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DEMONSTRATION PROJECT 103

Design & Construction Monitoring of Soil Nail Walls

Project Summary Report

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16. Abstract:

The purpose of Demonstration Project 103 was to introduce the concept of soil nailing use into the American transportation construction practice. The Manual for Design and Construction Monitoring of Soil Nail Walls (FHWA-SA-96-069R) and Soil Nailing Field Inspectors Manual (FHWA-SA-93-068) were published as a part of this demonstration project. Also, GOLDNAIL (soil nail design software) was developed and distributed thru this demonstration project. This report is a summary of the activities of Demonstration Project 103. It includes the history, concept, construction procedures and cost data for soil nail walls.

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I. INTRODUCTION

FHWA Demonstration Project (DP 103) was initiated in 1992. The purpose of Demonstration Project 103 was to introduce the concept of soil nailing use into the American transportation construction practice. DP 103 provided guidance for selecting, designing, and specifying soil nailing at sites which were technically suited and economically attractive for its application. Initial experience gained from early test projects resulted in the development of guide construction specifications and a construction inspectors manual (Publication No. FHWA-SA-93-068). After design techniques were proven in test projects, FHWA identified the GOLDNAIL software as a practical, user friendly tool which could expedite design of soil nail projects. FHWA produced adequate number of software licences for GOLDNAIL such that every State DOT and FHWA office could use the program.

Engineers responsible for design and construction of public works usually need long-term monitoring of new techniques pioneered in the private sector before the technology can be confidently incorporated in permanent public projects. DP 103 provided the documentation of the long-term performance of soil nail walls for 20 years of use in Europe and the United States to permit immediate implementation of this technology nationwide. Implementation of permanent soil nailing is consistent with national efforts to upgrade the safety and efficiency of the transportation system in the most cost-effective manner possible. The goal of this FHWA demonstration project was to assist U.S. transportation agencies in implementing the safe and cost-effective use of permanent soil nail designs as routine alternate bid items to the standard wall systems presently used to retain steep excavation cut slopes. That goal has been achieved through DP 103.

The showcase of Demonstration project 103 was the development of “Manual for Design and Construction Monitoring of Soil Nail Walls” (Publication No. FHWA-SA-96-069R). This manual discusses in detail the practical implementation of the soil nail technology. It includes detailed design procedures and comprehensive worked design examples, along with an example set of plan details and comprehensive guide construction specifications. In addition, a series of training workshops were presented in various states to provide an overview of soil nail technology and an in depth study of the design procedures for soil nail walls. Also, on-site, project specific technical assistance, soil nail construction inspection training and technical review of the designed projects was provided as a part of this demonstration project.

II. THE CONCEPT OF SOIL NAILING

The basic concept of soil nailing is to reinforce and strengthen the existing ground by installing closely-spaced steel bars, called "nails", into a slope or excavation as construction proceeds from the “top down.” This process creates a reinforced section that is internally stable and able to retain the ground mass. As with mechanically stabilized earth (MSE) walls, the reinforcements are passive and develop their reinforcing action through nail-ground interactions as the ground deforms during and following construction. Nails work predominantly in tension but may develop bending/shear in certain circumstances. The effect of the nail reinforcement is to improve stability by (a) increasing the normal force and hence the soil shear resistance along potential slip surfaces in frictional soils; and (b) reducing the driving force along potential slip surfaces in both frictional and cohesive soils. A construction facing is also usually required and is typically shotcrete reinforced by welded wire mesh. The steel nail bars are typically 20 to 35 mm in diameter, with a yield strength in the range of 420 to 500 N/mm^2, and are typically installed into drillholes having diameters in the range of 100 mm to 300 mm and at a spacing between 1 and 2 meters. The nail lengths are typically 70 to 100 percent of the wall height. Nail inclinations are generally on the order of 15 degrees below horizontal to facilitate grouting.

Soil nails typically consist of steel reinforcement inclusions and may be categorized on the basis of their method of installation and degree of corrosion protection. For conventional drill and grout nail installations, the nail grout consists typically of a neat cement grout with a water-cement ratio of about 0.4 to 0.5. Where a stiffer consistency grout is required (e.g., to centralize the nail when no centralizers are used in a hollow stem auger installation or to control leakage of grout into the ground such as in highly permeable granular soils or highly fractured rock), a lower slump sand-cement grout may be used. Sand-cement grout may also be used in conjunction with large nail holes for economic reasons.

III. HISTORY OF SOIL NAILING

Soil nailing has been used in a variety of civil engineering projects in the last two decades. The technique originated as an extension of rock bolting and of the "New Austrian Tunneling Method" (NATM) which combines reinforced shotcrete and rockbolting to provide a flexible support system for the construction of underground excavations. In North America, the first recorded application of the system was in Vancouver, B.C. in the early 1970's for temporary excavation support. In Europe, the earliest reported works were retaining wall construction in France (1972), and Germany (1976), in connection with highway or railroad cut slope construction or temporary building excavation support.

The French contractor Bouygues, in joint venture with the specialist contractor Soletanche, is credited with the first recorded application of soil nailing in Europe (1972/73) for an 18-m-high 70 degree cut slope in Fontainebleau Sand, as part of a railway widening project near Versailles. A total of 12,000 m^2 of face was stabilized by over 25,000 steel bars grouted into pre-drilled holes up to 6 m long.

The first major research program (Bodenvernagelung) on soil nailing was undertaken in Germany by the University of Karlsruhe and the contractor Bauer (1975-1981). This program involved full-scale testing of a variety of experimental wall configurations. As a result of the increasing use of soil nailing within France following its initial applications and the perceived lack of a defensible design methodology, the French initiated their own experimental program (Clouterre) in 1986. The Clouterre program involved three large-scale experiments in prepared fill (Fontainebleau sand) and the monitoring of six full-scale, in-service structures. The results of the initial Clouterre program have been published and a second phase of work, Clouterre II, has begun.

Within the 20 years since the introduction of soil nailing to Europe and the subsequent conduct of the two major national experimental programs, soil nailing has been and is now used very extensively in both France and Germany. The major attractions of the method are its economy, construction flexibility, ability to make use of small construction equipment that is particularly suited for use in urban environments, and its overall adaptability for special applications. Within France, it is reported that over 100,000 m^2 per year of soil nail walls are presently being constructed for public works alone, with perhaps hundreds of smaller undocumented walls constructed for private owners. To date, the great majority of these walls have been temporary in nature and have used shotcrete for the structural facing. The highest vertical soil nail wall in France is 22 meters high (at Montpelier). The highest battered soil nail wall (73 degree face angle) is almost 30 meters high (Dombes tunnel portal, near Lyon). In Germany, over 500 walls are estimated to have been constructed to date, with the majority being temporary basement walls using structural shotcrete facings.

IV. CONSTRUCTION OF SOIL NAIL WALLS

Figure 1 shows the typical sequence to construct a soil nail wall using the drill and grout method of nail installation, which is the most common method used in North America. The details of the construction sequence are as follows:

1. Excavate Initial Cut

Before commencing excavation, all surface water must be controlled by the use of collector trenches to intercept and divert surface water. The initial cut is excavated to a depth slightly below the first row of nails, typically about 1 to 2 meters depending on the ability of the soil to stand unsupported for a minimum period of 24 to 48 hours. Where face stability is problematical for these periods of time, a stabilizing berm can be left in place until the nail has been installed and final trimming then takes place just prior to application of the facing.

Mass excavation is done with conventional earth moving equipment. Final trimming of the excavation face is typically done with a backhoe or hydraulic excavator. Usually, the exposed length of the cut is dictated by the area of face that can be stabilized and shotcreted in the course of a working shift. Ground disturbance during excavation should be minimized and loosened areas of the face removed before shotcrete facing support is applied. The excavated face profile should be reasonably smooth and regular in order to minimize subsequent shotcrete quantities.

A level working bench on the order of 10 meters width is typically left in place to accommodate the drilling equipment used for nail installation. Smaller tracked drills are available that can work on bench widths as narrow as 5 meters and with headroom clearance as low as 4 meters. Larger bench widths may be necessary depending upon the equipment to be used during nail installation.

2. Drill Hole for Nail

Nail holes are drilled at predetermined locations to a specified length and inclination using a drilling method appropriate for the ground conditions. Drilling methods include both uncased methods for more competent materials (rotary or rotary percussive methods using air flush, and dry auger methods) and cased methods for less stable ground (single tube and duplex rotary methods with air or water flush, and hollow stem auger methods).

3. Install and Grout Nail

Plastic centralizers are commonly used to center the nail in the drillhole unless the nails are installed through a hollow stem auger in a stiff (200 mm or lower slump) grout mix. The nails are inserted into the hole and the drillhole is filled with cement grout to bond the nail bar to the surrounding soil. Grouting takes place under gravity or low pressure from the bottom of the hole

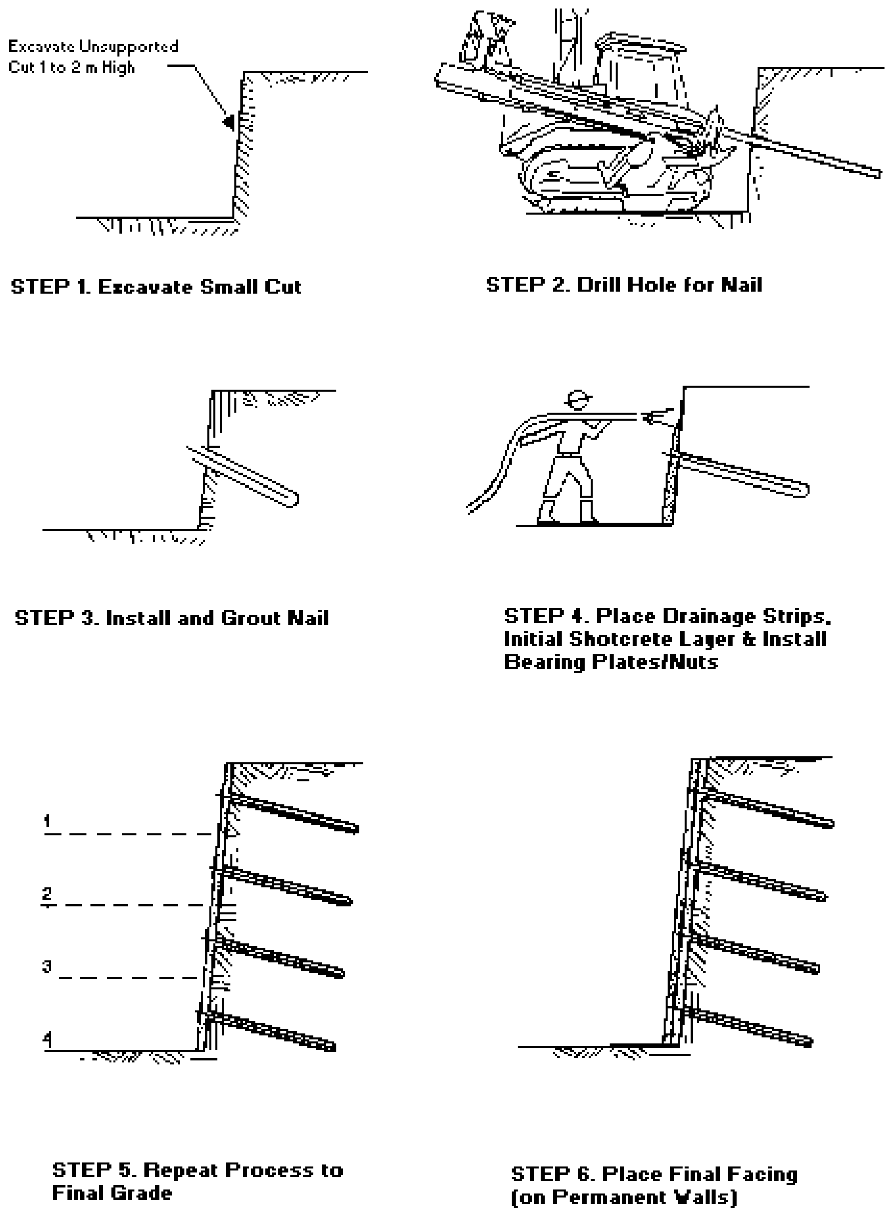

Figure 1. Typical Soil Nail Wall Construction Sequence

upwards, either through a tremie pipe for open-hole installation methods or through the drill string (or hollow stem) or tremie pipe for cased installation methods.

4. Place Drainage System

A 400 mm-wide prefabricated synthetic drainage mat, placed in vertical strips between the nail heads on a horizontal spacing equal to that of the nails, is commonly installed against the excavation face before shotcreting occurs, to provide drainage behind the shotcrete face. The drainage strips are extended down to the base of the wall with each excavation lift and connected either directly to a footing drain or to weep holes that penetrate the final wall facing. These drainage strips are intended to control seepage from perched water or from limited surface infiltration following construction. If water is encountered during construction, short horizontal drains are generally required to intercept the water behind the face.

5. Place Construction Facing and Install Bearing Plates

The construction facing typically consists of a mesh-reinforced wet mix shotcrete layer on the order of 100 mm thick, although the thickness and reinforcing details will depend on the specific design. Following placement of the shotcrete, a steel bearing plate (typically 200 mm to 250 mm square and 15 mm thick) and securing nut are placed at each nail head and the nut is hand wrench tightened sufficiently to embed the plate a small distance into the still plastic shotcrete.

6. Repeat Process to Final Grade

The sequence of excavate, install nail and drainage system, and place construction facing is repeated until the final wall grade is achieved. The shotcrete facing may be placed at each lift prior to nail hole drilling and nail installation, particularly in situations where face stability is a concern.

7. Place Final Facing

For architectural and long term structural durability reasons, a cast in place (CIP) concrete facing is the most common final facing being used for transportation applications of permanent soil nail walls. The CIP facing is typically structurally attached to the nail heads by the use of headed studs welded onto the bearing plates. Under appropriate circumstances, the final facing may also consist of a second layer of structural shotcrete applied following completion of the final excavation. Pre-cast concrete panels may also be used as the final facing for soil nail walls.

V. COST DATA

Costs for soil nail retaining structures are a function of many factors, including type of ground, site accessibility, wall size, facing type, level of corrosion protection, temporary or permanent application, and regional availability of contractors skilled in the construction of nail or tieback-type walls and shotcrete facings. In Europe, soil nailing costs in ground suitable for soil nailing are, in general, 20 percent lower than comparable tieback structures. In the U.S., a 30 percent saving was documented in DP 103 for projects where soil nailing was bid as an alternate to tieback walls. During the initial 2 years of DP 103, savings of \$3 million were documented. In 1997, the project manager estimated that the savings were about \$40 million on U.S. federal aid transportation projects completed to that date.

A major cost item for permanent soil nail walls is the facing. The addition of cast-in-place or precast facings placed over an initial 100 mm-thick construction shotcrete facing may be 40 to 50 percent of the total wall cost.

If installed in ground conditions well suited for soil nail wall construction (i.e., ground with good short-term face stability and in which open hole drilling methods can be used), soil nailing has proven to be a very economical method of constructing retaining walls. For cut retention, experience on U.S. highway projects indicates soil nail walls, when used in ground well suited to soil nailing, can provide 10 to 30 percent cost savings versus permanent tieback walls or conventional cast-in-place walls with temporary shoring.

Typical cost range for soil nail walls based on U.S. highway project bidding experience to date is:

- Temporary Walls: \$200-\$300/m^2
- Permanent Walls: - Roadway Cut \$300-\$400/m^2
    - End Slope Removal (Under Existing Bridges) \$400-\$600/m^2

Cost and other project data for a number of U.S. highway soil nail wall projects are included in Table 1.1. Costs are total in-place cost in dollars per square meter of wall face area.

TABLE 1.1 COST DATA FOR SOIL NAIL WALLS ON U.S. TRANSPORTATION PROJECTS

Project	Interstate 78 Allentown, PA	Interstate 10 San Bernadino, CA	Cumberland Gap Tunnel Project, KY	Interstate 90 Seattle, WA
Bid	1987	1988	1988	1989
Wall Application	Retain slope cut on ¼:1 slope between two rock cuts.	Allow widening of existing I-10 exit ramp.	Retain cut slope above tunnel portal.	Retain temporary cuts next to existing tunnel portal.
Soil/Rock Type	Colluvium and highly weathered rock	Silty, gravelly sand with cobbles and boulders.	Colluvium and weathered rock.	Silty sand (upper) Stiff clay (lower)
Field SPT (blowcounts)	NP	25 to 80	NP	7 to 77
Max. Wall H (m)	12.2 (2-tiered walls, each 6.1 m high with 3m offset).	6.7	Wall 1 – 12.2 Wall 2 – 5.5	10.7
Wall Length (m)	61	183	Wall 1 – 152 Wall 2 – 40	111
Nail Spacing (m)	1.5H x 1.5V	1.5H x 1.5V	1.5H x 1.2V 1.8H x 1.2V	1.2H x 1.2V
Nail Length (m)	8.2 to 10.7	5.8 to 7.0	5.8 to 13.1	3.0 to 13.4
Nail Design Load (kN)	127 to 232	NP	12 to 193	22 to 149
Estimated Ground-Grout Bond (Adhesion) (kN/m^2)	218 to 446 ult.	69 ult.	143 ult. * 207 ult. **	55 Design
Corrosion Protection	Galvanized bars	Fully encapsulated	Epoxy coated bar	Grout only (temporary nails)
Shotcrete Thickness (mm)	140 to 170	200	130 to 170	200
Permanent Facing	Precast panels (VSL).	Exposed shotcrete hand finish.	Exposed shotcrete gun finish sandstone color coloring agent	Reinforced shotcrete gun finish.
Face Batter	Vertical	1 on 10	1 on 8	1 on 4
Total Area (m^2) Nail Wall Face (bid)	646	809	999	744
Cost/m^2	\$580	\$290	\$390	\$300
Remarks	\$390 (nails and shotcrete) \$190 (face panels).		* Weathered Shale * Weathered Sandstone	

NP = Not Provided in Information Made Available

TABLE 1.1 (Cont.) COST DATA FOR SOIL NAIL WALLS ON U.S. TRANSPORTATION PROJECTS

Project	Interstate 5 Tacoma, WA	Route 37 Vallejo, CA	Interstate 5 Portland, OR	Interstate Highway 35 Laredo, TX
Bid	1989	1990	1990	1990
Wall Application	Widening under existing Bridge. Bridge abutment on spread footing.	Cut retention – Route 37, New I/C.	Widening under existing bridge. Abutment on piles.	Widening under existing bridge. Abutment on shafts.
Soil/Rock Type	Glacially consolidated dense sand, gravel, cobbles, boulders.	Weathered and fractures mudstone, clayey silt and gravel.	Clean loose sand	Gravelly sand.
Field SPT (blowcounts)	NP	25 to 57	4 to 29	NP
Max. Wall H (m)	6.1	10.4	6.1	5.6
Wall Length (m)	44	276	78	59
Nail Spacing (m)	1.5H x 1.5V	0.6 to 1.5H 0.8 to 1.5V	1.4H x 0.9V	0.9H x 0.9V
Nail Length (m)	7.3	3.0 to 6.4	4.0 to 7.3	5.5
Nail Design Load (kN)	35 to 136	NP	9 to 153	44
Estimated Ground-Grout Bond (Adhesion) (kN/m^2)	72 Design	55 ult.	48 ult.	25 Design
Corrosion Protection	Fully encapsulated	epoxy coated bar	epoxy coated bar	epoxy coated bar
Shotcrete Thickness (mm)	230	100	200	50
Permanent Facing	Finished structural concrete with pigmented sealer.	150 mm CIP plus precast panels and masonry block veneer.	Exposed shotcrete Class 1 finish with horizontal and vertical scoring strips. Pigmented sealer.	230mm CIP face with 25mm Fractured Rib surface treatment.
Face Batter	Vertical	Vertical	1 on 12	Vertical
Total Area (m^2) Nail Wall Face (bid)	186	1620 (one wall)	382	205
Cost/m^2	$430	$510* $910**	$630	$340
Remarks	Nail wall and tieback wall bid as alternates. Tieback wall bid at $610/m	* Soil nail wall and facing. ** Cost including change order for additional longer nails to stop landsliding.		

NP = Not Provided in Information Made Available

TABLE 1.1 (Cont.) COST DATA FOR SOIL NAIL WALLS ON U.S. TRANSPORTATION PROJECTS

Project	Interstate Highway 35 Olympia Park, TX	GW parkway at I-495, VA	Route 85 San Jose, CA	Route 23A Hunter, NY
Bid	1990	1990	1990	1990
Wall Application	Widening under existing bridge.	Widening under existing bridge. Bridge abutment on spread footing.	Cut retention – new depressed freeway.	Slope retention to accommodate structure.
Soil/Rock Type	Clayey sand.	Dense micaceous silt and weathered schist.	Clay with gravels and cobbles.	Silty gravel, sandy with clay and boulders.
Field SPT (blowcounts)	NP	25 to 50	NA	4 to 55
Max. Wall H (m)	5.6	7.9	8.5	8.5
Wall Length (m)	38	198	604	146
Nail Spacing (m)	0.9H x 0.8V	1.2H x 1.2V (under abut.) 1.5H x 1.5V (outside abut.)	1.5 to 2.4H 1.4 to 2.4V	1.8H x 1.8V
Nail Length (m)	5.5	6.1 to 10.1	7.9	3.1 to 7.6
Nail Design Load (kN)	44	126 to 203	NP	35 to 269
Estimated Ground-Grout Bond (Adhesion) (kN/m^2)	22 Design	48 Design	NP	219 Design
Corrosion Protection	Epoxy coated bar	Fully encapsulated	Epoxy coated bars	Epoxy coated bars
Shotcrete Thickness (mm)	50	180	100	279
Permanent Facing	230mm CIP face with 25mm Fractured Rib surface treatment.	180mm structural shotcrete. 150 mm CIP ribbed fascia wall.	200mm CIP with fractured fin texture.	CIP concrete and stone facing.
Face Batter	Vertical	Vertical	Vertical	1 on 12
Total Area (m^2) Nail Wall Face (bid)	79	1358	4438 (two walls)	777
Cost/m^2	$370	$580	$300 *$330	$748
Remarks		Soil nail wall VE substitute for tieback wall to eliminate traffic disruption caused by installing soldier piles through holes in bridge deck.	* Including change order for differing site conditions. NA – Not available.	Seepage at exc. face caused soil to slough prior to application of shotcrete.

NP = Not Provided in Information Made Available

TABLE 1.1 (Cont.) COST DATA FOR SOIL NAIL WALLS ON U.S. TRANSPORTATION PROJECTS

Project	Virginia Beach Toll Road at Independence Blvd, Virginia Beach, VA	I-66 over 495 Fairfax Co. VA	Minnesota Ave, NE Washington, DC	Highway 50 Sacramento, CA
Bid	1990	1990	1990	1991
Wall Application	Widening into bridge end slope, temporary wall.	Widening into bridge end slope.	Cut retention street widening.	Bridge end slope retention for freeway widening, spread footing abutment.
Soil/Rock Type	Silty clayey sands	Silt, silty clay	Silty clay	Silty sand and sandy silt with some clay
Field SPT (blowcounts)	7 to 13	7 to 13	7 to 25	16 to 100+
Max. Wall H (m)	5.0	6.0	3.5	4.7 at 1 ½ :1
Wall Length (m)	71	67	30	34
Nail Spacing (m)	1.8H x 1.8V	1.5H x 1.4V	0.9H x 0.9V	1.2H x 1.2V
Nail Length (m)	2.4	6.7	5.0	7.3
Nail Design Load (kN)	112	112	NP	NP
Estimated Ground-Grout Bond (Adhesion) (kN/m^2)	96 Design	96 Design	92 Design	42 ult.
Corrosion Protection	None	Fully encapsulated	None	Epoxy coated bars
Shotcrete Thickness (mm)	80	80	100	NA
Permanent Facing	None	250mm CIP	None	80mm CIP slope paving. 200mm CIP at bearing plate.
Face Batter	Vertical	1 on 12	Vertical	1 ½ on 1
Total Area (m^2) Nail Wall Face (bid)	317	330	100	257 (two slopes)
Cost/m^2	NP	$1000	$410	$450
Remarks	Temporary shoring for permanent CIP wall.	Field modification from auger/socketed soldier pile wall.	Temporary wall for construction.	

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TABLE 1.1 (Cont.) COST DATA FOR SOIL NAIL WALLS ON U.S. TRANSPORTATION PROJECTS

Project	Industrial Parkway OC @ I-880 Hayward, CA	Highway 101 San Jose, CA	Route 85 San Jose, CA	Route 89 Tahoe Pines, CA
Bid	1991	1991	1991	1991
Wall Application	Cut retention at bridge overcrossing for on-ramp. Abutment on piles.	Cut retention – freeway widening.	Cut retention – new depressed freeway.	Stepped wall, cut retention – road widening.
Soil/Rock Type	Silt clay with minor gravel.	Silty clay to clayey silt with minor sand and gravel.	Silty, gravelly sand and sandy gravel with minor clay.	Silty decomposed granite sand with cobbles and boulders.
Field SPT (blowcounts)	9 to 27	6 to 63	20 to 100+	NP
Max. Wall H (m)	4.0	6.1	6.7	4.3 (two tiered wall)
Wall Length (m)	55	685	2035	193
Nail Spacing (m)	1.1 to 2.6H x 1.1V	1.5H x 0.9 to 1.1V	1.8H x 1.1V	1.5H x 0.9 to 1.5V
Nail Length (m)	3.0 to 5.5	3.7 to 7.6	3.0 to 6.7	3.7 to 4.6
Nail Design Load (kN)	NP	NP	NP	NP
Estimated Ground-Grout Bond (Adhesion) (kN/m^2)	42 ult.	69 ult.	69 ult.	69 ult.
Corrosion Protection	Epoxy coated bars	Epoxy coated bars	Epoxy coated bars	Epoxy coated bars
Shotcrete Thickness (mm)	100	100	100	130
Permanent Facing	150mm CIP.	200mm CIP with fractured fin texture.	200mm CIP with fractured fin texture.	180mm CIP with simulated rock texture.
Face Batter	Vertical	Vertical	Vertical	1 on 10 (5.7 degrees)
Total Area (m^2) Nail Wall Face (bid)	169 (one wall)	3234 (three walls)	8909 (four walls)	604 (two walls)
Cost/m^2	$520	$390	$330	$420
Remarks				

NP = Not Provided in Information Made Available

TABLE 1.1 (Cont.) COST DATA FOR SOIL NAIL WALLS ON U.S. TRANSPORTATION PROJECTS

Project	Route 400 Atlanta, GA	Tonawanda Dr. Route 54 San Diego, CA	Route 85 Los Gatos/Saratoga, CA	Route 680 Walnut Creek, CA
Bid	1991	1992	1992	1992
Wall Application	Cut retention freeway	Cut retention.	Cut retention – new depressed freeway.	Cut retention – freeway widening.
Soil/Rock Type	Granite gneiss and saprolite.	Clayey sand and silty sand.	Sandy silt to silty sand with some gravel and clay.	Silty clay, clayey silt and silty clayey sand, with minor siltstone and claystone.
Field SPT (blowcounts)	30 to refusal	NA	24 to 100+	14 to 100+
Max. Wall H (m)	7.6	7.9	6.6	7.0
Wall Length (m)	98	154	551	365
Nail Spacing (m)	1.5H x 1.5V	1.8H x 1.6V	1.2 to 1.8 H 0.5 to 1.5V	0.8 to 2.1 H 0.6 to 1.8V
Nail Length (m)	12.2	5.5 to 6.1	3.7 to 7.0	3.0 to 7.9
Nail Design Load (kN)	222	NP	NP	NP
Estimated Ground-Grout Bond (Adhesion) (kN/m^2)	98 Design	103 ult.	62 ult.	42 ult.
Corrosion Protection	Fully encapsulated	Epoxy coated bar	Epoxy coated bar	Epoxy coated bar
Shotcrete Thickness (mm)	100	100	100	100 to 130
Permanent Facing	305mm CIP	200mm CIP with textured surface.	200mm CIP with fractured fin surface.	150mm to 250mm CIP with fractured fin texture.
Face Batter	Vertical	Vertical	Vertical	Vertical
Total Area (m^2) Nail Wall Face (bid)	502	975	1732 (six walls)	1863 (three walls)
Cost/m^2	$364	$422	$380	$300
Remarks	Wall added by supplemental agreement and price negotiated.	Soil nail wall VE substitute for tieback wall. Cost savings $268/m^2		Tieback slide retention wall on same project. Bid at $830/m^2

NP = Not Provided in Information Made Available

<u>TABLE 1.1 (Cont.) COST DATA FOR SOIL NAIL WALLS ON U.S. TRANSPORTATION PROJECTS</u>

Project	Interstate 80 Berkeley, CA	Route 121 Napa County, CA	Route 85 San Jose, CA	Route 85 San Jose, CA
Bid	1992	1992	1992	1992
Wall Application	Cut retention – freeway widening.	Cut retention for climbing lane and saving heritage oak tree.	Cut retention – new depressed freeway.	Cut retention – new depressed freeway.
Soil/Rock Type	Silty clay and silty sand.	Very dense decomposed volcanic tuff and conglomerate.	Silty clay and sandy clay to clayey sand with minor gravel.	Clay and silty gravel to silty sand with gravel.
Field SPT (blowcounts)	2 to 70+	50 to 100+	13 to 50	4 to 100+
Max. Wall H (m)	4.8	9.9	6.1	7.3
Wall Length (m)	110	62	1159	939
Nail Spacing (m)	0.6 to 1.5H x 1.2V	1.5 to 1.8H 0.9 to 1.8V	1.6H x 0.6 to 1.2V	0.8 to 1.5H 0.6 to 1.1V
Nail Length (m)	4.3 to 4.9	3.7 to 6.7	3.0 to 6.1	4.9 to 9.8
Nail Design Load (kN)	NP	125 to 160	NP	NP
Estimated Ground-Grout Bond (Adhesion) (kN/m^2)	28 to 55 ult.	NP	NP	14 to 48 ult.
Corrosion Protection	Epoxy coated bar	Epoxy coated bar	Epoxy coated bar	Epoxy coated bar
Shotcrete Thickness (mm)	130	100	100	100
Permanent Facing	150mm CIP with fractured fin texture.	170mm CIP with brush hammered texture.	200mm CIP with fractured fin texture.	200mm CIP with fractured fin texture.
Face Batter	Vertical	1 on 6	Vertical	Vertical
Total Area (m^2) Nail Wall Face (bid)	314	301	4591 (two walls)	3434 (four walls)
Cost/m^2	$495	$536 $601*	$270	$230
Remarks			* Includes brush hammer and stain finish.	

NP = Not Provided in Information Made Available

<u>TABLE 1.1 (Cont.) COST DATA FOR SOIL NAIL WALLS ON U.S. TRANSPORTATION PROJECTS</u>

Project	Quioccasin Road Richmond, VA	Route 2 Dixon IL	Interstate 80 Elmswood Park, NJ	Route 217 Cedar Hills Interchange Portland, OR
Bid	1992	1993	1993	1993
Wall Application	Temporary cut retention for road widening.	Cut retention – freeway widening.	Widening under existing bridge abutment on piles.	Cut slope retention for light rail.
Soil/Rock Type	Silty sand weathered granite.	Sand, highly fractured and sound sandstone.	Silty, gravelly sand	Clayey silt (Portland Hills Silt) over cobbly gravel.
Field SPT (blowcounts)	6 to refusal	7 to 80	6 to 75	4 to 49
Max. Wall H (m)	7.0	7.6	4.6	8.1
Wall Length (m)	335 (2 walls)	84	78	335
Nail Spacing (m)	1.5H x 1.5V	1.5H x 1.5V	1.2H x 1.5V	1.8H x 1.8V
Nail Length (m)	3.0 to 6.1	5.5	6.4	3.7 to 7.0
Nail Design Load (kN)	90 to 180	156	53	12 to 23 (Portland Hills Silt) 42 to 81 (Rubble basalt)
Estimated Ground-Grout Bond (Adhesion) (kN/m^2)	60 Design	69 ult.* 345 ult.**	48 Design	14.6 Design (Portland Hills Silt) 51.1 Design (Rubble basalt)
Corrosion Protection	None	Epoxy coated bar	Galvanized	Fully encapsulated epoxy coated bars
Shotcrete Thickness (mm)	100	100	76	102
Permanent Facing	None	200mm CIP with texture.	305mm CIP	203mm CIP with random board finish.
Face Batter	Vertical	Vertical	Vertical	1:12
Total Area (m^2) Nail Wall Face (bid)	1285	446	316	1958
Cost/m^2	$234	$431	$1242	$411
Remarks	Temporary cut for permanent CIP wall.	* Weakly cemented highly fractured sandstone. ** Sound sandstone.		

NP = Not Provided in Information Made Available

TABLE 1.1 (Cont.) COST DATA FOR SOIL NAIL WALLS ON U.S. TRANSPORTATION PROJECTS

Project	Route 217 Cedar Hills Interchange Portland, OR	Route 217 Cedar Hills Interchange Portland, OR	Route 26 Portland, OR	Route 28 over I-66 Fairfax County, VA
Bid	1993	1993	1993	1993
Wall Application	Cut slope retention for light rail.	Permanent wall supporting MSE wall	Cut slope retention for light rail.	Widening into bridge and roadway cutslopes.
Soil/Rock Type	Gravel and cobbles unit with silty sand matrix.	Clayey silt (Portland Hills Silt) over cobbly gravel.	Clayey silt and fragmented cobbly gravel.	Silt, silty sand weathered sandstone.
Field SPT (blowcounts)	8 to 36	7 to 44	6 to 32	20 to refusal
Max. Wall H (m)	5.3	9.1	10.0	5.5
Wall Length (m)	61	434	220	1299 (4 walls)
Nail Spacing (m)	1.8H x 1.8V	1.8H x 1.8V	1.8H x 1.8V	1.8H x 1.4V
Nail Length (m)	5.5 to 6.1	5.2 to 7.0	4.3 to 7.9	3.0 to 5.0
Nail Design Load (kN)	42 to 81	12 to 23 (Portland Hills Silt) 42 to 81 (Rubble basalt)	12 to 23 clayey silt 42 to 81 cobbly gravel	90 to 150
Estimated Ground-Grout Bond (Adhesion) (kN/m^2)	51.1 Design	14.6 Design (Portland Hills Silt) 51.1 Design (Rubble basalt)	14.6 Design (clayey silt) 51.1 Design (cobbly gravel)	96 Design
Corrosion Protection	Fully encapsulated epoxy coated bars	Fully encapsulated epoxy coated bars	Fully encapsulated epoxy coated bars	Epoxy coated bars
Shotcrete Thickness (mm)	127	127	100	100
Permanent Facing	204mm CIP with random board finish.	230mm CIP with random board finish.	200mm CIP with random board finish.	150mm CIP
Face Batter	1:12	1:12	1:12	1 on 24
Total Area (m^2) Nail Wall Face (bid)	164	3045*	1425	6080
Cost/m^2	$419	$465	$410	$360
Remarks	Top row of nails post-tensioned to restrict deflection under bridge abutment spread footing.	* 60% of wall area is MSE wall. Total cost includes MSE wall.		VE in lieu of auger/socketed soldier pile wall.

NP = Not Provided in Information Made Available

<u>TABLE 1.1 (Cont.) COST DATA FOR SOIL NAIL WALLS ON U.S. TRANSPORTATION PROJECTS</u>

Project	Route 101 Olympia, WA	Route 167 Seattle, WA	Interstate 90 Seattle, WA	Interstate 90 Seattle, WA
Bid	1993	1993	1993	1993
Wall Application	Roadway widening cut retention	Cut retention under bridge abutment for highway widening.	New depressed off-ramp.	Replacement of an old depressed concrete gravity wall.
Soil/Rock Type	Consolidated sand, silt; silty sand; silty gravelly sand.	Dense silty sand with layers of sandy silt.	Dense sandy gravel (fill) or clayey silt, clay or sandy clay (native ground).	Dense silty sand (backfill and glacial outwash)
Field SPT (blowcounts)	6 to 100+	21 to 100+	4 to 77	24 to 100+
Max. Wall H (m)	7.3	5.3	12.5	4.8
Wall Length (m)	236	121	187.4	57
Nail Spacing (m)	1.2 to 1.8H 0.9 to 1.2V	1.8H by 1.2V 1.6H by 1.2V*	1.2 to 1.8H 0.6 to 1.2V	1.5 to 1.8H 1.5 to 1.8V
Nail Length (m)	2.7 to 7.3	7.9 to 15.5	4.6 to 11.6	4.6 to 5.5
Nail Design Load (kN)	9 to 89	93 to 262	61 to 160	58 to 125
Estimated Ground-Grout Bond (Adhesion) (kN/m^2)	57 Design	69 Design	58 Design	71 Design
Corrosion Protection	Epoxy coated bar	Epoxy coated bar	Epoxy coated bar, fully encapsulated below footing.	Fully encapsulated
Shotcrete Thickness (mm)	150	150	150	250
Permanent Facing	180mm CIP with fractured fin finish.	180mm CIP with fractured fin finish.	180mm CIP with board finish and parapet.	140mm finished shotcrete over 110mm shotcrete.
Face Batter	Vertical	Vertical	1 on 10	1 on 12
Total Area (m^2) Nail Wall Face (bid)	1429	552	1414	214
Cost/m^2	$393	$336 w/ traffic barrier $334 w/o	$163	$462
Remarks		* Under bridge footing		Nails were installed through old wall prior to removing old wall face.

NP = Not Provided in Information Made Available

<u>TABLE 1.1 (Cont.) COST DATA FOR SOIL NAIL WALLS ON U.S. TRANSPORTATION PROJECTS</u>

Project	Interstate 5 Seattle, WA	Interstate 5 Tukwila, WA	Fort Baker – Fort Barry Tunnel Marin County, CO	Route 50 Cannon City, CO
Bid	1993	1993	1994	1994
Wall Application	Highway widening for HOV lanes.	Cut retention for highway widening for HOV lanes.	Temporary excavation support for tunnel reconstruction.	Cut retention highway widening and historic site protection.
Soil/Rock Type	Medium dense to very dense silty gravelly sand.	Dense glacial till, silty sand and gravel with cobbles and boulders.	Low to medium plastic clay, sandy clay, clayey gravel and clayey sand.	Sandy gravel with boulders.
Field SPT (blowcounts)	23 to 100+	3 to 42	8 to 50	NA
Max. Wall H (m)	7.8	2.6	7.9	4.9
Wall Length (m)	796 (five walls)	157	158	32
Nail Spacing (m)	1.2 to 1.5H 0.9 to 1.5V	1.8H (only one row of nails)	1.8H x 1.2 to 1.8V	1.2H x 1.2V
Nail Length (m)	1.7 to 11.9	3.9	3.7 to 9.8	4.0
Nail Design Load (kN)	9 to 144 (static) up to 179(dynamic)	58	129	174
Estimated Ground-Grout Bond (Adhesion) (kN/m^2)	40 to 86 Design	72 Design	67 ult.	137 ult.
Corrosion Protection	Epoxy coated or fully encapsulated below br. fnd.	Fully encapsulated	None (temporary wall)	Epoxy coated bar
Shotcrete Thickness (mm)	180 or 200	120	80	80
Permanent Facing	150mm CIP with fractured fin texture.	Hand-trowel finished shotcrete 120mm to 200mm as-built.	None	100mm timber.
Face Batter	Vertical	Vertical	1 to 6	1 on 8
Total Area (m^2) Nail Wall Face (bid)	3277 (five walls)	407	808	102
Cost/m^2	$341 w/ traffic barrier $326 w/o	$718	$341	$645
Remarks	Wall 11 has top 3 nail rows prestressed to 50% D.L. under bridge abutment spread foundation to limit deflection.	VE substitution, approximately $146,000 savings over CIP wall with temporary shoring.	VE substitution for temporary tieback shoring. Cost savings $112,000 (37%).	Cost includes timber facing.

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<u>TABLE 1.1 (Cont.) COST DATA FOR SOIL NAIL WALLS ON U.S. TRANSPORTATION PROJECTS</u>

Project	Interstate I-70 St Louis, MO	I-40/Route 220 Interchange Greensboro, NC	Albion Bridge Rehabilitation Lincoln, RI	Interstate 35 at Frio River, Pearsall, TX
Bid	1994	1994	1994	1995
Wall Application	Temporary Excavation support for freeway widening.	Cut retention below highway.	Slope retention at realigned bridge approach.	Retain existing embankment supporting highway.
Soil/Rock Type	Lean clay.	Severely to lightly decomposed granite.	Fine to coarse sand with silt and gravel.	Sand, clay, and gravel.
Field SPT (blowcounts)	NA	4 to 100+	10 to refusal	10 to 40
Max. Wall H (m)	5.5	6.4	5.5	4.6
Wall Length (m)	46	85	49.4	152
Nail Spacing (m)	1.2H x 1.2V	1.5H x 0.6 to 1.5V	1.2H x 1.2V	1.3H x 1.1V
Nail Length (m)	10.1	3.0 to 5.2	9,2	3.0 to 6.4
Nail Design Load (kN)	28	123 to 150	NP	62
Estimated Ground-Grout Bond (Adhesion) (kN/m^2)	16 ult.	97 to 138 Design	98 Design	62 Design
Corrosion Protection	None	Epoxy coated bar	Fully encapsulated	Epoxy coated bar
Shotcrete Thickness (mm)	100	80	220	76
Permanent Facing	None	200mm CIP	Granite rubble veneer	229mm CIP
Face Batter	Vertical	Vertical	1 on 16	Vertical
Total Area (m^2) Nail Wall Face (bid)	231	400	161	539
Cost/m^2	$459	$777	$1098*	$393
Remarks	VE substitution for tieback wall.	VE substitution for anchored shaft. Cost savings of $53/m	*Soil nailed wall only. First soil nail wall in Rhode Island.	Replacing gravity wall.

NP = Not Provided in Information Made Available

VI. RESEARCH

As a part of Demonstration Project 103, various research projects were funded by the FHWA to learn and explore more about the soil nailing technology. Early research was completed to confirm basic concepts prior to development of the design procedure. Later research was directed at fine tuning. Following are examples of some of these research projects.

Synthesis Report on Soil Nail Wall Facing Design, January 1998, prepared by Golder Associates Inc., Redmond, Washington.

The report of FHWA's Soil Nailing Scanning trip to Europe in September and October, 1992, concluded that a rational design method for the shotcrete construction facings for soil nail walls needed to be developed. The Europeans had not rigorously designed these facings because design formulae were not available to satisfactorily predict their structural capacity nor their contribution to the overall soil nail structure. Use was based primarily on successful experience in the field rather than by rigorous structural calculations. FHWA engineers (Chassie and Keeley) conducted a series of meetings in early February, 1993 with U.S. soil nail designers and contractors that confirmed an identical situation in the United States. Dr. Frieder Seible of the University of California at San Diego (UCSD) was selected as a subcontractor to CFLHD's engineering consultant, CH2M HILL, to develop and conduct a full scale laboratory testing program which was then used to calibrate a non-linear finite element analytical computer program (PCYCO). The PCYCO program was then used to analyze extensive parameter variations for construction and permanent facings from which preliminary design formulae for flexural strength and shear strength were developed. The testing and analysis results for the UCSD project are documented in a series of four reports from the University of California at San Diego (Report Numbers TR-94/03, TR-95/02, TR-95/03, and SSRP-96/01) and a series of three reports from SEQAD Consulting Engineers, Inc. (Report Numbers 94/10, 95/11, and 95/13).

Finalized flexure and shear design formulae were prepared by Golder Associates, Inc., (GAI), the FHWA DP103 consultant contractor, utilizing the UCSD full-scale testing and calibrated analytical parameter studies and further analytical work done by GAI for preparation of the FHWA manual for Design and Construction Monitoring of Soil Nail Walls (FHWA-SA-96-069). FHWA then commissioned GAI to produce this final report titled Synthesis Report on Soil Nail Wall Facing Design to provide an overall summary and background document in support of the finalized flexure and shear design formulae presented in the DP103 design manual.

The development and implementation of this overall facing design project was guided by a steering group of public and private design practitioners and soil nail wall and shotcrete specialty contractors. The project began with a planning meeting in San Diego on April 29, 1993, and concluded in December, 1995.

This FHWA facing testing program has resulted in the development of new flexure and shear design formulae that enable strength determination of the thin (typically 100 mm thickness) reinforced shotcrete facings being successfully used in Europe and the United States. The strength of these facings could not be adequately predicted by existing structural design specifications in Europe or the United States before the development of the DP103 formulae. Previous design methods used in Europe and the United States for the thicker permanent facings did not represent the actual structural performance of these facings either.

The new DP103 formulae for flexure utilize yield-line theory (as validated by the UCSD facing testing program) as opposed to the more traditional elastic methods used by many practitioners. The yield-line theory enables much better prediction of the facing's flexural performance and the determination of higher capacities. The new DP103 formulae for shear allow the full thickness of the shotcrete facing to be used for punching shear computations for external bearing plate details (as validated in the UCSD facing testing program) as compared to previous existing specifications that allow only the depth to the reinforcing steel (typically about half the facing thickness) to be used.

Implementation of the research under DP 103 resulted in a significant increase in the number of permanent shotcrete facings for soil nail walls.

Soil Nailing of a Bridge Embankment (Interstate-5 Swift Delta Soil Nail Wall), July 1995, prepared by Claude T. Sakr and Robert Kimmerling (FHWA Region 10), Oregon Department of Transportation

This report describes the design and the performance of the Interstate-5 soil nail wall, in North Portland, Oregon. The instrumentation program implemented during the construction of the wall is discussed in detail in this report. The instrumentation data at two vertical cross sections is presented and data interpretation is discussed. The performance predicted by the original design methodology is compared critically to the measured performance. Based on the results the study, it may be concluded that: a) the Interstate-5 Swift-Delta soil nail wall is performing well within structural safety limits for both the wall and the bridge abutment, b) tensile forces are maximum inside the soil nailed earth mass at some distance from the facing, c) a relative movement in the range of 1/8 to 1/4 (3.18 mm to 6.34 mm) is necessary to mobilize the tensile capacity of the soil nails, d) the Davis Method overestimates the nail forces in the lower nails and underestimates the nail forces in the upper nails, and e) Terzaghi and Peck’s braced cut empirical earth pressure diagram appears to be in reasonable agreement with measured loads to date.

This research confirmed the design procedures which were then promoted nationally in DP 103 workshops.

Evaluation of Design Methodologies For Soil Nailed Walls, Volume 1; Evaluation of Design Methodologies For Soil Nailed Walls, Volume 2: Distribution of Axial Forces in Soil Nails Based on Interpretation of Measured Strains; Evaluation of Design Methodologies for Soil Nailed Walls. Volume 3: An Evaluation of Soil Nailing Analysis Packages, July 1998, prepared by Sunirmal Banerjee, Andrew Finney, Todd Wentworth, and Mahalingam Bahiradhan, Department of Civil Engineering, University of Washington, Seattle, Washington.

Comparative evaluations of seven soil nail wall design computer programs are described and analyzed in these three volumes. The performance evaluations of the available programs SNAIL, NAIL-SOLVER, STARS, NAILM, GOLDNAIL, TALREN, and COLDUIM was accomplished by conducting a number of example analyses. Ten hypothetical cases and five case studies used in the analyses represented common scenarios. Also, examined were the magnitude and distribution of loads on the nails under normal working conditions. This was accomplished by observing the response of soil nails for a number of walls instrumented with strain gages. From this a general approach for estimating nail loads from strain history data was developed.

This research concluded that the GOLDNAIL software which was distributed to highway agencies by DP 103, adequately modeled the design of soil nail walls.

VII. PUBLICATIONS

The following publications were published as a part of Demonstration Project 103. All of the manuals mentioned below are available thru the National Technical Information Service (NTIS).

Manual for Design and Construction Monitoring of Soil Nail Walls (Publication No. FHWA- SA-96-069R) was finalized in October 1998. The original manual (FHWA-SA-96-069) and the revised version (FHWA-SA-99-069R) was written by R. John Byrne, David M. Cotton, James A. Porterfield, C. Wolschlag and G. Ueblacker of Golder Associates Inc.

This revised version of SA-96-069 incorporates primarily clarification and format changes received in the project workshops. However, the basic design and construction procedures are unchanged from the original. This manual is intended to permit engineers to rationally and confidently specify permanent soil nailing in cost-effective situations. A comprehensive review of current design and construction methods has been made and the results compiled into a guideline procedure. The intent of presenting the guideline procedure is to ensure that agencies adopting soil nail wall design and construction follow a safe, rational procedure from site investigation through construction. This manual is practitioner oriented and includes: description of the soil nailing concept and its applications; summary of experimental programs and monitoring of in -service walls; recommended methods of site investigation and testing; recommended design procedures for both Service Load Design (SLD) and Load and Resistance Factor Design (LRFD); worked design examples; simplified design charts for the preliminary design of cut slope walls; wall performance monitoring recommendations; discussion on practice and quality control of shotcrete application in soil nailing; discussion of contracting procedures and guidance on the preparation of soil nail design and construction documents; and presentation of procedures for determining the structural capacity of nail head connectors and wall facings, including demonstration calculations. This manual is intended to be used by engineers who are knowledgeable about soil mechanics and structural engineering fundamentals and have an understanding of the principles of soil-reinforcement technology and earth work construction.

Close attention was given to the presentation of suggested construction specifications and plan details. Contract documents such as these, which provide the transition from design analyses to field construction, frequently decide the success or failure of new design concepts. Every effort was made in the sample specifications to give all experienced nailing contractors an opportunity to use innovative methods or equipment in construction. Such specifications encourage contractors to seek cost-effective improvements to current soil nailing methods.

Soil Nailing Inspectors Manual - Soil Nail Walls (Publication No. FHWA-SA-93-068), April 1994, prepared by by R. John Byrne, David M. Cotton, James A. Porterfield of Golder Associates Inc.

The purpose of this manual is to provide field inspectors with knowledge necessary to effectively monitor and document the construction of soil nail retaining walls. This manual provides information useful to both the experienced and inexperienced soil nail inspectors. It is organized into two main parts: Preconstruction Preparation and Construction Inspection. Checklists are provided throughout the Construction Inspection sections of the manual which summarize key items discussed in the text.

FHWA Tour for Geotechnology - Soil Nailing *(Publication No. FHWA-PL-93-020),* June 1993, prepared by R. John Byrne, Ronald G. Chassie, James W. Keeley, Donald A. Bruce, Peter Nicholson, John L. Walkinshaw, Al DiMillio, Ken A. Jackura, Ron Chapman, and Claus Ludwig.

A scanning team of ten engineers, composed of FHWA, State Highway, and industry representatives traveled to Europe to collect and review soil nail design and construction information including contracting practices, and research and development activities from within the European community. During the three week trip (September 20 thru October 11, 1992), the team members met with individual or groups representing 21 different companies, research facilities, universities and public sector agencies in Great Britain, France and Germany. The Europeans have established themselves as leaders in the field of soil nailing technology and practice. The on-going and completed research projects have made a major contribution to our understanding of the mechanics of soil nailing behavior. Although we have constructed soil nail walls within North America which are equal in size to some of the largest walls constructed in Europe, the overall scope of soil nailing activity in Europe in 1992 was considerably larger than in North America. In addition, the Europeans have significant experience with some soil nailing construction techniques which had not yet been employed in North America. From a technological and a construction practices view, therefore, there was much valuable information to be obtained from the European experience. The results of their scanning efforts are summarized in this report.

Recommendations Clouterre 1991 *(Publication No. FHWA-SA-93-026).* This manual consists of recommendations that have been complied from studies of the French National Project CLOUTERRE, which was performed from 1986 to 1990. These studies were carried out from 1986 thru 1990 by a group of contracting authorities, prime contractors, research centers and laboratories, consulting firms, and construction companies under the auspices of The Economic and International Affairs Division of The Ministry of Public Works, Housing, Transport and Space, and the National Federation of Public Works. The English translation publication was sponsored by the Federal Highway Administration in July 1993.

VIII. WORKSHOPS

A total of 36 workshops were presented in various states over a period of two years, February 1997 thru February 1999. A list of these workshops is presented in Table 2.1. The workshops were presented by Mr. Richard S. Cheney (FHWA), Mr. Bob Leary (FHWA), Mr. Barry Siel (FHWA), and Dr. R. John Byrne and Mr. James Porterfield from Golder Associates Inc. The workshops consisted of 2 days of training. The intent of the workshops was to provide both an overview of soil nail technology and an in depth study of the design and construction procedures for soil nail walls. General topics such as a soil nail construction methods, construction inspection, and contracting methods were covered on day 1. The day 2 session was devoted to the detailed design procedures, including both LRFD and SLD design approaches. In addition, a demonstration of the computer programs, GOLDNAIL and SNAIL were presented on day 2.

The Demonstration Project presentation on day 1 was designed to accommodate a wide audience from the highway agency including: design engineers (geotechnical, structural, and roadway), construction engineers, project engineers, inspectors, and structural engineers who will be involved in the computation design aspects of soil nail walls. Day 2 involved very detailed presentations of both structural and geotechnical design computations which were specifically directed at design engineers.

The personnel who were intended to benefit most from this workshop were the first line supervisors/design engineers involved in the day to day design of highway structures. The target of the workshop was to convince the chief structural, design, and construction engineers to use soil nail walls on future Highway Agency projects.

IX. TECHNICAL ASSISTANCE AND REVIEW

Technical assistance was provided in the form of on-site, project specific technical assistance, soil nail construction inspection training and technical review of the designed project. Table 3.1 details some of the technical assistance and design review provided to the different states and government agencies. This table only includes the major cost saving projects where long term observations of performance has been documented.

X. CONCLUSION

The objective of Demonstration Project 103 was to assist U.S. transportation agencies in implementing the safe and cost-effective use of permanent soil nail designs as alternate bid items to the standard wall systems presently used to retain steep excavation cut slopes. This objective has been accomplished through research, manual publications, workshops and technical assistance and technology transfer of the soil nailing concept. State highway agencies are now considering soil nailing as a routine alternative to conventional techniques.

TABLE 2.1 SCHEDULE OF PRESENTED DP 103 WORKSHOPS

WORKSHOP LOCATION		DATE	NUMBER OF ATTENDEES
City	State		
Denver	Colorado	2/19/97	51
Sterling	Virginia	3/18/97	29
Vancouver	Washington	3/25/97	29
Raleigh	North Carolina	4/1/97	48
Salem	Oregon	4/15/97	30
Sacramento	California	5/13/97	65
Sacramento	California	5/15/97	40
Austin	Texas	5/20/97	51
Lacey	Washington	6/11/97	41
Nashville	Tennessee	7/29/97	48
Concord	New Hampshire	8/18/97	30
Montpelier	New Hampshire	8/20/97	17
Hudson	Wisconsin	9/23/97	50
Albany	New York	10/8/97	38
Topeka	Kansas	11/4/97	40
Jefferson City	Missouri	11/6/97	30
Harrisburg	Pennsylvania	12/9/97	48
Baltimore	Maryland	12/11/97	34
Montgomery	Alabama	1/21/98	36
Carson City	Nevada	2/3/98	40
Louisville	Kentucky	2/10/98	40
Atlanta	Georgia	3/4/98	55

TABLE 2.1 (cont.) SCHEDULE OF PRESENTED DP 103 WORKSHOPS

WORKSHOP LOCATION		DATE	NUMBER OF ATTENDEES
City	State		
Phoenix	Arizona	3/18/98	25
Springfield	Illinois	4/8/98	27
Tallahassee	Florida	4/1/98	39
Cheyenne	Wyoming	5/5/98	40
Boise	Idaho	5/27/98	44
Honolulu	Hawaii	7/20/98	37
Honolulu	Hawaii	7/22/98	21
Indianapolis	Indiana	9/9/98	40
Trenton	New Jersey	10/7/98	37
Albuquerque	New Mexico	10/21/98	40
Ann Arbor	Michigan	11/3/98	36
Oklahoma City	Oklahoma	11/17/98	34
San Juan	Puerto Rico	2/3/99	48
Boston	Massachusetts	2/9/99	36
Providence	Rhode Island	2/11/99	23

TABLE 3.1 DP 103 TECHNICAL ASSISTANCE SUMMARY REPORT (February 1994 thru May 1996)

DATE	AGENCY	PROJECT	APPLICATION	TECHNICAL ASSISTANCE (FHWA/GAI)	REMARKS
February, 1994	FHWA-CFLHD	Ft. Baker-Barry tunnel; San Francisco, CA	Temporary retaining wall for cut and cover tunnel	VE design review; Inspector training	First soil nail wall; provided $100,000 VE savings; Received appreciation letter from project engineer
February, 1994	FHWA-CFLHD	FH 007-4(6) Mendicino Pass, CA	Shotcrete repair of root pile slope stabilization structure	Design assistance on wall repair scheme	Recommended repair method consisting of new shotcrete facing and wall drainage. Received appreciation letter from CFLHD Division Engineer.
March, 1994	Washington DOT	SR-5, Seattle, WA	Permanent retaining walls: 3 cut slope; 2 bridge abutment end removal	Design review; 3-hour design/construction training class; Inspector training	Provided geotechnical recommendations during construction for resolution of design plan errors and site construction difficulties; Estimated $500,000 cost savings provided by soil nail walls
April, 1994	Colorado DOT	Pinnacle Rock, SR-50 Cannon, CO	Permanent retaining wall: cutslope stabilization to protect historical site	Design review; 3-hour design/construction training class; Inspector training	First CDOT soil nail wall; Estimates $35,000 cost savings; Provided geotechnical recommendations for resolution of site construction difficulties
May, 1994	Missouri DOT and Industry	Soil Nail Field Demonstration; St. Louis, MO	At industry request, participated in field demonstration of soil nail installation	Participation and technical assistance	Field demonstration done by industry to facilitate acceptance of soil nail technology by Missouri DOT and local consultants. Received appreciation letter from demonstration sponsor
August, 1994	FHWA-WFHD	Sylvan Pass Road; Yellowstone National Park, WY	Proposed permanent retaining wall: cutslope	Design feasibility review	First WFLHD soil nail wall; Estimated $70,000 savings versus permanent tieback wall or CIP wall, Reduced environmental impact

TABLE 3.1 (cont.) DP 103 TECHNICAL ASSISTANCE SUMMARY REPORT
(February 1994 thru May 1996)

DATE	AGENCY	PROJECT	APPLICATION	TECHNICAL ASSISTANCE (FHWA/GAI)	REMARKS
Septeber, 1994	Missouri DOT	Retaining Wall A5316, SR-70; St. Louis, MO	Temporary retaining wall; bridge abutment end slope removal	Design review; Inspector training; Construction problem resolution	First MDOT soil nail wall; Estimated $70,000 cost savings; received appreciation letters from Project Engineer, State Geotechnical Engineer, and Design Consultant
September, 1994	Maine DOT	SR-210, Moscow, ME	3 proposed permanent retaining walls: cutslope	Design feasibility review; 3-hour design/construction training class	First MDOT soil nail wall; Provided geotechnical recommendations for resolutions of site construction difficulties
November, 1994	North Carolina DOT	SR-220 and I-40 Interchange, Guilford County, NC	Temporary retaining wall: cutslope	Design review; Construction Inspection training	First NCDOT soil nail wall; Provided $52,000 cost savings; Received appreciation letter from NCDOT
April, 1995	AASHTO T-15 Retaining Wall Sub-committee	UC San Diego, FHWA test program for soil nail wall facings	Nationwide application for temporary and permanent soil nail wall	Presentations made to AASHTo T-15 subcommittee members	Presentations made to obtain input from and facilitate adoption of DP 103 design and construction specifications by AASHTO
May, 1995	Vermont DOT	SR-100, Readsboro-Whitingham, VT	2 proposed permanent retaining walls; cutslope	Design feasibility review	First VDOT proposed soil nail wall; Provided recommendations regarding design/construction issues due to difficult ground conditions
May, 1995	Arizona DOT	SR-87, Payson, AZ	Permanent rock slope repair	Design review; Construction inspection training	First ADOT soil nail wall; Estimated $90,000 savings; Provided resolution of site construction difficulties

TABLE 3.1 (cont.) DP 103 TECHNICAL ASSISTANCE SUMMARY REPORT (February 1994 thru May 1996)

DATE	AGENCY	PROJECT	APPLICATION	TECHNICAL ASSISTANCE (FHWA/GAI)	REMARKS
June, 1995	Idaho DOT	SR-95, Bonners Ferry, ID	Proposed permanent retaining wall: cutslope	Design feasibility review; 3-hour design/construction training class	Provided geotechnical design/construction recommendations for first IDOT proposed soil nail wall; Estimated $200,000 savings versus permanent tieback wall and reduced environmental impact
July, 1995	Ohio DOT	I-75, Findley, OH	Repair of older corroded metal binwall	Design assistance; Provided guide construction and specification	First Ohio DOT proposed soil nail wall; Estimated $20,000 savings versus wall replacement and no traffic disruption
August, 1995	Maine DOT	SR-1, Brunswick, ME	2 proposed permanent retaining wall: bridge abutment and slope removal	98% plan review	First MDOT bridge abutment soil nail wall; Estimated $50,000 savings; Provided example design-build plans and construction specifications
March, 1996	Nevada DOT	I-15 and US 95 Interchange, Las Vegas, NV	2 permanent soil nail retaining walls: bridge abutment and slope removal	Design review; Construction inspection training	First NDOT soil nail wall; Provided geotechnical recommendations for resolution of site construction difficulties
January, 1996	Missouri DOT	Route 71, City of Grandview	Bridge and end slope removal	Construction and wall performance monitoring technical assistance	First permanent soil nail wall in Missouri for bridge abutment application
May, 1996	Utah DOT	Provo Canyon, SR-189, Provo, UT	8 permanent soil nail retaining walls; cutslope	Design review and construction inspection training	First UDOT soil nail walls; Provided geotechnical recommendations for resolution of plan and specification deficiencies and site construction difficulties

REFERENCES

1. Banerjee, S., Andrew Finney, Todd Wentworth, and Mahalingam Bahiradhan, 1998, *Evaluation of Design Methodologies For Soil Nailed Walls, Volume 1; Evaluation of Design Methodologies For Soil Nailed Walls, Volume 2: Distribution of Axial Forces in Soil Nails Based on Interpretation of Measured Strains; Evaluation of Design Methodologies for Soil Nailed Walls. Volume 3: An Evaluation of Soil Nailing Analysis Packages*, Department of Civil Engineering, University of Washington, Seattle, Washington.

2. Byrne, J.R., Ronald G. Chassie, James W. Keeley, Donald A. Bruce, Peter Nicholson, John L. Walkinshaw, Al DiMillio, Ken A. Jackura, Ron Chapman, and Claus Ludwig, 1993, *FHWA Tour for Geotechnology - Soil Nailing*, Federal Highway Administration, Washington D.C., FHWA-PL-93-020.

3. Golder Associates Inc., 1998, *Synthesis Report on Soil Nail Wall Facing Design.*

4. Porterfield, J.A., Cotton, D.M., Byrne, R.J., Wolschlag, C., and Ueblacker, G., 1998, *Manual for Design and Construction Monitoring of Soil Nail Walls*, Federal Highway Administration, Washington D.C., FHWA-SA-96-069R.

5. Porterfield, J.A., Cotton, D.M., Byrne, R.J., 1994, *Soil Nailing Inspectors Manual*, Federal Highway Administration, Washington D.C., FHWA-SA-93-068.

6. Sakr, C.T., and Robert Kimmerling, 1995, *Soil Nailing of a Bridge Embankment (Interstate-5 Swift Delta Soil Nail Wall)*, Oregon Department of Transportation.

7. *Recommendations Clouterre*, *1991*, Federal Highway Administration, Washington D.C., FHWA-SA-93-026.

APPENDIX

SOIL NAIL WALL INSTALLATION AND COST SAVINGS PROJECT EXAMPLES

Figure A-1. Black Lake Interchange, WSDOT Olympia, WA - Prior to Construction

Figure A-2. Black Lake Interchange, WSDOT Olympia, WA - Soil Nail Wall Construction

Figure A-3. Black Lake Interchange, WSDOT Olympia, WA - Completed Soil Nail Wall Project

Highway 101 - Olympia, WA
Black Lake Interchange (WSDOT)

	Wall Alternatives	Cost
1988	CIP + temporary shoring (Consultant Design)	$1,300,000 (Est.)
1990	Permanent Tieback (WSDOT Design)	$ 900,000 (Est.)
1993	Permanent Soil Nail Wall	$ 500,000 (Est.)

Figure A-4. Black Lake Interchange, WSDOT Olympia, WA - Alternative Wall/Cost Comparison

Figure A-5. I-5, WSDOT Tacoma, WA - Soil Nail Wall in Tacoma (Bridge End Slope Removal)

COST DATA
I-5 TACOMA (WSDOT)

Wall Quantity 2,000 S.F.

Bid Alternates

Four Bidders

Permanent Tieback Wall (1 Bid)	$ 57/S.F.
Permanent Soil Nail Wall (Low Bid)	$ 40/S.F.

30% Savings

Figure A-6. I-5, WADOT Tacoma, WA - Alternative Wall/Cost Comparison