Implementation of Soil-Nailing Technologies in the United States

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Throughout history builders have met the challenges of implementing the designs presented to them by engineers and architects. In the past, land was more readily available, construction was mostly undertaken with manual labor, and time to completion was sometimes measured in centuries. In modern times, the large population increase, expansion of urban areas, and soaring land values have placed new demands on designers of private or public works. Even more challenged are the contractors of the underground portions of these works. Underground subsurface conditions, even after the most comprehensive geotechnical exploration programs, will often provide surprises and vary to some degree from those that were anticipated.

To remain competitive and stay in business, contractors must continually come up with innovative construction techniques, tools, and products to complete their projects. The successful techniques almost always include a certain amount of flexibility to adapt to changing ground conditions. The profit incentive has boosted the development of a vast array of innovative ground support, ground improvement, and deep foundation systems in the last 30 years.

Unfortunately for designers, these changing technologies are often not well documented at first, and consequently the desire to incorporate them into new projects is hampered by the engineering time it takes to become familiar with the technique and the risk or liability to be assumed. Additionally, with the traditional owner/designer/contractor relationships practiced in the United States, there is little incentive for the designer to suggest "unproven" cost-saving techniques for clients if it means taking on more risk and liability. This is particularly true for public works projects, for which it is sometimes difficult to include and enforce prequalification statements or special provisions in the contract documents to ensure that the contractor will be familiar with the intricacies of the ground behavior and installation techniques associated with the "new" system.

The Federal Highway Administration has established an International Technology Scanning Program, which has been described in more detail by Bravo (*1*) in the November–December 1993 issue of *TR News*. The primary purpose of this program is to facilitate exchange of information on technology between foreign countries and the United States. The passage of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), which asks FHWA to "inform the domestic highway community of technological innovation abroad that could significantly improve highway transportation in the United States," greatly supported and enhanced the activities under the already established International Technology Scanning Program. An overview of the development and implementation strategy developed by FHWA for Demonstration Project 103 on Soil Nail Walls is presented in the following sections.

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Soil Nailing

Soil nailing is a construction technique used to reinforce and strengthen proposed earth cuts or slopes in existing ground. It is accomplished by installing closely spaced, passive, structural inclusions known as "nails" into the soils to increase their overall shear strength.

One of the unique features of soil-nailed walls is that they are built from the top down in small, typically 2-meter (6 feet or less), successive, lifts (see Figure 1). The construction of each lift involves the following three steps, which are repeated until the final depth is achieved:

1. Excavation,
2. Nail installation, and
3. Shotcreting.

Permanent walls typically include an additional step consisting of placement of a permanent wall facing (cast-in-place concrete, precast elements, or additional shotcrete) over the initial shotcrete layer (see Figure 2).

The nails normally consist of steel bars grouted into holes drilled into the ground. Other methods of installation have been developed by some specialty contractors. The term "passive" means that the nails are not pretensioned when they are installed, as is the case with tiebacks. The nails are "tensioned" as the ground deforms laterally in response to continued excavation. A structural facing connected to the nails is used when the slope angle exceeds some critical value or when the environmental conditions would cause deterioration of the exposed

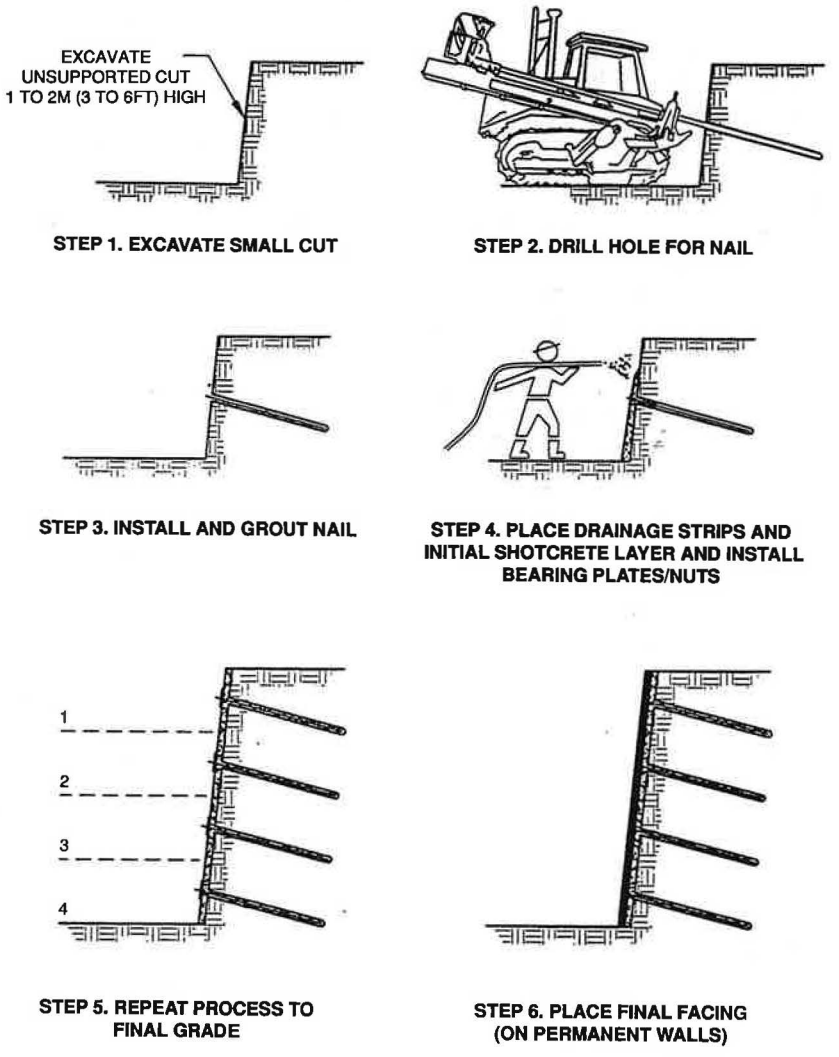

FIGURE 1 Typical nail wall construction sequence.

face over its design life. Although the concept bears some resemblance to mechanically stabilized earth (MSE) walls, soil nails are not used in bottom-up fill construction.

To date soil nailing has been used principally for temporary support of excavations at building sites or for slope stabilization along transportation corridors. At building sites, vertical walls are quite common. Permanent applications have been fewer in number but offer the potential for significant cost savings (often 10 to 30 percent) over conventional earth-retaining wall systems when designed and constructed in appropriate ground conditions. The cost savings are obtained primarily from the expediency of construction and the structural benefits of distributing the face loads over a large number of nails. The elements of the system are currently sized using accepted design techniques that are typically considered to be conservative.

History of Soil Nailing

The first soil-nail walls were built in France in 1972 and in the United States in 1976. They were used mostly in Europe, primarily in France and Germany, and it was not until the late 1970s in Germany or mid-1980s in France that major research and testing on the performance of the system was undertaken. As a result, most of the engineering data developed to date are located in those countries.

In 1985 FHWA initiated a research project on the soil-nailing technique. A final report on this research was published in 1991 (2). Although the final research report contained some useful information, the "limitations" section included the sentence, "As with any developing technique, not all of the principles of in situ reinforcement or the influence of various installation techniques are completely understood." Further, a design method that was sufficiently validated or usable by practicing engineers was not presented in the report. More work was required before the soil-nailing technique could be actively implemented by state transportation agencies.

Development and Marketing Strategy

In 1989 a technical advisory committee (consisting of state and FHWA geotechnical engineers) met to rank in priority order funding for the various technologies under the "umbrella" FHWA Demonstration Project 82, Ground Modification Techniques. MSE walls and soil-nail walls were recommended as the top priorities for which FHWA would develop geotechnical demonstration projects. In November 1993 the FHWA Office of Technology Applications (OTA) decided to make the soil-nail wall demonstration a stand-alone project.

From the outset, a marketing strategy has been part of the development process for the soil-nail wall demonstration project. The strategy has included interaction and active cooperation with interested state highway agencies and technical

groups from the American Association of State Highway and Transportation Officials (AASHTO) and industry. The development and marketing strategy included the following major elements, of which the first nine items have been accomplished as of February 1994 and the remaining are in progress.

1. *Lead-off Meeting with Office of Technology Applications (OTA)*

In 1990 an initial planning meeting was held in Washington, D.C., to review the project. One of the most important things to come out of that meeting was the idea that any new product to be marketed must be technically sound. Research needs and development or experimental work would be assessed first, and then the demonstration project development planned accordingly.

2. *Developing the Expertise*

The FHWA project engineer (Chassie) spent approximately two years going through the "learning curve" for soil-nailing technology. This included extensive reading of the technical literature, site visits to construction projects to gather case history information and cost data, visits and discussions with specialty contractors and consultant designers, and—as increased knowledge was obtained—providing technical assistance on design and construction projects to state highway agencies, FHWA federal lands offices, and private industry.

3. *Comparison of Design Methods*

Early on, it was apparent that no "standardized" method existed for the design of soil-nail walls. Review of the literature and discussion with other U.S. engineers revealed that there were several different design methods that had been developed and were in use. An informal design methods comparison, initiated by the demonstration project engineer, was then conducted. Several representative example problems were developed and sent to five different groups to complete using their design method. This exercise led to the identification of the two most viable U.S. design methods.

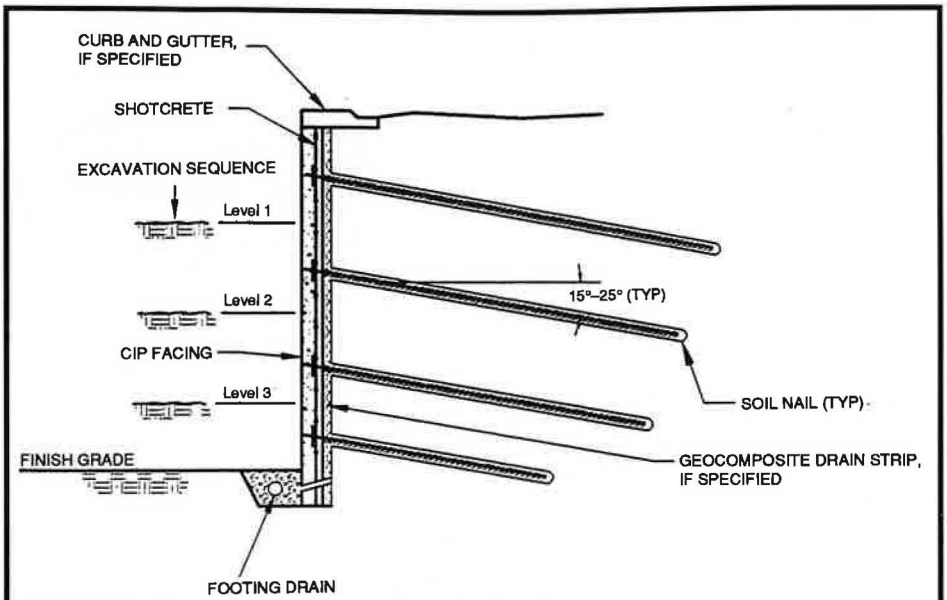

FIGURE 2 Typical section through vertical wall.

4. *Translation of French Soil-Nailing Manual*

Through review of the literature, the authors obtained a copy of the recently completed French manual on soil nailing, which was the culmination of an extensive five-year, 22 million French francs ($5 million) research project on soil nailing conducted from 1986 to 1991 by the French government in cooperation with French contractors, consultants, and universities. Through a cooperative agreement with the French, FHWA has obtained permission to translate the manual into English. That translation has been done through a voluntary effort by French, United Kingdom, and U.S. engineers (3). OTA published the report for U.S. distribution in early 1994.

5. *Interaction with Industry and AASHTO*

From the start of the demonstration project development, a commitment was made to give industry the opportunity to provide input. This is being successfully accomplished, to the betterment of the products being developed. Transportation Research Board committees in the geotechnical engineering field sponsored technical sessions on soil nailing at the 1991 and 1993 TRB Annual Meetings. Two specialty contractors participated in the European Scanning Tour (see Item 6). Specialty contractors, through the International Association of Foundation Drilling Earth Retention Committee, have assisted in a critical review of the Field Inspector's Manual (see Item 9). Written commitments have been received from 10 contractors and consultants to contribute to the cooperative effort on structural testing of nail wall facings (see Item 10). Technical working groups composed of state highway agency, specialty contractor, consultant, university, and FHWA engineers have been formed to guide the development of both the nail wall facing structural testing programs and development of the design and construction guidelines manual and workshop (see Item 12).

6. *European Scanning Tour*

After reviewing all the literature published in English on the subject and discussions with industry, it was determined that additional information from Europe was necessary to resolve detailed design and construction issues faced by American engineers. In 1991, during a personal visit to Switzerland, one of the authors was asked to contact a few of the princi-

pal French authors of papers on "clouage," as soil nailing is called in France. Following that visit, it was recognized that a multidisciplinary team was desirable for a technical scanning tour. The team's objectives would be to gather information and, even more important, to help disseminate the team's recommendations to the engineering community after the trip.

Before the selection of team members took place, one of the most important steps taken was to write a description of the tasks for and functions of each team member. These included a description of their responsibilities before, during, and after the trip and helped define the team size required and the expertise needed. The team was composed of two geotechnical engineers, a structural and a research engineer from FHWA, a state department of transportation (DOT) computer specialist, a consulting engineer, and representatives from two specialty contracting firms.

During the three-week trip in September–October 1992, team members met with individuals or groups representing 21 different companies, research facilities, universities, and public sector agencies in England, France, and Germany. The information gathered on the scanning tour (4) has proven invaluable to the development of the demonstration project. One of the major payoffs of the tour was obtaining wall instrumentation and test data for several test and in-service walls built in France and Germany. These data represent money that will not have to be expended in the United States to duplicate work that has already been done in Europe.

7. *Identification of Additional Research and Development*

With the help of the scanning tour, it has been possible to identify the significant missing gaps in the technology (4). This has led to the initiation of two state planning and research (SPR) projects that are running concurrently with the demonstration project development work. These include an SPR project being conducted at the University of Washington to prepare a case history data base and perform a more detailed design methods evaluation and validation. This research project is being cofunded by Washington State DOT ($60,000) and FHWA ($50,000). A second SPR project, being conducted at Portland State University, is studying the interaction of nail walls and bridge abutments for nail walls used in pile-supported bridge abutment applications. That project is being cofunded by the Oregon Department of Transportation ($25,000) and FHWA ($25,000).

Completed, permanent soil-nailed wall along highway in Germany. Tiered to allow plantings, it is known as a "greening" wall. Wall facing is dry-mix structural shotcrete left-in-the-gun finish.

8. *Experimental Features Projects*

Concurrently with the demonstration project development work, several U.S. highway projects have been supplied with performance-monitoring instrumentation as "experimental features" projects. The experimental features designation allows the use of construction funds to pay for the instrumentation, data gathering, and evaluation, freeing scarcer demonstration funds to be used for development work. Instrumented experimental features projects have been performed in Seattle and Renton, Washington; Fairfax, Virginia; Portland, Oregon; Dallas, Texas; Haines Falls, New York; and Atlanta, Georgia.

9. *Development of Soil-Nailing Field Inspectors Manual*

Previous experience with other demonstration projects on reinforced earth and tieback walls indicated that one of the major hindrances to implementation of such new geotechnology was the lack of specific detailed guidance to construction inspectors. Initially, construction inspectors have no experience or knowledge of the new technology. With funding from OTA, an excellent *Soil-Nailing Field Inspectors Manual* has been prepared. The manual is now finished and will be published and distributed in 1994 (5).

10. *Structural Testing of Soil-Nail Wall Facings: A Cooperative Effort*

The European scanning tour revealed that the major gap in research and work completed to date was the lack of any testing to determine the actual structural capacities of shotcrete and cast-in-place facings used for soil-nail walls. This has led to the initiation of a cooperative testing program between FHWA and industry. OTA and the Turner Fairbank Highway Research Center are cofunding the FHWA portion of the testing program. State highway agencies, industry, and consultants are contributing time, materials, and labor. Formulation of the detailed testing plan is under way and the testing program will be performed later in 1994. The goal of this testing effort is to develop a nail wall facing structural design procedure that can easily be adopted by AASHTO and which will also be in accord with the new AASHTO load and resistance factor design bridge specifications. This portion of the development is being undertaken by FHWA's Western Bridge Design Office, Denver, Colorado, with active coordination with the AASHTO Bridge Subcommittee on Retaining Walls.

11. *Development of Guide Construction Specification and Guide Nail Testing and Acceptance Procedures*

These documents are currently under preparation and will assist state DOTs with the implementation of this new technology, particularly those that have not yet used it.

12. *Development of Design and Construction Guidelines Manual and Two-Day Workshop, and Provision of Technical Assistance*

This constitutes the final phase of the demonstration project development and the beginning of active demonstration. A well-qualified engineering consulting firm has now been selected to assist with development. Great emphasis is being placed on the development of design procedures that are practical, easy to understand, and aimed at practicing engineers and that can be easily codified into AASHTO design specifications. Manual preparation will be completed in early 1995.

After completion of the design and construction guidelines manual, a two-day training workshop will be prepared. The workshop will then be made available to any transportation agency that requests it. Project-specific technical assistance on design and construction inspection of nail walls, construction troubleshooting, and shotcrete technology will also be provided during both the development and active presentation portions of the demonstration project.

Conclusion

The development work on this demonstration project has vividly illustrated that an implementation and marketing strategy must be considered and included as part of the development process. The goal is to achieve high-quality demonstration products, which, when ready to "go on the street" and be actively promoted and marketed, will already have been accepted by state DOTs, AASHTO, and industry. Throughout the development of the soil nail wall demonstration project, the emphasis has been on achieving a quality product, for quality products sell themselves.

Acknowledgments

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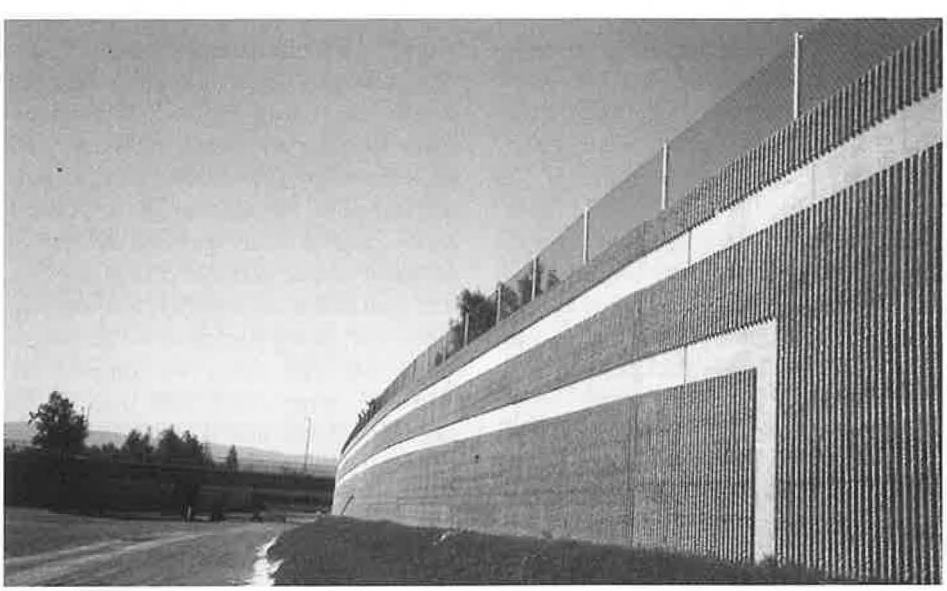

Completed permanent soil-nail wall in California along Route 85, San Jose, California. Wall facing is cast-in-place concrete placed over temporary shotcrete.

Coming and Going, New PBS Series

Coming and Going, a three-part television series on transportation, will premiere on the Public Broadcasting System on Fridays, June 3, 10, and 17 (check local listings for time). The myriad ways that travel and transportation have influenced the way Americans live—and a look ahead to the challenges of the future—are the subjects of this new series.

The first one-hour program, "Over the Long Haul," examines the transportation services—the ships, trains, and trucks—that haul freight. The second, "Coast to Coast," offers an ode to America's wanderlust. The final episode, "Road to the Future," looks at how transportation can both destroy and create the idea of community, along with new solutions to enable transportation to serve the needs of Americans.