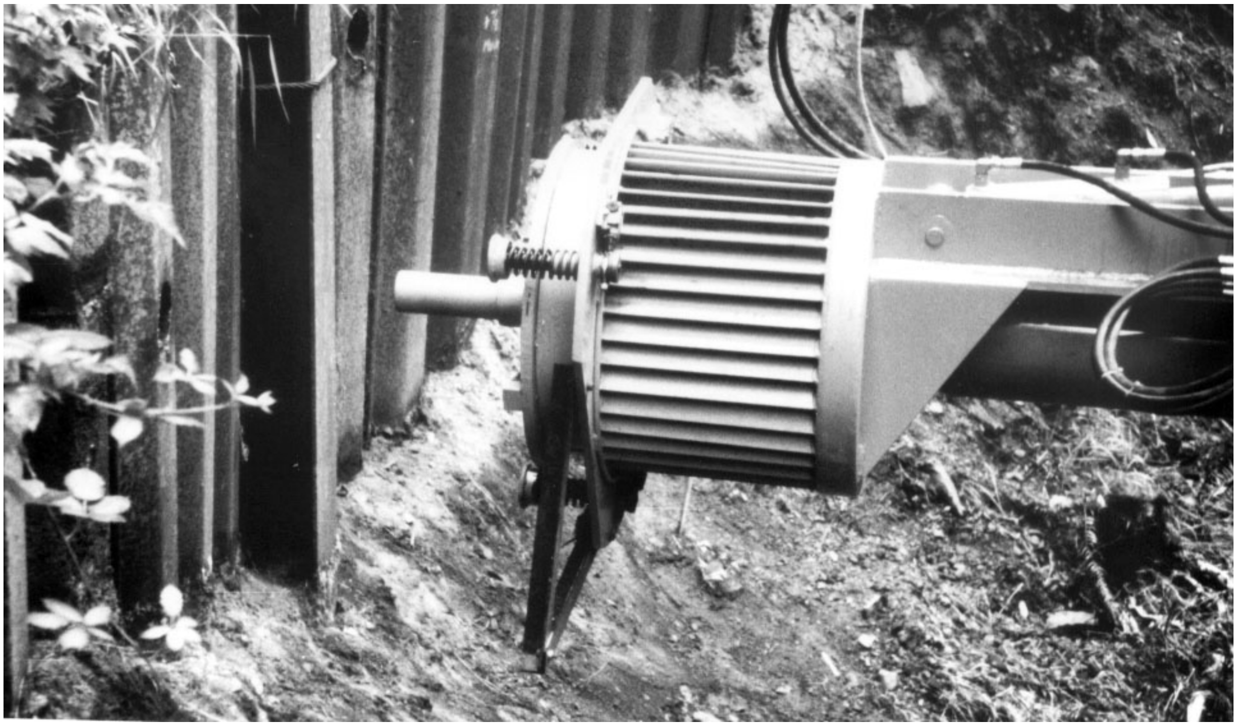


Photo 22. The launcher approaching the wall. Note the guide tube attached to the launcher to guide the nail into the hole.

Photo 23. About 1.5 feet (0.5M) of the 18-foot (4.5 M) soil nail launched into the retaining wall backfill.

Appendix B--
Project Contacts

Appendix B - Project Contacts

The following individuals coordinated the site demonstrations or are familiar with the soil nail launching operations. They are listed below as an opportunity for the reader to contact them for further information or clarification.

John Mohney, Geotechnical Engineer — (503) 326-2738
Pacific Northwest Region, USFS — FAX (503) 326-5745
333 S.W. First Street
Portland, OR 97204-3440

Edward Stuart, Regional Geotechnical Engineer (Retired)
Contact: Ken Inouya
Pacific Southwest Region, USFS — (510) 825-9800
Pleasant Hill Engineering Center — FAX (510) 687-0125
2245 Morello Ave.
Pleasant Hill, CA 94523

Don Loetterle, Regional Geotechnical Engineer (Retired)
Contact: Duane Davey
Rocky Mountain Region, USFS — (303) 275-5200
740 Simms Street — FAX (303) 275-5170
Lakewood, CO 80401

John E. Steward — (202)205-1448
USDA Forest Service — FAX (202) 205-0861
Chief Geotechnical & Dams Engineer
201 14th Street, S.W.
Washington, D.C. 20250

Mauricio Ribera, Assistant Forest Engineer
Siuslaw National Forest — (503) 750-7140
4077 Research Way — FAX (503) 750-7234
Corvallis, OR 97333

Robert Young — (503) 750-7160
Geotechnical Engineer — FAX (503) 750-7234
Siuslaw National Forest
4077 Research Way
Corvallis, OR 97333

Cliff Denning — (503) 666-0681
Geotechnical Engineer — FAX (503) 666-0641
Mt Hood National Forest
2955 N.W. Division
Gresham, OR 97030

Richard Van Dyke — (503) 247-7026
Geotechnical Engineer — FAX (503) 247-2816
Siskiyou National Forest
West Side Engineering Zone
93976 Ocean Way
Gold Beach, OR 97444

Ed Rose (916) 842-6131
Geotechnical Engineer FAX (916) 842-6327
Klamath National Forest
1312 Fairlane Rd.
Yreka, Ca. 96097

Richard Wisehart (209) 532-3671
Geotechnical Engineer FAX (209) 533-1890
Stanislaus National Forest
19777 Greenley Rd
Sonora, CA 95370

Stephen Hemphill, Civil Engineer
Grand Mesa, Uncomphadre, Gunnison Nat'l Forests (303) 874-7691
2250 Highway 50 FAX (303) 874-6698
Delta, CO 81416

Michael Burke, Geotechnicl Engineer (303) 385-1271
San Juan National Forest FAX (303) 385-1243
701 Camino Del Rio
Durango, CO 81301

Al Kilian (Retired) (206) 753-7111
Contact: Tony Allen Fax (206) 586-4611
Geotechnical Engineer
Washington Department of Transportation
P.O.Box 167
Olympia, WA 98504
(Now with the FHWA in Vancouver, WA)

Robert (Bob) K. Barrett (303)-248-7231
District 3 Geologist FAX (303)-248-7254
Colorado Department of Transportation
222 South Sixth Street
P.O. Box 2107
Grand Junction, CO 81502

Bernard Myles (0222) 777707
Soil Nailing Ltd FAX (0222) 793447
5 Pascal Close,
St. Mellons,
Cardiff CF3 OLW.Wales
United Kingdom
Contact: Peter Stevenson (803) 855-0619
Soil Nailing Ltd FAX (803) 859-1698
226 Sitton Road
Easley, SC 29642

Ron Chassie (503) 326-2095
FHWA FAX (503) 326-3928
222 S.W. Columbia
Portland, OR 97201

Robert Trivett, Mechanical Engineer
(0446) 760612
Compact Loaders Ltd.
FAX (0446) 760289
St. Brides Super Ely
Cardiff, Wales U. K.
CF5 6EZ

Appendix C--
Questionnaire with
Detailed Summary

Appendix C - Questionnaire with Detailed Summary

QUESTIONNAIRE--RESPONSES
SOIL NAIL LAUNCHER DEMONSTRATION PROJECT

Demonstration date: ______

RETURN QUESTIONNAIRE
to
Mauricio Ribera,
Assistant Forest Engineer
Siuslaw NF
4077 Research Way
Corvallis, OR 97333
FAX (503) 750-7234
(503) 750-7140.

To receive future information:
(Spring 1993)
Applications Guide: YES___ NO___
Applications Video: YES___ NO___
Name:________________________
Unit/CO.:______________________
Address:______________________
____
____
Phone: ___-___-____
FAX: ___-___-____

1. APPLICATION OF THIS TECHNOLOGY:	Low	Med	High	Average
	0	5	10	
a. Road shoulder reinforcement:	1	11	29	8.4
b. Road backslope reinforcement:	2	13	24	7.8
c. Slope reinforcement:	5	18	23	9.1
d. Existing wall reinforcement:	9	23	14	5.8
e. Horizontal drain insertion:	8	17	17	5.5
f. New walls:	8	18	11	5.6
g. Anchor insertion:	10	13	10	5.0
OTHER:				
h. Basement excavation		1		
i. Anchor for rockfall barriers		1		
j. Tunnels/underground		1		
k. Excavation shoring		1		
l. Inclinometers?				
m. Ground water monitoring?				
n. Small slide stabilization		1		
o. Tiedowns (small towers, poles, etc.)		1		
p. Sliver fill road failures (1a)				

COMMENTS:

- Usage would depend on availability and price.
- The presentation by Bernard Myles was informative and delightful. The field demonstration was equally enlightening. I hope to learn more about this procedure and to encourage its consideration where applicable.
- There may also be room for further development of the launcher having a blend of explosive and compressed air or varying sizes for varying needs.
- I see a lot of potential for the method.
- For new walls; probably limited to low height walls.
- Most uses likely to be temporary only, due to lack of data regarding long-term corrosion resistance. Further study/data on ability

of corrosion protection to remain effective after installation is needed prior to acceptance by design community for permanent usage.

- Shorter low capacity anchors for uphill walls, sign foundations, etc.
- Technology seems to lend itself to retrofitting/auxiliary attachment to backhoes/excavators similar to rock breakers, tamper attachments. Thus, reducing the capital investment required for the excavator.

2. VOLUME OF WORK:
How much work do you see for launched soil nails for your organization*:

NATIONAL FOREST "A" in NW		USDA-FS REGION "A"	
	# Projects # Nails/Proj**	# Projects	# Nails/Proj
1a	6 @ 50 = 300		
1b	5 @ 50 = 250		
1c	2 @ 100 = 200		
1d	1 @ 30 = 30		
1e	1 @ 30 = 30		
1f	3 @ 50 = 150		
1g	3 @ 5 = 5		
TOTAL	21 @ 46 = 965	12 @ 100 = 1200	

CITY WATER BUREAU		NATIONAL FOREST "B" in NW	
1a	5 @ 5 = 25	100 to 2000 nails/year	
1b	5 @ 5 = 25	for 625,000 acres with	
1c	5 @ 5 = 25	2500 miles of roads.	
1d	4 @ 4 = 16		
1e	5 @ 5 = 25		
1f	5 @ 5 = 25		
1g	5 @ 5 = 25		
TOTAL	34 @ 5 = 166	100 to 2000	

NATIONAL FOREST "C" in NW		NATIONAL FOREST "A" in CALIF	
1a	10@ 40 = 400		
1b	4 @ 10 = 40		
1c	4 @ 10 = 40		
1d			
1e	2 @ 4 = 8		
1f			
1g			
TOTAL	20 @ 24 = 488	2 projects/year	

	STATE DOT BRIDGE UNIT in NW		NATIONAL FOREST "B" in CALIF	
1a	5-10	@ 200-400/project	2	@ 30 = 60
1b				
1c			2	@ 30 = 60
1d				
1e				
1f				
1g				
TOTAL	5-10	@ 200-400/Project = 1000 to 4000/Year #	4	@ 30 = 120 ##

1a is based on a rough estimate of small embankment/cut failures that could be stabilized with launched soil nails. A better estimate could be provided by maintenance personnel, who could also provide information about any existing retaining walls that may benefit from launched soil nails.

3,000 miles of road. Any soil nailing projects will likely be sporadic, unless there should be a major storm damage program with lots of wall needs, and cut and fill slope failures. Its use will be limited unless we have a regional or national contract, or soil nail launchers become common.

	FHWA FEDERAL LANDS HWY DIV "A"		USDA-FS REGION "B"	
1a				
1b				
1c				
1d				
1e				
1f				
1g				
TOTAL	8	@ 3505 = 28040 #	1 Project/ 3-4 Years	

8 potential projects identified with rough very rough "ballpark" estimate.

	NATIONAL FOREST "D" in NW		CONSULTANT IN PORTLAND, OR	
1a				
1b				
1c				
1d				
1e				
1f				
1g				
	10-12 Sites/Year	@ 100/site = 1000 to 2000/Year #	3	@ 100-500/Site = 300 to 1500/Year

I could see one contract per year repairing an existing road system. Assume 6 to 10 major roads: if one per year or part of one is repaired per year, and had 10 to 12 sites/road at 100 feet per site @ $12,000 per site, the cost would be $120,000 to $140,000/year. After 5 to 10 years the numbers would decrease.

NATIONAL FOREST "E" in NW

1a	200	@	130	=	26000
1b	75	@	400	=	30000
1c	10	@	400	=	4000
1d	2	@	15	=	30
1e	1	@	130	=	130
1f			______		______
1g			______		______
TOTAL	288	@	209	=	60,130

—Assumes unlimited funds
—$60/nail more beneficial than $130/nail

* Organization covers (Road miles? Area included?, etc.).
** Assume 3-foot-by-3-foot pattern and $130/nail without facing.

COMMENTS:
- Entire organization sees much potential, but I haven't done many in the last 6 years due to drought.
- (2000 ft. by 6 ft. = 130 nails/site x $130/nail = $17,000/site) This would probably be too expensive. The price were dropped to $60 if per nail, it would become more feasible.
- Technical data to help determine pattern and other design considerations would be appreciated. What facing systems are employed? Are they effective in containing small/intermediate shale or mudstone surface slips? (Steep-bedded or well-fractured surface conditions)
- My agency may be in a position to suggest this alternative technology, however, availability is obviously a limiting problem!
- Potentially large number of slides; objective is to reduce the incidence of storm-associated landsliding (on National forests).

3. EQUIPMENT PREFERENCE:
What type soil nail launcher carrier would be most useful?

a. Tracked excavator (as demonstrated)	28
b. Portable (skid mounted)	4
c. Truck-mounted excavator	10
d. Other (specify)	

COMMENTS:
- Would want to avoid an extra flatbed for daily moves.
- Most applications would be on roadway prism, approximately 40 feet up or downslope from surface.
- Much bigger excavator.
- Order most useful is a, b, c.
- 4 by 4 or 6 by 6 truck is more mobile.
- (Favor truck mounted excavator) Most of our work is on paved mountain roads 12 to 24 feet wide. Rarely would we need to enter the worksite where a crawler would be needed.

- Track-mounted is more versatile; truck-mounted possible for road work. (2)

4. FEATURES:	Importance Very Low		None		Very High	(Ave.)
	-10	-5	0	5	10	
a. Reinforce in situ				11	22	(8.3)
b. Keep road open		1	6	14	13	(5.7)
c. Rapid			3	9	30	(8.2)
d. Cost			1	9	28	(8.6)
e. High technology	5	4	18	5	3	(-.4)
f. Controllability		1	6	15	11	(3.9)
g. Mobility			4	16	20	(7.0)
h. Rapid deployment		1	8	16	14	(5.5)
i. Specialized equipment	6	4	13	9	6	(0.7)
j. Use in sensitive areas		1	8	13	16	(5.8)
k. Minimum ground disturbance			3	12	17	(7.2)
l. Stay within right-of-way		2	8	10	15	(5.4)
m. Use in restricted areas		2	6	15	13	(5.4)
Rapid insertion				1		
Measure depth penetration					1	
Reduce sediment					1	
Install in rain					1	
Minimize traffic disturbance						
Dewater clays					1	
Temporary excavation support					1	
Small slide stabilization				1		
Tiedowns				1		

5. COMMENTS ON SOIL NAIL LAUNCHER TECHNOLOGY:

a. Limitations?

- Highly dependent on subsurface condition. If subsurface conditions are unknown, some of the design assumptions may not be valid and the solutions may not work.
- Trial and error process of launching nails when desired length is needed. —> You have to trade off the energy expended for embedment to get a desired length extending from the ground.
- Controlling the depth of the nail appears to be a problem.(4)
- Until the noise is controlled, it will probably be limited to rural areas.
- Reach of machine. (5)
- Probably limited to small slides (pop-outs) and maintenance repair applications for State highway projects.
- Could be used by contractors during construction, but would have to be proposed by contractor.
- Length of nails; depth of slide (smaller slide only). (7)
- Restricted to road access; access could be limiting. (2)
- Noise. (3)
- Skittering of plastic collets.
- Damage to unknown utilities.

- Penetration depth in adverse (rocky) conditions:
  - Gravelly or cobbly soils. (6)
  - Competent, sound bedrock could also limit penetration. (2)
- Short nails. (3)
- Cost? (3)
- Refacing considerations—are nails as anchors for securing a facing/surface system to contain weathering/fractured cut shales and such an option?
- Corrosion protection; epoxy coated nails not assessed. (2)
- Face plate attachment— number of steps could be reduced.
- Availability. (5)
- Our (county) roads are also utility easements and may be used as such. Procedures that retain the soil leave the road open for installations.
- Time required to prepare a contract.
- Labor required to load nails into launcher. Carousel similar to rock bolter would ease handling problems for larger nails and speed installation.
- Air compressor too small.
- Will not be able to use in real wet areas.
- Can it penetrate adequately into the competent side of the failure plane after having penetrated a significant thickness of overburden?
- Don't know what happens to the nail underground after launching (like piling).
- Variation in nail placement length.
- Number of contractors available. (2)
- Limited data avaialbe on applications. (2)
- In contract situation, difficulty in achieving a specified tip elevation.
- May have difficulty keeping air supply dry in humid conditions (i.e. SE Alaska).
- Engineers will want to design it on a slide repair in order to feel confident that the money is well spent.
- Construction company can only lease machine.

b. Advantages?

- Fast; speed. (18)
  - Install with little delay after exposing face of cut.
- Inexpensive (relatively); competitive price. (5)
  - Almost a cheap as new guard rail.
- Requires little or no excavation and replacement. (4)
- Easy. (3)
- Minimum ground disturbance. (3)
  - Maybe can replace construction of retaining walls, which disturbs area less.
- Minimum preparation work; mark site and install. (2)
- None labor intensive.
- Not many mechanical parts, therefore, less down time.

- Mobility; access; deployment. (11)
  - Avoids constructing an access.
  - Quick fix of roadway threats; probably save the road (3).
- No digging.
- Cost? Maybe not.
- Flexibility of installation; ability to place extra nails if deemed needed (3).
- Low cost/nail installed. (4)
  - What will production costs be?
- Truck mounted machine would be especially advantageous with regard to mobility
- Nails are injected rather than driven.
- Tight work space.
- A good machine.

c. Design information:

What is needed?
- Subsurface conditions: A good subsurface investigation is mandatory since you have to know what you are dealing with. Must know type of material, depth of slide planes, bedrock, etc. (2)
- Pullout resistance in typical soils to aid in preliminary design. (6)
- Need short training on design methods and procedures! No one will use or recommend it if they are not comfortable with doing designs.
- Need some full scale projects as examples so can build confidence of designers and agencies. (2)
- Technical data to help determine pattern and other design considerations would be appreciated.
- What facing systems are employed? Are they effective in containing small/intermediate shale or mudstone surface slips? (Steep-bedded or well-fractured surface conditions.)
- Refacing considerations—are nails as anchors for securing a facing/surface system to contain weathering/fractured cut shales and such an option?
- Need general design considerations used in evaluating failed planes.
- What effective depth can be expected in general?
- Will soil anchor systems be developed?
- What design considerations are incorporated into foundation stabilization efforts?
- Further study/data on ability of corrosion protection to remain effective after installation is needed prior to acceptance by design community for permanent usage. (2)
- Nail density specification may be a problem due to small soil/nail surface area contact relative to conventional grouted soil nails.
- Some basic empirical data or "rules of thumb." (3)
  - Types of soil mixes allowed (for instance, cobbles will deflect?)

- Average range of conditions.
- A way to estimate depth of penetration from STP's or something. (2)
- What angles to insert for various failures.
- Will application of surcharge start the failure again? What capabilities will be restored?
- Should have handed over some design information with the demonstration.
- Need to penetrate boulders in both cuts and fills; more rock than soil in northern California.
- How to identify depth to failure plane and nail depth quickly and with a minimum number of soil parameters.

How well will current methods apply?
- Present design methods probably do not apply
- Would be nice to launch with attached cable that could be cut to desired length. Cable could then be post-tensioned for design loads, holding up facing material, and so forth.
- A camera or mirror mounted on the gun will allow the operator to place the nail without assistance.
- Conventional soil nail design appears to be a good starting point.
- Possibility of pullout tests performed by contractor in order to provide site specific design information.
- Have little expertise in this area (design).
- Current methods about okay.
- Should be independent of installation procedures.
- Seems to be an art rather than a rational engineering design procedure.
- PSI Force—is it on the collet area or on the nail area? Is it air in the tank or driving force?
- Case histories. (2)
- Side by side comparisons with conventional soil nailing.
- Difficult to use current design methods as these would appear to underpredict capacity.
- Is there a method of "capping" nails to provide a wider area to place weight on top of nails (vertical nails) if used to support buildings to limit settlement?
- A practical design guide. (3)

6. FACING NEEDS & SUGGESTIONS:

a. What uses require a facing system? What type facing is needed?
- Vegetation for soil erosion; could use staked jute mat or wire mesh independent of the nails.
- Walls/shotcrete; conventional soil nailing may be more appropriate.
- Soil nail walls.
- Slope stabilization or protection.
- Erodible soils. (2)
- Retaining structures or retrofit walls. (2)
- Steep slopes. (3)

- R-O-W restrictions. (3)
- Environmentally sensitive areas.
- Loose materials.
- Urban areas.
- Corrosive environments.
- Slope with loose materials.
- Excavation shoring; temporary walls. (3)
- Contain end dumped embankment material.
- Near vertical road failures. (4)
- Where "arching" or apparent cohesion is inadequate for practical spacing.
- Shore protection.
- Lake front slopes.
- Visual quality normally not important.
- Limited need; most slide applications would not need facing. (2)

b. What ideas do you have for facing systems? Attachments of the nails to the facing system? Attachment of the nails to a wall face? Sketches?

- Gabions over nails
- Rockery
- Precast panels
- Wire Fence
- Welded wire mesh
- Geotextiles
- Timber over nails
- Tie log cordons
- Welded plate to nails
- Reinforced shotcrete
- Cast in place formed walls (2)
- ute mats
- Wire mesh baskets
- Geogrid
- Erosion matting
- Precast panels
- Deadman for gabion baskets
- Shot crete with wire reinforcement (4)
- Good looking precast panels with simulated rock patterns.
- Concrete in urban areas; more natural materials in forests and scenic areas.
- Inexpensive but strong materials.
- Threadbar nails and attach rebar horizontal member then shotcrete skin with fiber reinforcement.
- Conventional shotcrete/face plate with steel or wire reinforcements.
- Precast panels with ready holes. Soil nails shot through holes as an anchor. (2)
- Chain link fencing over nails on slopes wth loose materials. (2)

c. Other comments; Ideas:

- Blockout and bursting steel in precast concrete panel.
- Seems like conventional face attachment details would work with these nails, too.
- Application for 1-inch wire injected into the slopes.
- Methane problem was a brilliant usage.
- Saltwater applications with nonmetal nails.

- Consider recycling plastic parts.
- Automatic nailing system—10 shot clip?
- Machine has great potential; would like to see someone get one and put it to work.
- Would like to see someone borrow/rent nail launcher for 6 to 12 months and try it on slow moving slopes, walls, and such. Instrument sites; compare before and after performance and compare with alternate methods.

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Application Guide
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