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16. Abstract

In June 2002 the scan team met in Europe with technical and industry leaders representing Belgium, Germany, Italy, the Netherlands, Sweden, and the United Kingdom to identify and evaluate innovative European technologies in accelerated construction of bridge and embankment foundations. The scan team also explored opportunities for cooperative research and development and implementation of accelerated construction technology.

The scan team identified and evaluated 30 technologies and 15 processes with the potential for accelerating construction in the areas of bridge foundation systems, equipment, and ground improvement methods; embankment deep foundation systems, equipment, and ground improvement methods; embankment mat foundation systems and equipment; embankment construction equipment and methods; innovative earth-retention systems; and processes and implementation methods. The report provides tabular summaries of these technologies along with a relative ranking in terms of anticipated improvements in construction time, cost, and quality.

The overall goal of the scan trip is to implement technologies of best practice in the United States. With this objective clearly in mind, team members developed an implementation ranking. The technologies that were selected for immediate implementation action are:

- Column-supported embankments
- Continuous flight auger and cased secant pile bridge foundations
- Automated computer installation control and installation documentation
- Self-compacting concrete

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Innovative Technology for Accelerated Construction of Bridge and Embankment Foundations In Europe

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The National Cooperative Highway Research Program (Panel 20-36) of the Transportation Research Board

SEPTEMBER 2003

FHWA INTERNATIONAL TECHNOLOGY EXCHANGE PROGRAMS

The Federal Highway Administration's (FHWA) international programs focus on meeting the growing demands of its partners at the Federal, State, and local levels for access to information on state-of-the-art technology and the best practices used worldwide. While FHWA is considered a world leader in highway transportation, the domestic highway community is interested in the advanced technologies being developed by other countries, as well as innovative organizational and financing techniques used by FHWA's international counterparts.

The International Technology Scanning Program accesses and evaluates foreign technologies and innovations that could significantly benefit U.S. highway transportation systems. Access to foreign innovations is strengthened by U.S. participation in the technical committees of international highway organizations and through bilateral technical exchange agreements with selected nations. The program is undertaken cooperatively with the American Association of State Highway and Transportation Officials and its Select Committee on International Activities, and the Transportation Research Board's National Cooperative Highway Research Program (Panel 20-36), the private sector, and academia.

FHWA and its partners jointly determine priority topic areas. Teams of specialists in the specific areas of expertise being investigated are formed and sent to countries where significant advances and innovations have been made in technology, management practices, organizational structure, program delivery, and financing. Teams usually include Federal and State highway officials, private sector and industry association representatives, and members of the academic community.

FHWA has organized more than 50 of these reviews and disseminated results nationwide. Topics have included pavements, bridge construction and maintenance, contracting, intermodal transport, organizational management, winter road maintenance, safety, intelligent transportation systems, planning, and policy. Findings are recommended for follow-up with further research and pilot or demonstration projects to verify adaptability to the United States. Information about the scan findings and results of pilot programs are then disseminated nationally to State and local highway transportation officials and the private sector for implementation.

This program has resulted in significant improvements and savings in road program technologies and practices throughout the United States, particularly in the areas of structures, pavements, safety, and winter road maintenance. Joint research and technology-sharing projects have also been launched with international counterparts, further conserving resources and advancing the state of the art.

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Abbreviations and Acronyms

AASHTO	American Association of State and Highway Transportation Officials
ADECO	Analysis of Controlled Deformation
ADSC	International Association of Foundation Drilling
CDW	Continuous diaphragm wall
CFA	Continuous flight auger
CIP	Cast-in-place
CPT	Cone penetration test
CSP	Cased secant pile
CSV	Soil stabilization with vertical columns
DOT	Department of Transportation
EC	European Commission
EU	European Union
FHWA	Federal Highway Administration
FWD	Falling weight deflectometer
GEC	Geotextile-encased columns
GRP	Glass-reinforced plastic
IBRC	Innovative Bridge Research and Construction
LRFD	Load and resistant factor design
MSE	Mechanically stabilized earth
NDM	National Deep Mixing Cooperative Research program
QA	Quality assurance
QC	Quality control
RPUM	Reinforced Protective Umbrella Method™
SASW	Spectral analysis of surface waves
SCC	Self-compacting cement
TRB	Transportation Research Bureau
UK	United Kingdom

CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

PURPOSE

In June 2002, the Federal Highway Administration (FHWA), in a joint effort with the American Association of State Highway and Transportation Officials (AASHTO), organized a geotechnical engineering scan tour of Europe. Its purpose was to identify and evaluate innovative European technology for accelerated construction and rehabilitation of bridge and embankment foundations. The scan team also explored opportunities for cooperative research and development and implementation of accelerated construction technology.

The scan team evaluated the following technologies for accelerated construction and/or rehabilitation:

- Bridge foundation systems, equipment, and ground improvement methods.
- Embankment deep foundation systems, equipment, and ground improvement methods.
- Embankment mat foundation systems, equipment.
- Embankment construction equipment and methods.
- Innovative earth-retention systems.
- Processes and implementation methods.

METHOD

The geotechnical scan team members included both geotechnical and structural (bridge design) engineers representing Federal, State, academic, and private industry sectors. Team members were invited to participate on the basis of their positions as leaders in the development and implementation of new technologies. The team met with technical and industry leaders in Sweden, Finland, the United Kingdom, Germany, Italy, and Belgium to acquire detailed design and construction information for possible application in the United States. To effectively evaluate the equipment and techniques that may be used for accelerating construction, approximately 50 percent of the scan team's activities were devoted to viewing physical demonstrations of the technologies and methodologies in Sweden, the Netherlands, Germany, Italy, and Belgium. Team members also conducted interviews, including case study briefings, with contractors and equipment manufacturers.

OVERVIEW OF TECHNOLOGIES AND PRACTICES OBSERVED

The team identified 30 technologies and up to 15 processes that offer a potential for accelerating construction and rehabilitation of bridge and embankment foundations. Many of the technologies also offer a potential for cost savings and, in a majority of the cases, an improvement in the quality over current practice. This report includes complete tables with a relative ranking of all the technologies in terms of anticipated improvements in construction time, cost, and quality (located in chapter 6). The technologies that offer the greatest potential for success in terms of construction expediency and ease of implementation are summarized in the following sections.

Team members also gained insight on other, related construction practices in Europe that may benefit U.S. practice. In several European countries, the emphasis is on maintaining traffic during construction, which often dictates the construction procedures and has led to innovations in parallel bridge construction. Team members reviewed several projects in which the new bridge was constructed adjacent to the old bridge, foundation support was improved under the old bridge while maintaining traffic, then the new bridge was moved into final position by a specialized truck transporter (as shown in the example in figure 1) or by sliding. Traffic disruption was held to a minimum, for example, less than 72 hours in two cases. Another emphasis is on the reduction of noise (also a key issue in the United States), which drove the use of some of the technologies identified in the scan tour. Public relations plays an important role, and sometimes includes offers to relocate families during the construction period.

FINDINGS

The overall goal of the scan trip is to implement technologies of best practice in the United States. With this perspective in mind, the team identified European technologies and methods to accelerate construction and devised new ways in which these technologies could be applied in both the United States and Europe. This process resulted in a vast and broad array of cross-applications of technologies, methods, and processes that was so large and complex that concise and effective communication of the scan team's findings became a major concern. After much thought and discussion, the team strongly agreed that the findings should be presented in an easy-to-use tabular format that is organized around end users' needs. The goal was to devise tables such that engineers could enter with a specific need, and quickly see a list of applicable scan findings along with important supplemental information about the use of a specific technology for their specific need. The following paragraphs summarize selected technologies highlighted by the team as having a high potential for accelerating construction while maintaining or improving both cost and quality.

Bridge Foundations

For bridge foundation construction, the standard of practice in the United States for poor to marginal foundation conditions is driven piles or drilled shafts. Because of quality control/quality assurance (QC/QA) problems with auger-cast piling, auger-cast or continuous flight auger (CFA) piles are rarely used in U.S. bridge construction. CFA piles with automated computer control for monitoring installation and automated QC would appear to offer a rapid alternative to the current practice that could be easily implemented. Bored cased secant pile (CSP) techniques with automated computer control should also be evaluated as an alternate accelerated method that can provide both bridge support and excavation support in cut situations. For large projects with difficult drilling conditions and/or tight spaces, the use of a diaphragm wall constructed with a Hydro-Mill™ offers a rapid construction method with low noise and low vibrations that could also be used to support large loads.

Figure 1. Example of rapid bridge replacement showing transport of new bridge with specialized lift (from Belgian presentation).

Embankment Foundations

For embankment foundation construction over soft, compressible soils, the Europeans are using column-supported embankments to accelerate construction instead of the classical method of using surcharge with or without wick drains. The approach is preferred because of its much shorter construction time, simplicity of QC, environmental friendliness, and its nonimpact on the performance of existing roadways, rail lines, and buildings.

Although this is a familiar technology in the United States, it is often associated with high cost and difficult access problems. However, advances in pile and geosynthetic bridging platform technology identified on this tour convinced the scan team that column-supported embankments is an attractive method for accelerated construction and should be explored as a viable alternative for most soft ground projects.

The team also identified new technology for the stabilization of the upper 10 to 16 ft (3 to 5 m) of soil materials through either mass mixing or rapid impact compaction that may also hold some promise in constructing foundation support mats with and without deep foundation systems.

Embankment Construction

Several technologies evaluated on the tour offer the potential to accelerate placement and compaction of fill for construction of the embankment itself, while maintaining or improving cost and quality. Lightweight fills have been used in the United States to a limited extent to reduce placement and surcharge time in soft soil conditions. The frequency of this use in Europe appears to be increasing (it is almost routine). Expanding its use in the United States should increase availability and decrease cost, making lightweight fills such as geofoam an attractive alternative to surcharge fills, and also should accelerate construction. The rate of embankment construction could also be significantly increased through the use of high-energy impact, rolling compactors and rapid impact hydraulic hammer compactors, both of which appear to provide a much greater depth of compaction, allowing for placement of thicker fills. Another promising technology application is the use of instrumentation on the compaction equipment to measure dynamic modulus in real time, which can be used for improving compaction uniformity and effective compaction effort. Most importantly, the ability of instrumented compaction equipment to provide 100 percent QC coverage should allow the use of performance-based approaches to specifications, leading to the effective implementation of warrantees and guarantees for both earthworks and pavements (as is currently the practice in Europe).

Earth-Retention Systems

Rapid construction alternatives to conventional bridge retaining wall construction (i.e., using sheeting and shoring with cast-in-place walls) were identified that could be easily implemented. These technologies include bored CSP techniques and continuous diaphragm walls, both of which are applicable for the retaining wall as well as the support of the bridge. These methods can provide considerable speed and cost savings where (1) access space is limited (widening projects); (2) sound walls will be attached to the top of the retaining wall; and (3) difficult drilling is anticipated. In addition, both methods produce low noise and low vibrations, which could significantly increase their production because such equipment could be operated for a greater number of hours during a day than conventional equipment.

Processes and Approaches

The team agreed that the scan tour findings with the greatest potential for accelerated construction are processes and approaches used in the development of projects or in project control. The common theme among all of these processes is *simplicity through sophistication*.

Practically all of the equipment and construction methods employ real-time automated installation control and documentation. These systems monitor, measure, control, and document critical aspects of the technology and, thereby, allow for rapid construction without compromising quality. In fact, in most cases they improve quality. In addition to faster installation, these technologies and methods accelerate construction by reducing or eliminating QC methods that are intrusive to the construction process. Another extremely important aspect of these methods is that they have allowed the realization and implementation of rational performance specifications and warrantee/guarantee requirements.

We also observed the simplicity through sophistication approach being applied to construction materials. Specifically, one of the most exciting finds of the trip was the common usage of self-compacting concrete (SCC) in Sweden. SCC is not a new technology, but SCC research, development, and implementation to the highly advanced level of common usage is a new achievement.

By using advanced SCC technology, Sweden is able to pour concrete in intricate forms and/or dense reinforcement situations significantly faster, using far fewer workers, and smaller pumps, while still achieving superior quality. SCC should lead to a longer life via superior coverage of reinforcement and low permeability. It provides significant benefits when post tension or other ductwork is present. Since vibration is not needed, ductwork cannot be pushed out of alignment or crushed, thereby avoiding costly and time-consuming field repairs. The scan team is working to utilize SCC in new ways not observed during the scan trip (e.g., the use of SCC in drilled shaft foundations in high seismic regions).

The scan team identified several other European Community (EC) standard processes that could lead to improvements in both construction rate and quality at a moderate cost, including:

- Requiring the designer and the contractor to have a QC/QA program modeled after the ISO 9000 series process, providing more consistency in design and construction quality.
- Increasing requirements for computer automated equipment control and requiring generated data to be provided as part of the QC program, automatically producing complete real-time reports of all data, resulting in improved construction efficiency and essentially 100 percent QC.

The German Federal Highway Research Institute (BASt) presented a process to evaluate which method would provide optimum acceleration considering the total scope and integration with all phases of the project (i.e., how accelerated construction methods fit in with the critical path for project completion). This process is detailed in this report and will be used by the team as a model to help agencies identify opportunities and the optimum method for accelerated construction.

RECOMMENDATIONS

The overall goal of the scan trip is to implement technologies of best practice in the United States. With this objective clearly in mind, team members developed an implementation ranking using the following two-step process:

(1) The team as a whole reviewed and discussed each technology with respect to its potential for accelerating construction.

(2) Each team member selected the two technologies for which he had the strongest desire to champion implementation.

The technologies that were selected for immediate implementation action are:

- Column-supported embankment
- CFA and CSP bridge foundations
- Automated computer installation control and installation documentation
- Self-compacting concrete

Many of the other technologies identified in the scan tour show great promise, but successful implementation requires a champion. In addition, given the diversity of the team members (contractor, consultant, Department of Transportation [DOT], Federal, geotechnical, and structural engineers), the ranking should be an excellent indicator of the accelerated technologies preferences of the highway construction community as a whole.

The above list is not necessarily a ranking of technologies with the greatest technical potential for accelerating construction. Instead, it is a list of European accelerated construction technologies with the greatest potential for implementation in the United States. This type of focused selection should ensure that our resources are focused and not diluted. Plans for implementation of all potentially beneficial technologies are detailed in this report.

IMPLEMENTATION

At the end of the tour, team members reviewed an implementation plan, which consisted of:

- Presentations on new technologies, as identified in the body of this report, at engineering meetings.
- Invited equipment demonstrations by manufacturers.
- Cooperative efforts with European organizations.
- Local efforts by team members to use the technologies within their organizations on demonstration projects.

A Scan Technology Implementation Plan team was organized to develop a request for seed funding to assist in the implementation efforts for specific, high-priority technologies. The complete implementation program is detailed in this report.

CHAPTER ONE
OVERVIEW

BACKGROUND

The interstate highway system is a key component to the well-being of the U.S. economy. In recent years, however, the American public has been subjected to the effects of an aging and deteriorating highway system, while at the same time the highway system has seen significant increases in traffic. The resulting increase in congestion impedes the mobility of society and adds costs associated with the movement of commerce. Traffic disruption during construction and maintenance of bridges and structures is now frequently resulting in disruptions to local economies, and motorists, far in excess of the capital outlay for the construction activity itself. The competing problems of replacing an aging system and adding capacity, versus the economic and safety requirements for maintaining existing traffic flow has created a "feedback" amplification of the problem by significantly lengthening the construction process. This in turn has resulted in an even larger negative impact on motorist safety and local economies.

It is clear that these problems will only accelerate in the coming decades. According to statistics reported by the Federal Highway Administration (FHWA), approximately 14 and 16 percent of the bridge inventory falls into the functional and structural deficient categories, respectively (*Report to Congress: 1999 Status of the Nation's Highways, Bridges, and Transit: Conditions and Performance*, pp. 6-17, Exhibit 6-13, May 2, 2000). Furthermore, States are experiencing increasing problems with the deterioration and even failure of other highway structures, such as retaining walls, culverts, sign bridges, and light standards. In 1997, nationwide bridge expenditures related to system preservation and construction of new highway bridges were US$6.1 billion and US$10.0 billion, respectively (*Report to Congress: 1999 Status of Nation's Highways, Bridges, and Transit: Conditions and Performance*, pp. 6-17, Exhibit 6-13, May 2, 2000).

Therefore, development and implementation of accelerated construction and rehabilitation technology is imperative to the long-term health of the U.S. infrastructure system and economy. Recognition of accelerated construction as a national imperative is underscored by the recent Transportation Research Board (TRB) Task Force AST60 Workshop "Accelerating Opportunities for Innovation in the Highway Industry." The American Association of State Highway and Transportation Officials (AASHTO) also has a companion activity through the AASHTO Technology Implementation Group, which has selected high-speed construction as a potential product and has formed Accelerated Construction Technology Teams to advance its implementation.

Drawing on European technology and expertise in the area of high-speed construction can significantly increase the pace of the development and implementation process and reduce costs. Europe's procurement process and population density have driven forward and necessitated rapid innovation in accelerated construction. For example, many of the leading European foundation contractors research, develop, and build their own equipment to suit their specific needs and proprietary foundation system. In addition to speed of construction requirements, their technology addresses many issues that are coming to the forefront of U.S. highway construction—limited space, noise limitations, vibration control, and pollution.

Other areas of proven leadership in Europe include rapid embankment construction on soft soils. This issue is becoming prominent in the United States, as demonstrated by the soft ground problems at the I-15 reconstruction project in Salt Lake City, Utah, and the Woodrow Wilson Bridge (WWB) Project in Northern Virginia. In the case of the WWB project, ground improvement costs are expected to exceed US$30 million. Europe has invested heavily in ground improvement technology and continues to do so. Currently, the European Commission is spending US$4 million to fund the EuroSoilStab project, which consists of 17 partners from six countries (see figure 2). The industrial objective of the project is to provide the European construction industry with competitive construction techniques, backed by guidance documents for their use, to stabilize soft organic soils.

Figure 2. EuroSoilStab project on deep soil mixing (from BRE presentation).

PURPOSE

The primary purpose of the European scan tour was to discover and evaluate innovative European technology for accelerated construction and rehabilitation of bridge and embankment foundations. The scan team's goal was to identify successful and most promising technologies that have potential for immediate application in the United States and to transfer these best practices to the U.S. transportation community. Other fundamental objectives of the scan included seeking out opportunities for cooperative research, development, and implementation of accelerated construction technology. The tour also provided an opportunity to obtain information on accelerated construction of the superstructure, such as using prefabricated bridge structures and foundations. Acceleration of the superstructure construction is also part of the current TRB and AASHTO initiatives on accelerated construction. This information could be used to plan a future tour for a structural engineering group. The tour gave the team the opportunity to follow up on the European experience in applying the limit state design methods in Eurocode 7, a primary subject of a previous geotechnical engineering practices tour in 1999.

METHODOLOGY OF STUDY

The scope of the scan trip was to evaluate the applicability of technology currently being used in Europe for accelerated construction. The team members accomplished such evaluation through physical demonstrations of the technology, interviews, and case study briefings. The team sought specific information on:

- New bridge and embankment foundation systems.
- Foundation equipment and technology for accelerated construction and rehabilitation.
- Innovative earth-retention systems for accelerated construction and rehabilitation.
- Innovative technology for accelerated ground improvement of bridge and embankment foundations.

The study tour provided an opportunity for face-to-face meetings with key individuals who are recognized experts on specific technologies and industry leaders. To effectively evaluate the equipment and techniques that may be used for accelerating construction, approximately 50 percent of the scan activities were devoted to physical demonstrations of the technologies or methodologies.

The geotechnical scan team members included both geotechnical and structural (bridge design) engineers representing Federal, State, academic, and private industry sectors, who are considered leaders in the development and/or implementation of new technologies. Table 1 presents the team members, their representation on the scan team, and their affiliations. The team originally met in the winter of 2001 to compile a list of basic amplifying questions on each of the topics of interest. The amplifying questions, which were sent to each of the countries prior to the visits, are listed in Appendix A.

The scan team selected which countries to visit on the basis of their experience with implementing the technologies of interest. A "Desk Scan" of innovative European and Asian activities in accelerated construction of bridge and embankment foundations was performed to assist in the selection process. The team met with technical and industry leaders in Sweden, Germany, Italy, and Belgium to acquire detailed design and construction information for possible application in the United States. The sessions in Sweden included representatives from Finland and the United Kingdom. The principal representatives from each country and their affiliations are shown in table 2. A complete list of the names of all contacts with their contact information is included in Appendix B.

The hosts extended a generous amount of hospitality and consideration in response to the amplifying questions. In most countries, hosting agencies prepared an agenda of expert presentations, based on the questions that had been forwarded to them in advance. This presentation usually included briefings with contractors and equipment manufacturers. In Italy, an equipment manufacturer/contractor and two international contracting firms served as hosts in three separate locations. In addition to the presentations and roundtable discussion (figure 3), site visits were arranged to

Table 1. Geotechnical Engineering Scan Team Members

Name	Representation	Organization
Chris Dumas	Team Co-leader FHWA, Geotechnical Engineer	FHWA Eastern Resource Center
Randy R. Cannon	Team Co-leader AASHTO, Bridge Design Engineer	South Carolina DOT
Maung Myint Lwin	FHWA Structural Design Engineer	FHWA Western Resource Center
Sam Mansukhani	FHWA Geotechnical Engineer	FHWA Midwestern Resource Center
Kevin W. McLain	State Geotechnical Engineer	Missouri DOT
Thomas W. Pelnik, III	State Geotechnical Engineer	Virginia DOT
Dr. Ali Porbaha	State New Technologies and Research Geotechnical Engineer	California DOT
Dr. Sastry Putcha	State Construction Geotechnical Engineer	Florida DOT
Dr. Dan A. Brown	Professor – Geotechnical Engineering	Auburn University
Alan Macnab	The International Association of Foundation Drilling (ADSC)	Condon-Johnson & Associates Inc.
Richard D. Short	The Deep Foundations Institute	Kleinfelder, Inc.
Dr. Barry Christopher	Report Facilitator	Geotechnical Engineering Consultant

Table 2. Host Representatives

Sweden	Matti Huuskone Lennart Axelson	Swedish National Road Administration (SNRA)
Germany	Frau Kellermann	German Federal Highway Research Institute (BASt)
Italy	Stefano Trevisani Carlo Crippa Stefano Talone	The Trevi Group Rodio Corporation Impregilo/G.G.F. S.p.A
Belgium	Gauthier van Alboom	Ministry of Transport, Flemish Geotechnics Division

demonstrate the application and performance of accelerated construction methods. In all locations, the scan team shared information with international counterparts on U.S. policy, initiatives, and research activities to promote innovative geotechnical engineering worldwide.

Figure 3. Subject matter presentations were often provided.

ORGANIZATION OF REPORT

The primary focus of the tour was to identify and implement innovative technologies of best practice for accelerated construction of bridge and embankment foundations. Accordingly, the report provides more details on these subjects than on the secondary subjects of evaluating and exploring new or improved geotechnical products or practices. The first sections of the report summarize the visits to each country. The last two sections present the team's findings, conclusions, and recommendations. The findings section includes tables that an engineer can enter with a specific need and quickly see a list of applicable scan findings along with important supplemental information about the use of a specific technology. Each host country provided a significant amount of supporting literature, and a bibliography is included in Appendix C of the report. Appendix D contains contact and biographical information on scan team members, and Appendix E provides a summary of the development, content, and status of EN1997 Eurocode 7: Geotechnical Design.

CHAPTER TWO
SWEDEN, FINLAND, AND UNITED KINGDOM

The first scan sessions took place in Sweden on June 17 and 18, 2002. The review involved formal meetings held at the Solna regional office of the Swedish National Road Administration (SNRA) with presentations by engineering and managerial transportation officials from the SNRA; an engineer from Konsult; two Finnish representatives from Finnish Road Enterprise; and a United Kingdom (U.K.) representative from the research group BRE, Centre for Ground Engineering and Remediation. Representatives from the private sector involved in the design, contracting, and construction sectors also joined in the discussions, including Skanska Teknik AB, Skanska Berg och Bro, Möbius, de neef Northern Europe, Hercules Grundläggning AB, and Tyrens. Presentations on the second day were held in the Södra Länken (Southern Link) exhibition room and focused on the Southern Link Road Construction project, which had used several innovative features to maintain traffic and to reduce public inconvenience (e.g., noise issues). The team also made field visits to several sites, including the Traneberg Bridge, a major bridge reconstruction project for which vehicle and rail traffic has to be maintained throughout the project (figure 4); a soil nailing project in which self-drilling and grouting nails are being used to stabilize a slope (figure 5); and several portions of the Southern Link Road Construction project in Stockholm, including a soil and rock tunnel section (figure 6).

In Sweden, several innovative technologies were presented, including mass stabilization, in which cement, fly ash, or blast furnace slag are mixed with the upper 10 to 16 ft (3 to 5 m) of poor soils (e.g., peat, mud, or soft clay) to provide a method for accelerated ground improvement. Advances in deep soil mixing, an emerging technology in the United States, were identified in terms of testing and equipment. Presentations highlighted the results of research carried out under the European Union (EU)–sponsored EuroSoilStab project for the development of design and construction methods to stabilize soft organic soils. In four of the countries involved in the study, full-scale field trials were completed, three using the dry method and one (in the United Kingdom) using the wet method. One of the contractors presented a cost comparison of deep soil mixing and other soil improvement technologies.

Figure 4. Traneberg Bridge reconstruction project.

Figure 5. Hollow, drilled-in soil nails are used to stabilize a slope.

Figure 6. Site visit to a rock tunnel portion of the Southern Link road construction project.

IDENTIFIED ACCELERATED CONSTRUCTION TECHNOLOGIES

SCC is being used in Sweden for foundation construction and offers a potential to reduce noise generated from compaction as well as reduced construction time. A wire type rock saw is used to cut rock in lieu of blasting or line drilling, thereby limiting noise and vibration and speeding up construction. Reduction of noise was emphasized in several presentations. Public relations plays an important role, and sometimes includes offers to relocate families during the construction period.

The use of geotextile-encased columns, a German technology, was introduced as a fast method of soft soil stabilization (more details were provided during the German tour). A Dutch method for constructing piled embankments in very soft soils using plastic pipe filled with concrete was also briefly reviewed. In addition, developments in the use of self-drilling and self-grouting micropiles and nails were presented, and the nail technology was demonstrated during a site visit.

The United Kingdom's presentation reviewed the results of EuroSoilStab research carried out at BRE on deep mixing to stabilize organic soils and how it can help accelerate construction. In addition, relevant work to accelerate construction was presented on ground treatment (surcharging, dynamic compaction, and rapid impact compaction); soft ground foundation systems (vibro stone columns, vibro concrete columns, and deep soil mixing); building on fill; and driveability of steel sheet piles. The presentation concluded with a preview of an EU project called TOPIC, which is in progress, and an EU project about to start on the re-use of foundations. Information also was presented on vibro-jet sheet pile driving for rapid installation of temporary sheeting. Information on advancements in piles was offered, including on screw piles, which reportedly can be installed in one-third of the time required for auger-cast piles; piles that are tailored to match the soil type; and piles that minimize concrete requirements. Literature was provided on high-energy compaction using impact type, noncircular rollers.

The Finnish presentation provided several valuable accelerated construction technologies and complementary methodologies. Geotechnically, rapid automated site investigation methodology is being used in Finland. For example, new resistivity technology is being used to estimate water content and consolidation settlement in existing roadway embankments. With this technology and software, they are able to do a geophysical site investigation along with preliminary design, time, and cost calculations in a few days instead of the typical time of several months or more. In addition to being rapid, this methodology quickly locates and brings project focus/ resources to bear upon areas of the most importance with respect to project time lines, costs, and performance objectives. Consequently, project site investigations and designs are significantly faster, less costly, more cost-effective to construct, and have lower probabilities for delays and claims during the total project cycle.

Structurally, steel pipe piles are predominantly used in Finland to achieve rapid installation, especially in areas with boulders. To complement this rapid approach, they have developed a direct connection design detail that attaches the pile directly to the superstructure (steel, precast concrete, or cast-in-place bridge girders). This ingenious approach eliminates the pile cap, pier columns, and the pier cap. Literally, the construction of the entire substructure, excluding the piles, is eliminated, resulting in typical savings of between 10 and 15 percent of the entire bridge cost.

LESSONS LEARNED: ACCELERATED CONSTRUCTION METHODS

The following section reviews the accelerated construction methods identified in Sweden, the United Kingdom, and Finland in relation to the amplifying questions.

The **mass stabilization technique** was identified in Sweden as a method that saves time when compared with preloading (see figure 7). The technology came from Finland about 10 years ago. In the mass stabilization technique, the upper 10 to 16 ft (3 to 5 m) of the soft subgrade is mixed with a cement, fly ash, or blast furnace slag stabilizing agent over the entire surface area of a project. The stabilizing agent is typically applied at a rate of 30 to 40 lb/ft^2 (150 to 200 kg/m^2). At this rate, approximately 400 to 650 yd^3 (300 to 500 m^3) of soft soil can be stabilized per day. Mass stabilization projects performed to date show that settlements develop rapidly in stabilized peat and underlying unstabilized soils. This method does require specialized mixing equipment. The equipment is patented but the process is not. The availability of equipment in the United States is unknown, but it is possibly being used in the waste industry.

For design, the properties of the stabilized mass are determined on the basis of correlation with lab test data and local experience. The technique has worked well for peat, mud, and soft clay, but as previously indicated, is only effective for the upper 10 to 16 ft (3 to 5 m). Quality control (QC) and quality assurance (QA) are evaluated through the use of conventional geotechnical field measurements, including the cone penetration test (CPT) to determine the differences in permeability properties and to control homogeneity in the mass stabilized peat; standard column penetration test (SPT); column vane test; spectral analysis of surface waves (SASW) measurement; settlement; horizontal movement; and pore pressure measurements. The technique requires little training. Average equipment contractors and inspectors can be taught in a few days. Training is required to be able to determine the amount of stabilization agent (cement, fly ash, blast furnace slag) to mix, as well as types, properties, and volume of agents.

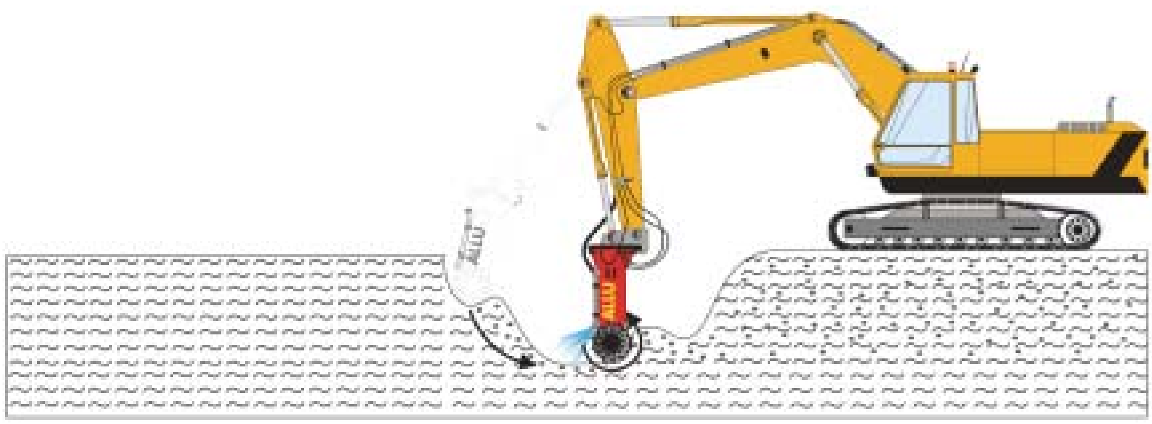

Figure 7. Mass stabilization technique.

Some safety issues are associated with this technology, including transport of cement from the truck to the mixing machine. Using the current technology, cement can spread easily over the site (e.g., windblown) and can cause burns to the skin and eyes as well as breathing problems. This transfer process will have to be changed for U.S. implementation. In Sweden, the technology is contracted using a performance-based specification in which the contractor is responsible for the performance. The contractor provides a 5-year warranty. Performance is defined as the ability of the system to limit settlement, as measured initially on the basis of lab tests on the soil-cement mixture and in the long term on the basis of field monitoring. The University of Lund in Sweden is currently performing research on this technology. The technology has not been used in seismically active regions. Cold weather and freezing soil do not appear to affect the application, at least in the mass stabilization projects performed to date. The thermal conductivity of stabilized peat is of an order at which it can be expected to influence the frost penetration of the whole road structure. The measured thermal conductivity factors have been of an order of $\lambda = 0.2$ to 0.6 W/Km, which corresponds to thermal conductivity of natural peats (Carlsten, 1988;

Helenelund, 1980). This insulating effect can be taken into account at the frost dimensioning stage (Tielaitos, 1995).

Lime/cement columns (deep soil mixing) has been introduced in the United States; however, a significant amount of development work has been performed in Sweden. Much of the effort has gone into QC and QA, with some advances reported to the team on the rate of mixing and on in situ testing. Ongoing research on mixing energy, i.e., relating strength to mixing time (rotations), was presented. Deep soil mixing uses specialized, patented equipment, much of which is readily available in the United States. The process is not patented. A presentation was conducted on the analysis of composite ground using a mean strength method. The EuroSoilStab Consortium, headquartered at the Swedish Soil Stabilization Research Center of the Swedish Geotechnical Institute, has ongoing research projects on this subject.

Self-compacting concrete (SCC; also known as self-consolidating concrete) was identified as a rapid construction technique currently being used and evaluated in Sweden. Finnish and German representatives indicated that they also are using SCC in bridge construction. SCC is a special, fine grain, fluid concrete mix (similar to a mortar mix) that rapidly consolidates after placement to form a dense, high-strength concrete. Fluidifiers are used as admixtures to maintain the consistency of the mix. It has significant advantages: no vibration is required, the mix is very fluid, thereby flowing easily into tight areas, and segregation is not a problem. Main applications have been for structural components, such as facing units for tunnel linings, but the technology offers significant potential for use in deep foundations, such as drilled shafts. The technique does not require specialized equipment. Neither the equipment nor the process is patented, and the equipment is readily available in the United States. SCC is contracted in Sweden on a unit cost basis. Means and methods of applications are based on specification of mix design verification requirements and sampling and testing of concrete.

Geotextile-encased columns (GEC) consist of inserting continuous, seamless, high-strength geotextile tubes into soft soil with a mandrel and filling the tube with sand (or fine gravel) to form a column with a high bearing capacity. The application is similar to sand piles used in Japan and stone columns, which are widely used in the United States. It is suitable for soft soils and where high bearing capacity is desired. The method has been used for supporting new roadway embankments and large pavement areas on 15 ft (5 m) of soft peat material. Advantages of this system over stone columns include: (1) the column is confined in such a way that it does not intrude into the soft soil; (2) a consistent diameter is maintained by the geotextile tube; and (3) improved shear capacity is provided by the high strength of the geotextile and the confinement of the sand or gravel. The geotextile also provides a filter to prevent the intrusion of fines (and long-term loss of soil) while allowing water to pass. This significantly improves drainage and accelerates consolidation. Following classical consolidation theory with drainage improvements provided by the columns, consolidation rates on the order of 80 to 90 percent have been achieved within three months. The technique allows for rapid installation of the columns with minimum noise. Although this technique has not been used for seismic applications, such as stone columns and sand piles, it has potential for liquefaction mitigation. Weather is not a problem.

AuGeoä piling, a Dutch technology and a registered trademark of Geotechnics Holland BV, was also introduced in Sweden as a rapid, economical method for constructing column-supported embankments in very soft soils. This method consists of using a mandrel to push, vibrate, or drive a large-diameter plastic pipe through soft soil, then filling the pipe with concrete to form a column. QC uses conventional concrete sampling and testing. Load testing is performed to confirm performance. For design, the scan team believes that field measurements of spacing, diameter, and depth could easily be evaluated. The scan team also believes that only average pile equipment skills would be required. Contracts could be prepared on performance-based specification with concrete samples and testing performed by the owner for confirmation. Additional information will be solicited on this technology as part of the scan implementation program.

The **rock saw**, a cable type saw, is an alternative to blasting for making rock cuts and shafts in rock. The technique does not appear to be any faster than blasting, as the rock saw requires predrilled holes for setup. However, the technology may still speed up construction by allowing for night construction in urban areas given its low noise and lack of vibration. The technique also results in a uniform, smooth cut, which reduces the noisy jackhammer dental work. The technique does require specialized equipment. However, we understand that neither the equipment nor the process is patented. The equipment is also readily available in the United States because it is commonly used in quarrying operations. A video demonstrating this technology was provided, as is listed in the bibliography section of this report (see Appendix C).

Rapid impact compaction, as indicated in the previous section, is a technique using a 5-ton, 1-meter drop hydraulic pile hammer to compact the soil, and was presented as an accelerated construction method by the United Kingdom’s representative from BRE. This technique basically uses a hydraulic piling hammer to drive a large foot into the ground. This technology eliminates excavation and allows for compaction of shallow layers up to 9 ft (3 m) thick. The technique was initially developed by the military for repair of bomb damage to airfields. (Reportedly, the U.S. Army Corps of Engineers also performed some initial work on this technology for rapid airfield repair.) The British are currently evaluating this technique for compaction of loose fills such as construction rubble, shallow refuse, industrial waste fills, or loosely placed dumped fill. The team also discussed use of the technique for increasing conventional lift thickness during embankment construction.

The technique may also have some application in densifying shallow, liquefiable layers to limited depths in seismic zones. Cost information was not available. The technique requires specialized equipment, but there does not appear to be a patent on the process or the equipment. The equipment is readily available in the United States, and no special training should be required to apply this technology. The scan team also believes that standard density testing could be used for quality control. Contracting could be performed on a performance-based specification with results measured by CPT tests before and after placement. The contractor is responsible for performance of method on the basis of testing results. Some noise and vibration issues may have to be addressed, similar to pile driving.

Vibro-jet sheet pile driving, currently being evaluated by the United Kingdom, combines vibratory pile driving with jetting procedures to significantly speed up sheet pile installation. This technique allows the effective installation of sheet piling through clays that are far too stiff for conventional impact or vibratory hammer methods. The team also noted that the jet conduits could be used after driving to grout the sheets in place and, thereby, eliminate any reduction in lateral fixity caused by the jetting process.

Jetting may reduce duration of vibratory driving. However, if spoil is undesirable, jetting may not be a viable option. The technique requires specialized equipment, but patents do not exist on the equipment or the process. The equipment is readily available in the United States. Design techniques for conventional sheet piles would apply; however, the use for axial loading capacity is unknown. QC would be based on field observations of the performance. Training would be required to operate a vibratory hammer. Calibration would be required to suit site conditions. As with conventional sheet pile installation, contracting could be performed on a performance-based specification. Usually sheet piling is temporary, so the contractor is solely responsible for performance.

A unique research opportunity exists for vibro-jet sheet piles. The British organization performing research on this technology, BRE, has currently exhausted its funds for further research and has raw data from vibro-jet research that has yet to be put into final form. Included in this report is information from recent projects. BRE would be very interested in sharing this information, if the United States wanted to continue the evaluation of this technology.

Screw piles are also being used in the United Kingdom, with installation requiring one-third the time required for auger-cast piles. Advanced information was presented to a few of the scan team members in England prior to the tour. Two types of systems were discussed during the Swedish session, including: (1) **D2A** in which the hole size is matched to the soil type, and (2) **Screwsol** in which the concrete required to form the pile is minimized. Discussions included load testing and special training requirements for both techniques. Performance-based contracting is being used by the British for both pile types with the owner making measurements on the in-place piles. Significant information on this technology was presented during the Belgium tour, as is reviewed later in this report. Load testing special training is required.

The British are also evaluating the **reuse of foundations** as a method to accelerate construction. This technology eliminates time to replace foundations. Evaluation consists of load testing, field verification of existing foundations and their dimensions, and nondestructive tests for integrity and durability. This technology has also been used in the United States, and, like the British, we have found that a very special effort is required by the geotechnical engineer. Contracts are usually based on a time and materials basis.

The use of **steel pipe piling,** identified by Finland as its most common pile type, is based on the speed of driving through boulders. This piling method is common practice in the United States and is not necessarily a new accelerated construction method; however, because of its extensive use, Finland has also developed an innovative direct connection from the steel pipe piles to the superstructure. The elimination of a pile cap, pier column, and pier cap saves significant time during construction. The installation of the piles is conventional technology that is contracted on a performance basis based on blow counts. The connection is a standard detail requiring no special training. Noise and vibration potentially limit urban production, but the piles can be prebored to limit this problem.

Another advancement in Finland is the development of an **automated rapid site investigation** technique using resistivity. This is an extension of Finland's work in evaluation of pavement systems, which combines resistivity and falling weight deflectometer (FWD) measurements. The Finnish are currently evaluating the use of resistivity profiles to rapidly estimate water content and consolidation settlement. This technology has significant potential to save time in preliminary geotechnical investigations and layout of final borings. A similar initiative is under way by the FHWA in the United States, and a cooperative effort could provide for a more rapid development.

LESSONS LEARNED: PREFABRICATED TECHNOLOGIES

SCC, as discussed in the previous section, was also identified by the team as a prefabricated technology with significant U.S. application potential. SCC requires no vibration and thus produces no noise and speeds up construction. The technology has been used successfully in Sweden over the past 4 years on more than 20 projects. For example, SCC was used in the concrete rock lining of the Södra Länken Tunnel Project, which the team visited. Based on the Swedish project experience, a 10 to 15 percent time and cost savings has been identified in addition to the positive impact on the work environment (i.e., low noise and vibration). Because of the low noise, this technology would also benefit nighttime construction. Specialized equipment is not needed, but new processes and skills are needed to handle the more fluid mix (e.g., workability test, pour rate, form pressure, and form design). Sweden does not have design requirements for earthquake, and thus has no experience in application in seismic regions. Special consideration for cold weather concrete placement may also be needed.

The direct connection of pipe piles to the bridge structure used by Finland, which was discussed in the previous section, is another prefabricated technology.

LESSONS LEARNED: STATUS OF LIMIT STATE DESIGN

In relation to limit state design, the United Kingdom provided us with a special issue of *Civil Engineering* magazine on Eurocodes (November 2001, Volume 144, Special Issue Two), which contains an excellent overview of the development and current status of the Eurocodes, including Eurocode 7: Geotechnical Design. The information on Eurocode 7 is reproduced in Appendix E with permission of Civil Engineering, Thomas Telford publishers, as a follow-up to the previous 1999 geotechnical engineering practices tour.

CHAPTER THREE
GERMANY

The second visit of the study tour was to Cologne, Germany, on June 20 and 21, 2002, for meetings at the German Federal Research Highway Institute (BASt), which is similar to the FHWA Turner-Fairbank research facility. The review involved formal meetings with and presentations by representatives of various departments within the BASt as well as a representative from the Bundesministerium for Verkehr, Bau- und Wohnungswesen (Germany Ministry of Traffic, Construction and Housing). Presentations were also made by representatives of the private sector, including:

- Möbius Bau-Gesellschaft GmbH & Co., a contractor with specialization in the installation of geosynthetic-encased columns.
- Huesker Synthetic GmbH & Co. KG, a geosynthetics manufacturer and developer of the geotextile for geosynthetic-encased columns.
- Bauer Spezialtiefbau GmbH, a design-build contractor and equipment manufacturer with specialization in soil stabilization with vertical columns (CSV) and deep soil mixing.
- Friedr. Ischebeck GmbH, a specialty contractor and developer of self-drilling and grouting nails and micropiles.
- BOMAG GmbH & Co. OHG, a manufacturer of compaction equipment.

On the second day in Germany, the team met with the highway department in Meschede and attended a presentation on its activities, including a roadway construction project where extensive rock slide and cut slope stabilization problems have occurred. We made a field visit to the roadway construction project site (figure 8). The team then made a second site visit to a geosynthetic-reinforced, mechanically stabilized earth retaining wall project, which was constructed with a “green” steel mesh facing using recycled, contaminated construction debris as fill (figure 9). The use of contaminated fill for embankment construction was also encountered in several locations in Belgium (airport and rapid rail).

The current construction of rapid rail lines in the Netherlands, Belgium, Germany, and Italy has been a showcase for innovation. On the way to Germany, the team took the opportunity to visit the Giessen-Oudeker project (a high-speed freight rail project) in the vicinity of Rotterdam, the Netherlands. At this specific portion of the project, the Betuwe route, they were constructing a cut and cover tunnel for the twin rail line below an existing river in a residential area (figure 10). Self-boring micropiles are being used to act as both a tiedown for hydrostatic pressure and vertical support as the trains pass through the tunnel.

Figure 8. Field visit to Meschede roadway slope stabilization project.

Figure 9. Green-faced wall site visit.

Figure 10. Site visit to the Betuwe railway line (in the Netherlands).

IDENTIFIED ACCELERATED CONSTRUCTION TECHNOLOGIES

In Germany, a process was presented to evaluate which method would provide optimum acceleration considering the total scope and integration with all phases of the project (i.e., how accelerated construction methods fit in with the critical path for project completion). A project study on accelerated construction with regard to the Autobahn A-26 was presented to demonstrate the technique.

The German group presented their experience with a variety of foundation technologies, including geotextile-encased columns, which accelerate dewatering plus improve support; embankments on piles, which eliminates preloading; geosynthetic reinforcement support of embankments on piles or columns; a combined soil stabilization system (CSV), which provides a one-step installation of cement columns; and the drilled-in, self-grouting micropiles used on the project in the Netherlands. Another presentation discussed the use of instrumentation on the compaction equipment to measure dynamic modulus for improvement compaction uniformity and evaluated required effort and use of this equipment for compaction control. Discussions were also held on keeping the designer on board during construction to rapidly resolve issues or modify design and bring the contractor in during design to identify methods to accelerate construction.

As in Sweden, the significant factor in Germany is maintaining traffic during construction, which often drives the construction procedures and has led to innovations in parallel bridge construction. The German group presented information on their current use of prefabricated steel bridges to save time and cost over traditional precast concrete bridges. They also reviewed several bridge reconstruction projects in which the new bridges were constructed adjacent to existing bridges, and then moved into place on the existing alignment after the old bridge was demolished. Total project disruption to traffic: approximately 72 hours.

LESSONS LEARNED: ACCELERATED CONSTRUCTION METHODS

The following section reviews the accelerated construction methods identified in Germany in relation to the amplifying questions.

In Germany, a more in-depth presentation was made on the use of **geotextile-encased columns (or geotextile-coated columns)**, a technology identified during the Swedish tour. As noted in the section on Sweden, this technology consists of inserting continuous, seamless, high-strength geotextile tubes into soft soil with a mandrel and filling the tube with sand (or fine gravel) to form a column with a high bearing capacity. Displacement methods can be used for installation of the columns in very soft soils, and excavation (e.g., augering) methods can be used in stiffer soils. Construction loads are transferred through the columns onto the underlying natural foundation. In addition, the soil surrounding the columns is improved through consolidation, which further improves the embankment support conditions and decreases secondary settlements. A horizontal layer of high-strength geotextile is placed over the column heads to transfer load between columns. Construction time is saved through direct embankment support, decreasing or eliminating staged construction and surcharge loading. Time for secondary settlements of the soft soil is also decreased. Several case histories were presented, which demonstrated both the construction techniques and the potential for use of this rapid method for stabilizing very soft ground or organic soil. Documentation of these applications was made available (in German) with field measurements. This information requires critical evaluation for instrumentation, especially in relation to design. No design code is currently available. The method is currently designed and installed with the assistance of the proprietary contractor and system supplier. QC and performance are evaluated through detailed instrumentation. The geotextile manufacturer and contractor provide the expertise. The scan team believes that performance could also be evaluated through in situ testing using standard penetration tests (SPT) and/or CPT. Nominal training of 2 to 3 days is required. The system is patented and is available to licensed firms. Contracting is currently performed in Germany on a performance basis.

Column-supported embankment is a conventional technique for construction over soft subgrade that has often been dismissed because of its relatively high cost. However, the Germans have found that this method provides such a significant time savings over preloading and surcharging that the additional cost is often outweighed. This is the fastest embankment foundation stabilization method. Settlement of the embankment is more controlled than with preloading. This is especially important for soft ground embankment widening projects and construction adjacent to other structures. Since conventional piling equipment is used, the technique does not require specialized equipment. There are no patents on the equipment or process, and the equipment is readily available in the United States. The advent of new piling techniques as discussed in this report, some of which use lightweight equipment and improved pile installation, make this application even more attractive. In addition, geosynthetic reinforcement used to spread the load over piles, a recent practice in the United States and Europe, allows for increased pile spacing, thus reducing the number of piles required. A presentation on the design of geosynthetic reinforcements was given in Germany. The column-supported embankment technology uses conventional practice for all aspects of design, specification, and construction such that it can be readily implemented. Design is relatively mature and well developed. Conventional monitoring methods, such as settlement monitoring and field observations of pile installation, are used to control construction. Routine soil sampling and strength testing are used to develop design information and construction performance. Special training is not required for construction crews. Standard performance-based specifications are already in place, and the owner can measure performance by measuring settlement of the embankment.

The **CSV soil stabilization system** is a flexible foundation system formed by installing small-diameter columns of cement-sand or lime-sand mixture using a displacement auger. The auger runs through a container filled with the dry granular mixture, turning against the drilling rotation and downward movement to transport and compact the dry mix into the ground. This technique applies to most soils because it does not use the in situ soil as a binder. The main limitation is the need for ground water to hydrate the dry sand-cement mix. This one-step process allows for rapid installation of the columns for ground improvement in soft cohesive soils, organic soils, or loose sand (approximately 1 minute of installation time per meter of depth). The installation equipment is low weight and thus easy to mobilize. The benefits of this system include low noise, no vibration, no soil spoils for disposal, and real-time instrumentation for automated installation and documentation.

The installation does require the use of specialized equipment and process, which are both patented. The equipment is available in the United States. Design is based on on-board monitoring and experience backed by field tests. Termination of the column in competent soil is based on crowd pressure. The equipment includes a data recording system for monitoring the crowd pressure, rotary speed, and withdrawal speed. Field quality control is based on the installation of "calibration" columns, which are installed at numerous locations on a site prior to production work. Static load tests using the same installation equipment and lab testing of the cores are performed on the calibration columns. If satisfactory results are achieved, the production columns will be installed using the on-board automatic installation method with the same settings as those used to install the accepted calibration columns. Special training is required for the equipment operator. Helpers can be hired locally, and the crew usually requires up to 3 days of training. Performance-based specifications are used. Research on CSV is currently in process between the U.S. Army Corps of Engineers and the University of Tulane. In Germany, the research and development has been performed by the private sector without government funding as yet. There is a significant amount of related research being performed by an international group dealing with pile-raft foundations, which is discussed in the section on Belgium.

The real-time **automatic controlled variable roller compaction** and documentation system allows for optimization of compaction rates and real-time quality control. The system works by using accelerometers to monitor the speed of the dynamic wave through the soil induced by the vibratory rollers in order to measure the dynamic stiffness of the soil, which generally increases with higher compaction. Efficient fill densification is achieved via automatic adjustment of compaction energy and the measurement/documentation feedback, eliminating time wasted on compacting areas that are already adequately compacted. This energy variability and efficiency is achieved by the use of two counter-rotating weights in the drum rather than the conventional single, one-directional eccentric weight. The weights rotate in opposite directions and only come together in a common direction in the downward vertical inclination. This eliminates unwanted and wasteful movements in the lateral and upward directions that occur with conventional compaction drums. Internally, the entire counterweight assembly is rotated to adjust the direction of the point where the two weights act together. If the onboard monitoring system determines the soil is compacted to a satisfactory level, it will automatically reduce the vertical component of force at the specific time and location.

In addition, the ability to monitor density improvement during compaction both speeds up and improves the aerial extent of QC. Most importantly, the ability of instrumented compaction equipment to provide 100 percent QC coverage enables the use of performance-based approaches to specifications and the effective implementation of warrantees and guarantees for both earthworks and pavements.

This method does require proprietary, specialized monitoring equipment, but the equipment and process are not patented. The equipment is readily available in the

United States and requires nominal operator training. Contracting this technology is based on standard contracting for fill placement. Currently, the proprietary equipment manufacturer has researched the procedure and there is a need for an independent study. Again, this technology is used with normal compaction procedures; therefore, there are no additional environmental concerns to normal compaction activities.

Self-boring and self-grouting hollow bar nails and micropiles (for sheet piling, slope stability, retaining walls), which were reviewed in Sweden and on the project site in the Netherlands, were presented by the developer in Germany. These hollow bars are installed using a one-step installation procedure for drilling and grouting. Eliminating the normal micropile (and nailing) requirements of auger, inserting the micropile (or soil nail), and then grouting, should reduce construction time. There is also some reported improvement in adhesion, which may reduce pile lengths. In this proprietary procedure, the same high-strength steel is used to drill, grout, and reinforce. Specialized equipment is required, but there are no patents on the equipment or process. The equipment is readily available and currently in use in the United States. This technology is commonly used by private industry in several regions of the United States, but it has not made significant inroads into public sector contracting, primarily because of questions concerning corrosion. Corrosion issues need to be addressed; however, the manufacturer has composite galvanization and epoxy-coated systems available. A coextruded material with an outer, noncorrosive material is also under evaluation at this time. Design is conventional and relatively mature, with current design and construction installation guidance covered in FHWA's guidelines documents. Load tests are used as with conventional micropiles to evaluate minimum cover provided. Skilled and experienced laborers are required and make a big difference in performance. This technology is contracted per rod installed, with contractor confirming performance through load tests. With regard to environmental issues, the technology is relatively quiet and produces low vibrations. Grout is used, and there is some spoil to be disposed.

With regard to micropiles, a significant French research project called FOREVER was supposed to be completed in September 2002. There is also ongoing research at the University of Munich. Corrosion issues are currently being investigated internally by the manufacturer and will require independent evaluation.

LESSONS LEARNED: PREFABRICATED TECHNOLOGIES

Germany presented projects in which replacement bridges were completely "prefabricated" next to the existing bridge, and then moved into final position (jacking or specialized trucks) once the existing bridge was rapidly demolished (see figure 11). In all cases, the time savings were significant, with two structures reported to have been completely replaced (demolishing and moving the new bridge into position) within 72 hours. The opportunity to use this technology depends on site conditions and traffic control requirements. This approach also minimizes impact to the environment.

The Germans have traditionally used precast, prestressed concrete girders. In recent years they started to use steel prefabricated members to reduce weight and increase length of prefabricated segments. Prefabricated construction is suitable for improving speed of construction, reducing traffic interruption, and minimizing environmental impact. Prefabricated elements can be built in an enclosed environment during bad weather conditions. The weight reduction from using two I-girder systems and prefabricated steel replacement bridges makes it easier to move the structure into place after destruction of the old bridge structure. German designers do not have special design consideration for fracture-critical members in a two I-girder bridge system. The lighter weight of the structure also makes use of existing foundations more feasible without significant modification. Seismic concern is not a consideration in German bridge design.

LESSONS LEARNED: STATUS OF LIMIT STATE DESIGN

With regard to Eurocode 7, the Germans still use their own design standards, but they have converted a significant portion of their code to the Eurocode limit state design (load and resistant factor design [LRFD] in the United States) format. By the end of 2003, the Germans should have evaluated all issues with the new Eurocode.

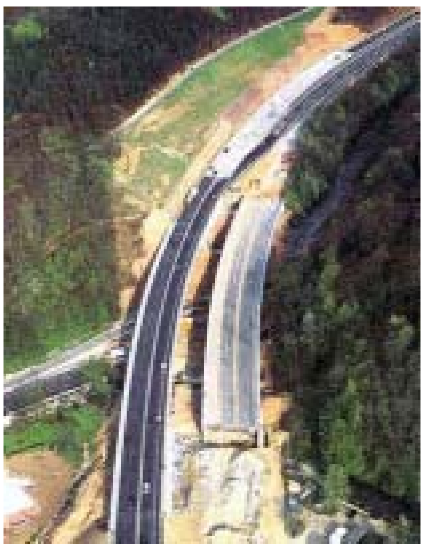

Figure 11. Jacking a bridge into final position (from German presentation).

CHAPTER FOUR

ITALY

The visit to Italy on June 23 through June 26, 2002, focused on meetings with foundation designers, contractors, and construction equipment manufacturers. In Cesena, the Trevi Group, specialists in international foundation engineering and a foundation equipment manufacturer, was the host for a program that included:

- Formal presentations from its engineering unit, Trevi, and the construction and construction equipment manufacturing unit, Soilmec.
- A tour of the Soilmec factory (figure 12).
- A site visit to view secant piles used to support an excavation and the below-grade structure (figure 13).
- A site visit to a location of a high-speed rail project in which a column pile supported embankment was being constructed with Soilmec continuous flight auger (CFA) equipment (figure 14).

Figure 12. The Soilmec factory tour.

Figure 13. Secant piles used for excavation and wall construction in the Trevipark (from the TREVI Group presentation).

Figure 14. CFA pile-supported embankment project for the high-speed rail project: (a) CFA pile installation and (b) installed CFA piles.

The second stop was in Turin where the group met with representatives from the Rodio Corporation, an international geotechnical construction firm, headquartered in Milan. Rodio is currently working on the new Italian metro in Torino and a section of the high-speed rail line being constructed from Milan to Naples. The Rodio program included:

- Formal presentations on the Rodio Corporation and the Turin subway project.
- Detailed discussion on the design methodologies employed on the project, and the interaction of the contractor with the design consultants and owner.
- Site visits to four separate construction locations where underground stations were being built for the Turin subway project. Rodio arranged site visits for the Turin projects and presentations by and discussions with their engineers at site offices (figures 15 and 16).

Figure 15. Turin subway project site visit showing: (a) station excavation and (b) continuous diaphragm wall construction.

Figure 16. Turin subway grouting project site visit showing: (a) grouting and (b) grout pump station.

The last meetings of the Italian tour were held in Milan at the offices of Impregilo/ S.G.F. S.p.A., one of the world's largest international contracting firms that was formed by merging three companies specializing in the infrastructure, building construction, and environmental fields. The meeting included:

- A formal presentation on the Impregilo Group and SGF-Inc S.p.A. and their collective worldwide activities.
- A presentation on the high-speed rail tunnel in the mountains between Naples, Bologna, and Florence.
- A presentation on "Analysis of Controlled Deformation" (ADECO) methodology and its application on tunnel projects (figure 17).

DESIGN MOMENT	SURVEY PHASE	Analysis of existing natural equilibrium	CONSTRUCTION MOMENT	OPERATIONAL PHASE	Application of the stabilization instruments for controlling deformation response
	DIAGNOSIS PHASE	Analysis and prediction of deformation response in the absence of stabilization measures		MONITORING PHASE	Evaluation and measurement of deformation response as the response of the rock mass during tunnel advance (measurement of extrusion at the face and convergence at the control of the cavity at varying distances from it inside the mass of the ground)
	THERAPY PHASE	Control of deformation response in terms of stabilization system chosen		FINAL DESIGN ADJUSTMENTS	Interpretation of deformation response Balancing of stabilization systems between the face and the perimeter of the cavity

Figure 17. Schematic of the ADECO methodology presented by the Impregilo Group.

- A presentation on rehabilitation work on the Tanro River Bridge (using Hydro-Millä).

IDENTIFIED ACCELERATED CONSTRUCTION TECHNOLOGIES

Several technologies were reviewed with respect to accelerated construction for lateral excavation support and/or vertical foundation support, including:

- CFA piles. These can be rapidly installed (reinforced or unreinforced) at low cost.
- CFA cased secant pile (CSP) technique for rapid installation of large-diameter (up to 5 ft [1.5 m]) piles of high quality (uses a temporary casing) providing both vertical and lateral support.
- Continuous diaphragm walls. Three different techniques were reviewed: Saw Millä, Hydro-Millä, and continuous diaphragm wall (CDW). CDW is a non-crane-mounted method that can operate in extremely tight areas of limited vertical and lateral access. All of these techniques allow for top-to-down rapid excavation methods. Some of these methods are also employed for bridge foundation retrofit work where headroom is extremely limited.
- Micropiles. Used economically for excavation support above the water table, known as a “Berlin Wall.” Can be installed rapidly in soils with cobbles and boulders via downhole hammers.
- Turbo-jet construction of vertical columns for soil or foundation support. A form of rapid soil mixing where the mixed columns can be left unreinforced, or reinforcing such as an H-pile can be added when it is used as a foundation element.
- Fiberglass nails and grouting for excavation support (e.g., in the face of a tunnel), and pretunneling methods where the lining is installed before the soil is removed.
- The ADECO methodology was reviewed by one of the contractors for a tunnel project in which the design is modified to accommodate the actual project conditions as they are encountered on the basis of real-time continuous feedback from instrumentation and lab testing (see figure 17).

Other important issues reviewed included a European requirement for all contractors and designers to have ISO 9000 series quality certification programs in place. Contractor warrantees for up to 10 years are also not unusual.

LESSONS LEARNED: ACCELERATED CONSTRUCTION METHODS

The following section provides a review of the accelerated construction methods identified in Italy in relation to the amplifying questions.

The **CSP technique** was developed as a rapid construction method for continuous cantilever walls. The cantilever wall provides high-capacity vertical and lateral earth support and could have applications for bridge support in cut situations and for cut embankment support and temporary excavations. The CSP system is constructed using augers housed inside a casing to make the excavation. The auger and casing are driven by two independent rotaries to optimize spoil removal and casing of the hole.

Intersecting columns are formed, which are up to 5 ft (1.5 m) in diameter and up to 87 ft (26.5 m) [66 ft (20 m) cased] in depth. Two micropiles per CSP may be drilled to increase vertical capacity. Excavation of the piles is performed without bentonite mud regardless of the kind of soil or the presence of water table. The technique does require specialized equipment that is patented, but several types are available from different suppliers and the equipment is readily available in the United States. The process is not patented. Design is conventional, relatively mature, and is currently done in the United States; however, the design procedure is not addressed in AASHTO specifications. CSP can be designed for seismic forces where needed. Italy has high seismicity in the north and south, and the system has been used in both regions. The scan team also had a significant interest in the potential use of CSP techniques for installation of individual bridge piles.

The production rate for a 3-ft- (0.9-m-) diameter pile was reported to be 413 ft (126 m) per day. It is efficient for large circular excavation (e.g., Trevipark, an underground silo-type facility constructed for an automated parking garage using CSP). A general bridge/foundation contractor with CSP equipment can install the system. Only nominal training would be required for experienced personnel. It is the scan team's opinion that inspectors can readily inspect pile diameter, depth, and materials used in construction. Rotating out the casings as is done in this technology appears safer than the conventional procedure of pulling out pile or drilled shaft casings with a crane. The system has low noise and vibration. It is not affected by the weather, except as associated with delivery of the concrete.

CSP technology is contracted under performance-based contracts. Design-build contracting is also used (e.g., engineering and construction personnel from one of the scan team's hosts, the Trevi Group, indicated that they do design-build on a regular basis). In these types of contracts, both performance based and design-build, the owner usually retains 5 to 10 percent of total billings as a warranty. If problems arise, the contractor is required to fix the problems. Research on this technology has been sponsored by the industry. The team's host, the Trevi Group, spends US$6 to US$8 million dollars a year on research and development (approximately 2 percent of its yearly company intake). The Trevi Group provides a complete transfer of knowledge of the technology.

CDW is a technology for forming cut-off walls for excavation support, or vertical support using simultaneous excavation and concreting. As indicated in the developer's presentation (the Trevi Group), the diaphragm wall is formed by excavating the soil with a special cutting module. The module is inserted into the soil and dragged along the extension of the diaphragm wall. The diaphragm wall's thickness and depth are defined by the width and length of the cutting module. A template is used for proper alignment. First, the module is inserted into the soil until it reaches the final level of the diaphragm wall and, subsequently, it is shifted along the extension of the diaphragm wall. Concrete is poured into a plastic slip-form placed in the excavation immediately behind the cutting bar. The weight of the concrete provides an additional driving force against the cutting bar to facilitate excavation. This driving technique is particularly useful in cases of headroom restrictions.

The continuous placement of concrete during excavation precludes the use of slurries or other excavation-support techniques. The excavation method does not require the use of bentonite mud, even in the presence of cohesionless soils under the water table. A conveyor belt is used to dump the trenched material directly onto the truck and therefore provides a free and clean working area. The absence of joints makes the continuous wall safe from possible hydraulic sealing problems. The diaphragm wall may be reinforced by inserting steel piles into the newly concreted wall sections.

In situations where the headroom is low, e.g., with 20 ft (6 m) of headroom, a wall up to 33 ft (10 m) deep can be constructed. Production rates of 110 to 160 sq ft (10 to 15 sq m) per hour of completed diaphragm wall have been achieved. The maximum wall depth is 45 ft (15 m).

CDW does require specialized equipment. The equipment is patented, but several types and suppliers are available; however, the equipment is not currently available in the United States. The process is not patented, and design is based on conventional diaphragm walls. Only the construction technique is unique. The best application and production appears to be for temporary bracing or diaphragm cut-off walls in low headroom situations. For depths beyond 23 ft (7 m), concrete pressures need to be carefully monitored. This technique apparently does not work well for clean sand. In the scan team's opinion, QA/QC would be similar to typical diaphragm walls (depth and width). The scan team also believes that specific training and experience for operators and technicians is needed. Weather does not appear to be a problem, except when the delivery of the concrete is affected.

Performance-based contracts are typically used for CDW technology. Our hosts again indicated that they are being regularly contracted on a design-build basis. The owner usually retains 5 to 10 percent of the total billings as a warranty. If problems arise, the contractor is required to fix problems (presuming that issues concerning differing site conditions are not precluded).

Reinforced Protective Umbrella Method (RPUM) is an accelerated construction method for soft ground tunnel excavation support, and was identified by the scan team as having potential for applications in bridge and embankment excavations. The RPUM system entails the execution of subhorizontal consolidation works along canopies around the section to be excavated, preventing caving during excavation and minimizing the deformation behavior of the tunnel by redistributing the stresses on the supports. The components of the system include forepolings, jet-grouting columns, and fiberglass nailing.

The fiberglass nails are installed as forepoles around the tunnel walls and behind the tunnel face and allow excavation directly through the stabilized nailed section. Nails are drilled in at a rate of 223 ft (68 m) per hour. This rapid drilling rate allows up to 100, 72-ft- (22-m-) long fiberglass nails to be installed and grouted in 32 hours. The tunnel is cut using automated controls equipped with 27 sensors that control the position of the blade and cutting force of the equipment. The tunnel can be advanced at a rate of 7 ft (2 m) per day, including consolidation, temporary support, and liner. Since the application is internal, weather is not a problem. This technology provides maximum safety conditions—excavation proceeds under the concrete lining. The scan team is uncertain if this method is actually faster, but it was reported to allow for consistent progress and an easier cash flow forecast.

The RPUM technology requires specialized equipment, which is patented. It was apparent to the scan team that specialized experience and training are required to operate this equipment. Several types of the equipment are available in Europe and the United States. The process is not patented. It is suitable for tunneling in rural and urban areas. Specialized design-build tunneling contractors currently use this technology. Performance-based contracts are usually used with the owner retaining 5 to 10 percent of total billings as a warranty. If problems arise, the contractor fixes them.

Pretunneling is another accelerated soft ground tunneling method that the scan team identified as having potential in other embankment and bridge excavation applications. Pretunneling is a new, advanced method for the construction of large section tunnels. In pretunneling the final load-bearing structural lining of the tunnel is constructed first, before the soil excavation, without first-phase consolidations ribs and shotcreting. The concrete shells are built by excavating the soil using a suitable cutting module. The equipment and excavation techniques are similar to CDW. The cutting module is initially inserted into the soil like a blade, excavating the soil at its frontal section. The concrete is simultaneously pumped into a slip-form to fill the cavity left by the cutting module. The module is then shifted transversally following the vault section.

This technology may be used to widen existing tunnels and to construct final tunnel lining before excavating the soil. Blade size and boulders will pose a problem with this technique. Since the technique is performed inside a tunnel, weather is not a problem. It is unclear to the scan team if this technique is actually faster than conventional tunneling methods; however, it clearly appears to be safer. Specialized, patented equipment, which is required for this technology is available, however, not in the United States. As with RPUM, specialized design-build contractors use this technology.

CFA piles provide a method for rapid installation of vertical or slight batter piles for soil or foundation support. As the name implies, a CFA assembled on a central hollow pipe is used. The auger is rotated into the ground removing a minimum of soil. At completion of boring operation, the auger is extracted while concrete is pumped through the internal hollow pipe. Concrete with a maximum aggregate size of 0.6 in (15 mm) and a slump value higher than 9 in (220 mm) is required. The steel reinforcement cage is finally lowered (or sometimes helped with static or dynamic vibration) into the fresh concrete. Piles with a diameter ranging from 1.3 to 5 ft (0.4 to 1.5 m) in diameter and a maximum depth of about 100 ft (31 m) can be constructed with this method. The piles are formed with a partial soil removal, thus the lateral soil compression resulting from the installation provides an increase in the final load-bearing capacity. Automated controls are used to maintain consistent performance. The crowd pressure plus the pressure on the concrete pump and concrete volume are used to maintain a consistent-diameter pile.

The CFA pile method allows for installation of 1300 to 1600 ft (400 to 500 m) of pile per day at low cost. The piles can be reinforced or unreinforced. Spoil is deposited in a single location at each pile. It is not suitable for soils with obstructions, such as rocks and boulders. However, the method does appear to have potential for applications in liquefaction control in high seismic areas. Weather is not a problem, except as affected by the delivery of the concrete. This technology requires specialized, patented equipment. Several of these types of equipment are readily available in the United States. The process is not patented, and conventional pile design is used. Currently, several applicable pile methods exist in the United States. A bridge/foundation contractor with the proper equipment can install this system. A significant advancement in the equipment is the computer-controlled system on the rig, which controls extraction speed and maintains the desired pile diameter. Computer printouts can be reviewed for QC/QA. Experienced operators and technicians can be trained at the manufacturer's facility (in Cesena, Italy) in less than 1 week. The technology also offers cleaner site conditions and automated operations (laborers working near an open hole are not needed), which makes this a safer process than typical drilled shaft installations. The technology is usually contracted on a performance basis with the owner retaining 5 to 10 percent of the total billings as a warranty. The developer of this technology often introduces it through design-build contracts. The technique produces low noise, low vibrations, and reduced spoils, making it suitable for urban environments.

Widespread research papers exist on CFA piles. The relationship of construction control systems to performance needs documentation, although some work has been done at the University of Ghent, Belgium, and elsewhere, as discussed in the Belgium section of this report.

Geo-jet/turbo-jet is a combination deep soil mixing and jet-grouting technology that is used to form a vertical soil-cement column for soil support. Applications include temporary shoring, secant walls, and ground improvement. The scan team could not clearly identify this technology as providing accelerated construction; however, the technology appears to work well and to have better control than jet grouting. The production rates for drilling and withdrawal reportedly are on the order of 1.6 to 33 ft (0.5 to 10 m) per minute. It is also possible to install steel reinforcement into the columns. The technique utilizes automated controls on the equipment to provide real-time monitoring of drilling and withdrawal speed, rotation speed, torque hydraulic pressure, and delivery rate and pressure of the cement grout mixture. The monitoring control, along with the shape of the tool itself, provide consistent, predictable length and diameter of columns. Another advantage is the low spoil quantity, estimated at one-sixth to one-third of the treated soil volume. The technique is suitable for different types of soils, from cohesive to loose granular materials, but does not work well where obstructions are present. It also requires specialized equipment for the drilling, mixing, and jetting with high installation power (i.e., 1000 hp). The equipment is patented, but several units are available in Europe and the United States. It was apparent to the scan team that specialized experience and training are required to operate the equipment. The process is also patented. Design is the same as done for lime/cement columns. Performance-based contracts are generally used to contract this technology. Contract bid prices are usually per linear foot. This technology is also often introduced by the developer through design-build contracts.

The work is often performed on a design-build basis. The owner retains 5 to 10 percent of total billings as a warranty. If problems arise, the contractor fixes them.

Berlin wall (micropile wall) is a technology that uses small-diameter pipe piles for lateral earth support systems with vertical capacity. This technology has been in use for many years in Europe and the United States. It is relatively quick, especially when a downhole hammer is used. The technique is not labor intensive. Micropiles are economical, costing 10 to 15 percent less than driven piles.

The equipment is simple, but specialized. The equipment is patented, but a variety is readily available in Europe and the United States. The process is not patented, and design for excavation support is straightforward, no different than for other secant pile walls. Micropile walls are used to overcome difficult drilling conditions, such as boulders, which would make soldier pile drilling problematic. Another significant advantage over other pile techniques is the low headroom requirement. Small-diameter drilling is not as messy and does not produce as much spoil as conventional diaphragm wall construction. It produces low noise and vibration. The technology is environmentally friendly, using a technique to collect dust and spoil that does not produce pollution. Weather is not a problem. Research has typically been performed internally by equipment manufacturers.

The **Hydro-Millä diaphragm wall for vertical and lateral earth support** was identified by the scan team as a good use of a common hydro-milling technology in excavation of soil with closed spoil return resulting in a clean site. The production rate for a 3.3-ft- (1-m-) thick wall averages 65 to 75 sq ft (6 to 7 sq m) per hour for an 8- to 10-hour shift, at a cost of US$28 to US$33 per sq ft (300 to 350 Euros per sq m), including excavation and concrete. However, this cost does not include reinforcement, which can be significant. Hydro-Millä is used to overcome difficult soil conditions, such as nested boulders and cobbles, which make use of clam bucket methods problematic. This technology requires specialized equipment. The equipment is patented, but a variety is available in Europe and the United States. A separation plant is used in conjunction with the Hydro-Millä to clean the excavated soil and separate it into fines, aggregate, and cobbles for reuse as backfill. The technique requires a relatively large number of personnel. Trained personnel include one shift inspector, one plant operator, and an equipment operator (with a total of 10 people for an operation, including laborers). The process is not patented, and design is the same as for conventional diaphragm walls. The technology works well for both temporary and permanent earth support and has very good alignment control. This technology produces little noise and no vibration. Hydro-Millä is used in place of micropiles by our host, Rodio, when a high water table exists. The contractor (in this case the scan tour host, Rodio) works in conjunction with the project designers. QC is done with detailed documentation. The contractor has a QC as well as QA plan. The technology is applied using performance-based contracts, with the contractor providing guarantees for 10 years. The owner often retains 5 to 10 percent of total billings as a warranty. If problems occur, the contractor fixes them.

Fiberglass or glass-reinforced plastic (GRP) nails, similar to those used in the RPUM tunnel method discussed previously in this section, were presented as a standalone method for face stabilization in tunnels and excavations. Use of this technology allows for excavation directly through the nailed stabilized section, eliminating shielding and shoring requirements. Specialized equipment is required for installing the nails, and the equipment was reported to be patented. A variety of equipment is available in Europe and the United States. However, since the process is not patented, standard nail installation equipment could also be used for installation, although installation would not be as rapid. Design is based on standard nailing procedures, as covered in FHWA design guidelines.

Real-time design was identified by the scan team as a process that could be used to accelerate construction. **ADECO-RS** is an example of real-time design being used in Italy for tunnel design and construction. In the ADECO-RS procedure, design alternatives for a variety of conditions, which could be encountered during tunneling, are developed prior to construction. Instrumentation is installed to monitor the deformation response of the surrounding materials during excavation of the tunnel. Advance cores from the face, roof, and walls are transferred to the laboratory as soon as they are taken, and the laboratory tests are performed immediately with the results automatically transferred via computer to the designer. In-depth stress-strain analysis is then performed using mathematical tools to determine the anticipated deformation behavior. With automated, real-time, continuous feedback from the field instrumentation and the laboratory on the deformation response of the materials prior to excavation, the designer and contractor can immediately select the most appropriate stabilization and excavation procedure for the next section of the tunnel. This method was found to have an indirect effect on accelerating the completion of the project. While the procedure did not speed up the tunneling drive rate, there were no delays in decision making and downtime for contractor response to changed conditions. The overall construction has been found to be uniform, predictable, and usually well ahead of schedule.

As a side issue, contractors in Europe generally seem to have flexibility to work with the project designers in finding the most effective designs and to look for faster approaches. Alternate bids are often accepted during the bidding stage (as was found during the 1999 geotechnical engineering tour), precluding value engineering, which does not exist. As previously indicated, many of the above technologies are introduced through design-build, performance-based contracts, with the contractor often providing warranties for up to 10 years.

Mandated quality certification for contractors and designers is another process identified by the scan team during this portion of the tour that could have implications in accelerated construction. One of the concerns in accelerated construction is maintaining the quality of the completed facility. In Europe, the Eurocode requires that all contractors and designers have ISO 9000 series quality certification programs in place as a prerequisite to bidding on a project.

LESSONS LEARNED: PREFABRICATED TECHNOLOGIES

Prefabricated technologies were not identified during this portion of the scan tour.

LESSONS LEARNED: STATUS OF LIMIT STATE DESIGN

No information on limit state design was obtained during this portion of the scan tour.

CHAPTER FIVE
BELGIUM

The last visit of the study tour was to Belgium on June 27 and 28, 2002, where the program consisted of formal and informal meetings and presentations at several locations. On the first day, the scan team met with representatives of the Ministry of Transport, Flemish Geotechnics Division, in Zwijnaarde. Activities included:

- Formal presentations by Prof. van Impe from the University of Ghent on “Screw Pile Foundation Systems” and “Accelerated Consolidation of Soft Soils and Staged Construction” (including underwater vacuum consolidation).
- A presentation on the design and construction of the rapid replacement of the bridge Ternesselei at Wommelgem and the bridge over the Ruggeveldlaan at Deurne on highway E313-A13.
- A visit was made to the construction site of the new high-speed train line near Antwerp. The scan team was given a formal presentation on the rapid rail project and visited the construction site to view some innovative methods used to maintain existing bridge traffic (figure 18). Above-ground tunnels are being used to mitigate noise and vibration from the surrounding residential area. Also, the team observed a large sound barrier berm containing construction debris and hazardous materials and capped with a geosynthetic liner system (figure 19). An interesting presentation was made on the geological conditions in the region.

Figure 18. Site visit to the high-speed rail line project near Antwerp.

Figure 19. Sound barrier construction using capped debris and contaminated soil mound.

On June 28, the team met with representatives of the Belgian Building Research Institute (BBRI) at its facilities in Limelette for presentations and discussions. BBRI activities included:

- Overview presentation of BBRI activities and funding methods.
- Detailed presentation on a large-scale screw pile test site and project (figure 20).

Figure 20. Screw pile test site at the Belgian Building Research Institute (BBRI).

- Construction and monitoring of a geosynthetic-reinforced steepened sound-mitigation embankment constructed to encapsulate hazardous materials.
- The team then attended project presentations and a tour of the completed canal bridge (cast on site using an incremental launch construction method), and the 230-ft- (70-m-) high ship elevator structures in Strepy (figure 21).

Figure 21. Bridge canal project visit in Strepy, showing: (a) canal bridge under construction and (b) aerial view of project, including boat elevator.

IDENTIFIED ACCELERATED CONSTRUCTION TECHNOLOGIES

A significant amount of work has been done in Belgium on screw piles, which are friction piles for embankments, retaining walls, and light structures. A variety of systems were presented, and results from comparative studies were shown. An interesting project was presented in which two bridges were replaced within an 82-hour traffic-disruption period by constructing the replacement bridges near the old bridges on site, demolishing the old bridges, and then moving the new bridges into position on wheeled transport platforms. Two recent geotechnical developments that were presented included the use of underwater horizontal vacuum consolidation with horizontally installed drains and the use of vegetated geosynthetic-reinforced berms as sound barriers.

During the site visit to the rail project, the team observed the use of lime stabilization to allow marginal soils to be placed behind retaining walls and a berm with a geosynthetic-lined cap that is being used as a sound barrier and to retain contaminated construction waste. At the bridge canal site visit, presentations were given on two major features of the canal project: a 150-ft- (46-m-) wide, 1640-ft- (500-m-) long canal bridge to support the canal over a river valley containing two multilane roadways, and a very high ship elevator.

LESSONS LEARNED: ACCELERATED CONSTRUCTION METHODS

The following section provides a review of the accelerated construction methods identified in Belgium in relation to the amplifying questions.

Screw piles are rapidly emerging pile systems consisting of steel or concrete piles with either the tip or the entire pile formed in a helical screw shape that are literally screwed into the ground. Screw piles can also be cast in situ (e.g., CFA piles are a form of screw piles). This system provides low-capacity vertical and lateral earth support. The vertical capacity is lower than that of driven piles for most systems because the zone below the pile is not compacted. There are numerous types of piles, and the equipment for installation varies considerably (e.g., Fundex, Altas, Olivier, DeWaal, and Omega). The newer generation of screw piles includes displacement screw piles, precast screw piles, and tapered multihelic screw piles. The significant advantage of screw piles over driven piles is lower noise and vibration to the extent that the use of driven piles in Europe is decreasing, while the use of screw piles is increasing. Another advantage is relatively lightweight installation equipment. However, increased torque was identified as a recent advancement in improving capacity, which may result in heavier equipment requirements. These friction-type piles are used for embankments, light structures, and retaining walls, similar to applications of driven piles. Screw pile installation rates of up to 500 ft (150 m) per day can be achieved. Diameters range from 16 to 32 in (400 to 800 mm).

Specialized equipment is required for installing screw piles. Most of the equipment is patented, but a variety is available. Screw pile equipment is readily available in the United States. The process is not patented. Several empirical design methods are well established, most of which are based on CPT. Ongoing research will provide updated parameters for design. One disadvantage is that a uniform calibration test does not exist for screw piles. The performance is sensitive to installation skill, and load tests are required to confirm capacity. Screw pile installation is usually contracted (in the United States) on a linear footage basis.

The BBRI's screw pile study is financed by the Belgian Federal Ministry of Economic Affairs. Systems manufacturers are also conducting internal research. Future developments are in the areas of improved pile tip soil interaction, improved shaft capacity, and casting the concrete for precast systems. Prof. van Impe suggests potential benefits in research on pile group capacities with pile tips located shallower than those determined from individual piles.

Lime stabilization clay was also presented to the scan team as an accelerated method of construction of embankments and fills behind retaining walls with marginal soils. This technique is a common practice in many regions of the United States. The ongoing research at the University of Ghent and BBRI could provide valuable information for extending the use of this technology. A final report of the BBRI field test study will be available.

Geotextile/sound barrier embankment is an innovative use of geotextile-reinforced mechanically stabilized earth (MSE) walls. MSE walls are already considered an accelerated construction method, and this extension of their use could increase application of this technology in the United States. The geosynthetic-reinforced walls at the Brussels airport were constructed berms with a vegetated face to provide a sound barrier. Marginal soils were used to construct the walls.

Underwater vacuum consolidation appears to be an innovative variation of vacuum consolidation, a standard technique that has been used in Belgium and the United States since about 1960. In the United States, its use has been limited because of higher costs than for classical surcharge methods. In vacuum consolidation, a stress is applied to soft soil through a vacuum to remove water. Normally, a large membrane is required to be placed over the surface. In the method presented in Belgium, the vacuum was applied through horizontal drains. Vertical drains could also be used. The technology could be used for dredge spoil, soft sites where access for placement of surcharge is not practical, underwater stabilization of soft soils, and for underwater slope stability improvement for underwater embankments as presented during the meeting in Belgium. This method avoids the construction of a surcharge load and is therefore faster than surcharging. However, it still is a slow process, as it requires the same amount of consolidation time as surcharging. The technique requires specialized, patented equipment. At this time the equipment is not available in the United States. The process is basically a standard vacuum consolidation and is not patented. Basic consolidation theory is used, with some accounting for strain-dependent soil properties (large strain theory). Measuring settlement and pore water pressure is used to control quality. Means and methods contracts are currently used to apply this technology with the requirements specified by the geotechnical engineer. The geotechnical engineer provides detailed methods and procedures for installation and monitoring. The scan team believes that specialized training would be required for technicians. This method has no impact on the environment. Research is ongoing at the University of Ghent using field data from offshore sites.

LESSONS LEARNED: PREFABRICATED TECHNOLOGIES

Similar to the prefabricated technology reviewed in Germany, a completed bridge was moved into its final position on a project in Belgium. On the Belgian project, two bridges were replaced by building new bridges adjacent to the old bridges. Within 82 hours, the old bridges were demolished, the new bridges were rolled into place, and the roadway was reconstructed and opened to traffic. Sand-cement mixture was used for backfill behind the abutment wall to reduce the lateral load on the bridge wall and to accelerate placement and construction. The width of the bridge wall was reduced from 3.3 ft to 1.3 ft (1 m to 0.4 m) to decrease the bridge load and allow it to be rolled into position. This technology was again primarily utilized to minimize disruption to traffic, as well as to save time. The application of this technology would depend on the site conditions and traffic control requirements. The scan team sees no impacts to the environment in using this technology.

A second accelerated bridge technology viewed in Belgium was the canal bridge constructed using a cast-on-site incremental launch construction method. The method was invented in Germany several decades ago, and has been used most commonly for bridges over deep ravines or valleys in the mountainous areas of Europe. This method eliminates the need for expensive and time-consuming temporary supports, and it allows on-site casting to occur year round (the bridge box segments are cast within an enclosed facility located at the bridge abutment). The application of this technology for construction of the canal bridge demonstrated accelerated construction solutions that are common to highway construction problems (i.e., speed of completion and noninterference with existing traffic). The bridge was completed nearly a year earlier than would have been possible with conventional construction, and without impact to the roadway below the bridge.

LESSONS LEARNED: STATUS OF LIMIT STATE DESIGN

The status of limit state design in the context of Eurocode 7 was not reviewed during this portion of the scan tour.

CHAPTER SIX
MAJOR FINDINGS

The team identified 30 technologies and up to 15 processes that offer a potential for accelerating construction and rehabilitation of bridge and embankment foundations, which are listed in table 3. Many of the technologies also offer a potential for cost savings and, in a majority of the cases, an improvement in the quality over current practice. Tables 4 through 8 summarize the technologies evaluated and rank them in terms of anticipated improvements in construction time, cost, and quality. The table in Appendix C lists web sites where additional information can be obtained for many of the technologies. The technologies that offer the greatest potential benefit clearly lead to recommended practices as outlined in the next section of this summary report.

Table 3. Technologies (a.) and Processes (b.) for Accelerated Construction of Bridge and Embankment Foundations

3a. List of Technologies:
1. Embankment on Columns
2. Lightweight Aggregates
3. Deep Mixing (Lime-Cement) Columns
4. Mass Stabilization
5. Geotextile-Encased Columns (GEC)
6. Rapid Impact Compaction (Building on Fills)
7. Vibro-Jet Sheet Pile Driving
8. Load Transfer Mat Concrete Slab
9. Load Transfer Mat – Caps and Geosynthetics
10. Automatic Controlled Variable Roller Compaction
11. Reinforced Soil Sound Barriers
12. Self-Drilling Hollow Bar Nails and Micropiling
13. Screw Piling
14. Combined Soil Stabilization (CSV) System
15. Accelerated Site Investigation
16. Continuous Flight Auger (CFA) Piles
17. Bored Piling – Cased Secant Piles (CSP)
18. Berlin Wall (Micropile Wall)
19. Continuous Diaphragm Walls (CDW)
20. Hydro-Millä Diaphragm Walls
21. Reinforced Protective Umbrella Method (RPUM) Glass-Reinforced Plastic Bar
22. Pretunneling
23. Micropiling Rod Carousels
24. Rock Saw
25. Computer Controlled Consolidation Grouting
26. Turbo-Jets
27. Horizontal Vacuum Consolidation
28. AuGeoä
29. Dynamic Stiffness Gauge
30. Higher Energy Compaction Impact Roller

3b. Processes and Approaches:

A. Public Relocation during Construction
B. Communication with the Public
C. Designer on Board during Construction
D. Contractor Involved in Design
E. Contractor/Designer QC/QA Required ISO 9000
F. Real-Time Lab Testing and Data Storage
G. Real-Time Design (e.g., ADECO-RS (Analysis of Controlled Deformation)
H. 10-Year Warranties/Insurance
I. Pile Load Test Program/Certification for Screw Piling (Recommendations)
J. Self-Compacting Concrete
K. Prefabricated Bridge Parts (Bayonet Pipe Pile Connection)
L. Moving Completed Bridges on Site
M. Automated GPR for Pavement
N. Maintenance-based Payment Procedure
O. Automated Control QC Documentation of Installation

BRIDGE FOUNDATIONS (TABLE 4)

For bridge foundation construction, the standard of practice in the United States for poor to marginal foundation conditions is driven piles or drilled shafts. Because of QC/QA problems with auger cast piling, auger cast or CFA piles are rarely used in U.S. bridge construction. CFA piles with automated computer control and automated QC/QA would appear to offer a rapid alternative to the current practice that could be easily implemented. CSP piles should also be evaluated as an alternate accelerated method that can provide both bridge support and excavation support in cut situations. Both systems are limited in load support by the maximum diameter of piles that can be formed. For large projects with difficult drilling conditions and/or tight spaces, the use of a diaphragm wall constructed with a Hydro-Mill™ offers a rapid construction method with low noise and low vibrations that could also be used to support large loads.

EMBANKMENT FOUNDATIONS (TABLES 5 AND 6)

For embankment foundation construction over soft, compressible soils, the Europeans use column-supported embankments to accelerate construction over classically using a surcharge load with or without wick drains. Although this is familiar technology in the United States, it is often associated with high cost and difficult access. However, with some of the advances in pile technology (i.e., faster installation, lighter equipment, and lower cost) as identified on this tour, column-supported embankments are considered by the team as a much more attractive alternative that should be explored as a viable alternative for most soft ground projects.

An embankment mat support system may be required to spread the load over the foundation soil or piles, depending on the soil conditions, type of pile, and deep foundation spacing. Load-transfer mats constructed with geosynthetic reinforcements, and often combined with lightweight aggregates or geofoam, offer a viable solution, with the design methods supported by both U.S. and European practice. Stabilization of the upper 10 to 16 ft (3 to 5 m) of soil materials through either mass stabilization or rapid impact compaction may also hold some promise in constructing foundation support mats with and without deep foundation systems.

EMBANKMENT CONSTRUCTION (TABLE 7)

Several technologies evaluated on the tour offer the potential to accelerate placement and compaction of fill for construction of the embankment itself, while maintaining or improving cost and quality. Lightweight fills have been used in the United States to a limited extent to reduce placement and surcharge time in soft soil conditions. The frequency of use in Europe appears to be increasing (almost routine). Increasing the use in the United States should expand availability and decrease cost, making lightweight fills such as geofoam an attractive alternative to surcharge fills, and accelerate construction. The rate of embankment construction could also be significantly increased through the use of high-energy impact, rolling compactors and rapid-impact hydraulic hammer compactors, both of which appear to provide a much greater depth of compaction, allowing for placement of thicker fills. Another promising technology is the use of instrumentation on the compaction equipment to measure dynamic modulus, which can be used for improving compaction uniformity, effective compaction effort, and, potentially, compaction QC.

EARTH-RETENTION SYSTEMS (TABLE 8)

Rapid construction alternatives to conventional bridge retaining wall construction (i.e., using sheeting and shoring with cast-in-place walls) were identified that could be easily implemented. The technologies include bored CSPs and CDWs, both of which can be used for the retaining wall as well as the support of the bridge. Both methods can be used on sites where difficult drilling is anticipated, and both methods produce low noise and low vibrations.

PROCESSES AND APPROACHES

The scan team agrees that the scan findings with the greatest potential for accelerated construction are the processes and approaches listed at the bottom of each of the tables. The common theme among all of these processes is *simplicity through sophistication*.

Practically all of the equipment and construction methods presented in tables 4 through 8 employ real-time automated installation control and documentation. These systems monitor, measure, control, and document critical aspects of their technology and, thereby, allow for rapid construction without compromising quality. In fact, in most cases they improve quality. In addition to faster installation, these technologies and methods accelerate construction by reducing, or eliminating, QC methods that are intrusive to the construction process.

The scan team also observed the simplicity through sophistication approach being applied to construction materials. Specifically, one of the most exciting finds of the trip was the common usage of SCC in Sweden. SCC is not a new technology, but SCC research, development, and implementation to such a highly advanced level of common usage is a new achievement.

By using advanced SCC technology, Sweden is able to pour concrete in intricate forms and/or dense reinforcement situations significantly faster, with fewer workers, less dependence on worker skills, smaller pumps, and higher quality. SCC should lead to a longer life via superior coverage of reinforcement and very low permeability. It provides significant benefits when post-tensioning or other ductwork is present. Since vibration is not needed, ductwork cannot be pushed out of alignment or damaged.

Several other European Community (EC) standard processes were also identified that could lead to both improvements in construction rate and quality at a moderate cost, including (1) requiring the contractor and designer to have a QC/QA program modeled after the ISO 9000 series process, and (2) increasing requirements for computer automated equipment control and requiring generated data to be provided as part of the QC program. A process to evaluate which method would provide optimum acceleration considering the total scope and integration with all phases of the project (i.e., how accelerated construction methods fit in with the critical path for project completion) was presented by the BASt. This process could be used as a model to help agencies identify opportunities and the optimum method for accelerated construction.

Table 4. Bridge Foundation Systems, Equipment, and Ground Improvement Methods for Accelerated Construction and Rehabilitation on Poor Subgrades

Technology or Process	Anticipated Accelerated Construction Performance	Relative* Potential for Accelerated Construction	Applicable Conditions for Accelerated Construction	Relative Cost*	Improvement in Quality*	Design and Construction Issues*				Comments
						Settlement Reduction	Equipment Mobility	Soil Excavation	Vibration & Noise	
Base-line Technology for Comparison – Driven Piles and Drilled Shafts										
Vibro-Jet of Sheet Pile Driving	Speeds driving of sheet piles through layered soils	M	Same as conventional sheet piles	L	L	L-M	M	Y	M	Bridge abutments with grouting through vibro-jet pipes
Self-Drilling Hollow Bar Nailing & Micro Piling	Self-drilling and grouting for one-step installation	H	Difficult ground for drilling/ driving	L	H	M	H	N	L	Confined conditions with difficult ground for drilling or driving
Screw Piling	Requires 1/3 the time of auger cast piles and lighter/smaller equipment. Similar to driven piles.	L	Relatively weak soil conditions. Foundations with low vertical and lateral loads per pile.	M	L	H	H	N	L	Auto control Depth < 100 ft (30 m) Nonartesian
Continuous Flight Auger Piles (CFA)	Rapid pile installation for vertical or slight batter piles	H	Best in weak to medium soil	M	L	H	H	Y	M	Use only with automated control and documentation. Not suitable for difficult drilling and obstructions.
Bored Piling – Cased Secant Pile (CSP)	Rapid pile installation for vertical piles	H	Cut situations and temporary excavations	M	M	L-M	H	Y	L	Casing assists in some soil conditions
Hydro-Mill™	Rapid excavation of wall with no mess.	M	Difficult drilling conditions, large loads	M	H	H	L	Y	M	Use on large projects with difficult drilling conditions, large loads, low noise & vibrations, tight spaces

Applicable Processes from Scan Tour:

- **Contractor/Designer QC/QA Required ISO 9000**
- **Self-Compacting Concrete**
- **Automated Control QC Documentation of Installation**

* H, M, L = High, Moderate, Low; Y, N = Yes, No.

Table 5. Embankment Foundation Systems, Equipment, and Ground Improvement Methods for Accelerated Construction on Poor Subgrades

Technology or Process	Anticipated Accelerated Construction Performance	Relative* Potential for Accelerated Construction	Applicable Conditions for Accelerated Construction	Relative Cost*	Improvement in Quality*	Design and Construction Issues*: Settlement Reduction	Design and Construction Issues*: Equipment Mobility	Design and Construction Issues*: Soil Excavation	Design and Construction Issues*: Vibration & Noise	Comments
Base-line Technology for Comparison – Surcharged Embankment on Poor Subgrade										
Column-Supported Embankments	Saves surcharge time; no surcharge required	H	Depth** < 120 ft	H	H	H	M to H	Y & N	M to H	Newer piles and columns (e.g., GEC, CSV, CFA, AuGeo™, Screw Piles) may reduce cost
Deep Mixing (Lime-Cement) Columns	Reduces surcharge requirements	M	Depth < 120 ft Low organic Nonartesian	M+	H	M	M	N	L	Advances in QC, mixing, equipment, and uniformity
Mass Stabilization	Saves time when compared with preloading	M to H	Depth < 25 ft High organic	M	M	M	H	N	L	Effective for 10 to 16 ft (3 to 5 m) depth in peat, mud, or soft clay
Geotextile-Encased Columns (GEC)	High bearing capacity, saves time required for surcharge, low noise	M to H	Depth < 60 ft Nonartesian	M	M	M	M	N	M	85% to 95% settlement in 3 months
Screw Piling	Similar to driven piles, low noise & vibration	H	Depth < 100 ft Nonartesian	H	H	H	H	N	L	Lower-capacity friction piles; variety of systems
Combined Soil Stabilization (CSV) System	One-step installation of sand-cement columns	M	Depth < 50 ft Nonartesian	H	H	M	M	N	M	Low weights, easily mobilized equipment
Continuous Flight Auger (CFA) Piles	Rapid pile installation for vertical or slight batter piles	H	Depth < 120 ft Nonartesian	H	H	H	H	Y	M	Installation rate up to 1600 ft (500 m) per day at low cost; not suitable for obstruction
Turbo-Jets	Rapid vertical column for soil support	M	Depth < 110 ft	M+	M+	M	M	N	M	Control appears better than jet grouting
AuGeo™	Fast piling system	H	Depth < 50 ft	H?	H	H	H	N	M	Not presented, more information required
Horiz. Vacuum Consolidation	Rapid consolidation without surcharge	M	Depth ?	H	H?	L	?	N	L	Potential technology; especially for hydraulic fill

Applicable Processes from Scan Tour:

- **Contractor/Designer QC/QA Required ISO 9000**
- **Automated Control QC Documentation of Installation**

* H, M, L = High, Moderate, Low; Y, N = Yes, No.

** 1 ft = 0.3 m

Table 6. Embankment Mat Foundation Systems and Equipment for Accelerated Construction on Poor Subgrades or over Deep Foundations

Technology or Process	Anticipated Accelerated Construction Performance	Relative* Potential for Accelerated Construction	Applicable Conditions for Accelerated Construction	Relative Cost*	Improvement in Quality*	Comments
Base-line Technology for Comparison – Normal (possibly staged) Fill Construction; Assumes Close Spacing and Arching for Piled Foundations						
Load Transfer Mat – Geosynthetics	No or reduced surcharge required	H	Close piles with soft tops	M	M	For hard piles/columns need to check punching shear; works well with soft piles
Light Aggregates	Reduces or eliminates surcharge	H	Soft foundations	M to H	H	Geofoam, flowable fill, etc.
Load Transfer Mat – Concrete Slab	No surcharge required; could use prefab mats	H	Soft foundations	H	H	Soft foundations – highest cost
Load Transfer Mat – Concrete Caps	No surcharge required	M	Hard piles or columns that are closely spaced	H	M	Requires hard piles/columns that are closed spaced
Load Transfer Mat – Caps and Geosynthetics	No or reduced surcharge required	M	Hard piles or columns with wide spacings	M to H	H	Arching and spacing versus geosynthetic strength
Mass Stabilization	Saves time when compared with preloading	M	Soft and/or organic ground	M to H	M	Works well for soft and/or high organic soils
Automatic Controlled Variable Roller Compaction	Speeds compaction eliminating wasted time.	M	Granular fill	M	H	Compaction efficiency and uniformity improved; minimizes passes required

Applicable Processes from Scan Tour:

- **Designer on Board during Construction**
- **Contractor Involved in Design**
- **Contractor/Designer QC/QA Required ISO 9000**
- **Real-Time Lab Testing and Data Storage**
- **Real-Time Design (for example: Analysis of Controlled Deformation [ADECO-RS])**
- **10-Year Warranties/Insurance**

* H, M, L = High, Moderate, Low

Table 7. Embankment Construction Equipment and Methods for Accelerated Construction

Technology or Process	Anticipated Accelerated Construction Performance	Relative* Potential for Accelerated Construction	Applicable Conditions for Accelerated Construction	Relative Cost*	Improvement in Quality*	Comments
Base-line Technology for Comparison – Normal (possibly staged) Fill Construction; Assumes Close Spacing and Arching for Piled Foundations						
Light Aggregates	Reduces or eliminates surcharge	M-H	Poor/soft foundations	M to H	H	Geofoam, flowable fill, etc.
Rapid Impact Compaction	Building with thick fills and rubble fills	M	Thick fills and rubble	M	L	Currently used for building on rubble fills; quality of compaction needs evaluation
Automatic Controlled Variable Roller Compaction	Speeds compaction eliminating wasted time plus rapid QC	M	All cases but best in granular fill	M	M	Compaction efficiency and uniformity improved; minimizes passes required
Accelerated Site Investigation	Large area rapid QC by using ground-probing radar or resistivity	M	Use of GPR or resistivity for QC. All cases.	L	L	Works for all cases
Horizontally Vacuum Consolidation	Rapid consolidation of soft soils and below-water soils without surcharge	M	Hydraulic fill and dredge spoil	L	L	Allows use of hydraulic fill and dredge spoil
Dynamic Stiffness Gauge	Rapid QC, approximately 2 minutes per test	L-M	Sands and gravels, possible rock fill	L	L-M	Works for granular soils
Higher Energy Compaction Impact Roller	Allows use of thicker fills	L-M	Thicker fills	M	L	Quality of compaction needs evaluation

Applicable Processes from Scan Tour:

- **Contractor/Designer QC/QA Required ISO 9000**
- **Real-Time Lab Testing and Data Storage**
- **10-Year Warranties/Insurance**
- **Auto Control QC Documentation of Installation**

* H, M, L = High, Moderate, Low

Table 8. Innovative Earth-Retention Systems for Accelerated Construction and Rehabilitation.

Technology or Process	Anticipated Accelerated Construction Performance	Relative* Potential for Accelerated Construction	Applicable Conditions for Accelerated Construction	Relative Cost*	Improvement in Quality*	Design and Construction Issues*				Comments
						Settlement Reduction	Equipment Mobility	Soil Excavation	Vibration & Noise	
Base-line Technology for Comparison – Temporary Sheeting and Shoring with Cast-in-Place (CIP) Wall										
Deep Mixing (Lime-Cement) Columns	Stabilizes soil to allow excavation without sheeting and shoring	M	Soft soils in low organic, nonartesian conditions	M	M	L-M	M	N	L	Wet method is not applicable in tight R/W conditions; requires CIP wall
Vibro-Jet of Sheet Pile Driving	Speeds driving of sheet piles through layered soils	H	Same as conventional sheet piles	M	L	L-M	M	Y	M	Quality can be improved with post- grouting
Self-Drilling Nails	Self-drilling and grouting for one-step installation	H	Difficult ground for drilling/driving	M	M	M	H	N	L	Use for difficult drilling (cobbles & boulders)
Cased Secant Pile (CSP)	Rapid vertical and lateral support	M	Cut situations	M	M	L/M	H	Y	L	Depressed section in weak ground
Berlin Wall (Micropile Wall)	Lateral wall support with vertical capacity	H	Difficult ground for drilling/driving	M	H	M	H	Y	L	Used for difficult drilling (cobbles & boulders) above ground water
Continuous Diaphragm Walls (CDW)	One-step excavation & concrete placement with minimum mess (no slurry)	H	Tight site conditions, low headroom	H	M	H	L	Y	L	Limited to 33 ft (10 m), setup cost is high
Hydro-Mill™ Diaphragm Walls	One-step excavation and slurry placement with minimum mess	H	Useful in difficult drilling conditions, i.e., cobbles and boulders	M	H	H	L	Y	M	High mobilization costs, good control on alignment with automated control system
Turbo-Jets	Rapid vertical columns with limited spoil	M	All soils	M	M	M	M	Y-M	M	Control appears better than jet grouting. Does not work well where obstructions.

Applicable Processes from Scan Tour:

- **Designer on Board during Construction**
- **Contractor Involved in Design**
- **Contractor/Designer QC/QA Required ISO 9000**

* H, M, L = High, Moderate and Low; Y, N = Yes, No.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS FOR IMPLEMENTATION

CONCLUSIONS

The overall goal of the scan trip was to implement technologies of best practice. With this objective clearly in mind, an implementation ranking was developed using the following two-step process:

(1) The team as a whole reviewed and discussed each technology with respect to its potential for accelerating construction.

(2) Each team member selected the two technologies for which he had the strongest desire to champion implementation.

The technologies that were selected for immediate implementation action are:

- Column-supported embankments
- CFA and CSP bridge foundations
- Automated computer installation control and installation documentation
- Self-compacting concrete

Many of the other technologies listed in the tables show great promise, but successful implementation requires a champion. In addition, given the diversity of the team members (contractor, consultant, DOT, Federal, geotechnical and structural engineers, academia), the ranking should be an excellent indicator of the accelerated technologies preferences of the highway construction community as a whole.

Therefore, the above list is not necessarily a ranking of technologies with the greatest technical potential for accelerating construction. Instead, it is a list of European accelerated construction technologies with the greatest potential for implementation in the United States. This type of focused selection should ensure that our resources are not diluted.

IMPLEMENTATION

At the end of the tour, team members reviewed an implementation plan, which consists of:

1) Presentations on new technologies, as identified in the body of this report, at engineering meetings.

2) Invited equipment demonstrations by manufacturers.

3) Cooperative efforts with European organizations.

4) Local efforts by team members to use the technologies within their organizations on demonstration projects.

A Scan Technology Implementation Plan team was organized to develop a request for seed funding to assist in the implementation efforts for specific, high-priority technologies. Several proposals have already been developed for advancing the implementation of these technologies, and several others are in progress. For example, the Office of Research, Development, and Technology has initiated an FHWA-led Pooled Fund study entitled "Geosynthetic Reinforced Pile Supported Embankment" based on the positive responses received from a number of states. In addition, the National Deep Mixing (NDM) Cooperative Research program, a consortium of 10 States, Federal government, and the private sector, initiated several applied research projects, including Development of Design Charts for Geosynthetically Reinforced Deep Mixed Columns; Design Guidelines for Excavation Support by Deep Mixing; and Design Guidelines for Embankments on Deep Mixed Columns. Moreover, three Swedish reports of EuroSoilStab on deep mixing technology were translated into English in a collaborative effort between the Swedish Geotechnical Institute and the NDM program. Partnering with FHWA, the International Association of Foundation Drilling (ADSC), and Auburn University, the South Carolina DOT has also applied for an Innovative Bridge Research and Construction (IBRC) grant for using SCC in drilled shaft foundations.

APPENDIX A
AMPLIFYING QUESTIONS

PRIMARY TOPIC: INNOVATIVE TECHNOLOGY FOR ACCELERATED CONSTRUCTION OF BRIDGE AND EMBANKMENT FOUNDATIONS

1. General

   What technology, methodology, or equipment have you used or developed to accelerate the construction of embankment and/or bridge foundations? In general this would include accelerated construction using, but not be limited to:

   A. New bridge and embankment foundation systems.

   B. Foundation equipment and technology for accelerated construction and rehabilitation.

   C. Innovative earth retention systems for accelerated embankment construction, rehabilitation, and widening.

   D. Innovative ground improvement technology for embankment and bridge foundations.

   E. Earthwork construction for the embankment.

   F. Contracting methods and procurement procedures.

      The technology or methodology could achieve the improved rate of construction by means such as those presented below.

      a. Faster rate of installation and acceptance. This would include:

         i. Faster production rates.

         ii. Simplified access via reduced size or environmental impacts/ restrictions.

         iii. A more consistent product, which reduces time spent on correcting defects, or mitigating time impacts to other aspects of the project.

         iv. A quality control and quality assurance method that streamlines construction and improves efficiency.

      b. Greater production rates. For example, the ability to work:

         i. 24 hours a day via low noise (nighttime).

         ii. 24 hours a day via low traffic impact (daytime).

         iii. Close to existing structures via low vibration, headroom, etc.

         iv. Faster production rates.

c. Elimination of or reduction in time to construct other steps in the foundation installation process. For example:

    i. Eliminate the need to dispose of soil, wastes, overburden, and hazardous materials.

    ii. Elimination of field placement of concrete or steel reinforcement in drilled or driven foundations.

    iii. Elimination of pre-construction, post-construction, or off-site environmental mitigation.

    iv. Reducing the need for subsurface borings and testing.

    v. Reducing time-consuming methods for protection of adjacent infrastructure and/or maintenance of traffic.

d. Elimination of or reduction in time to construct other steps in the overall project construction process. For example:

    i. Reducing time for issuing contracts and approvals.

    ii. Reducing fabrication time for on-site materials (e.g., prefabricated systems).

    iii. Simplification of constructing or connecting to the foundation system.

2. In relation to Item 1, how or why does the technology, method, or equipment provide acceleration of construction? Please describe its development, history of use, and documented performance.

3. With respect to Item 1, does your method(s) require any specialized foundation equipment? If so, please describe its special nature and provide any patent information.

4. With respect to Item 1, what is the basis for the design method? Please describe the method and note any modifications from conventional foundation design practice.

5. What conditions are favorable for the use of the accelerated construction methods that you described in Item 1 (i.e., how do you determine which method to use)?

6. For each of the methods described in Item 1, what quality control/quality assurance programs are parts of the accelerated construction program?

7. Do any of the methods, technology, or equipment described in Item 1 require special training, skills, or experience?

8. With respect to Item 1, what safety issues are associated with the accelerated technology, method, or equipment?

9. With respect to Item 1, how do you contract or purchase the skills associated with the accelerated technology, method, or equipment?

10. Is there direct owner/agency involvement in partnering or cost sharing with respect to the development, implementation, and/or use of any of the accelerated technology, methods, or equipment described in Item 1?

11. Do you have any ongoing research or have you identified any research needs required to advance any of the accelerated technology, methods, or equipment identified in Item 1? Please describe the method of sponsoring research for its development.

12. With respect to Item 1, please address the following regional or site-specific issues:

    A. Seismic considerations?

    B. Environmental (e.g., air and water quality, noise, vibrations, odors, wildlife, etc.) considerations?

    C. Weather considerations?

    D. Other?

SECONDARY TOPIC 1. PREFABRICATED BRIDGE STRUCTURE AND FOUNDATIONS

- Have you used prefabricated materials to accelerate the construction of the bridge or foundation systems? Please provide us with the information on the materials, successful performance, and case histories.

SECONDARY TOPIC 2. OTHER GEOTECHNICAL PRACTICES OF INTEREST

- Please describe your experience in applying the limit state design methods in Eurocode 7.

APPENDIX B

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APPENDIX C
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Table C1. Web Sites for Additional Information on Technologies and Processes for Accelerated Construction of Bridge and Embankment Foundations

List of Technologies:	Web Site
1. Column-Supported Embankments	
2. Light Aggregates	www.escsi.org
3. Deep Mixing (Lime-Cement) Columns	www.swedgeo.se/sd/
4. Mass Stabilization	http://gbsppsl/vvae/Documents/Avdelningsadministration/Teknikavdelningen/Geoteknik/Bilde/Masstab%20rv%2044/P3150012.JPG
5. Geotextile-Encased Columns (GEC)	http://www.ihcholland.com/B_ihc_dredging/B08/b08.5_beavers_work/b08.5_werner_mobius.htm and www.huesker.com
6. Rapid Impact Compaction (Building on Fills)	http://www.pennine-group.com/rapid-impact-compaction.html
7. Vibro-Jet Sheet Pile Driving	
8. Load Transfer Mat Concrete Slab	
9. Load Transfer Mat – Caps and Geosynthetics	
10. Automatic Controlled Variable Roller Compaction	http://www.bomag.com/worldwide/index.aspx
11. Reinforced Soil Sound Barriers	http://www.recywall.be/centres/ukcstc.htm
12. Self-Drilling Micropiling and Nails	www.ischebeck.com
13. Screw Piling	http://www.bbre.be/ http://terzaghi.rug.ac.be/bap.html
14. Combined Soil Stabilization (CSV) System	http://www.demflood.co.uk/pages/products/csv.htm
15. Accelerated Site Investigation	
16. Continuous Flight Auger (CFA) Piles	http://www.soilmec.it/mainFrSet.asp?Content=foundation
17. Bored Piling – Cased Secant Pile (CSP)	http://www.trevispa.com/innovazioni_csp_e.html
18. Berlin Wall (Micropile Wall)	
19. Continuous Diaphragm Walls (CDW)	http://www.trevispa.com/innovazioni_cdw_e.html
20. Hydro-Millä Diaphragm Walls	
21. Reinforced Protective Umbrella Method (RPUM) Glass-Reinforced Plastic Bar	http://www.trevispa.com/tecnologie_gallerie_e.html
22. Pretunneling	http://www.trevispa.com/innovazioni_pretunnel_e.html
23. Micropiling Rod Carousels	
24. Rock Saw	
25. Computer Controlled Consolidation Grouting	
26. Turbo-Jets	http://www.trevispa.com/tecnologie_consolidamenti_e.html
27. Horizontal Vacuum Consolidation	
28. AuGeoä	http://www.geotechnics.nl/uk/augeo.html
29. Dynamic Stiffness Gauge	
30. Higher Energy Compaction Impact Roller	

Processes and Approaches:	Web Site
A. Public Relocation during Construction	www.taranebergsbron.nu
B. Communication with the Public	www.taranebergsbron.nu
C. Designer on Board during Construction	
D. Contractor Involved in Design	
E. Contractor/Designer QC/QA Required ISO 9000	
F. Real-Time Lab Testing and Data Storage	
G. Real-Time Design (e.g., ADECO-RS, Analysis of Controlled Deformation)	http://www.rocksoil.com/ing_tec_progetto_adeco.html
H. 10-Year Warranties/Insurance	
I. Pile Load Test Program/Certification for Screw Piling (Recommendations)	
J. Self-Compacting Concrete	
K. Prefabricated Bridge Parts (Bayonet Pipe Pile Connection)	
L. Moving Completed Bridges on Site	
M. Automated GPR for Pavement	
N. Maintenance-Based Payment Procedure	
O. Automated Control QC Documentation of Installation	

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Randy R. Cannon (Co-Chair) is the Bridge Design Engineer for the South Carolina DOT in Columbia, South Carolina. He is the voting member for South Carolina on the AASHTO Bridge Subcommittee and is chairman of T-15 - Technical Committee for Substructures and Retaining Walls. He also serves on T-3 - Technical Committee for Seismic Design and T-9 - Technical Committee for Corrosion. Before being appointed the Bridge Engineer, Mr. Cannon was the Bridge Geotechnical Engineer, with earlier positions as Bridge Team Leader in structural design and work in the bridge boring crew; road, and bridge construction. Mr. Cannon is a graduate of the University of South Carolina, with bachelor of science and master of engineering degrees. He is a licensed professional engineer in South Carolina and serves as current vice president of the South Carolina Council of Engineering and Surveying Societies. He is also president of South Carolina Society of Engineers and is a member of the American Society of Engineers and National Society of Professional Engineers.

Christopher E. Dumas (Co-Chair) is currently employed by the FHWA as a Geotechnical Engineer for the Eastern Resource Center in Baltimore, Maryland. In his current position, Mr. Dumas uses his expertise to provide assistance to State highway departments and their consultants in geotechnical design, construction, value engineering, and in the implementation of new geotechnology (e.g., software, training courses, construction equipment, design code specifications). His current 14-State service area extends from Virginia to Maine, but he also is frequently involved with other State Highway Agencies and consultants from around the United States. Through his regional and national design and construction activities, Mr. Dumas saw a critical U.S. market need for accelerated construction, and developed the subject Scan Proposal. Mr. Dumas has a bachelor of science degree in civil engineering and a master of science degree in geotechnical engineering from the University of Florida. Mr. Dumas also is the current Chairman of the National Science Foundation's TRB's Committee on Foundations, and is a member of the World Road Congress Technical Committee on Embankments, Drainage, and Subgrades (PIARC C-12).

Dr. Barry R. Christopher (Report Facilitator) is an independent geotechnical engineering consultant specializing in reinforced soil and other ground improvement technologies, geosynthetics application and design, and geotechnical/geosynthetics testing and instrumentation. He has authored numerous technical papers on these subjects, including six design manuals for the FHWA and a textbook on geosynthetics. He currently teaches training courses in reinforced soil walls and slopes, geotechnical instrumentation, geosynthetics, and foundation evaluation for the FHWA and private industry. Dr. Christopher has more than 23 years of geotechnical engineering experience, much of which was gained from his previous work as a principal engineer for a major geotechnical consulting firm, where he was heavily involved in deep foundation design and embankment construction. He also gained significant experience on soft foundation projects while working as the technical director for a geosynthetics manufacturer. He has a BSCE degree from the University of North Carolina at Charlotte, an MSCE degree from Northwestern University, and a Ph.D. from Purdue University. He is a registered professional engineer in six States, has chaired several national and international professional committees and is currently active in ASTM, ASCE, IGS, NAGS, the GeoCouncil, and ISO/CEN.

Dr. Dan A. Brown is a member of the Civil Engineering faculty at Auburn University in Auburn, Alabama. Dr. Brown's research emphasis includes construction and design of deep foundations for highway bridges, response of pile group foundations to extreme event loadings, and field testing of deep foundations. Prior to joining the Auburn faculty in 1987, he was employed in private practice in Louisiana. Dr. Brown is a graduate of the Georgia Institute of Technology and holds a doctorate from the University of Texas. He is a licensed professional engineer in several States, and is an active member of TRB Committee A2K03 and the Deep Foundations Committee of the Geo-Institute of ASCE (Past Chairman).

Maung Myint Lwin is the Structural Design Engineer for the FHWA Western Resource Center in San Francisco, California. Mr. Lwin currently is responsible for providing technical support in bridge engineering to the FHWA Division Offices and State DOTs. He is involved in the structural design of bridge foundations and soil-structure interaction in seismic analysis. Before joining FHWA in January 2000, he was the State Bridge Engineer for Washington State. Mr. Lwin is a graduate of the University of Rangoon, Burma, and holds a master's degree in civil engineering from the University of Washington in Seattle, Washington. He is a licensed civil and structural engineer in Washington State. Mr. Lwin serves on several technical committees of the TRB and AASHTO, and chairs NCHRP Research Project Panel 24-09 Static and Dynamic Lateral Loading of Pile Groups.

Alan Macnab is the Business Development Officer for Condon-Johnson & Associates, located in Seattle, Washington. He has been involved in the construction and management of projects in the earth retention and deep foundation contracting market for 30 years. Mr. Macnab has extensive experience in drilled shafts, driven piles, soldier piles and lagging, secant piling, tiebacks, micropiles, soil nailing, and soil mixing. He is a licensed professional engineer who graduated with a BSCE from the University of Western Ontario. He is the president-elect of the Geo-Institute, past president of the ADSC –The International Association of Foundation Drilling, and currently chairs the ADSC Standards and Specifications Committee. In addition he sits on the DFI Committee on Soil Mixing and chairs the WSDOT/ADSC Task Force on Drilled Shafts. Mr. Macnab has published a number of papers on earth retention, drilled shafts, nondestructive testing, and dispute resolution. He has also written a book, published by McGraw-Hill, called *Earth Retention Systems Handbook*. He has lectured frequently on these issues at industry-, FHWA-, and academic-sponsored events.

Sundru (Sam) Mansukhani is a Geotechnical Engineer for the FHWA at the Midwestern Resource Center (MRC) in Chicago, Illinois. Mr. Mansukhani currently serves as a national geotechnical engineering expert on individual projects for the design and construction of bridge foundations, pavement support systems, and earth retaining structures. He provides leadership in programs for improving the geotechnical engineering practices used by the State and local highway agencies serviced by the MRC. Prior to joining the MRC in 2000, he served as the executive vice president of a major national geotechnical consulting company and directed the activities of chief engineers, consultants, and senior vice presidents. Mr. Mansukhani is a graduate of the Indian Institute of Technology, and holds a master's degree in civil engineering from the State University of New York at Buffalo. He is a licensed professional engineer in Alabama, Arizona, and numerous other States; a member of the ASCE, and serves on several research advisory committees and national technical working groups for the development of new FHWA geotechnical programs.

Kevin W. McLain is a Geotechnical Engineer with the Missouri DOT (MODOT) in Jefferson City, Missouri. Mr. McLain currently works with new geotechnical engineering technologies and applications for the MODOT Geotechnical Section. These technologies and applications have included soil nailing, reinforced slopes, and use of and application of SCPTU tests in Missouri. He is currently working on developing geotechnical design procedures for seismic-prone areas of the state. Mr. McLain graduated in 1988 with a bachelor of science degree in civil engineering from Kansas State University. He is currently working on a master's degree in civil/ geotechnical engineering through the Division of Continuing Education at Kansas State. He is a licensed professional engineer in Missouri. He is also a registered geologist in the State of Missouri, and is currently working on a FHWA technical committee on soil nailing.

Thomas W. Pelnik III is a Geotechnical Engineer for the Virginia DOT (VDOT). He manages the Geotechnical Engineering Program for the VDOT Central Office Materials Division in Richmond, Virginia. Mr. Pelnik currently is responsible for geotechnical investigations, laboratory soil testing, and geotechnical design of projects over difficult ground conditions. His current engineering emphasis includes in situ testing and ground improvement for highway construction. Before joining VDOT in March 2000, he was a geotechnical engineering consultant in Boston, Massachusetts, and in Richmond, Virginia. Mr. Pelnik is a graduate of Worcester Polytechnic Institute and holds a master's degree in civil engineering from the University of Rhode Island. He is a licensed professional engineer in New York State and the Commonwealth of Virginia. Mr. Pelnik serves on VDOT's Design-Build Committee, VDOT's Geotechnical Research Advisory Committee, and the advisory board for the Virginia Tech Center for Geotechnical Composite Systems; works with technical committees of the Virginia Tech Center for Geotechnical Practice and Research and the TRB; and is a member of the ASCE.

Dr. Ali Porbaha is a researcher with New Technology and Research (NT&R), California DOT (CALTRANS) in Sacramento, California. Dr. Porbaha currently directs the Geosystems Research in CALTRANS that involves developing design tools and design manuals for innovative ground modification technologies. Prior to joining the research staff at NT&R in 2000, he served as a National Science Foundation postdoctoral fellow at the Port and Airport Research Institute (PARI), the national laboratory of the Japanese government; and also worked for the TOA Technical Research Institute in Japan. Dr. Porbaha is a graduate of the University of Maryland and holds a doctoral degree in geotechnical engineering. His publications include more than 60 articles prepared for professional journals and international conferences on the subjects of ground improvement, ground reinforcement, and ground treatment. He is a licensed professional engineer in several States, and currently directs the National Deep Mixing (NDM) program, a nationally coordinated research collaboration among the federal government and nine State governments.

Dr. Sastry Putcha is the State Construction Geotechnical Engineer for the Florida DOT (FDOT) at the Central Office at Tallahassee, Florida. He is responsible for developing and issuing Statewide policy and procedures for all construction-related geotechnical features used in the transportation program. He is also currently the Program Manager of various research and development projects involving innovative technology that reduces the cost of foundation installation and embankment construction. Dr. Putcha has served FDOT for about 13 years and has more than 20 years of experience in geotechnical engineering for State highway administrations and in the private sector. Dr. Putcha holds a Ph.D. in bio & ag engineering from North Carolina State University and master’s and bachelor’s degrees in civil engineering from the Indian Institute of Technology, India. He is a licensed professional engineer in Florida. He is a member of the ASCE and has served on committees of the TRB.

Richard (Dick) Short is a Senior Geotechnical Engineer and Area Manager for Kleinfelder, Inc., located in Oakland, California. He specializes in deep foundation design and construction for all types of private and public works facilities. His experience includes pioneering the use of European technologies in the San Francisco Bay Area, such as Tubex piles and the Fundex (PLT) rapid load test method. He heads his firm’s Emerging Technologies Initiative designed to inform staff and clients of the latest technologies in the geotechnical field. He received his BSCE from the University of Nevada, Reno, and his MS in geotechnical engineering from the University of California, Berkeley. Mr. Short is a past president of the California Geotechnical Engineer’s Association and is also the current vice president of the Deep Foundation Institute and co-chairman of the International Committee. He also is the board member in charge of overseeing the upcoming October DFI conference in San Diego, the theme of which is “Accelerated Design and Construction Techniques.”

APPENDIX E

EN1997 Eurocode 7: Geotechnical Design

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EN1997 *Eurocode 7: Geotechnical design*

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Geotechnical engineers have long stood out from the other professional disciplines within civil and structural engineering—not least for their approach to design. Geotechnical calculations have traditionally relied on highly subjective assessments of design parameters whereas everything above the ground uses a more explicit and codified approach. Eurocode 7 aims to bridge the gap. It presents a comprehensive list of conditions which geotechnical designers need to consider and places much greater emphasis on serviceability and how this may be satisfied through ultimate-limit-state design. With four different design methods and three different approaches to limit-state design, it offers great flexibility at the same time as increased rigour.

In 1980 the European Commission asked the International Society of Soil Mechanics and Foundation Engineering to survey existing geotechnical codes of design practice within European Community member states and to draft a model code which could be adopted as Eurocode 7.

Following many consultations and international meetings, the Society produced a draft geotechnical code in 1987. The Commission then sponsored three more years' work on the draft, after which the document was transferred in 1990 for development, issue and maintenance to Comité Européen de Normalisation (CEN)—the European standardisation body.

Part 1 of Eurocode 7 was published as an ENV (EuroNorm Vornorm) pre-standard in October 1994 and by BSI the following year.[1] Two years later, the ENV was subjected to voting and accepted in July 1997 for further development into an EN (EuroNorm) standard. The status of the latest, unpublished, draft is as a provisional standard (prEN).

In 1998 a commentary[2] on the ENV was published in the UK to assist engineers better to understand the novel aspects of the Eurocode and to give worked examples showing its application using the British national application document in the BSI version. Further explanation of the ENV, with worked examples, was published in 1999.[3]

Harmonising with other Eurocodes

The positive vote to proceed from ENV to EN was achieved on the understanding that some member states reserved the right to propose changes to the ENV text. Particularly, this concerned the basis of geotechnical design section that is required to conform with EN1990 *Eurocode—Basis of structural design*.[4] Consequently, the technical content of several sections of the ENV was amended between 1998 and 1999. During this period and subsequently, a number of important negotiations with the project team producing EN1990 took place in which both Eurocodes were amended to enable EN1997-1 to conform with EN1990.

Part 1 of Eurocode 7, EN1997-1, provides in outline all the requirements for design of geotechnical structures. It provides little assistance or information,

Table 1: Contents of part 1 of Eurocode 7

Subjects	Section
Overall approach	1. General 2. Basis of geotechnical design
Ground investigation	3. Geotechnical data
Design aspects of construction activities	4. Supervision of construction, monitoring and maintenance
Design of specific elements	5. Fill, dewatering, ground improvement and reinforcement 6. Spread foundations 7. Pile foundations 8. Anchorages 9. Retaining structures 10. Hydraulic failure 11. Overall stability 12. Embankments

"Eurocode 7 recognises four fundamental ways of carrying out geotechnical design"

which the designer must therefore seek from other texts. It relies on other Eurocodes and CEN documents.

The code provides extensive checklists of conditions to be investigated, assessed and designed for and places greater emphasis on the serviceability requirement for geotechnical design than is found in many national codes. Table 1 shows the contents of part 1.

The code strongly emphasises the importance of geotechnical investigations. It requires that the final design be accompanied by formal reports, both factual and interpretative, of the investigations on which it is based.

EN1997-1 is supported by two other parts: ENV1997-2 and ENV1997-3, design assisted by laboratory and field testing respectively. Conversion of these parts into ENs is expected to begin in late 2001.

Five ultimate limit states to be considered

In common with all the Eurocodes, Eurocode 7 is based on the principles of limit-state design. ENV1997-1 required the designer to consider three ultimate limit-state design cases A, B and C, which were sets of partial factors for both actions and material strengths (or resistances, in the case of piles). This design system complied with the then draft of EN1990. Case A dealt with loss of static equilibrium, in which actions were largely in balance with little if any contribution from material strengths. The factors of case B were derived from structural codes and those of case C from an earlier draft of Eurocode 7. In order to provide consistent and safe design of structures involving ground behaviour, the ENV required that all designs should comply with all three cases in all respects, both geotechnical and structural; that is, complete designs of the geometry and structural strength were to be checked separately for all three sets of partial factors. It was noted that in many situations the critical case might be obvious by inspection, in which event it would not be necessary to produce formal calculations for all three cases.

Fig. 1. The GEO limit state is often critical in the sizing of retaining structures

The present prEN1997-1 text defines five ultimate limit states as follows

- loss of equilibrium of the structure or the ground, considered as a rigid body, in which the strengths of structural materials and the ground are insignificant in providing resistance (EQU)
- internal failure or excessive deformation of the structure or structural elements—including footings, piles and basement walls—in which the strength of structural materials is significant in providing resistance (STR)
- failure or excessive deformation of the ground, in which the strength of soil or rock is significant in providing resistance (GEO)
- loss of equilibrium of the structure or the ground due to uplift by water pressure (bouyancy) or other vertical actions (UPL)
- hydraulic heave, internal erosion and piping in the ground caused by hydraulic gradients (HYD).

Limit state GEO is often critical to the sizing of structural elements involved in foundations or retaining structures (Fig. 1) and sometimes to the strength of structural elements.

A comparison with prEN1990 clause 6.4.1 shows that definitions of the ultimate limit states common to both codes, EQU, STR and GEO, are broadly in agreement, with only minor textual differences and that specific geotechnical limit states UPL and HYD have been added to prEN1997-1. The limit state of fatigue (FAT) in prEN1990 is absent from prEN1997-1.

The ultimate limit state UPL involves failure by hydraulic uplift and occurs when, for example, the shear strength of the ground acting on the periphery of a buried structure plays only a very minor role (compared to the self-weight of the structure) in providing resistance against uplift (buoyancy) forces. Problems of failure in the ground caused by pressure and flow of groundwater due to hydraulic gradients (HYD) are considered in a special and separate geotechnical limit state that is closely related to GEO in that it involves loss of strength of the ground.

Four ways of carrying out geotechnical design

Eurocode 7 recognises four fundamental ways of carrying out geotechnical design

- using calculations based on an analytical, semi-empirical or numerical model
- adopting prescriptive measures involving conventional and generally conservative, nationally determined rules or approaches in design and specification, and in the control of materials, workmanship, protection and maintenance procedures
- using experimental models and load tests carried out on a sample of the actual construction or on full scale or smaller scale models
- using the observational method,[5] in which the design is continuously reviewed during construction.

Historically, the limit-state method became popular at about the time that partial factors began to be adopted. The two are therefore often linked though there is no fundamental connection between them. A calculation using global factors or directly assessing pessimistic design values could be sufficient to demonstrate that limit states will not occur. Limit-state calculations are usually carried out by showing that the design properties of materials are sufficient to withstand the design values of all applied actions. The design values generally incorporate all the required safety elements, with no further overall factor of safety. Calculations are principally to be carried out by applying partial factors to characteristic values of soil parameters. The code generally does not specify the precise form of calculations but states what criteria are to be checked by the calculations.

Prescriptive methods may be used when comparable experiences make calculations unnecessary or calculation models are not available. Examples in the UK would be the minimum foundation depth of 450 mm to avoid frost heave, or of 1000 mm to avoid seasonal movements in highly plastic clays.

A UK example of the experimental/load-test approach would be the application of an α factor in the range 0·4–0·6 to the undrained shear strength of London clay when calculating the shaft resistance of a pile (Fig. 2)

With regard to the observation method, it is a principle of EN1997 that the limits of acceptable behaviour are established together with the range of possible behaviour and a plan of the monitoring regime. A plan of contingency actions must also be devised, to be adopted should monitoring reveal behaviour outside acceptable limits.

The four approaches may be used in combination. Simplified design procedures may be adopted depending on the complexity of the geotechnical design and risk considerations.

Three new approaches to limit-state design

The application of limit-state design in geotechnics (as formulated using partial factors) has been under debate for several decades. Although the approach has some obvious, and generally accepted, benefits, it has proved very difficult to reach agreement on where in the calculation processes partial factors should be applied.

Fig. 2. The experimental and load test approach can be used to determine the α factor on the ground strength when calculating shaft resistance of piles

Although some engineers would still argue for single global factors of safety, the main alternative views now relate to applying factors either to primary variables—material properties and actions, or to some variable obtained part way through the calculation—resistances and action effects. A related question is the application of factors to models, both resistance and action effect models.

It has long been argued by the supporters of the ENV cases A, B and C that, where possible, factors should be applied to the uncertainties themselves so that their effects on derived quantities may result from the calculation, rather than being assumed by code drafters. In the drafting committee, two broad groups emerged: one generally supporting factoring of materials and actions and another supporting factoring of resistances and action effects. To accommodate the latter group particularly, new design approaches have been introduced, with corresponding changes to EN1990 for conformity.

The intentions of the proponents of the new approaches have been

- to reduce the perceived number of geotechnical calculations required by the ENV
- generally to introduce factors on resistances and action effects rather than on material properties and actions
- to introduce model factors.

Their introduction resulted in far greater complexity in the document than was found in cases A, B and C of the ENV. The Appendix sets out how prEN1997-1 states the approaches should be used to avoid ultimate limit states.

Alternative sets of partial factors were needed for the different design approaches for the different geotechnical structures, such as bored and driven piles, with much repetition in order that each set was separately consistent. This complexity was heavily criticised by BSI and recent simplifications have been adopted which reduce the number of partial factor values from more than 200 to around 60! These simplifications are summarised in Table 2 in which the terms A ('action'), M ('material') and R ('resistance') refer to sets of partial factors given in tables in annex A of EN1997-1; some of the partial factors and their recommended values are reproduced in Table 3.

The values of the partial factors recommended in annex A of the code are subject to national determination, in common with all the Eurocodes.

Gravity retaining wall example

The way in which different combinations of factors are applied, for the different design approaches, may be seen in Table 4, for the example of a gravity retaining wall founded on sand.

For design approach 1 it can be seen that two cases must be considered

- combination 1 in which partial factors on actions exceed 1·0, with factors on material strengths set to 1·0 (the STR limit state)
- combination 2 in which factors > 1·0 are applied to geotechnical material strengths with factors on actions set to 1·0 (the GEO limit state).

In design approach 1, for all designs, checks are required in principle for two sets of partial factors, applied in two separate calculations. This is akin to the cases B and C of the ENV. Where it is obvious that one of these sets governs the design, it will not be necessary to carry out calculations for the other set. Generally, factors are applied to actions, rather than to the effects of actions, though with one noted exception.

> In some design situations, the application of partial factors to representative values of actions coming from or through the soil (such as earth or water pressures) could lead to design values which are unreasonable or even physically impossible. In these situations, the factors may be applied directly to the effects of actions derived from representative values of the actions.

This exception applies specifically to the design of piles and anchors.

In design approaches 2 and 3, a single calculation is required for each part of a design, and the way in which the factors are applied is varied according to the calculation considered. In design approach 2,

Table 2. The three design approaches

Design approach DA1	DA2	DA3
- Except for the design of axially loaded piles and anchors, it shall be verified that a limit state of rupture or excessive deformation will not occur with either of the following combinations of sets of partial factors: Combination 1: A1 + M1 + R1 Combination 2: A2 + M2 + R1 - For the design of axially loaded piles and anchors, it shall be verified that a limit state of rupture or excessive deformation will not occur with either of the following combinations of sets of partial factors: Combination 1: A1 + M1 + R1 Combination 2: A2 + (M1* or M2†) + R4 * when calculating the resistance of the piles or anchors; † when calculating unfavourable actions on the pile owing to negative skin friction or lateral loading. - Where it is obvious that one of these combinations governs the design, it will not be necessary to carry out calculations for the other combinations. However, different combinations may be critical to different aspects of the same design. NOTE: In this approach, the design is checked for two sets of partial factors separately.	- It shall be verified that a limit state of rupture or excessive deformation will not occur with the following combination of sets of partial factors: Combination: A1 + M1 + R2 NOTE 1: In this approach, partial factors are applied to actions or to the effects of actions and to ground resistances. NOTE 2: If this approach is used for slopes and overall stability analyses, the resulting effect of the actions on the failure surface is multiplied by $\gamma_{R,e}$ and the shear resistance along the failure surface is divided by $\gamma_{R,e}$	- It shall be verified that a limit state of rupture or excessive deformation will not occur with the following combination of sets of partial factors: Combination: (A1* or A2†) + M2 + R3 * on structural actions † on geotechnical actions. NOTE 1: In this approach, partial factors are applied to actions or the effects of actions from the structure and to ground strength parameters. NOTE 2: For slope and overall stability analyses, actions on the soil (e.g. structural actions, 'traffic' loads etc.) are treated as geotechnical actions by using the set of load factors A.2 Key • A = partial factors applied to actions • M = partial factors applied to material properties • R = partial factors applied to ground or foundation resistances • += in combination with.

factors are applied to either actions or effects of actions and to resistances. Design approach 2 is an action (effect) and resistance factor approach. In design approach 3, factors are applied to actions or effects of actions from the structure and to ground strength parameters. Design approach 3 is an action (effect) and material factor approach.

Table 3. Selected sets of partial factors for limit states STR and GEO, and their recommended values

(1) Partial factors on actions (γ_F) or the effects of actions (γ_E)						
Action		**Symbol**	**Set**			
Duration	Condition		A1	A2		
Permanent	Unfavourable	γ_G	1·35	1·0		
	Favourable		1·0	1·0		
Variable	Unfavourable	γ_Q	1·5	1·3		
	Favourable		0	0		
(2) Partial material factors (γ_M)						
Material property		**Symbol**	**Set**			
			M1	M2		
Shearing resistance		γ_ϕ	1·0	1·25		
Effective cohesion		γ_c	1·0	1·25		
Undrained strength		γ_{Cu}	1·0	1·4		
Unconfined strength		γ_{qu}	1·0	1·4		
Weight density		γ_σ	1·0	1·0		
(3) Partial resistance factors (γ_R) Spread foundations						
Resistance		**Symbol**	**Set**			
			R1	R2	R3	
Bearing		γ_{Rv}	1·0	1·4	1·0	
Sliding		γ_{Rh}	1·0	1·1	1·0	
Pile foundations (driven)						
Resistance		**Symbol**	**Set**			
			R1	R2	R3	R4
Base		γ_b	1·0	1·1	1·0	1.3
Shaft (compression)		γ_s	1·0	1·1	1·0	1.3
Total/combined (compression)		γ_t	1·0	1·1	1·0	1.3
Shaft in tension		$\gamma_{s,t}$	1·25	1·15	1·1	1.6

Implications for practice in the UK

Design calculations include many sources of uncertainty

- actions
- derivation of action effects by an action effect model
- material strengths
- resistances of structural sections or zones of ground, derived using a resistance model.

The effect, later in a calculation, of an uncertainty at one point in a calculation is not easily foreseen and may be highly disproportionate.

It is important, however, that the number of factors be kept as small as possible, in order to minimise the risk of confusion, which could cause mistakes in calculation. In this case it is important that the principal uncertainties are directly factored, especially any which might have disproportionate, or non-linear effects elsewhere, with the intention of giving a sufficient margin to cover those not factored. In geotechnical design, material strength is often the principal uncertainty, suggesting that the strength of the ground should be factored at source.

EN1990 *Eurocode—Basis of structural design* notes an important point in relation to actions.

> For non-linear analysis (i.e. when the relationship between actions and their effects is not linear), the

Table 4. Partial factors for a gravity retaining wall founded on sand

Design approach	Combination	Actions A		Materials M		Resistances R		Comments
		Permanent unfavourable	Variable unfavourable	tan ∅	Weight density	Bearing	Sliding	
1	1 (A1 + M1 + R1)	1·35	1·5	1·0	1·0	1·0	1·0	Like ENV case B
	2 (A2 + M2 + R1)	1·0	1·3	1·25	1·0	1·0	1·0	Like ENV case C
2	'Rupture' (A1 + M1 + R2)	1·35	1·5	1·0	1·0	1·4	1·1	
3	Rupture (A1 or A2) + M2 + R3	Structural 1·35 Geotechnical 1·0	Structural 1·5 Geotechnical 1·3	1·25	1·0	1·0	1·0	

following simplified rules may be considered in the case of a single predominant action.

(a) When the action effect increases more than the action, the partial factor γ_F should be applied to the representative value of the action.
(b) When the action effect increases less than the action, the partial factor γ_F should be applied to the action effect of the representative value of the action.

In other words, the factor should be applied to the basic variable, or to a quantity derived later in the calculation, according to where its effect will be most severe. If the same approach is applied to materials, particularly that of non-linear, frictional materials, it will generally require that factors be applied to material strength, rather than to calculated material resistances. For example, bearing capacity increases more, in proportion, than the angle of shearing resistance (or tan ϕ) from which it is calculated, so it is appropriate in this case to apply the factor to the material property, tan ϕ, rather than to bearing resistance itself.

Another example arises in the design of embedded retaining walls, where the magnitude of the maximum bending moment increases more than linearly with the applied earth pressures, which themselves change more than linearly with soil strength, expressed as tan ϕ. The prEN1990 rule would here imply that factors should be applied directly to earth pressures, or better still to tan ϕ, rather than to the action effect, bending moment.

It is for these reasons, primarily, that the UK national annex that will be a part of the BS EN1997-1 will require designs in the UK to follow design approach 1 exclusively. Additionally, in the long run-up to the completion of the ENV, extensive calibration studies were performed to demonstrate that the use of cases A, B and C, with the partial factor values recommended in the ENV (these have not changed in prEN1997-1) would deliver safe foundations and geotechnical constructions that were sometimes cheaper than traditional practice using national codes.

There are published examples covering flexible retaining structures (Fig. 3), piles and spread footings.[2] Also published is further discussion[6] and a demonstration of how use of design approach 2 may lead to an anomalous result in which the application of the factors provides no safety.[7]

Defining characteristic values

In addition to the application of partial factors in a limit state design methodology, another contentious aspect of the adoption of Eurocode 7 has concerned the definition and determination of the characteristic value of a variable in the design, especially for ground properties. EN1997-1 discusses characteristic value in 12 clauses, in all, and states that.

> The characteristic value of a geotechnical parameter shall be selected as a cautious estimate of the value affecting the occurrence of the limit state.

The surrounding clauses make it clear that the characteristic value is to incorporate the designer's assessment of relevant ground conditions, based both on test results and other information, especially published information, including the effects of construction processes that might change the strength of the ground. This is clearly somewhat different from the statistical analysis of test results, which defines characteristic values in structural design. The code goes on to state.

> If statistical methods are used, the characteristic value should be derived such that the calculated probability of a worse value governing the occurrence of the limit state under consideration is not greater than 5%. In this respect, a cautious estimate of the mean value is a selection of the mean value of the limited set of geotechnical parameter values, with a confidence level of 95%; a cautious estimate of the low value is a 5% fractile.

There has been much debate in the UK (and elsewhere) about the determination of characteristic values of ground properties. The authors feel that many geotech-

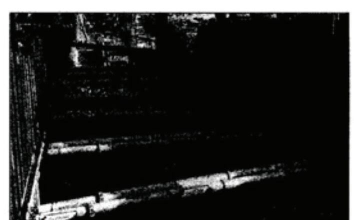

Fig. 3. Many types of geotechnical structures have been calibrated against the pre-standard version of Eurocode 7. Published examples are available[2]

nical engineers instinctively select values that lie close to that determined using the definition given above.[2]

Conclusions

In all the intense debate and criticism, from some quarters, that has accompanied the development of Eurocode 7, sight has often been lost of the fact that, for the first time, civil and structural engineers have a geotechnical code based upon a methodology common to both the ground and the superstructure; the uncomfortable discontinuity in logic that existed between geotechnical calculations based upon highly subjective assessments of design parameters and the far more explicit, codified structural calculations has been significantly bridged in the package of structural Eurocodes.

Eurocode 7 presents a comprehensive list of conditions to be considered in all aspects of those circumstances commonly encountered in geotechnics and places greater emphasis than hitherto on the serviceability condition and how this may be satisfied through ultimate-limit-state design methods. It offers great flexibility in the choice of design methodology yet introduces greater discipline in having to think more explicitly about the many sources of uncertainty in geotechnical design.

Very few British geotechnical engineers have yet tried to use the ENV and it is earnestly to be hoped that the arrival of the BSEN will encourage them to do so.

Appendix—avoiding ultimate limit states

The following discussion concerns the latest prEN1997-1 text being finalised at September 2001, which, although unlikely, could still change before formal voting in June 2002.

In designing by calculation to avoid the occurrence of ultimate limit states, cases A, B and C have been replaced by a system that has three design approaches. It is clearly stated that the particular design approach to be used shall be according to national determination. The occurrence of an ultimate limit state shall be avoided as follows.

When considering a limit state of rupture or excessive deformation of a structural element or the ground (STR or GEO), it shall be verified that

$$E_d \leq R_d \qquad (1)$$

where E_d is the design effects of actions and R_d is the design resistance. The design effects of actions shall be derived from the following equation

$$E_d = E\{F_d, X_d, a_d\} \qquad (2)$$

where F_d is the design value of an action, X_d is the design value of a material property and a_d are design values of geometrical data. At this point, one of the three different design approaches enters the calculation. Partial factors on actions may be applied either to the actions themselves (F_{rep}) or to their effects (E), according to national determination

$$E_d = E\{\gamma_F F_{rep}, X_k/\gamma_M, a_d\} \qquad (3)$$

or

$$E_d = \gamma_E E\{F_{rep}, X_k/\gamma_M, a_d\} \qquad (4)$$

where F_{rep} is the representative value of an action, γ_F is a partial factor for an action which takes account of the possibility of unfavourable deviations from the representative value, γ_E is a partial factor for an effect of actions which takes account of the possibility of unfavourable deviations from the representative value, X_k is the characteristic value of a material property and γ_M is a partial factor for a material property, also accounting for dimensional variations.

Equations (3) and (4) include X_k/γ_M in the calculation of actions because ground material properties may affect the values of geotechnical actions in some cases.

EN 1990 states that γ_f is a partial factor for an action and takes account of the possibility of unfavourable deviations of the action value from its characteristic value. Likewise γ_{Sd} is a partial factor taking account of uncertainties in modelling the actions and in modelling the effects of actions. EN 1990 allows γ_{Sd} and γ_f to be combined into one factor multiplying F_{rep}

$$\gamma_F = \gamma_{Sd} \cdot \gamma_f$$

It can be seen that γ_F is applied to the action itself in equation (3) while γ_E is applied to the effect of the action in equation (4). In both cases, γ_M is applied directly to the characteristic material strength, X_k.

Similarly, choices of design approach are introduced into calculations of the design resistance, R_d, as follows. The design resistance shall be derived from the following equation

$$R_d = R\{F_d, X_d, a_d\}/\gamma_R \qquad (5)$$

where γ_R is a partial factor on resistance. Partial factors may be applied either to material properties (X_k) or resistances (R) or to both, according to national determination

$$R_d = R\{\gamma_F F_{rep}, X_k/\gamma_M, a_d\} \qquad (6a)$$

or

$$R_d = R\{\gamma_F F_{rep}, X_k, a_d\}/\gamma_R \qquad (6b)$$

or

$$R_d = R\{\gamma_F F_{rep}, X_k/\gamma_M, a_d\}/\gamma_R \qquad (6c)$$

The three design approaches in effect adopt different combinations of equations (3), (4), (6a), (6b) and (6c).

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